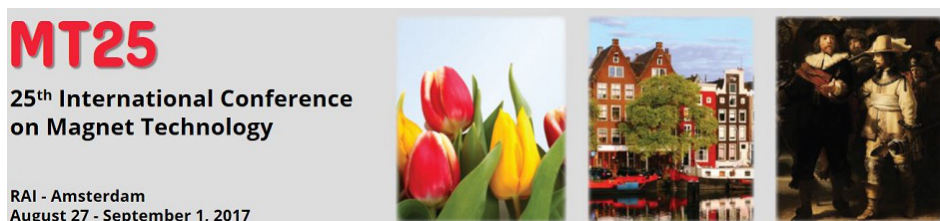


MT25 Conference 2017 - Timetable, Abstracts, Orals and Posters

Sunday 27 August 2017 - Friday 01 September 2017

RAI Congress Center, Amsterdam, The Netherlands



Report of Abstracts

**Book of Abstracts of the MT25 conference,
Amsterdam, August 27 - September 1, 2017**

Wed-Mo-Pl6 / 1248

1.3 GHz (30.5 T)-class super-high field NMR in a persistent current operation using HTS inner coils

Thu-Mo-Or32 / 785

10 kA joints for Multi-Tape HTS Cables

Author(s): Jaakko Samuel Murto¹**Co-author(s):** Glyn Kirby²; Jeroen Van Nugteren; Francois-Olivier Pincot²; Gijs De Rijk²; Lucio Rossi²; Janne Ruuskanen³; Antti Aleksis Stenvall; Jerome Fleiter²¹ *Tampere University of Technology (FI)*² *CERN*³ *Tampere University of Technology*

Abstract— Future HTS high field magnets using multi-tape HTS cables need 10 KA low resistance connections. The connections are needed between the poles of the magnets and at the terminals in a wide operating temperature range, from 77 - 1.9 K.

The EuCARD-2 WP10 Future Magnets collaboration aims at testing HTS-based Roebel cables in an accelerator magnet. Usually, LTS cables are jointed inside a relatively short soldered block. Powering tests at CERN have highlighted the high internal resistance of a joint following classical LTS joint design.

The HTS Roebel cables are assembled from meander-shaped REBCO-coated conductor tapes in a transposed configuration. Tapes are mechanically stabilized by a highly resistive stainless steel substrate layer. Tape-to-tape contact resistance remains high, and varies between tape manufacturers, which limits the current redistribution through the tapes.

A low-resistance joint requires a sufficiently large interface area for each tape. Within one twist pitch length, each tape is located at the surface of the cable over a relatively short distance. This geometry prevents making a low resistance joint in a compact length along the cable. To minimize the effect of the tape internal resistance, the soldered joint connection must be on the superconducting side of each tape, and not on the steel substrate side.

This paper presents a compact joint configuration for the Roebel cable overcoming these practical challenges. The transposed configuration of the cable is opened and the tapes are connected individually to copper fins in a stacked assembly, called Fin block. The Fin block is clamped to the terminal with adaptor pieces. The joint resistance is estimated computationally. Finally we present test results as a function of current and temperature.

Submitters Country:

Finland

Thu-Af-Po4.09 / 467

24kA DC Energy Extraction Switch for LARP Magnet Testing at BNL

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Abstract: The high luminosity upgrade of the Large Hadron Collider (LHC) at CERN will consist of Nb₃Sn based superconducting magnets operating at about 22kA DC. When these magnets quench, the power source has to be disconnected and stored energy should be discharged into a dump resistor very quickly. For this purpose, a 24kA DC current interruption switch based on Insulated Gate Bipolar Transistors (IGBT) has been developed. As opposed to Thyristor or mechanical switches which take milliseconds to interrupt the current, an IGBT based switch interrupts the current in microseconds. The switch is realized by paralleling twelve 3600A IGBTs. Paralleling of high current IGBTs made from different batches of silicon and of different voltage ratings is a challenging task. This paper discuss techniques developed to synchronize the turn off of twelve 3600A IGBTs made by Infineon Inc. Techniques developed pertain to gate charge control, snubber design, steady state and transient current sharing, stray inductance and thermal management.

Index Terms- LARP, LHC, IGBT, Quench

Submitters Country:

USA

Wed-Af-Po3.11 / 395

2G HTS Magnet Stability Improvement via V2O3 Material and perforated HTS Wire

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Co-author(s): Seog-Whan Kim¹ ; Rock-Kil Ko¹ ; Dong-Woo Ha¹ ; Young-Sik Jo¹

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In this paper, we propose an improved wire structure that easily causes current bypass when the V2O3 material is applied turn-to-turn in 2G HTS no-insulation coils. A characteristic of the V2O3 material is that when a quench causes the coil temperature to rise the turn-to-turn resistance is lowered and current is bypassed. However, due to the high material resistance of the original 2G HTS wire, the turn-to-turn resistance is large and the resulting amount of bypassed current is small. Therefore, in order to reduce the turn-to-turn resistance of the original 2G HTS coil, a short sample test and a FEM analysis were performed of the perforated wire. We also applied the proposed method to the coil and verified its validity through experimental results.

Submitters Country:

Republic of Korea

Tue-Mo-Or15 / 948

32T Protection Design and Operation

Author(s): Patrick Noyes¹

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The 32T Magnet system, under development at the NHMFL, is a large all superconducting user magnet that is comprised of a 15 T LTS outsert magnet, made by Oxford Instruments, and a 17 T REBCO inner magnet, made by the NHMFL. With the high critical temperature and low quench velocity of REBCO conductors, even at fields as high as 32 T, a large amount of thermal energy must be quickly deposited in the HTS insert magnet in order to properly protect it. In order to distribute enough energy to prevent strain or thermal damage, a series of protection heaters have been integrated to the coil and are powered by a large bank of lead acid batteries and a redundant array of switches. Fault detection is performed by two independent systems that are each capable of activating the protection heaters and triggering the outsert protection system. Details on the detection scheme, hardware, circuits, levels of redundancy, and the performance of the system are presented.

Submitters Country:

United States

Tue-Af-Po2.06 / 5

3D Electromagnetic Analysis of Tubular Permanent Magnet Linear Launcher

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Co-author(s): Kun Liang² ; Rui Nie² ; Xiao Liu²

¹ *China University of Mining & Technology*

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A short stroke and large thrust axial magnetized tubular permanent magnet linear launcher (TPMLL) with non-ferromagnetic rings is presented in this paper. Its 3D finite element (FE) models are established for sensitivity analyses on some parameters, such as air gap thickness, permanent magnet thickness, permanent magnet width, stator yoke thickness and four types of permanent magnet material, ferrite, NdFeB, AlNiCO5 and Sm2CO17 are conducted to achieve greatest thrust. Then its 2D finite element (FE) models are also established. The electromagnetic thrusts calculated by 2D and 3D finite element method (FEM) and got from prototype test are compared. Moreover, the prototype static and dynamic tests are conducted to verify the 2D and 3D electromagnetic analysis. The FE software FLUX provides the interface with the MATLAB/Simulink to establish combined simulation. To improve the accuracy of the simulation, the combined simulation between the model of the control system in Matlab/Simulink and the 3D FE model of the TPMLL in FLUX is built in this paper. The combined simulation between the control system and the 3D FE model of the TPMLL is built. A prototype is manufactured according to the final designed dimensions. The photograph of the developed TPMLL prototype with thrust sensor and the magnetic powder brake as the load are shown. It can be seen that the simulated voltage waveforms and current waveforms of the winding, the simulated frequency curves of the mover with the movement range from -6mm to 6mm are accordant with the tested results. Hence the correctness of established FE models is further verified, and the feasibility of proposed control strategy is testified. The frequency response is rapid. Thus, the great dynamic performance of the prototype, effectiveness of the adopted control strategy and the corresponding combined simulations based on the 3D FE model are verified.

Submitters Country:

China

Mon-Af-Po1.04 / 489

3D Electromagnetic Design and Analysis of a 1-HP-Class HTS Rotating Machine integrated with a Contactless HTS Excitation Device

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Co-author(s): Chang Ju Hyeon¹ ; Huu Luong Quach¹ ; Sang Heon Chae¹ ; Min Hyeok Kang¹ ; Eel-Hwan Kim¹ ; Yong Soo Yoon² ; Jeyull Lee³ ; Haeryong Jeon³ ; Seunghak Han³ ; Young-Gyun Kim⁴ ; Haigun Lee⁴

¹ Jeju National University

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³ Yonsei University

⁴ Korea University

This paper presents electromagnetic design and 3D finite element analysis (FEA) results to develop prototype machine system for the high-temperature superconducting (HTS) rotating machine integrated with a contactless HTS excitation device (CHED). This is connected and integrated on the same shaft of the rotating machine and charge the HTS field coils by pumping magnetic flux with non-contact method. Therefore, this can be excellent alternative to replace a contact type conventional excitation device which has thermal and mechanical instability by physically connecting cryogenic temperature environment inside HTS rotor with room temperature environment outside HTS rotor. In this paper, 1-HP-class HTS rotating machine was basically designed by analytical method to build 3D FEA model and then, the initial design model was electromagnetically analyzed using commercial 3D FEA software. The basic magnetic field distribution information on HTS rotating machine with CHED was investigated and the various output performances of HTS rotating machine in steady state operation were analyzed. Especially, the real charging data achieved by preliminary experiment with HTS coil and CHED prototype was used in 3D FEA as a input boundary condition to simulate the electromagnetic characteristics in initial charging mode of 1-HP-class HTS rotating machine.

Acknowledgement: This work was supported in part by the Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), grant funded by the Ministry of Trade, Industry & Energy, and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP), Republic of Korea. (Nos. 20164030201230 and 2016R1A2B4007324)

Submitters Country:

Republic of Korea

Wed-Af-Po3.01 / 380

3D Magnetic and Mechanical Design of Coil Ends for the Race-track Model Magnet RMM

Author(s): Etienne Rochepault¹

Co-author(s): Susana Izquierdo Bermudez¹ ; Juan Carlos Perez¹ ; Daniel Schoerling¹ ; Davide Tommasini¹

¹ CERN

The Racetrack Model Magnet (RMM) is a racetrack test magnet being developed at CERN. Its main goal is to demonstrate, in view of future high field accelerator magnets, that a nominal field of 16 T can be reached in a 50 mm bore, with margins and limited training. Also, this program gives the opportunity of studying field quality, and the opportunity of exploring coil manufacturing concepts as well as loading strategies. In the coil ends in particular, the peak field has to be reduced in order to keep a safe margin. Also, the high longitudinal Lorentz forces must be managed to limit the motion of the coil ends, which would degrade performances. This paper presents a 3-D magnetic and mechanical study and proposes solutions to achieve a peak field in the ends lower than in the straight section, while containing the electromagnetic forces. The structure features tie rods and end-plates, which have been designed to provide an adequate support to the coil ends, in different loading configurations. In particular, the impact of different materials, and the role of friction has been studied. Different solutions are compared and a final design is proposed, which offers the best compromise in terms of magnetic and mechanical criteria.

Submitters Country:

Switzerland

Mon-Af-Po1.08 / 170**3D Stress-Strain Modeling of Nb3Sn wire****Author(s):** Jingping Chen^{None}**Co-author(s):** Ke Han ; yuhu zhai

The performance of Nb3Sn multifilament wires is highly strain-sensitive. Although the overall strains on the wire are used to describe the critical properties ~ strain relationship, the strains in each filament are the real reason responsible for strain-related behavior. Therefore, it is important to build a relationship between the strains in each filament and external loads. In this study, a 3D model, consisting of all major components, is developed to address the relationship. The internal strains in the filament are studied in terms of external load, filament shape and wire architecture. At the end of this paper, a potential experimental approach for verifying the modeling work is discussed.

Submitters Country:

USA

Wed-Af-Po3.01 / 300**3D mechanical design and analysis of 20-T twin-aperture common-coil accelerator dipole magnet**

Zhang Kai¹ ; Xu Qingjin^{None} ; Zhu Zian^{None} ; GianLuca Sabbi² ; Tengming Shen³ ; Wang Chengtao^{None} ; Wang Yingzhe^{None} ; Cheng Da^{None} ; Kong Ershuai^{None} ; Feipeng Ning⁴ ; Quanling Peng⁴

¹ *IHEP*² *LBNL*³ *Fermilab*⁴ *IHEP,CAS*

Conceptual 3D mechanical design for 20-T common-coil dipole magnet has been carried out to meet our previous magnetic design for SppC dipole magnet. In accordance to the previous magnetic layout, the most inner two top and bottom HTS racetrack coils bend outward to provide space for the beam pipes instead of using flared ends. Specifically, the 75 mm thick Shrink-fit Multilayered Aluminum Shell (SMAS) is used to support the superconducting coils; the split iron yokes are used to transfer the preload and orientate the inner HTS coils bending outward. The coils are firstly preloaded by a bladder pressure of 80 MPa and then further preloaded after cool-down for the horizontal direction. The required preload in the vertical direction can be provided after the bladder operation in the horizontal direction and cool-down. In the axial direction, four aluminum tie rods are pre-tightened to provide axial preload to the coils. This paper will present the details of the dipole magnet's 3D configuration and the loading procedures, with special care on the stress distribution in the coil straight section and the coil ends at different load steps.

Submitters Country:

China

Wed-Af-Or27 / 976

60 Tesla Pulse Coil Design and Manufacturing Facility

Author(s): Todd Adkins¹

Co-author(s): Iain Dixon¹; Kurt Cantrell¹; Lee Marks¹; Justin Deterding¹; Scott Bole¹; James Michel²; Doan Nguyen; Donald Richardson

¹ *NHMFL*

² *LANL*

The pulse magnet program located at Los Alamos National Laboratory (LANL) has partnered with the National High Magnetic Field Laboratory (NHMFL) in developing a new winding facility for the revised design of the 60T pulse coil. The NHMFL has been contracted to manufacture coils 3, 4, and 7 for the 60T coil assembly. The new winding facility has upgrades that include a new payoff machine, automated taping machine, pitch guided rollers, upgraded winding machine, and improved epoxy impregnation. In addition to the new winding facility several design modifications were implicated into the coils to reduce operation stresses and ease in manufacturability. Details on specific design changes, tooling upgrades, manufacturing processes, and quality control are presented.

Submitters Country:

USA

Wed-Af-Or22 / 240

A 2.5 T, 1.25 m free bore superconducting magnet for the Magnum-PSI linear plasma generator

Author(s): Hans van Eck¹

Co-author(s): Herman Ten Kate²; Alexey Dudarev²; Tim Mulder³; Alain Herve⁴

¹ *Dutch Institute for Fundamental Energy Research (DIFFER)*

² *CERN*

³ *University of Twente (NL)*

⁴ *University of Wisconsin-Madison (US)*

The interplay between a nuclear fusion plasma and the reactor wall determines the performance and lifetime of fusion reactors. DIFFER's main experiment Magnum-PSI is the only laboratory setup in the world capable of exposing materials to plasma conditions similar to those of future fusion reactors. The success of the Magnum-PSI experiment depends on the generation of a 2.5 T magnetic field without restricting the diagnostic access and operational aspects of the experiment. This has been achieved with a magnet consisting of five superconducting solenoids wound on a 2.5 m long stainless steel coil former positioned in a cryostat offering a 1250 mm warm bore. A copper stabilized (Cu/Sc.: 8.7) multifilamentary NbTi conductor with a 3.48 mm² cross section has been used, thus the magnet exhibits a total inductance of 500 H and a stored energy of 15 MJ. This presents some challenge for the protection scheme that has been implemented using a mix of back-to-back cold diodes and an external dump resistor. The coils generate a plateau shaped magnetic field adjustable up to 2.5 T over a distance of 1750 mm between the exit of the plasma source and the end of the target plate, while the distance between the coils allows for 16 room temperature view-ports. Taking advantage of these, the large warm bore provides an excellent access to the experiment for diagnostics and maintenance. The coils are cooled with liquid helium using a re-condensing system operated with cryocoolers, while the magnet system cycles between zero and full field every day. The magnetic stray field is shielded down to 1 mT outside the experimental area by iron walls that flank the magnet. Design, assembly and testing of the magnet system are described, and the Magnum-PSI experiment and its capabilities will be introduced.

Submitters Country:

The Netherlands

Tue-Af-Or16 / 1191

A 8T Focusing Superconducting Solenoid for FRIB

Chao Li¹ ; Peng Ma² ; Zhengfu Ge² ; Pingxiang Zhang¹¹ *Northwestern Polytechnical University*² *Xi'an Superconducting Magnet Technology Co.,Ltd*

This paper presents a 8T solenoid used to focus and steer the heavy ion beams of the Facility for Rare Isotope driver linac at Michigan State University. It includes a main focusing solenoid, two bucking coils, two pair of horizontal and vertical correctors. The magnet is assembled with an entire length of 516 mm, including the helium vessel, ICR vacuum flanges and also the VCR for the helium supply port. Linear and nonlinear optimization method was used for the calculation of the magnetic field to meet the requirement of integrated squared field strengths and stray field with minimized superconducting wires. The corrector dipoles are placed between the bucking coils and the main solenoid. The helium vessel structural analysis, fabrication and test results are presented in this paper.

Submitters Country:

China

Tue-Af-Po2.04 / 1019

A 9 T Cryocooler Cooled High current density NbTi superconducting magnet

Bai Lifeng¹ ; Li Chengshan¹ ; Zhang Pingxiang¹¹ *Northwest Institute for Nonferrous Metal Research*

We have developed A 9 T Cryocooler Cooled NbTi superconducting magnets. The system has a 60 mm cool bore and 0.1% homogeneity over a 10 mm diameter and 15mm length region. The cooling power of the cryocooler is 1.5 W at 4.2 K. The cool down time from room temperature to operating temperature is 15 hours. Three different diameter NbTi wire was used for winding the magnet. The maximum engineering current density is 795 A/mm². In case of a quench the current density in the copper stabilizer is 1400 A/mm². A network of resistors and diodes was used to protect the magnet. This paper presents the magnet design, construct and the test results.

Submitters Country:

China

Wed-Af-Po3.03 / 269

A Compact Test Bed for Critical Current Evaluation on High Temperature Superconducting Tape Samples

Yinming Dai¹ ; Hui Wang¹ ; Jianhua Liu¹ ; Jinshui Sun¹ ; Xinning Hu¹ ; Chunyan Cui¹ ; Shunzhong Chen¹ ; Qiuliang Wang^{None}¹ *Institute of Electrical Engineering, Chinese Academy of Sciences*

A compact test bed was developed for the critical current evaluation for the High Temperature Superconducting (HTS) tape samples under transverse magnetic field. The test bed is composed of a

conduction-cooled superconducting magnet and an insert dewar which HTS short sample is hold in liquid nitrogen. The superconducting magnet, which can provide 3.5T horizontal magnetic field in its vertical bore, is integrated with two pairs of coaxial NbTi coils in a split magnet structure. A HTS short sample holder inside the insert dewar is designed in a way to fit changeable magnetic field direction. Electromagnetic and thermal analyses on the test bed are discussed and test results are presented.

Submitters Country:

China

Wed-Af-Po3.07 / 991

A Design of Outer Yoke and Enclosure Considering Magnet Eddy Current Loss of Magnetic Gear

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¹ *Chosun Universtiy*

² *Chosun University*

³ *Sungkyunkwan University*

A magnetic gear is a device that shows characteristics of a gear through the magnetic force of a permanent magnet. Permanent magnets are attached to the input and output rotors and transmit power using magnetic coupling without mechanical contact. Due to the non-contact power transmission method, it is possible to solve the problem of noise and wear due to the friction of the mechanical gear. However, there is a need to consider losses by the magnetic fields as magnetic fields are used. Magnetic gears use NdFeB series permanent magnets that exhibit high residual magnetic flux densities to exhibit high power densities [6]. Since this permanent magnet is made of a conductive material, an eddy current loss occurs due to a magnetic field which changes with time. In addition, the lamination technique like a laminated core is not developed, resulting in a very high eddy current loss. In this study, we found that the yoke thickness of the outer rotor affects the permanent magnet eddy current loss of the outer rotor during the research to reduce the eddy current loss generated from the magnetic gear. In addition, it was confirmed that the eddy current loss may occur in the enclosure depending on the thickness of the yoke. This paper focuses on this phenomenon and establishes the design process of the yoke and the enclosure that can minimize the permanent magnet eddy current loss and improve the output of the magnetic gear.

Submitters Country:

Rep. of Korea(south)

Wed-Af-Po3.12 / 641

A Digital Electrometric Method for Measuring the AC loss of a HTS Coil

Author(s): Zhong Xia¹

Co-author(s): Yuejin Tang ; Li Ren ; Jing Shi

¹ *Huazhong University of Science and Technology,R&D Center of App*

Abstract-AC loss is an important factor in designing and running of high temperature superconducting (HTS) devices. Recent years have seen many studies on the measurement of AC loss of HTS coils carrying sine-wave current. However, in fact, many practical HTS devices don't operate under sine-wave current. For instance, the current waveform of a superconducting magnetic energy

storage (SMES) coil is similar to triangle. In order to measure the AC loss of a HTS coil carrying triangular-wave current, this paper proposes a digital electrometric method. In this method, the voltage and the current of the coil are converted to digital signals so that the signal can be processed by computer. The AC loss is obtained by processing the signals and the details of the algorithm are given. We built an experiment platform based on this method. Simulations and experiments were conducted under identical circumstances and the results were compared to validate the measuring method. Furthermore, real time measurement on the AC loss of HTS coils can be implemented by using DSP instead of computer to process data.

Submitters Country:

China

Wed-Af-Po3.12 / 179

A Facile Method to Estimate Screening Current-Induced Fields in REBCO Pancake Coils

So Noguchi¹ ; Hiroshi Ueda² ; Seungyong Hahn³ ; Atsushi Ishiyama⁴

¹ *Hokkaido University*

² *Okayama University*

³ *Seoul National University*

⁴ *Waseda University*

Screening currents induced in HTS coils generate an irregular magnetic field. In particular, a large amount of screening currents are induced in REBCO tapes due to the tape shape, consequently a large screening current-induced fields is produced. Screening current-induced fields are a crucial problem for NMR/MRI applications. However, it is not easy to estimate screening current-induced fields at magnet design stage. So far, a few methods were proposed to estimate screening currents and their induced field. However, the already proposed methods are highly complicated and state-of-the-art simulation techniques, such as a finite element method with a thin approximation method, a fast multipole method, etc., are necessary to develop them. In addition, it takes a lot of time to simulate screening currents in REBCO tapes. As the result, most of researchers cannot use these simulation tools. In this paper, hence, we propose a facile method to estimate screening currents and their induced fields in REBCO pancake coils. In the proposed method, equivalent inductances of screening-current circuits are derived from magnet shapes, and then the induced screening currents are computed from the equivalent inductances and the magnetic fields penetrating into REBCO tapes. Then, the screening current-induced fields are estimated from the computed screening currents. Although accurate screening current-induced fields can be obtained by the previously proposed state-of-the-art simulation methods, the proposed method cannot give so accurate results. However, it is easy to get the screening current-induced fields with rough accuracy in a short computation time. No special advanced simulation skill is needed. We will present the facile method to estimate screening current-induced field, and the estimated results are compared with measurements and results obtained by the finite element method with the thin approximation method.

Submitters Country:

Japan

Thu-Af-Po4.06 / 1150

A Field Modulated Linear Permanent Magnet Generator for Direct-Drive Wave Energy Conversion

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Co-author(s): Haitao Yu ² ; Rong Guo ² ; Tao Xia

¹ Southeast University

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In the last two decades, the linear permanent magnet (PM) machines which could directly realize linear movement without any additional transmission mechanisms converting the rotary motion into linear motion, are applied in direct-drive wave energy conversion (WEC) [1-4]. In particular, a conventional linear permanent magnet generator (CLPMG) reciprocates at such low-speed wave motions and makes the generator considerably heavy. If operating in high-speed mode, linear generators would have high power density and low cost. Potentially, the field-modulated linear permanent magnet generator (FMLPMG), which integrates the concept of magnetic-field modulation into the linear PM machine, becomes a good candidate for a direct-drive WEC system. The slow reciprocating wave motion is directly harnessed by the translator of the proposed generator, and then the translator accelerated by magnetic field modulated principle to actuate the generator, hence producing higher output voltage. By finite element method (FEM) and experimental tests, the performances of FMLPMG and CLPMG are analyzed and compared, which confirm that the FMLPMG can offer higher power density, lower cost and higher efficiency than the CLPMG. Therefore, the direct-drive WEC system mainly composed of FMLPMG is feasible and effective and could be used to supply electric power for oceanographic observation instruments in the isolated islands. The structure of FMLPMG is similar in shape to the CLPMG, including the stator and the translator. Particularly, the translator of FMLPMG is of 9 pole-pairs PMs, and winding connection in the stator is of 4 pole-pairs, which must be equal to the pole-pairs number of the largest asynchronous space harmonic in the airgap. Moreover, the stator teeth are the function of magnetic-field modulation, which are equal to the sum of the pole-pairs number of PMs on the translator and the stator winding, viz.13.

Submitters Country:

China

Mon-Af-Po1.03 / 518

A Field-Shaking System to Eliminate the Screening-Current Field in the 800-MHz HTS Insert of the MIT 1.3-GHz LTS/HTS NMR Magnet: A Small-Model Study

Jiho Lee¹ ; Dongkeun Park¹ ; Philip Michael¹ ; Juan Bascuñán¹ ; Yukikazu Iwasa¹

¹ Massachusetts Institute of Technology

In this paper, we present results, experimental and analytical, of a small-model study, from which we plan to develop and apply a full-scale field-shaking system to minimize or even eliminate the screening current-induced field (SCF) in the 800-MHz HTS Insert (H800) of the MIT 1.3-GHz LTS/HTS NMR magnet (1.3G) currently under construction—the H800 is composed of 3 nested coils, each a stack of no-insulation (NI) REBCO double-pancakes. In 1.3G, H800 is the chief source of a large error field generated by its own SCF. To study the effectiveness of the field-shaking technique, we use a set of 3-nested and series-connected coils (3-Coil Sample) composed of 3 NI REBCO double-pancakes, one from each of the 3 H800 coils, and place it in the bore of a 5-T/300-mm room-temperature bore external magnet (5TM). 5TM is used not only to induce SCF in the 3-Coil Sample but also eliminate it by the field-shaking. For each run, we induce SCF in the 3-Coil Sample at an axial location where the external radial field $B_r > 0$, then for the field-shaking, move to another location where the external axial field $B_z \gg B_r$. To examine if other SCF eliminating techniques, e.g., the current-sweep-reversal (CSR) method, is applicable to H800 even when L500 and H800 are series-connected, we perform similar sequences of test for other combinations of the 3-Coil Sample axial locations. Additionally, we energize the 3-Coil Sample to study SCF dependence on transport current. In this paper, we report 77-K experimental results, develop an analysis that satisfactorily explains the results, and apply the analysis to design a field-shaking system for 1.3G at full operation.

Acknowledgment: Work supported by the National Institute of General Medical Sciences of the National Institutes of Health.

Submitters Country:

United States

Tue-Af-Po2.10 / 969

A Hybrid Method for the Sound Pressure Level Analysis of a Balanced Armature Receiver

Author(s): Dan-Ping Xu¹ ; Sang-Moon Hwang²**Co-author(s):** Joong-Hak Kwon³ ; Yuan-Wu Jiang¹¹ *School of Mechanical Engineering, Pusan National University*² *Pusan National University*³ *Research and Development Center, EM-TECH*

As an inherent nonlinear device, a good performance analysis method considering nonlinear characteristics of a balanced armature receiver (BAR) is necessary. This paper presents the sound pressure level (SPL) analysis of a BAR considering the nonlinear characteristics. However, based on our previous research, a mass of simulations with 3D finite element (FE) method applied in electromagnetic analysis is too complex and time consuming in modeling and simulation, especial in the processing of optimization. In order to overcome the problem mentioned above, a hybrid method maintaining both accuracy of results and computation time is proposed in this paper. In electromagnetic analysis, instead of 3D FE method, a simplified lumped parameter magnetic circuit of BAR is applied to calculate the total force and the back-EMFs generated on armature, thus the nonlinear magnetic characteristics included the cogging force, the force factor, the inductance, and the speedance could be obtained. It should be mentioned that the cogging force is the magnetic stiffness and can be considered as the negative mechanical stiffness. To eliminate the effect of cogging force, the stiffness of the vibration system should be reduced by using 3D FE static mechanical analysis. Thus the modal analysis of the vibration system is obtained. The 3D boundary element method is used in acoustic analysis. A coupling analysis with an assumed loading of forced harmonic modal based vibro-acoustic response is executed in frequency domain to acquire the assumed vibration displacement of pin and the assumed pressure on detection area. By using the nonlinear magnetic characteristics and assumed vibration displacement obtained, another coupling analysis to obtain the actual force is promoted in MATLAB. At last, with the relationships among the assumed loading, the assumed pressure, and the actual force, the actual pressure and related SPL can be obtained. The hybrid method will be verified experimentally.

Submitters Country:

Korea

Wed-Af-Po3.03 / 893

A Method for Designing an HTS Magnet Processes High-Performance and High Thermal Stability

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Since 2011, the application of a new concept of a high-temperature superconducting (HTS) coil, the so-called no-insulation (NI) winding technique, is proposed. The applied concept realizes the high-accuracy field generation and operation reliability of an HTS coil applied in next-generation high-field magnetic resonance imaging (MRI). To date, many experimental and analytical investigations

have been conducted to verify that the NI coil has high thermal stability, even during an extreme environment such as over-current. However, the forward indicators that how to realize high speed charging, high current density, and high thermal stability of meter-class NI coil in the magnet design for the practical application of MRI, have yet to be clarified. We herein reproduced the transient electromagnetic and thermal behaviours of a practical meter-class NI coil assembled in the coil-system of a 3-T HTS MRI system, during a local normal-state transition, using our proposed analysis model "PEEC-thermal coupling model". According to the the behaviours, we clarify the influence of contact resistance on the charging characteristic, and the influence of the Cu-stabilizer thickness of REBCO tape and the load factor on the thermal stability of meter-class NI coil. Finally, we hence propose a method for determining the design criteria for the meter-class compact NI coil featuring high-speed charging (tens of seconds), high current density (> 500 A/mm²@20 K), and high thermal stability ("defect irrelevant").

Submitters Country:

Japan

Thu-Af-Po4.07 / 438

A Method to Improve Forming Accuracy in Electromagnetic Forming of Sheet Metal Based on Field Shaper

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Co-author(s): Hao Huang ; Changzheng Deng ; Zhenxing Li ; Fangyu Li ; Liang Li ; Li Qiu

¹ *China*

Low forming accuracy is an important defect in electromagnetic forming process of sheet metal. One of the main reasons is that shape of coil and required workpieces cylindrical and hemisphere respectively. The distance between the coil and the deformed sheet is too far at side walls, which lead to a consequence that electromagnetic force is not enough. To solve this problem, a field shaper was designed and fabricated to improve forming accuracy for electromagnetic forming of sheet metal. To validate the effectiveness of the system, a circuit-electromagnetic-structure coupling finite element model was built for analyzing deformation process. The solenoid field shaper which was made up of copper with an inner diameter of 55 mm and an outer diameter of 150 mm was used to increase the electromagnetic force at side walls. And a series of experiments on the forming of AA1060 with a diameter of 200 mm and a thickness of 3 mm have been carried out. Experiments results showed that the maximum deviation was 0.2mm with field sharper but 2.1mm without field sharper at the side walls of the die. It was clearly proved that field shaper can greatly improve the forming accuracy in electromagnetic forming of sheet metal.

Submitters Country:

China

Tue-Af-Po2.04 / 528

A Modularon-PCB-boardhigh voltage capacitor bank charger

Houxiu Xiao¹ ; Fangmao Fu¹ ; Changran Li¹ ; Tao Peng¹ ; Xinyuan Du¹

¹ *Huazhong University of Science and Technology*

The high pulsed magnetic field is an important scientific research tool for physics, material science, chemistry, medicine and so on. And the pulsed power supply plays an important role in generating pulsed magnetic field. Among all kinds of pulsed power supply, the capacitor bank power supply is most widely used for its simply structure and high reliability. And the resonant constant current high

voltage charger is the key component of the capacitor bank power supply, it has the characteristics of high efficiency and constant current charging. However, the traditional monomer capacitor bank charger's volume is large and the cost is high.

This paper proposes a modular on-PCB capacitor bank charger to reduce the volume and the cost. Developing many identical small but full-featured LC resonant on-PCB charger, and then combining these modules through series-parallel connections to achieve voltage levels. In each module, all the components of IGBTs, diodes and step-up transformer are standard and in small size. When a module breaks down, it will be bypassed to keep the whole system properly work and can be replaced after the shot. So the present modularized charger is low cost, more compact, high reliable and easier to assemble or disassemble.

A prototype modular on-PCB charger has been successfully developed, the input voltage is AC 220 V, and the maximum output voltage is DC 2000 V, and mean charging current is 1A, and the main switches are IGBT K75T60 (75A / 600V) operated at 12.5 kHz. The serial combination experiments of three modules has been succeeded to charging a 6 kV capacitor bank. All the specific parameters and circuit schematics of one module or modules' combination will be presented as well as their experimental results.

Submitters Country:

China

Mon-Af-Po1.04 / 835

A Multi-Phase Doubly-Fed Doubly-Salient HTS Linear Motor for Vertical Transportation

Author(s): Wenlong Li¹

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As a vertical transportation apparatus for moving people and goods between floors, the elevator or lift plays an increasingly important role in the high-rise buildings. The requirements for fast velocity, comfort ability, reliability and safety issues become higher and higher. Due to its inefficiency and complicated operating system, the conventional cable elevators, which usually utilize rotational drives and hoist cables with counterweights, are no longer acceptable. By using the linear motor for propelling the elevator car, it can travel smoothly from standstill to high speed while eliminating the cables and counterweights. Hence, the efficiency, stability and reliability can be significantly improved. Linear induction motor (LIM), linear synchronous motor (LSM), and linear switched reluctance motor (LSRM) are applied for cableless elevators in recent years. For the reliability and safety concerns, LIMs and LSRMs which possess rugged and passive moving parts are favorable. The purpose of this paper is to propose a doubly-fed doubly-salient HTS linear motor (DFDS-HTSLM) for linear drives in the cableless elevator. The proposed linear motor possesses the advantages of both LSRM and LSM. It adopts a doubly-salient structure which is very similar to the LSRM. By equipping the HTS field winding for providing the field excitation, a higher thrust density can be achieved. Moreover, by adopting 5-phase armature design, the high fault-tolerance capability can be realized. With these merits, the proposed DFDS-HTSLM not only provides a high thrust density with flexible thrust control, but also can achieve higher reliability with fault-tolerant operation. By coupling the finite element method model of the proposed linear motor with the circuit simulator, the transient characteristics of the proposed motor will be performed at both the accelerating and decelerating conditions. This work is supported by a grant (Grant No. 51607114) from the National Natural Science Foundation of China.

Submitters Country:

China

Thu-Af-Po4.05 / 971

A Multi-Tooth Axial Field Flux-Switching Hybrid Excitation Machine

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Axial field flux-switching permanent magnet (AFFSPM) machine has the advantages of inherent sinusoidal back-EMF waveform, high power density, and large torque capability, which is suitable to use in electric vehicle (EV). However, the cogging torque of the AFFSPM machine is high and it is difficult to modify the flux, which limits the use in EV. In this paper, a novel multi-tooth axial field flux-switching hybrid excitation (AFFSHE) machine is proposed and investigated. The proposed multi-tooth AFFSHE machine is composed of two outer stators and one inner rotor both with a doubly-salient structure. The stator contains 6 modular multi-tooth U-shaped laminated segments, PMs, concentrated armature coils and field windings. A concentrated armature coil is wound around the two adjacent stator teeth with a piece of PM in the middle. The PMs are magnetized circumferentially and the magnetization is reverse in polarity from one magnet to the next. There is a magnetic bridge between the two adjacent stator teeth and the field windings are wound axially around the magnetic bridge. There is neither PMs nor coils on the rotor. The topology and the operation principle of the multi U-shaped stator tooth AFFSHE are analyzed. The power size equation is deduced and the size of the multi-tooth AFFSHE machine is suggested. Based on the 3-D finite element analysis, the electromagnetic performances of the multi-tooth AFFSHE machine, including the magnetic field distribution, flux-linkage, back-EMF, cogging torque, and output torque are investigated. The influence of the number of the stator tooth structure and the combination of the stator tooth number and the rotor pole number on the back-EMF and the cogging torque are investigated.

This work is supported by the Natural Science Foundation of Jiangsu Province (BK20161425), and the National Natural Science Foundation of China (51277025 and 51577027).

Submitters Country:

China

Tue-Af-Po2.06 / 693

A New Dual Stator Hybrid Excitation Flux Switching Machine with Iron Flux Bridge

Yi Du¹ ; Qi Wang¹ ; Xiaoyong Zhu¹ ; Li Quan¹ ; Chao Zhang¹

¹ Jiangsu University

Benefiting from the high energy permanent magnet (PM) excitation and flux-concentration effect, flux-switching PM (FSPM) machines usually possess the advantages of high power density and torque output. However, the FSPM motor suffers from a limited constant power operation range due to the uncontrollable PM excitation field. Therefore, hybrid excitation flux switching (HEFS) machines are proposed, which combines the merits of both PM machine and DC excitation synchronous machine. It should be noticed that all the traditional HEFS machines dispose armature windings, field windings, and PMs in its stator, thus suffering from crowded stator and poor space utilization. Consequently, the torque density and flux regulation capability will be degraded greatly. In this paper, a dual stator HEFS (DS-HEFS) machine is proposed, which is composed of an outer stator, an inner stator and a segmental rotor sandwiched between two stators. By adopted the iron flux bridge, an H-shaped laminated core can be composed and employed in inner stator. Then field windings can be wound around the iron flux bridges and PMs are sandwiched between the slots of every H-shaped core. When the field windings are unexcited, a part of PM flux is shorted by iron flux bridges, thus achieving the flux-weakening operation of proposed machine. When a DC current is fed into field windings, the iron flux bridges will be saturated and PM flux will be driven to pass through the airgap and linked by armature windings, so that a flux-enhancing operation can be performed. Compared with the torque and power versus speed characteristics, the proposed machine

has much higher flux regulation capability and torque density than traditional HEFS machines under the same PM volume. Detailed results and discussions will be given in the full paper.

Submitters Country:

China

Tue-Af-Po2.06 / 707

A New Magnetic Field Modulation Type of Brushless Double-Fed Machine

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² *Jiangsu University of Science and Technology*

Recently, brushless double-fed machines (BDFMs) have been widely developed due to the wide application prospects in electric power generation fields with variable speed, constant voltage and constant frequency performances and speed regulating systems using large capacity motor. The magnetic field generated by the two sets of windings, which are both located in the BDFM stator, indirectly coupled through the modulation of the rotor, thus resulting in the disappearance of the brush and slip ring. So the machine stability can be enhanced consequently. However, BDFM usually suffers from large size and low power density compared with that of permanent magnet (PM) machines because of the low airgap flux density provided by field windings. In this paper, a new magnetic field modulation type of brushless double-fed machine (MFM-BDFM) is proposed, which consists of a stator with two sets of windings and a rotor with permanent magnets (PMs) mounted on the rotor surface. The stator can be divided into an outer part and an inner part with different tooth number and different winding pole-pair number. The outer stator part adopts a conventional tooth-slot structure and the field windings are wound in its slots. The inner stator part is composed of segmental iron cores, which cling to the outer stator teeth, and the armature windings are housed between the neighboring iron segments. Compared with the conventional BDFMs, the excitation field provided by both of field windings and PMs are coupled with the armature windings field based on the indirectly modulation function of iron cores on inner stator part instead of the rotor, hence performing a high air gap flux density and an enhanced power density. The operation principle of proposed MFM-BDFM will be described and the electromagnetic performances will be calculated and analyzed in the full paper.

Submitters Country:

China

Tue-Af-Po2.06 / 702

A New Partitioned Stator Hybrid Excitation Flux Switching Motor with Ferrite Permanent Magnet

Yi Du¹ ; Qi Wang¹ ; Xiaoyong Zhu¹ ; Li Quan¹ ; Chao Zhang¹

¹ *Jiangsu University*

Recently, flux-switching permanent magnet (FSPM) motors have been widely developed due to the merits of high power density, essentially sinusoidal back-EMF, and high fault-tolerance capability. However, FSPM motors usually suffer from disadvantages of high usage of rare-earth permanent magnet (PM) material and relatively low flux-weakening capability. So hybrid excitation flux-switching (HEFS) motors, in which a part of PM blocks is replaced by field windings, has drawn wide attention. By feeding positive excitation current, the HEFS motor can maintain the power density

comparable with its PM counterparts, whilst deliver a wider power-speed range by flux weakening control based on negative field excitation. However there is still a conflict of locating space the armature winding, wound field winding and PMs. The goal of this paper is to propose a new partitioned stator HEFS (PS-HEFS) motor for avoiding that tradeoff. The proposed PS-HEFS motor is composed of an outer stator, an inner stator and a segmental rotor sandwiched between two stators. The tooth-slot structure is employed in inner stator, so that the field winding can be wound around the inner stator teeth and the outer stator is exactly same with conventional FSPM motors. Compared with the existing HEFS motor, the field winding is set in the inner stator. Thus, the conflict of location space in exiting HEFS motor stator can be avoided.

In this paper, the electromagnetic performances will be calculated and analyzed. The power density and torque output capability of proposed motor can be improved compared with that of the existing HEFS motor because the inner space can be utilized. And a higher Ampere-turn number is permitted for PS-HEFS motor to achieve a wider constant power speed range and higher power density benefiting from the larger slot area for field winding. Detailed results and discussions will be given in the full paper.

Submitters Country:

China

Thu-Af-Po4.07 / 757

A Novel Design of Repetitive Transcranial Magnetic Stimulator with Monophasic and Biphasic Waveform

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Transcranial magnetic stimulation (TMS) is a technique that uses time-varying magnetic field generated by pulsed coil current to induce time-varying electric field in the brain. It has been widely applied to neurological disease treatment and brain function research. Presently, the maximum usable repetitive rate of the stimulator is up to 100Hz, and the coil current normally used in TMS includes monophasic and biphasic pulses. The conventional monophasic waveform is less efficient than the biphasic pulse because of the electrical circuit, and most of the available repetitive TMS devices only provide biphasic pulse. However, as both waveforms may be preferably optimal in some applications, further study of devices that can efficiently generate these shapes at high stimulation rate is necessary. This paper presents a system topology, which is based on energy recycling method and can be used to realize both waveforms of monophasic and biphasic current for repetitive transcranial magnetic stimulator at high repetitive rate. The device system contains a LCC series-parallel resonant charging circuit, a storage capacitor, a parallel branch to the capacitor consisting of inductor and thyristor, a pair of reversed parallel discharge thyristors and an excitation coil. The energy lost during each discharge process is replenished by the resonant charging circuit, whereas the energy fed back to the storage capacitor is recycled through the parallel branch and discharge thyristors.

Based on the above design, we construct a prototype of the series-parallel resonant capacitor charge circuit and the energy-recovery discharge circuit. The experimental results show that the topology can improve the stimulation intensity at high repetitive rate with fairly low charging power, and provide both monophasic and biphasic waveforms at the same time.

Submitters Country:

China

Tue-Af-Po2.06 / 853

A Novel Five-phase Double-Stator Tubular Fault-tolerant Flux-Modulation Permanent Magnet Motor

Author(s): Huawei Zhou¹

Co-author(s): Junjie Zhang¹ ; Zhen Lu¹ ; Guohai Liu¹ ; Wenxiang Zhao¹

¹ *Jiangsu University*

Tubular permanent magnet (TPM) motors have been applied to many direct drive systems such as electromagnetic suspension. Double-stator structure can take best use of the motor space and increase the slot area. The flux-modulation structure is based on magnetic gear effect, which makes full use of effective harmonic components of magnetic field. Thus, this structure can increase the force density. Considering the motor reliability, which determines the stability of the electromagnetic suspension, the fault tolerant ability should be considered. A novel double-stator tubular fault-tolerant flux-modulation permanent magnet (DSTFT-FMPM) motor is proposed in this paper. The proposed five-phase DSTFT-FMPM motor is composed of outer stator, mover, and inner stator. The permanent magnets (PMs) are separated from the armature windings and located on the inner stator. The mover acts as modulation teeth to modulate the air gap magnetic field. The PM arrays have two magnetized directions, namely axially and radially. This improves the utilization of magnets as all PMs are used to produce the main flux, while the axial magnetized PMs reduce fringing leakage flux as compared with its counterparts. The main idea of the fault-tolerant teeth and single-layer concentrated winding is introduced to offer fault tolerance. The electromagnetic performances of the proposed motor are analyzed by using the finite-element method. The back electromotive force (EMF) is sinusoidal due to using PM arrays. The detent force is 30N after optimization. The thrust force is up to 840N with low thrust force ripple while the phase current is equal to 10A. Finally, the ratio of the mutual-inductance to self-inductance is only 2.2%. That is to say, the proposed motor offers lower detent force, higher force density and excellent fault-tolerance. More detailed content will be discussed in the full paper.

Submitters Country:

China

Tue-Af-Po2.06 / 1175

A Novel Flux-Focusing Doubly Salient Memory Machine

Hui Yang¹ ; Heyun Lin^{None} ; Z. Q. Zhu² ; Jiaming Jiang^{None} ; Shuhua Fang^{None} ; Yunkai Huang¹

¹ *Southeast University*

² *The University of Sheffield, U.K.*

This paper proposes a novel doubly salient hybrid magnet memory machine (DS-HMMM) with variable flux low coercive force permanent magnet (LCF PM) locating between the adjacent stator slots. The proposed machine is geometrically similar to a switched reluctance machine (SRM) having bi-ased flux-focusing PM excitations. The proposed machines offer the advantages of rotor robustness, assembly ease, expedient thermal management, and excellent fault tolerant capability. The magnetization state of the LCF PM can be flexibly varied by a current pulse fed by the additional DC magnetizing coils. Consequently, the energy-efficient flux regulation can be easily realized, which benefits the efficiency improvement over a wide speed range. In this paper, a 12 stator pole DS-HMMM with hybrid NdFeB and LCF magnets is presented. The developed DS-HMMM topology are characterized by parallel hybrid magnetic circuits. The high-energy-product NdFeB magnets are embedded in the stator yoke to improve the torque density, while the LCF PMs are placed between the neighboring stator slots to provide flexible air-gap flux adjustment. The magnetizing coils are wound on the slot below the LCF PM to change the PM magnetization state. In addition, the parallel magnetic circuit relationship between LCF PM and armature reaction fields permit excellent demagnetization withstand capability, which is advantageous to the on-load dynamic performance. The full paper will firstly highlight the topology and the operating principle of the proposed DS-HMMM. The design optimization will be established with the aid of the equivalent magnetic circuit modeling. The electromagnetic characteristics of the proposed machines having different rotor poles are

investigated and compared comprehensively. The DS-HMMM prototype will be manufactured and tested to experimentally verify the foregoing analyses.

Submitters Country:

China

Thu-Af-Po4.05 / 917

A Novel Partitioned Stator Flux-Reversal Memory Machine

Hui Yang¹ ; Z. Q. Zhu² ; Heyun Lin¹ ; Jiaming Jiang¹ ; Shuhua Fang¹ ; Yunkai Huang³

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² *The University of Sheffield, U.K.*

³ *Southeast University*

This paper proposes a novel partitioned stator flux reversal memory machine (PS-FRMM, which is geometrically similar to the magnetically geared machines having surface-mounted PMs and armature windings on two separate stationary bodies. The proposed machines offer the merits of alleviating the conflict between electric and magnetic loadings, and hence the armature slot areas can be increased so as to improve the torque density and efficiency. The magnetization state of the low coercive force (LCF) PM can be flexibly varied via a current pulse. Consequently, the energy-efficient flux regulation can be easily realized, which benefits the efficiency improvement over a wide speed range. Two 12-stator-slot 10-rotor-pole PS-FRMMs with hybrid NdFeB and LCF magnets are investigated in this paper. The only difference between the two models is the PM arrangements, which are characterized by series and parallel magnetic circuits, respectively. The magnetizing coils are wound on the inner stator teeth so as to change the magnetization state of LCF PMs. Besides, the spatial separation between PMs and armature windings makes the PMs far away from the hottest outer stator under heavy loaded operation. The existence of the rotor segments provides circulating path for armature fields. Hence, the PMs can well resist the demagnetization risks posed by the combined effect of temperature and armature reaction. The full paper will firstly highlight the structural features and the operating principle of the proposed PS-FRMMs. The magnetic circuit modelling will be employed to improve the magnet sizing so as to obtain a design tradeoff between torque density and flux regulation range. The electromagnetic performance of the two designs having identical overall dimensions will be compared comprehensively. Two demonstration PS-FRMM prototypes will be manufactured to experimentally verify the finite-element analyses.

Submitters Country:

China

Mon-Af-Po1.10 / 543

A Numerical Method for Simulating the Quench Behavior of Superconductors

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¹ *North China Electric Power University*

Based on finite element method (FEM) and difference method, a simulation method for the quench behavior of superconductors was introduced in this paper. With this method, the heat conduction equation of a superconductor under a thermal disturbance can be solved simply and visually. The stability of an YBCO high temperature superconducting tape under adiabatic approximation was simulated, and simulation results were in good agreement with experimental results. Based on this simulation method, two-dimensional even three-dimensional model of superconductors adiabatically or

non-adiabatically can also be developed. It is very important to study the electromagnetic characteristics of superconductors under thermal disturbances and develop superconducting magnets with high stability.

Submitters Country:

China

Thu-Af-Po4.11 / 982

A Preliminary Design of a Test Facility for testing 20 kA Nb₃Sn Cables in a Magnetic Field up to 15 T that is cooled using Small Cryogenic Coolers

Michael Green¹ ; Heng Pan²

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² *LBNL*

Cable testing in a magnetic field is usually done in liquid helium. Liquid helium is expensive to buy and in short supply. The changing of the sample can result in a lot of helium loss. Most cable test facilities are cooled and cooled-down using a large refrigerator. The refrigerator provides cooling to the sample, the magnet and all of the leads. As an alternate approach, coolers can be used to cool-down and cool the magnet and the sample and liquefy helium that is used for both the magnet and the sample. The tops of the 20 kA HTS current leads for the sample can be cooled using a single-stage cooler capable of delivering 200 W at some temperature ~70 K. If an 80 K intercept is used in addition, the tops of the HTS leads can be reduced to ~30 K. With a proper circuit, the cooler that cools the tops of the HTS leads can rapidly cool down the sample to 65 K. If separate 4 K coolers are used for the magnet and the sample one, can change samples and cool them down without affecting the superconducting magnet used to produce the test field for the conductor. This report discusses how this can be achieved using two existing Cryomech PT415 two-stage 4 K coolers and a single Cryomech AL-325 single-stage cooler that can produce 105 W at 30 K.

Submitters Country:

USA

Wed-Af-Or22 / 67

A Prototype Conductor by React&Wind Method for the EUROfusion DEMO TF Coils

Pierluigi Bruzzone¹ ; Kamil Sedlak² ; Boris Stepanov^{None} ; Davide Uglietti^{None} ; Luigi Muzzi³ ; Antonio della Corte³

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² *EPFL-SPC*

³ *ENEA*

The R&D method for the large Nb₃Sn magnets of the EUROfusion DEMO device was proposed since 2013 by the Swiss Plasma Center. A first prototype conductor (RW1) was tested in the EDIPO test facility in 2015 up to 82 kA at 13 T, confirming the low thermal strain and the lack of cyclic load degradation. After the baseline of the DEMO device was updated in 2015, the new requirements led to an updated conductor design, for 63 kA at 12.5 T. The manufacturing experience of the first prototype is exploited in a second prototype conductor (RW2), assembled and tested in 2017: the conductor aspect ratio is reduced and the segregated copper wires are replaced by a solid block of

mixed matrix stabilizer. Although designed for the TF coils, with substantially DC operation, the low AC loss of the flat cable makes the RW2 a good candidate also for the Central Solenoid (CS) conductor.

The Nb3Sn strand is supplied by WST (PRC) and the flat cable is made at TRATOS (I). The rationale of the design, the conductor manufacture, the sample assembly and the test results in SULTAN are reported.

Submitters Country:

Switzerland

Mon-Af-Po1.09 / 247

A Prototype of a 500 A class Bi-2223/AgAu Current Lead for a Conduction Cooled Superconducting Magnet

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Co-author(s): Jun Yoshida ¹ ; Yukio Mikami ¹ ; Hiroshi Ookubo ¹

¹ *Sumitomo Heavy Industries, Ltd.*

We have designed a 500 A class high temperature superconductor (HTS) current lead using Bi2223/AgAu tapes for a conduction cooled superconducting magnet. The HTS current lead consists of two terminal blocks, a support tube, and seven Bi2223/AgAu tapes with support tapes. An operating condition is 500 A at 70 K, 0.6 T by conduction cooling, and heat leakage through the current lead is 0.32 W from 50 K to 4 K. Based on the design, we fabricated a prototype of the HTS current lead (PHCL). Critical current value was 738 A at 77 K in self-fields. The initial critical current at 77 K was maintained after five thermal cycles. The PHCL could carry 500 A at 70 K, 0.6 T by conduction cooling even after 21,000 cycles of electromagnetic force (Lorentz force). These results showed that the HTS current lead had sufficient current capacity and strength against thermal stress and Lorentz force. In addition, the critical current value was measured under various magnetic field and temperature conditions. These results will be reported in this paper.

Submitters Country:

Japan

Thu-Mo-Or29 / 815

A REBCO Persistent-Current Switch, Immersed in Solid Nitrogen, Operating In the Temperature Range 10-30 K

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We present design and test results for a thermally-activated persistent-current switch (PCS) applied to a double pancake wound (DP) coil (151-mm ID, 172-mm OD), wound, using the no-insulation (NI) technique with a 120-m long, 76 micron thick, 6-mm wide REBCO tape. For the experiments reported in this paper, the NI DP assembly was immersed in a volume of solid nitrogen (SN₂), cooled to temperatures in the range from 10 K to 30 K by conduction to a two-stage coldhead, and energized at up to 600 A. The DP assembly operated in quasi-persistent mode, with the conductor tails soldered together to form a close-out joint with resistance below 15 nOhm. The measurements confirm PCS activation at heating powers below our ~1 W design value, and a field decay time constant in excess

of 300 h, limited by the finite resistance of our DP close-out joint.

Acknowledgement: This work was supported by the National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health.

Submitters Country:

USA

Thu-Af-Po4.05 / 1002

A Spoke-Type PM Vernier Machine with Multi Working Harmonics and Enhanced Flux Modulation Effect

Author(s): Tianjie Zou¹

Co-author(s): Dawei Li¹; Ronghai Qu¹

¹ *Huazhong University of Science and Technology*

With ever improving performance of rare earth permanent magnet (PM) material, PM machines have been widely used. PM vernier (PMV) machines, with the working principle of flux modulation effect, have gained increasing attentions due to their high torque density. Owing to the uniformly distributed ferromagnetic poles (FMPs), the fundamental magnetomotive force induced by rotor PMs interact with both constant and fundamental term of the airgap permeance, which produce two working flux density harmonics with different pole numbers. The stator winding is designed according to the smaller pole number. In general, the higher the pole ratio (defined as ratio of rotor to stator pole number) is, the stronger the flux modulation effect will be. It has been found that through changing the FMP pitch, i.e., configuring non-uniformly distributed FMPs, additional working permeance as well as flux density harmonics can be introduced for PMV machines. These advanced PMV machine topologies can improve the torque density by more than 20%. Based on this research work, a novel spoke-type PMV machine with multi working harmonics and enhanced flux modulation effect is proposed. This machine topology is developed from a regular spoke-type PMV machine with carefully chosen slot-pole combination, i.e., 6-slot, 18-FMP, 14-rotor pole pair and 4-stator pole pair. With a low pole ratio of 3.5, the regular topology shows no obvious advantage on output torque. Nevertheless, when the FMP pitch is changed, a main working harmonic with 2-pole pair is newly produced. Hence, the stator pole pair number is changed to 2, and the pole ratio is doubled. Through FEA, it is found that the new topology can significantly increase the back-EMF and output torque by more than 60%. The field distribution, operation principle, electromagnetic performance and design issues of the proposed machine will be investigated in detail in the full paper.

Submitters Country:

China

Mon-Mo-Or1 / 1183

A Statistical Analysis of Electrical Faults in the LHC Magnets

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¹ *CERN*

The Large Hadron Collider (LHC) at CERN has been operating and producing physics since September 2008, and has entered after a first long shut down its second, 4-year long physics run. The

LHC is to date the largest superconducting installation, counting some 10000 magnets along its 27 km long circumference. A significant operational experience has been accumulated, including the occurrence and consequences of electrical faults at the level of the main magnets, as well as their protection and instrumentation circuits. The purpose of this paper is to provide a first overview of the typical electrical faults and their frequency of occurrence in the first years of operation, and to perform a statistical analysis that can provide typical values for similar future productions.

Submitters Country:

Switzerland

Tue-Af-Po2.06 / 766

A Study for Flux-Variable Memory Motor Depending on the Position of the Permanent Magnets

SU YONG KIM¹

¹ *Korea/KETI*

Worldwide interest in the energy saving is increasing and motor industry having a significant portion of the world's electrical energy consumption also many efforts to improve the motor efficiency. Because of this reason, permanent magnet synchronous motor using rare earth-based permanent magnet is used in many areas such as vehicle equipment, household appliances. However, PMSM has a fatal flaw in view of operation speed range. When driving at high speed, it causes the high Back-EMF by Faraday's law and finally stops the motor. To solve this problem, flux weakening control is introduced. Using this method, when driving high speed, the d-axis current is applied to suppress the magnetic flux of the permanent magnet so it can operate without stop motor. However, the motor torque is independent of the d-axis current so this method leads to a decrease in efficiency. One of the solution of this problem is the variable-flux memory motor(VFMM). The VFMM has two types of the magnet. One type is a rare-earth magnet. It has high magnetic flux density. And second type has low flux density but it can magnetize and demagnetize. So using the second type magnet, total magnetic flux can be changed. Therefore the VFMM can take high torque through the high back-EMF when it magnetizing, and can take high-speed operation through the low back-EMF when it demagnetizing.

In this paper, how permanent magnets are placed in rotor is studied to get high mag/demagnetization characteristic. The VFMM having two kinds of permanent magnet materials(rare-earth, alnico) is proposed. The rotor is separated by three layers on stacking direction and analyzed using the finite element method to know how vary the magnetizing and demagnetizing voltage depending on the position of the permanent magnets. A prototype machine is produced and tested.

Submitters Country:

the Republic of Korea

Thu-Af-Po4.01 / 750

A Study of Irradiation Effects on Thermal Characteristics of COMET Pion Capture Solenoid

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COMET experiment is aiming to search for a muon to electron transition at J-PARC. It requires the muon beam with high intensity of $10^{11}\mu^-/s$. The muon beam is produced by using a series of superconducting solenoids. The solenoid magnet in which the production target is embedded, called as COMET pion capture solenoid, is estimated to be exposed to severe radiation such as the neutrons of $5 \times 10^{21} \text{ n/m}^2$. Since the irradiation induced a degradation of thermal conductivity in the thermal conduction path in the coils. The situation may cause a coil temperature rise during the beam operation and also induce difficulties in the quench protection. Therefore the quench simulation code is developed to calculate temperature distributions during a beam epration and at a quench including the irradiation effects. The estimated effects on the thermal characteristics of the superconducting coil will be presented in this paper.

Submitters Country:

Japan

Tue-Af-Po2.10 / 737

A Study on Analytical Methods of FEM-based Edge Heating System

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Co-author(s): Lee Ju

The steel industry can be regarded as indispensable key industry in all industrial fields such as automotive, machinery, shipbuilding, construction, and civil engineering industries. In the steel industry, final steel products such as hot-rolled and cold-rolled steel sheets and reinforcing steel are created by continuous casting and rolling processes after melting iron ores and iron scraps containing iron to create molten iron and reducing impurities. Among them, hot-rolled steel sheets are thin steel sheets created by pressing and stretching sheet iron after heating it formed by processing molten iron at high temperature. The edge heating system, the study subject in this paper, plays a role in maintaining the temperature by heating the edge in the process of heating hot-rolled carbon steel sheets at high temperature. Carbon steel moves at 0.5 m/s to 1.5 m/s, and the temperature increases by more than 60 °C from approximately 900 °C using the edge heating system. Eddy currents are generated in carbon steel by the magnetic flux of the edge heating system when carbon steel moves, and these eddy current are lost. The loss becomes a heat source, and carbon steel is heated to perform the role in the hot rolling process. Currently, however, characteristics analysis of the edge heating system has not been sufficiently studied. Therefore, this study aims to perform coupling analysis by coordinate mapping and to establish an analytical approach to the edge heating system.

Submitters Country:

Republic of korea

Mon-Af-Po1.08 / 580

A Study on Draw-ability of Nb Filaments for Manufacturing Nb3Sn Strand

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For the improvement of the critical current density of a multifilamentary Nb3Sn strand, a high integrity of Nb filaments should be obtained by the optimal cold-drawing process for reducing the

cross-section of the filaments. However, as the number of drawing cycles increases, the strain-hardening exponent of the Nb filaments also increases, which consequently hinders the area reduction, and even incurs the problem of breakage of the Nb₃Sn wires. In this study, the hardness and microstructure of Nb filaments were analyzed to evaluate the strain-hardening exponent changes with respect to the number of the drawing cycles. In addition, the stress analysis using the finite element method was conducted to investigate the effect of the drawing stress on the drawability.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical•electric power equipment].

Submitters Country:

Republic of Korea

Mon-Af-Po1.10 / 532

A Study on Post-Quench Behaviors of No-insulation HTS Magnet under Over-Current Conditions

Author(s): Yoon Hyuck Choi¹ ; Haigun Lee¹

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Recent studies on no-insulation (NI) winding techniques for high temperature superconducting (HTS) coils have demonstrated that an NI coil has a self-protecting feature: a localized quench heat inside the coil can be automatically diverted in the radial direction owing to the absence of turn-to-turn contacts. The obvious benefits of NI may resolve difficulties in the protection of the HTS coil, which is highly vulnerable to the quench. However, prior to applying the NI technique to the full-scale magnet including several double pancake (DP) coils, it is essential to examine the availability of the self-protecting features between the “axially connected DP coils” as well as between the turn-to-turn contacts in each DP coil. In this study, post-quench behaviors of an HTS magnet including four GdBCO DP coils were investigated through over-current tests. The purpose of the over-current tests was to intentionally quench the HTS magnet, thereby subjecting it to severe operating conditions, and then examine the thermal, electrical, and magnetic integrities of the magnet, validating the intactness of its axial self-protecting feature.

Acknowledgement: This work was supported by the Korea Basic Science Institute under Grant D37614.

Submitters Country:

Republic of Korea

Wed-Af-Po3.03 / 101

A Study on Temporal Stabilization of Magnetic Flux Focused by a Superconducting Magnetic Lens

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¹ *Hitachi Ltd.*

Superconducting magnets are required to be smaller and to use less electrical energy to generate higher magnetic fields for many applications. As a solution, Zhang et al. [1] suggested a magnetic lens using high-temperature superconducting bulks. However, the focused magnetic field kept decreasing at a rate of about 1.3%/hour even if the current flowing in the outer superconducting coil kept constant for 20 minutes. This study examines to study a method for stabilizing the focused magnetic fields. A magnetic lens was fabricated with three GdBCO bulks. The magnetic lens was inserted in to a bore of MgB₂ superconducting coil with an inner diameter of 220 mm. The MgB₂ coil and the magnetic lens were cooled down. The MgB₂ coil was energized up to 300 A. The current was kept constant afterward. The temperatures of the three bulks were controlled using heaters, and the temperatures were reduced at the same time when energization currents reached a value of an ignition current, which were used as a parameter and set from 200 A to 285 A. The magnetic fields were measured during the operation. At the constant current of 300 A for 20 minutes, the minimum reduction rate of the magnetic field was 237 ppm/hour for the ignition current of 285 A. In addition, a combination of the temperature-reduction method and current reversal sweep method [2] from 300 A to 285 A was tested. The combination method decreased the reduction rate of the magnetic field at a constant current to 30 ppm/hour. The methods effectively provided higher stability of the magnetic fields. Further studies on operation and design methods for a magnetic lens can realize higher stability of the magnetic fields.

Z. Y. Zhang et al., SUST, 26, (2013) 045001

Y. Yanagisawa et al., Physica C, 469, 22, 1996-1999

Submitters Country:

Japan

Wed-Af-Po3.11 / 567

A Study on Thermal and Electrical Characteristic of Metallic Cladding GdBCO Coil

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A no-insulation (NI) winding technique has been utilized in high-temperature superconducting (HTS) coils owing to enhanced thermal and electrical stabilities as well as high mechanical strength. However, the charge-discharge rate of the NI coil is considerably slower than that of completely insulated coils. Although metal-insulation (MI) and partial-insulation (PI) winding techniques have been suggested to ameliorate the slow charge-discharge rate of the NI coil, the current density of MI coils and mechanical strength of PI coils are respectively lower than those of their NI counterparts. Therefore, a metallic cladding (MC) winding technique that utilizes the HTS tape employing a μm -thick metallic cladding layer has recently been developed to resolve the drawbacks of the PI and MI coils. In this study, we examined the charge-discharge rate and thermal/electrical stabilities of the MC GdBCO coil through charge-discharge, sudden discharge and over-current tests. Based on the test results, we discussed the feasibility of the MC winding technique to obtain a thermally stable and mechanically robust HTS magnet with an enhanced overall current density.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical-electric power equipment] and in part by the Korea Basic Science Institute under Grant D37614.

Submitters Country:

Republic of Korea

Wed-Af-Po3.11 / 556

A Study on Thermal and Electrical Stabilities of GdBCO Coils Impregnated with Epoxy Composites Using Surface-Treated Carbon Nanotube Fillers

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Recently, there have been sustained efforts to develop novel epoxy composites including various fillers for improving the physical properties of the epoxy-impregnated superconducting coil. Among the various filler materials, carbon nanotubes (CNTs) have emerged as one of the promising candidates because of the high thermal conductivity as well as the superior mechanical strength. However, achieving the desired thermal and mechanical properties of CNT/epoxy composites is difficult due to poor dispersion of CNT fillers in epoxy resins. Therefore, the uniform dispersion of CNTs should be obtained through surface treatments such as acid treatment and amine treatment, to enhance the physical properties of superconducting coils impregnated with epoxy composites using the CNT fillers. In this study, the thermal and electrical characteristics of GdBCO coils impregnated with epoxy composites containing surface-treated CNT fillers were evaluated through the thermal quench, over-current, and repetitive cooling tests. In addition, the degree of dispersion of the CNT fillers in the epoxy resin was examined through scanning electron microscope (SEM) analysis.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical-electric power equipment] and in part by the Korea Basic Science Institute under Grant D37614.

Submitters Country:

Republic of Korea

Wed-Af-Po3.05 / 142

A Study on a New Structure Ferrite Magnet Motor with Improved Output Density and Mechanical Stability

Author(s): KIDOEK LEE¹

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¹ *Korea Electronics Technology Institute*

Recently, much research has been conducted on non-rare-earth magnet motors due to limited reserves and high prices of rare-earth materials. Among them, a magnetic flux concentrating motor using a ferrite magnet is being commercialized in many parts. However, it is disadvantageous to high-speed operation due to the structure of the rotor. In this paper, we propose a hybrid structure of a magnetic flux concentrating and an axial motor to solve this problem and named it FC-AFPM motor. In the axial direction motor, the axes for generating torque and centrifugal force are separated from each other to ensure mechanical stability. FC-AFPM can increase the power density by using ferrite magnets, and is excellent in mechanical stability and suitable for high-speed high-torque applications. Double-sided and Single-sided FC-AFPM motor were designed and evaluated, and the validity of the proposed new structure was verified.

Acknowledgements: This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy (No. 201520201065200)

Submitters Country:

Republic of Korea

Thu-Af-Po4.05 / 597

A Study on the Auto-MTPT Algorithm to Make the Speed-based Current-map of IPMSM for Traction of Inwheel

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Theoretical IPMSM control technique is complicated, and reliability is low, because of the changing parameters. Further, in case of general look-up table designing method which obtains torque characteristics(according to current and speed) or torque characteristics(according to magnetic flux through the entire control region), obtaining a precise result can be difficult and has the disadvantage taking too much time to establish a current look-up table. In this paper, the new auto maximum torque point tracking(MTPT) algorithm that automatically finds the optimum stator d-q axis electric current reference through the entire speed region is devised; consequently, it could establish a 3D look-up table with torque characteristics according to current and speed. In the case of using the devised auto MTPT algorithm, the result value detailed was obtained in comparison with the generalized look-up design technique, and checked to reduce the current look-up table establishment time.

Submitters Country:

Korea

Tue-Af-Po2.06 / 736

A Study on the Design of IPMSM for Reliability of Demagnetization Characteristics-based Rotor

Author(s): Geochul Jeong^{None}; Jong-Suk Lim^{None}; Gang-Seok Lee^{None}

Co-author(s): Ju Lee

The recent next-generation railway vehicles are aiming at energy saving and weight lightening and IPMSM(Interior Permanent Magnet Synchronous Motor) with a more improved efficiency and weight to output ratio than induction motor when rare-earth permanent magnet with high energy density is applied to synchronous motor have been developed a lot. Interior permanent magnet synchronous motor, used in this study is a high-capacity traction motor for railway vehicles and has a totally-enclosed structure to prevent dust, foreign materials, etc during operation as it is placed at the bottom of railway vehicles. This totally-enclosed structure is vulnerable to temperature because the cycle of heat is not good. The high-capacity traction motor for railway vehicles requires a high weight to output ratio and to increase the weight to output ratio, rare-earth neodymium permanent magnet with high energy density should be used, but are characterized by high-temperature demagnetization. Also, high current may flow due to failure in power converter and it may produce a big reverse magnetic field and be demagnetized by the reverse magnetic field. Demagnetization characteristics caused by such high- temperature demagnetization and reverse magnetization are characterized by permanent demagnetization as a new demagnetization curve called as recoil line is generated. This study proposes how to interpret demagnetization characteristics and carries out demagnetization analysis to obtain the reliability of rotor. It sets up an analysis scenario to drive electric motor based on demagnetization characteristics by considering recoil line and predicts the demagnetization of permanent magnet. And it examines the effects of output based on predicted demagnetization characteristics. It manufactures a model verified through analysis as test product and designs interior permanent magnet synchronous motor to obtain the reliability of rotor based

on demagnetization characteristics proposed in this study through performance test and saturation temperature tests.

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 800

A Study on the New Skew Methodology by Cross-Stacking in Spoke type Ferrite Magnet Motor

Won-Ho Kim¹ ; Sung-Gu Lee²

¹ *Gachon University*

² *Busan University of Foreign Studies*

Generally, skew of the motors is applied to the rotor to reduce the cogging torque and the harmonic components of electromotive force (EMF). In particular, a motor rotating at a high speed of 10,000 rpm or more is more important because of noise and controllability. However, in the case of the spoke type ferrite magnet motors (FMMs), the structural problem of splitting the magnets makes skew application difficult in mass production. In this paper, we propose a new method to obtain a similar effect to the rotor skew by cross-stacking two cores without splitting the magnets in the rotor structure of the spoke type FMMs. Generally, a motor rotating at a high speed includes a part for fixing the magnet and a part for fixing the injection molding to prevent scattering of the rotor. At this time, two parts are very different in shape, and the magnetic flux also flows in different paths. If two parts are formed asymmetrically around the pole piece, and the left and right sides are alternately stacked, two waveforms having different phases are merged to produce the same effect as skew. The objective function is amplitude of the cogging torque, the total harmonic distortion (THD) of the EMF, and the mechanical stiffness of the rotor at high speed. And the optimal design is performed using the above two parts shape design variables. To verify the feasibility of the proposed method, we applied it to the design of a driving motor for a drum washing machine rotating at a maximum speed of 18,000 rpm. The performance improvement was confirmed through manufacturing and testing. Finally, proposed method can be applied not only to Spoke type FMMs but also to interior permanent magnet synchronous motors (IPMSMs) and inset type permanent magnet synchronous motors.

Submitters Country:

Korea, Republic of

Mon-Af-Po1.04 / 841

A Study on the Optimal Design of Step Skew Considering End Effect and Interaction Between Layers in Step Skew

Author(s): SUNG GU LEE¹ ; Won-Ho Kim²

Co-author(s): Jaenam Bae³

¹ *Busan University of Foreign Studies*

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Cogging torque reduction is a design objective function which is very important in certain fields such as an EPS driving motor in which direct contact with a driver occurs. In order to reduce cogging torque, skew is applied to the stator or rotor in these applications. Rotor skew is preferred over stator

skew for improved mass productivity. In particular, a permanent magnet (PM) motor is subjected to a step skew instead of a continuous skew of the induction machine due to the permanent magnet of the rotor. Previous studies have used the following two assumptions in the step skew of a permanent magnet motor. First, each layer separated by step skew has a simple proportional cogging torque to the lamination length. Second, physical quantities such as magnetic flux density in each layer of step skew are changed into step functions. In other words, there is no interval of change of physical quantity between layers. But these two assumptions are wrong. The effective magnetic flux is reduced by the end effect of the layers located at the top and bottom of the lamination. As a result, cogging torque is generated in the layer of top and bottom smaller than the lamination length ratio. There is also a region in which physical quantities such as magnetic flux density continuously change between the layers. In this paper, we have modeled this actual situation by closed formula form using analytical method and FEM. Using these modeled equations, we have derived the optimal step skew angles under the conditions considering both the end effect and interactions between layers. The validity of the proposed results is verified by 3D FEM analysis and experiments of fabricated motor.

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 764**A Study on the Position Signal Compensation Control Technique of Hall Sensor Generated by Uneven Magnetic Flux Density**JONGSUK LIM¹ ; Lee Ju^{None} ; Sol Kim² ; Dong-Woo Kang³¹ *Hanyang university*² *Electrical Information Department, yuhan university*³ *Keimyung University*

BLDC motors and controllers are used in many industrial fields due to the decline of permanent magnet price and the lower cost semiconductor devices. The BLDC motor is easy to maintain as compared to the DC motor and has the advantage of small size, high power, low noise, etc. The BLDC motor is generally used a lot of 120degree energizing method. Also, this motor is commonly controlled by a Hall sensor, which is a relatively low-resolution position sensor, or by a sensorless control method, which is controlled without a position sensor. The hall sensor detects the magnetic field generated by the magnet inserted in the rotor of the motor and uses it as a position signal. When the hall sensor is used for control, the energizing period of the BLDC motor is determined by the position signals of the three hall sensors. These hall sensors detect the position of the rotor by attaching three hall sensors to the rotor at intervals of 120 degrees. However, there may be an error in the mounting position of the hall sensor. The incorrect energizing interval is caused by the mounting position error of the hall sensor. In this paper, the phenomenon of incorrect energizing interval due to the mounting position error of the hall sensor is analyzed. The value of this error is derived as an equation and an algorithm that compensates for the error value is studied. In addition, the maintenance of accurate energization interval is verified even though Hall sensor has the positional error. Therefore this paper provides the quantitative analysis of the error by the mounting position error of the hall sensor and the effectiveness of the algorithm which can compensate for the error.

Submitters Country:

South Korea

Wed-Af-Po3.08 / 510**A Study on the Power Converter Performance Comparison & Optimal design induction heating coil for IH jar**

Author(s): Hee-Jun Kim¹ ; Sang-Taek Lee²

Co-author(s): Yong-Seung Oh¹

¹ *Hanyang University*

² *Korea Electronics Technology Institute*

The principle of the induction heating is based on the Faraday's law of electromagnetic induction. High frequency AC current flowing through the working coil induces magnetic field to the designated direction. The induced magnetic field enables Eddy current to flow at the surface of the conduction material located in the magnetic field and the current flowing through the conductor produces thermal energy. The IH application has been rapidly developed according to the development of power semi-conductor devices since 1980 because of following advantages compared with the direct fired heating method. The IH technology is used for induction furnace, melting, and heat treatment of metal as industrial applications while microwave oven, IH rice cooker, IH cooker as kitchen applications. Especially, IH products for home cookware are highly interested. Among them, IH electric rice cookers are being developed mainly in Southeast Asia including Japan, Korea, and China. In this paper, modeling an electric circuit of a working coil and an inner pot and modeling integrated equivalent circuit for electric field analysis. Through the modeling results, working coil structure suitable for IH electric rice cooker to optimize heat conversion efficiency was optimized and designed. As a result of the experiment, it was confirmed that the conversion efficiency of about 3% was improved

Submitters Country:

Republic of Korea

Tue-Af-Po2.06 / 876

A Study on the Selection of the Optimal Number of Poles for Maximizing the Magnetic Flux of Spoke type Permanent Magnet Motor

SUNG GU LEE¹ ; Won-Ho Kim² ; Jaenam Bae³

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Permanent magnet (PM) motors are field magnetic fluxes generated from PMs without external current input, which is advantageous in terms of power density and efficiency than non-PM motors. Due to these advantages, it has recently been applied in various fields such as electric vehicle and home appliances. The PM motor used mainly in the past was a surface mounted type in which PMs were attached to the surface of the rotor core. Recently, however, the use of spoke-type PM motor, which is extreme forms of V shape Interior PM motors, is on the rise. This is because the spoke type motor is superior in terms of the output density and the efficiency than the conventional surface mounted type motor. In the surface mounted type motor, the total magnetic flux amount does not increase even if the number of poles increases when the PM usage is the same. Rather, as the number of poles increases, the leakage flux between poles increases, and the total flux decreases monotonically. However, the spoke type motor shows a form of a quadratic function having a maximum value of the total magnetic flux amount as the number of poles increases. As a result, the total magnetic flux of spoke type motor can be maximized by selecting the optimum number of poles. In this paper, we study the optimum number of poles to maximize magnetic flux of spoke type motor. For this purpose, the total magnetic flux of the spoke type motor was expressed as a closed formula of the motor parameters such as the number of poles, the air gap, and the PM size. Closed formulas are derived through analytical methods that combine magnetic equivalent circuit and conformal mapping. The validity of the proposed formula was finally verified by 3D FEM and experiments.

Submitters Country:

Republic of Korea

Thu-Af-Po4.01 / 1074

A Study on the Sextupole Design with Iron Yoke inside Solenoids for 56 GHz ECR Ion Source

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The third generation of electron cyclotron resonance (ECR) ion sources is in operation or under development in the world. The fourth generation ECR ion sources are expected to operate at a heating radio frequency greater than 40 GHz, requiring a higher confinement field. Such requirements provide the motivation to design the structure of the fourth generation ECR ion sources. The Nb3Sn wire, which can generate fields in the 10–20 T range, is considered to construct the magnet coils to analyze the sextupole in this study. Firstly, for both of solenoid-in-sextupole structure and sextupole-in-solenoid structure, the critical current of materials and the local magnetic field are analyzed and compared. By the comparison, sextupole-in-solenoid structure is selected to construct sextupole magnet for 56 GHz ECR ion source. Considering the characteristics of the wire, iron yoke is considered to be added around sextupole to provide a structure for the sextupole coils. Then, the confinement fields and the safety margin of the wire are analyzed and compared in the without iron yoke model and in the iron yoke model. The Lorentz force on sextupole ends w.r.t the length of sextupole is discussed. Finally, a design of sextupole with shorter iron yoke is presented in this study. With the suggested sextupole design, the length of sextupole and the total size of ECR ion source can be reduced.

Submitters Country:

Korea

Wed-Af-Po3.10 / 797

A Study on the V-t Characteristics of PPLP according to Electric Field Uniformity for a Superconducting Transformer

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The application of high voltage superconducting apparatuses is considered as one of the most promising countermeasures against the increased power consumption. In order to ensure the electrical safety of high voltage superconducting apparatuses such as superconducting transformers and superconducting cables, the electrical insulation design should be conducted considering aging characteristics. In this study, V-t characteristics of polypropylene laminated paper (PPLP) known as the most proper solid insulation material for a high voltage superconducting transformer. V-t characteristics of PPLP according to its electric field uniformity are experimented analyzed to ensure the reliability of long-term operation. Dielectric experiments are conducted in saturated liquid nitrogen of 77 K in temperature. Dielectric experiments on V-t characteristics of PPLP are performed with four kinds of sphere-plane electrode systems according to various pressures. It is found that aging characteristics of PPLP are dependent on the electric field uniformity as well as pressure.

Submitters Country:

Republic of Korea

Mon-Af-Po1.05 / 1124**A Superconducting Linear Variable Reluctance Machine for Urban Transportation Systems**T.W. Ching¹ ; Wenlong Li²¹ *University of Macau*² *The University of Hong Kong*

Electrification of urban transportation systems has been considered as the most promising solution for reducing the air pollution, the oil dependence and improving the energy efficiency. Therefore, it becomes more and more popular around the world. The fundamental components in these systems are electric motors which provide the propulsion force. Practically, the electric propulsion by linear motors is characterized by rapid acceleration / deceleration, negotiate steep gradients, immune to be bad weather and reduced maintenance cost. Thus, this technology attracts more and more attention recently. The purpose of this paper is to propose a new linear variable reluctance motor (LVRM) for the electric propulsion in urban transportation systems. The new LVRM will be equipped with both armature and field windings for a doubly excitation. Thus, the so-called excitation penalty existing in traditional VRMs can be alleviated. Furthermore, by introducing an additional superconducting DC field winding used for excitation, the air-gap flux can then be flexibly controlled hence extending the constant-power range, and improving efficiency. The stator (rail) is simply composed of iron core without windings nor PMs. This contributes to a very low inertia and low cost system, robustness and suitable for high speed operation. Since each phase of the proposed machine is magnetically decoupled from each other, it is easy to design a 5-phase machine based on the proposed machine topology. Within the mover (car), each phase is separated with a certain electrical degree. While inside the stator (rail), successive toothed-pole structure is adopted which is similar to other doubly-salient linear machines. The detailed design, analysis and verification will be presented in the full paper.

This work was supported by a grant (Project No. MYRG2015-00218-FST) from Research Council of the University of Macau, and a grant (Grant No. 51607114) from the National Natural Science Foundation of China, China.

Submitters Country:

Hong Kong

Wed-Af-Po3.07 / 1102**A Superconducting Magnetic Density Separation Laboratory Demonstrator****Author(s):** Jaap Kosse¹**Co-author(s):** Herman Ten Kate² ; Marc Dhallé¹ ; Marcel ter Brake¹ ; Peter Rem³¹ *University of Twente*² *CERN*³ *Delft University*

An optimized NbTi-magnet lay-out has been designed for a Magnetic Density Separation (MDS) system. MDS is a novel recycling technology that allows the separation of non-magnetic materials based on their mass density. In the process, products are submerged in a ferro-fluid stream that flows over a magnet system which produces a strong vertical field gradient. The combined weight

of the particles and magnetic force on the fluid results in different equilibrium heights for particles with different mass density. State-of-the-art MDS uses permanent magnets, limited in size and strength. This work replaces the permanent magnets with superconducting ones, enabling higher field strength and system size, resulting in a more dilute ferro-fluid and a deeper fluid bed. The main project goal is to demonstrate the benefits of superconducting MDS by building a NbTi-system integrated in a complete MDS set-up. Significant progress has been made towards the system design. To minimize fluctuations in particle trajectories, the magnetic field gradient ideally should only have a vertical component. This vertical gradient should be constant in the horizontal directions and in practice decays exponentially with the distance to the coils. Optimized coil configurations have been identified that minimize vertical magnetic field gradient variations. In a finite-length magnet system horizontal gradient components are unavoidable, which slow down particles. Thus a minimum flow speed is required to prevent clogging. Also, the particles need some time to reach their equilibrium heights. These contradictory requirements were investigated by numerical simulations of particle trajectories, leading to optimal system length and flow speed estimates. Construction of the magnet will start in the second half of 2017.

This work is part of the research programme “Innovative Magnetic Density Separation for the optimal use of resources and energy” with project number P14-07, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

Submitters Country:

The Netherlands

Wed-Af-Po3.05 / 975

A Superconducting Vernier Motor for Electric Ship Propulsion

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Due to the high efficiency, high power density and high flexibility for maneuvering and docking, electric propulsion systems for marine propulsion attract more and more attention in recent year. Generally, the motor for marine propulsion operates at a low speed which implies that the size of the motor tends to be large. By eliminating the transmission gear, the vernier permanent-magnet (PM) machine is very suitable for low-speed high-torque direct-drive applications. However, for those power levels beyond Mega Watts, the costs for PM machines are high and the PM is also subject to demagnetization due to overheat and mechanical vibrations. Based on these concerns, the superconducting motors are invented for the marine propulsion applications. In this paper, a new vernier machine (VM) is proposed which incorporates high temperature superconducting (HTS) field windings for the field excitation. Therefore, the power density of the proposed machine can greatly be improved and meanwhile avoiding the irreversible demagnetization of PMs. The proposed HTS-VM for electric ships adopts an inner-stator and outer-rotor configuration. The stator adopts the split-pole structure. Both the armature and the HTS field excitation windings are housed on the stator, therefore the structure of the stationary parts can be significantly simplified and the reliability is hence improved. Correspondingly, the rotor consists of iron lamination only. By using the iron core, the consumption of HTS wires will be reduced. The finite element method will be used for field calculation and machine analysis. Since the DC current in the HTS coils can be flexibly controlled, the starting torque can be enhanced and the constant power speed range can also be extended. Detailed design, analysis and evaluation will be presented in the full paper.

This work was supported by a grant (Project No. MYRG2015-00218-FST) from Research Council of the University of Macau.

Submitters Country:

Hong Kong, China

Mon-Af-Po1.04 / 1095

A Synthetic Frozen Permeability Method to Separate PM torque in Hybrid Permanent Magnet Variable-Flux Machine

Author(s): Meng Ge¹**Co-author(s):** Jian Li¹; Ronghai Qu¹; Yang Lu¹; Junhua Chen¹¹ *Huazhong University of Science & Technology*

Frozen permeability method has been widely used in separating the PM torque and reluctance torque and calculating inductance. For conventional frozen permeability method (CFPM), only the core permeability is fixed. It is suitable for the machine applying rare-earth PM materials such as NdFeB, since the material B-H curve is linear and coincide with the recoil line. However, when dealing with machines applying nonlinear PM materials, CFPM will cause obvious errors. Unlike rare-earth magnet, AlNiCo has nonlinear demagnetization curve and the recoil lines of different operate point are a set of parallel lines with different coercive force, causing the output of AlNiCo different. So when accounting for the effectiveness of AlNiCo, the recoil line should be kept as same as full load condition. Therefore, this paper proposes a synthetic FPM (SFPM) to accurately calculate torque components of machines applying nonlinear PM materials. Hybrid permanent magnet variable flux machines (HPM-VFM) applying both linear and nonlinear PMs are proposed to validate the accuracy of SFPM. For the machine analysis, nonlinear FEA at a particular load condition is carried out firstly. In each simulation block, operation points of AlNiCo are recorded and a linear PM material which passes through point (Bi, Hi) with a slope of the recoil permeability is defined. Then a FEA with this linear material is carried out. Entire machine torque calculated by SFPM is 6.36Nm, which matches well with the result calculated by the nonlinear FEA 6.52Nm with only 1.07% error. Besides, AlNiCo PM torque, NdFeB PM torque and reluctance torque calculated by SFPM is 2.46Nm, 3.90Nm and 0.23Nm respectively. The CFPM results, whose PM torque is 5.88Nm and reluctance torque is 0.23Nm has 6.29% error comparing with nonlinear FEA. More elaborate results of analysis and comparison will be exhibited in the full paper.

Submitters Country:

China

Thu-Af-Po4.04 / 402

A Tabletop Liquid-Helium-Free, Persistent-Mode 1.5-T/70-mm MgB₂ Osteoporosis MRI: Two Magnet Design Options

Author(s): Dongkeun Park¹**Co-author(s):** Timing Qu²; Min Cheol Ahn³; Juan Bascuñán¹; Philip Michael¹; Yukikazu Iwasa¹¹ *Massachusetts Institute of Technology, Francis Bitter Magnet Laboratory, Plasma Science and Fusion Center*² *Tsinghua University*³ *Kunsan National University*

In this paper we present two design options for a tabletop liquid-helium-free, persistent-mode 1.5-T/70-mm MgB₂ "finger" MRI for osteoporosis screening. Both designs, one with and the other without an iron yoke, satisfy the following criteria: 1) 1.5-T center field with a 70-mm room-temperature bore for a finger to be placed at the magnet center; 2) spatial field homogeneity of <5 ppm over a 20-mm diameter of spherical volume (DSV); 3) persistent-mode operation with temporal stability of <0.1 ppm/hr; 4) liquid-helium-free operation; 5) 5-gauss fringe field radius of <50 cm from the magnet center; and 6) small and light enough to use on an exam table. Although the magnet is designed to operate nominally at 14 K, maintained by a cryocooler, it has a temperature margin of 6 K to keep its 1.5-T persistent field over the 14-20 K operating temperature range. The magnet is immersed in a volume of solid nitrogen (SN₂) that provides additional thermal mass when the cryocooler is switched off to produce a vibration-free measurement environment. The SN₂ enables the magnet to

maintain its persistent field over a period of time sufficient for quiescent measurement, while still limiting the magnet operating temperature to no higher than 20 K. We discuss first pros and cons of each design, and then technical challenges and further studies of our proposed MgB₂ MRI magnet. Acknowledgement: Research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health

Submitters Country:

United States

Thu-Af-Po4.06 / 135

A Two-dimensional Equivalent Mode of a Homopolar Synchronous Machine

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Homopolar synchronous machine (HSM) has a solid rotor with no permanent magnet, winding and any other components. Therefore, the HSM has the merits of high speed operation, high energy storage density, brushless excitation, reliable structure, etc. However, when the HSM is analyzed and optimized by finite element analysis (FEA), the 3-D magnetic flux distribution in the HSM leads to the great demands on the computation resource and time. In order to solve the aforementioned problem and simplify the analysis, a 2-D equivalent mode is proposed in this work. Firstly, the method of air-gap flux density spatial overlay analysis is proposed and illustrated. Afterward, based on the above analysis, the structure and equivalent principle of 3-D to 2-D mode are investigated, such as the rotor structure, the value of exciting current, and so on. Finally, the air-gap flux density and back electromotive force of 2-D mode and corresponding 3-D mode are calculated by FEA. An experimental platform of HSM is also constructed to validate the proposed 2-D mode. The simulation and experimental results show that the proposed 2-D model can be equivalent to the 3-D HSM, which would be helpful for the design and optimization of this kind of machine.

Submitters Country:

China

Wed-Af-Po3.08 / 52

A Wide Aperture Superconducting Vector Magnet for photon beam-lines: WAVE Photons

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A 1 T Wide Aperture Vector magnet, WAVE Photons, dedicated to the soft x-ray experiment resonant scattering (SEXTANTS) beamline at Synchrotron SOLEIL, is developed by CEA, SOLEIL, Institut

Néel and the Company SIGMAPHI. The scientists study electronic and magnetic properties under applied magnetic field using different techniques such as Resonant Inelastic X-ray Scattering (RIXS), X-Ray Magnetic Resonant Scattering (XRMS), Coherent X-ray Imaging (CXI) and Fourier Transform Holography (FTH). New research will be led with the superconducting 1 T 3D WAVE photons magnet. It features a wide 200° horizontal aperture and a wide 10° vertical aperture. It offers a 60 mm vertical aperture and a 30 mm high side access for samples. WAVE photons is compatible with the existing experimental instruments and with the ultra-high vacuum of the experimental end-station. Based on an innovative design (patent FR12 62 070, US extension 14/105,711 and patent BD17525SG), WAVE photons has 16 NbTi solenoids, all with vertical axis, imbedded in an aluminum box and dry-cooled by two cryocoolers. The vertical field is produced by four flat coils (two coils in quasi Helmholtz position and two coils for active shielding), while the horizontal field is generated by 3 sets of 4 coils each, two above and two below the beam plane connected in an antisymmetric way. The WAVE coils are energized by four Current Supplies through HTS current leads. The magnet will be commissioned in 2018. This work is supported by the ANR Contract ANR-16-CE09-0009.

Submitters Country:

France

Thu-Af-Po4.11 / 868**A device for characterizing the circumferential strain dependence of the critical current in MgB₂ wires and tapes****Author(s):** Mario Kazazi¹**Co-author(s):** Christophe Berriaud²; Clement Hilaire³; Thierry Schild⁴; Loris Scola²¹ Cea Saclay² CEA Saclay³ CEA Saclay / Irfu⁴ CEA

From several years now at CEA/Saclay has been lunched a program that aims at developing design tools and technologies for conduction-cooled MgB₂ magnets. In the framework of this program, a device for investigating the circumferential strain dependence of the critical current density in MgB₂ wires and tapes has been designed. It has to be integrated into the existing test facility which provides 600 A dc current power, 3 T background field, and is conduction-cooled down to 4 K by a two-stage GM cryocooler. In this device a new spring geometry is investigated, where the conductor is tested in a magnet-like configuration by applying a uniformly distributed circumferential strain (up to 1%) to a ring-shape spring. The paper focuses on the mechanical design, analytic calculations, and numerical simulations of the spring geometry. Moreover, experimental tests on a mock-up model of the device are performed in order to validate the working principle and the materials properties.

Submitters Country:

France

Thu-Af-Po4.09 / 669**A fast 10 kA current switch for High Temperature Superconductor accelerator magnets****Author(s):** Marco Statera¹; Francesco Broggi²; massimo sorbi³**Co-author(s):** Antonio Paccalini⁴; Mauro Quadrio¹¹ INFN Milano - LASA

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INFN developed at LASA lab (Milano, Italy) a fast current switch in the framework of the EuCARD-2 project. A full prototype of a 10 kA fast switch based on insulated gate bipolar transistor (IGBT) modules operating in about 1 ms has been developed, installed and tested in the existing power supply at LASA lab. The upgraded power supply is meant to operate on the EuCARD-2 high temperature superconductor (HTS) accelerator prototypes. The design, the construction and the test of the fast switch are reported. The preparation of a test bench to test HTS magnet in a range of temperature from 4 K to 80 K is also reported.

Submitters Country:

ITALY

Thu-Af-Po4.10 / 805

A field mapper for the determination of the multipole components of the curved HESR dipole magnets

Author(s): Jan Henry Hetzel¹

Co-author(s): Jürgen Böker¹; Ulf Bechstedt¹; Steffen Quilitzsch¹; İlhan Engin¹; Christian Ehrlich¹; Bryan Bationo¹; Parth Tripathi¹; Helmut Soltner¹

¹ Forschungszentrum Jülich GmbH

Research Center Jülich is responsible for the design and construction of the High-Energy Storage Ring as a contribution to the future Facility for Ion and Proton Research (FAIR) at GSI in Darmstadt, Germany. In particular curved dipole magnets with a length of about 4.2 m are being manufactured, and their magnetic field should be characterized in terms of their multipole content. For these measurements we designed and built a mobile field mapper. It comprises eight triaxial Hall sensors, which can be moved along the curved center line of the dipole as well as rotated around it. Our contribution will highlight the design and first measurements with this new device.

Submitters Country:

Germany

Tue-Af-Po2.05 / 621

A long solenoid HTS magnet with the Joint-less winding technique

Author(s): Woo-Seok Kim¹

Co-author(s): Seyeon Lee²; Miyeon Yoon²; Sang Ho Park²; Ji-Kwang Lee³; Gye-Won Hong²; Kyeongdal Choi¹

¹ Korea Polytechnic University

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Persistent current mode operation of a second generation (2G) high temperature superconducting (HTS) magnet is one of the bottleneck techniques for an HTS NMR or MRI applications. In order to realize the persistent current mode in the HTS magnet, the authors had proposed the concept

of joint-less winding method with 2G HTS wide conductors and verified successfully that it could maintain reasonable amount of the persistent current in multiple stacked HTS pancake coils with perfect closed superconducting loops. In this paper, we will improve the quality of the magnetic field with a long solenoid HTS magnet wound by the similar technique. Instead of the multiple stacked pancake coils, a single long solenoid HTS magnet with layer winding will be fabricated for the better spatial homogeneity of the magnetic field. The magnet will be operated in the liquid nitrogen first to show the availability of the new solenoid HTS magnet wound by the joint-less winding technique. “This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning (2016R1A2B4013151)”, “This research was supported by Korea Electric Power corporation [grant number: 16104]”

Submitters Country:

South Korea

Thu-Af-Po4.10 / 155**A method based rotating coil to find magnetic center for series quadrupole magnets at IMP****Author(s):** Jing Yang¹**Co-author(s):** Wenjie Yang² ; Qinggao Yao² ; Guozhu Cai²¹ *Institute of Modern Physics Chinese Academy of Sciences*² *colleague*

For the quadrupole magnets of the Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU), the location of the magnetic center has to be known. The FRIB included 115 quadrupole magnets in seven kinds of specifications, to minimize the measurement time and cut the measurement costs, the IMP Magnetic and Machinery Department proposed a method using a rotating coil to measure the magnetic center of the quadrupole magnets with different diameter. The measurement procedure is described and the reproducibility is achieved. In addition, the measurement results of the quadrupole magnets with different diameter are illustrated.

Submitters Country:

China

Wed-Af-Po3.09 / 1031**A method of critical current measurement for HTS tape using pulsed current****A-Rong Kim**¹ ; **Zhong-Soo Lim**² ; **Taewon Kim**² ; **Minwon Park**³ ; **Kiwook YUN**⁴ ; **Sangwon Yoon**⁵ ; **In-Keun Yu**⁶¹ *Research Institute of Industrial Science & Technology (RIST)*² *Research Institute of Industrial Science & Technology*³ *Changwon National University*⁴ *Kyushu university*⁵ *SuNAM Co., Ltd.*⁶ *Changwon National University*

To evaluate the critical current (I_c) of HTS tape in various temperature conditions, the cryostat with conduction cooling system is widely used with DC power supply. But the continuously increasing

DC current affects the temperature rising of metallic parts such as copper terminal for conduction cooling, HTS tape holder, current leads, and contact parts by joule heating. The temperature increasing seriously affects the measuring factors which are voltage, resistance, or temperature, and then users may get the wrong results. To minimize the heating effect, the authors considered the pulsed current instead of DC current for power supply. A cryostat consists of cryogenic refrigerant for conduction cooling and metallic current leads for 2,500A. Both DC and pulsed current were tested in the same conditions which were HTS tape and temperature. The measurement results of HTS tape using pulsed current are given in this paper.

Submitters Country:

Republic of Korea

Thu-Af-Po4.02 / 588

A momentum-preserved node concept for thermohydraulic analysis of fusion magnet

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Fusion magnet typically consists of an array of cable-in-conduit conductors (CICC's) and liquid cryogen is supplied by a cryogenic network. As the cryogen supply is one of the decisive factors for magnet operation, a complete modeling including cryogenic network is necessary. In order to cope with a variety of cryogenic components, such as circulator, valves and pipes, a numerical node joining each component together is required. In SUPERMAGNET code, such a joint is called as 'volume' node which behaves like a small reservoir. It is assumed that the cryogen completely loses its velocity in the volume node so that only pressure and temperature variations are calculated. However, in real system, especially when there is severe AC loss at cryogen inlet, transient backward flow needs to be carefully examined. Here, we discuss a plausible momentum-preserved node concept suitable for thermohydraulic analysis of fusion magnet. The momentum-preserved node is assumed to be a zero-dimensional object in order to minimized computing time. This requires additional assumptions. For example, mass flow inlet and pressure boundary conditions are applied for the momentum-preserved node. But when there is a transient backward flow, these boundary conditions need to be modified accordingly. A minimal set of assumptions will be discussed. Furthermore, a comparative study in between the volume and the momentum-preserved nodes has been carried out. A simplified cryogenic network has been studied and its implication for the thermohydraulic analysis of fusion magnet will be discussed.

Submitters Country:

Korea, Republic of

Thu-Af-Po4.11 / 832

A multifunction test facility of cryogenic-electro-magneto- mechanical properties for superconducting wires/tapes under multi-fields

Author(s): Xingzhe Wang¹

Co-author(s): Youhe Zhou¹ ; Mingzhi Guan²

¹ *Lanzhou University*

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A prototype of multifunction test facility for providing cryogenic-electro- magneto-mechanical multi-fields to investigate the field-dependence properties of superconducting wires/tapes is recently constructed in our laboratory. The apparatus is self-designed with several relatively independent sub-systems. A superconducting racetrack magnet made of NbTi/Cu is used to generate a background field along transverse direction (0-3.5T) in a relative large space of homogeneous region. A sub-system of cryogenic and vacuum Dewar vessel with a visible widow directly cooled by commercial Gifford-McMahon cryocoolers is manufactured to provide the operating cryogenic environment for the SC magnet and wires/tapes. For the purpose of efficiently and independently cooling the magnet and superconducting specimens, two GM cryocoolers are equipped in which one is for cooling the magnet at operation low temperature 3-5K, another supplies the cryogenic condition for the SC wires/tapes by conduction cooling mode. Additionally, to produce continuous variation temperature for the specimens an integration differentiation temperature control with an optional temperature sweep rate is utilized. The high DC supply to the superconducting wires/tapes with the maximum value of 1000 A is implemented by designing a kind of commercial superconducting lead composed of YBa₂Cu₃O_{7-x} coated conductor and beryllium copper alloy. The sub-system of mechanical loading and measuring the specimens of SC wires/tapes is reconstructed by an electronic universal testing machine with widening and heightening design. Beside of recording the signals of electric, magnetic and temperature fields by means of contact measurement techniques with kinds of sensors, a contactless DIC method with a high speed/high resolution CCD camera is employed for the specimens of SC wires/tapes deformation and configuration measurements. Our preliminary experiment results show that the most functions of the multi-fields and the properties and responses of LTS/HTS wires/tapes as a function of magnetic field, cryogenic temperature, transport current, and deformation can be achieved successfully.

Submitters Country:

China

Tue-Mo-Or11 / 434

A new approach of tube bugling based on electromagnetic attractive force

Author(s): Qi Xiong^{None}

Co-author(s): Hongtao Tang ; Zhenxing Li ; Changzheng Deng ; Fangyu Li ; Liang Li ; Li Qiu

Small tube bulging by electromagnetic forming is a challenging issue because the coil must be placed inside of the pipe to generate repulsion electromagnetic force. To solve this problem, a novel method for forming pipe fittings by using electromagnetic attraction is proposed. To generate an electromagnetic attraction, a special current is used to drive the coil. This special current consists of a wide pulse current and a narrow pulse current. For the sake of verifying the feasibility of this method, a circuit-electromagnetic-structure coupling finite element model was built to analyze the deformation process, and an electromagnetic forming system with two sets of power supplies was designed and fabricated. Two capacitor bank power supplies (1MJ/25kV/3200 μ F & 75kJ/25kV/240 μ F) have been used to energize the coil which produces a pulsed magnetic field. A series of bulging experiments used of AA 1060 aluminum alloy tubes with a thickness of 1mm have been carried out on this system. The tubes were successfully deformed and the maximum deformation reached 5 mm.

Submitters Country:

China

Mon-Af-Po1.12 / 664

A new three-level repetitive pulse magnetic field power supply system

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² Huazhong University of Science and Technology

Repetitive Flat-top Pulsed High Magnetic Field (RFPHMF) could widely be applied to biology, materialogy, iatrology, condensed matter physics, and many industrial applications. Nowadays, the development direction of the RFPHMF focuses on accelerating the magnetic field establishment, elevating the pulse amplitude, extending the pulse duration, enhancing the flat-top precision, boosting the charging frequency. The magnet being energized, the coil resistance skyrocket to 7~10 times bigger due to the temperature rising, hence consuming more energy, jeopardizing the flat-top current precision and the cooling-process/charging-frequency. A three-level charging system has been brought out to acquire the high flat-top precision, high charging frequency magnetic field mentioned above. The structure of the 1st level, a bridge circuit of SCR Diode and IGBT, is used to obtain short rise time by using capacitor to charge the magnet with the cascaded protecting inductor, and to return the current/energy back to the capacitor after the flat-top stage, resulting capacitor's quick recharging and less heat-production/power-dissipation, thus less cooling process and higher charging frequency. The 2nd level structure, a capacitor with low initial voltage-setting and high capacitance, works as a current stabilizer in freewheeling stage to roughly compensate the decreasing flat-top current. Use the 2nd level capacitor to balance out the whole circuit energy-consumption, so that 1st level capacitor can be recharged to initial setting voltage. The 3rd level structure contains an H-bridge and a transformer parallel connecting to the protecting inductor through another big inductor, is designed to regulate the load current by controlling the applied voltage. A prototype of charging device and its matching magnet that can generate 10T magnetic field with precision of 0.1‰ and charging frequency of 10Hz has been designed and assembled. The simulation and the entity experiments validated the demanding index.

Submitters Country:

China

Wed-Mo-Pl6 / 1251

A new understanding of the heat treatment of Nb₃Sn superconducting wires

Tue-Af-Po2.11 / 780

A novel HTS Persistent Current Switch Controlled by AC Magnetic Field

Author(s): Chao Li¹

Co-author(s): Jianzhao Geng¹ ; Boyang Shen¹ ; xiuchang zhang ; Tim Coombs¹

¹ University of Cambridge

This paper will propose a fast high-current switching device that relies on the rapid superconducting transition of the material to the normal state. This transition is induced by the homogeneous alternating magnetic field generated by copper coil which is inductively coupled to the iron core. This design could be used as a fast current switch or a fault current limiter. If used as a fault current limiter, the device could accelerate the quench of the superconductive tape due to the change of current density and magnetic field density. On the other hand, if used as a fast current switch, the device could just enable the attainment of high off-resistance by the dynamic resistance created by the applied homogeneous alternating magnetic field. The most attractive advantage of the device is to operate the superconductor tape without the risk of quenching.

Submitters Country:

The United Kingdom

Tue-Af-Po2.04 / 361**A novel clamping method for resistive magnets****Author(s):** Frans Wijnen¹**Co-author(s):** Chris Wulffers²; Arno Engels²; Jos van Velsen²; Jos Perenboom²; Andries den Ouden (Adjunct Chairman)³; Nigel Hussey²¹ *Radboud University Nijmegen*² *Radboud University Nijmegen - High Field Magnet Laboratory*³ *High Field Magnet Laboratory Nijmegen*

High field resistive magnets are traditionally built by stacking hundreds of so-called Bitter disks together to form a coil. Nowadays, these disks have strongly elongated cooling holes, arranged in a staggered pattern that improves the distributions of hoop stresses by the Lorentz force load on the disks. Near the outer diameter one finds larger holes, round or flattened, to accommodate a tie-rod. These tie-rods assist in the assembly of the coils and are usually pre-tensioned to ensure a net compressive clamping force at the end of the coil at all times. However, at high fields the axial magnetic clamping forces dominate all other clamping forces reducing the compressive stress and the end plates to a very low value. We describe a novel clamping method that employs a water-filled, pressurised bellow that exerts a constant compressive force to the coils and due to its large stroke compensates the normal changes in coil length during operation. This new clamping method is a key element for the mechanical design of the resistive insert coils of the HFML 45 T hybrid magnet. Ultimately, the benefit of this clamping method would be the replacement of the present tie-rods by a much smaller support element that only provides the necessary support during coil stacking and magnet assembly. We expect such an element to be much smaller than the current tie-rods, thus increasing the efficiency of the coils.

Submitters Country:

The Netherlands

Mon-Af-Po1.12 / 851**A novel digital magnet power supply approach****Author(s):** Jan Marjanović¹; Denis Molaro¹**Co-author(s):** Enrico Braidotti¹; Mitja Guštin¹; Joachim Theiner¹¹ *CAENELS s.r.l.*

Programmable logic and integrated technologies, as SoC, FPGA and DSP, have become mature enough to be employed in high performance magnet power supply applications. The use of a configurable mixed current and voltage digital control, combined with adaptable complex algorithms for protections (e.g. quench in superconducting magnets) and auxiliary integration (e.g. transverse flux density in a dipole gap) allows obtaining the perfect fit for each specific magnet application. An entire series of power supplies, coming from a background of particle accelerator applications, has been developed for both bipolar and monopolar operation with high bandwidth (fast fields as in corrector magnets and steerers) and high adaptability with a user-friendly interface and an embedded Linux OS that allows users to implement their own applications directly on the power supply. The use of 24-bit Analog-to-Digital converters and state-of-the-art PWM generation (with possible application of dithering techniques to reach 60-65 ps resolution) enables to obtain fields actuations in the ppm-level range. Some power converters, for specific applications (usually dipoles or superconducting),

are equipped with closed-loop zero flux transducers that feeds their signals to temperature-stabilized electronics to reach current temperature coefficient values of 1 ppm/K.

Submitters Country:

ITALY

Wed-Af-Po3.01 / 1202

A novel method for greatly reduced edge effects design in CCT magnets

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Iron-free CCT magnet design offers many advantages, one being the excellent field quality and the absence of multipole components. However, edge effects are present, although they tend to integrate out over the length of the magnet. Many modern accelerator applications, however, require that these magnets are placed in an area of rapidly varying optics parameters, so magnets with greatly reduced edge effects have an advantage. We have designed such a magnet (a quadrupole) by adding multipole components of the opposite sign to the edge of the magnet, effectively resulting in a combined function magnet with multipole components that vary along its length. A possible application could be the final focus magnets of the FCC-ee, where beam sizes at the entry and exit point of the magnets vary by large factors.

Submitters Country:

Switzerland

Thu-Af-Po4.09 / 624

A novel quench detection method using radio frequency wave technology

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Co-author(s): Fu peng² ; Zhu Congming³

¹ *Institute of plasma physics chinese academy of science*

² *Asipp*

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The co-wound voltage tap sensor is considered suitable to pulse operation superconducting coil quench detection but it has a fatal weak point. There is no way to repair it in case of sensor failure, since the co-wound sensor will be embedded inside the coil. A novel quench detection method is presented in this paper to detect a quench using radio frequency wave technology. The RF detection relies only on external instrumentations, which means good maintenance. The first step is to balance the inductive component to be measured superconducting coil by using the balancing device Balun and then connect with steady-state RF power source through professional isolation component. The reflected power and phase of carrier signal will be changed if normal zone appeared even less than 2 milliohm which means a quench occurred. However, the high performance multistage cancellation systems are necessary in order to discriminate the large scale of unchanged components in the carrier signal. The simulation results have shown that radio frequency detection technology is applicable to the pulse superconducting coils as a backup method and this method gain

national patent. This paper introduces the principle, the conception design and simulation results. The preliminary test is under way in recent days.

Submitters Country:

P.R.China

Mon-Af-Po1.02 / 503

A passively shielded HTS magnet for polarized neutron scattering

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The use of spin-polarized neutrons in neutron scattering experiments provides fundamental information on magnetic properties. One of the key issues is to maintain the polarization of a neutron beam on its way through the large magnetic fringe fields produced by a high field superconducting magnet. Up to now, most Low Temperature Superconducting (LTS) magnets for neutron scattering use active shielding coils to reduce the fringe fields around the neutron spin flippers and an asymmetric mode to guide polarized neutrons through the region of the zero-field node. By exploiting the use of iron in the magnetic circuits, High Temperature Superconducting (HTS) magnets offer an easier solution to maintain neutron polarization. Recently a passively shielded 3T HTS magnet for polarized neutron scattering experiments was designed, constructed and tested by HTS-110. This split-pair magnet provides a maximum horizontal magnetic field of 3 tesla while the fringe field is less than 1 mT at 0.5 m from the magnetic center in the magnet axial direction and the fringe field is less than 0.1 mT at 1 m from the magnetic center in the magnet radial direction. Furthermore the zero-field nodes are located outside the magnet cryostat easing the control of neutron polarization at entry to the magnet. The magnet has a vertical room temperature bore of 80 mm in diameter for sample access and 4 horizontal bores with an opening angle of 32° for neutron access, allowing high flexibility without any material in the beam to cause a scattering background. In this paper we report the test results of this magnet. Aspects of HTS magnet design specific to the combined requirements of neutron scattering including magnetic field, fringe field and sample and neutron access are discussed.

Submitters Country:

New Zealand

Wed-Af-Po3.06 / 725

A performance study on the flux pump based modularized exciter for a large-scale HTS wind power generator

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⁴ *Changwon National University*

Recently, a high-temperature superconducting (HTS) generator module with brushless HTS exciter for large-scale wind turbines is suggested for improving the stability of the generator. The brushless HTS exciter is used for inducing the field current to the HTS module coil without power supply, current lead, and slip ring, and hence reduces total power loss. However, unbalanced field current may

occur due to the physical mismatch of major parameters of each module such as inductance and resistance, and it causes output degradation after all. In this paper, the authors performed a performance study on the flux pump based modularized exciter for a 12 MW class HTS wind power generator and suggested allowable range of the unbalanced field current of each modularized exciter. The value of the field current of the brushless HTS exciter was determined by some parameters of the brushless HTS exciter. Unbalanced rate of the field current was calculated by the difference between field currents of modules. Based on the calculated unbalanced rate, the electromagnetic characteristics of the unbalanced field condition were analyzed using finite element method. The results were compared to the results of the conventional HTS exciter, and the magnetic field distributions and output characteristics of the generator considering the conventional and brushless HTS exciters were presented. Compared to the conventional HTS exciter, the output characteristics were almost the same until 3% of the unbalanced rate. However, when the rate was over 3%, the output power decreased and the torque ripple increased exponentially. These phenomena are likely to cause serious mechanical problems such as noise, and stress of the generator. Therefore, the authors strongly recommend to apply a control algorithm in the brushless HTS exciters for maintaining the unbalanced rate under allowable range. The results can effectively be utilized to design a modularized large-scale wind power generator.

Submitters Country:

Republic of Korea

Mon-Af-Or9 / 924**A portable superconducting magnet system with trapped field > 3 T**Zhou Difan¹ ; Mark Ainslie¹ ; Yunhua Shi¹ ; Anthony Dennis¹ ; Kaiyuan Huang¹ ; John Hull² ; David Cardwell¹ ; John Durrell¹¹ *University of Cambridge*² *Boeing Company*

A portable magnet system based on bulk (RE)BCO, high temperature bulk superconductors, which constitute high-field magnets, has been designed constructed. The use of a small-volume sterling cryocooler with a base temperature of 50 K has enabled a portable and compact magnet design. The magnetization of the bulk superconductors was realized by a pulsed field magnetization (PFM) technique. The PFM process was considered difficult previously because of the high external field required to fully magnetise high quality bulk samples, according to limitations of the Bean model and to the generation of heat during the magnetisation process. A flux jump phenomenon observed during the rise of the pulsed field, however, was used to drive magnetic flux into the superconductor during the magnetisation process. A peak trapped field of 3.2 T has been achieved at the surface of the bulk superconductor by applying a pulsed field of only 4.86 T as part of this research.

Submitters Country:

United Kingdom

Wed-Af-Po3.07 / 475**A quantitative benefits study of the superconducting magnetic energy storage system hybridized with the battery****Author(s):** Jianwei Li^{None}**Co-author(s):** Weijia Yuan¹¹ *University of Bath*

Recently, advances in the superconducting energy storage system (SMES) have made SMES/battery hybrid energy storage systems (HESS) technically attractive. In the HESS scheme, two kinds of complementary energy storage technologies are designed achieving an optimised system which has the advantages of both primary energy storage systems meanwhile complementing the disadvantages of each ESS. By integrating the SMES into the battery based energy storage project, the battery lifetime can be dramatically improved. However, the knowledge gap lies on the quantitative evaluation of the battery lifetime extension enhanced by the SMES. A new method is introduced in this study to present the quantitative analysis of the advantages in an SMES/battery HESS. The proposed algorithm is implemented and tested in a case study. The quantitative method is shown to be a guide to SMES design and its cost-effective study.

Submitters Country:

United Kingdom

Thu-Af-Po4.11 / 1059

A set of equipment for measuring and investigating the magnetic field at the reference magnet of the NICA booster

Author(s): Ivan Okunev¹

Co-author(s): Alexander Batrakov¹ ; Andrey Molokoedov¹ ; Anton Pavlenko¹ ; Gennadiy Karpov¹

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The NICA accelerator complex is being constructed in JINR, Dubna. It includes Electron String Ion Source, 6.2 MeV/u linac, 600 MeV/u booster synchrotron and collider. The booster will accumulate $4 \cdot 10^9$ Au³²⁺ ions, accelerate heavy ions from 6.2 up to 600 MeV/u for Au³²⁺ and form required beam emittance with the help of electron beam cooling. The cryogenic magnetic system of the booster, in addition to superconducting bending dipoles and quadrupole magnets, contains a separate reference magnet. In this magnet a set of cryogenic magnetic sensors is located, which includes inductive sensors, as well as the "cold" NMR sensor. The first inductive sensor is intended to operate with the digital LLRF controller of the booster RF system. The second one generates signal for precision integrators, which allow investigate with high accuracy behavior of the magnetic field during accelerating cycle and also field ripples. The "cold" NMR sensor is planned for calibration of the inductive sensors in order to determine the sensor's area accurately. The report describes the design and technology of manufacturing cryogenic sensors, their parameters are given. The possibilities of electronic devices for working with sensors are presented.

Submitters Country:

Russia

Tue-Af-Po2.06 / 1163

A study on Double Layer V-Shape Magnet Type IPMSM design in view of demagnetization

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Among the various industries, the use of IPMSM in electric vehicle is increasing. In particular, in the case of an electric vehicle drive motor, the mechanical strength of the rotor is important because it operates in a high-speed operation region. Therefore, the double layer V-shaped magnet type IPMSM is more widely used in electric vehicles currently selling, because the double layer V-shaped magnet has better mechanical strength than other shapes. However, in the case of a double layer V-shaped magnet, the total magnet amount is similar to other magnet shapes, but it is thinner than the thickness of one layer magnet because it is composed of two layers. Since the thickness of the magnet has a great influence on the demagnetization, it can be seen that the double layer V-shaped magnet made of two layers is vulnerable to demagnetization. Therefore, in this paper, we study the design method of the double layer V-shaped IPMSM considering such characteristics. First, we study the demagnetization characteristics of double layer V-shaped IPMSM. We will study how the characteristics of the demagnetization vary depending on the operating point and how to change it according to various design parameters such as the position and size of the magnet. Second, based on the above research, we will study a design method that prevents demagnetization. In most cases, the initial design stage does not proceed with design considering demagnetization, but proceeds to find a design satisfying a given performance. If a demagnetization problem occurs when analyzing demagnetization characteristics with a design that satisfies the given performance, a detailed design that can prevent demagnetization while maintaining maximum performance is required. Therefore, we want to study design methods to prevent demagnetization of magnets while maintaining overall motor performance.

Submitters Country:

South Korea

Mon-Af-Po1.04 / 793**A study on the control method of lateral displacement and yaw angle in severely curved driving of IRWs system****Author(s):** JunHui Won¹**Co-author(s):** Kyoung-Jin Joo ; Gang Seok Lee² ; Ju Lee³ ; Seung-Joo Kim⁴¹ *Hanyang Univ*² *Hanyang Univ.*³ *Hanyang University*⁴ *Korea Testing Certification*

This paper proposes an optimal control algorithm through lateral displacement and yaw angle in curved road of shallow-depth subway systems. In the case of the surface transportation, which has recently been introduced, severe curved driving performance is required for the downtown. The existing researches are the main research theme of the lateral displacement restoration control, but there is a limit to smooth operation when the curve is run only by receiving the lateral information. However, when the yaw angle information is obtained, it is possible to consider the turning angle of the vehicle while the vehicle is driving in a curved road. However, it is difficult to control because the change of yaw angle is more sensitive than lateral drift. Therefore, this paper suggests an algorithm that uses both lateral displacement control and yaw control. The proposed method will be verified with the Matlab/Simulink model and the effectiveness of the proposed method will be verified through small-scale bogie system.

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 790

A study on the individual control method comparing the lateral displacement control of front wheel and rear wheel of IRWs system

Author(s): JunHui Won¹

Co-author(s): Kyoung-Jin Joo ; Gang Seok Lee² ; Ju Lee³ ; Seung-Joo Kim⁴

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This paper proposes an algorithm to obtain better results in the integrated control by reflecting the characteristics of the individual control of the front wheel and the rear wheel of shallow-depth subway systems. In the case of the surface transportation, which has recently been introduced, severely curved driving performance is required for the downtown. It is possible to decrease the curve radius and to improve the performance of the straight running with the individual torque control. Therefore, the individual torque control performance of the motor is the most important point of the surface transportation. The front and rear wheels have different torque characteristics, and the length of the bogie during curve travel also affects these results. This system is more controllable than the system with 1C4M (1 Controller 4 Motor) in the form of 2C4M with the front and rear wheels being individually controlled, allowing more precise control because of its higher degree of freedom. Because of this individually controlled characteristic, it is possible to control more precisely in the integrated control considering the characteristics of the front wheel and the characteristics of the rear wheel. The validity and usefulness of the proposed control algorithm is verified by experimental results using a small-scale bogie system.

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 14

A transverse flux single-phase tubular switched reluctance linear motor

Hao Chen¹ ; Rui Nie¹

¹ *China University of Mining & Technology*

A transverse flux single-phase tubular switched reluctance linear motor (TF-TSRLM) is proposed in the paper, and it is compared with the longitudinal flux single-phase tubular switched reluctance linear motor (LF-TSRLM) in electromagnetic thrust. The stator consists of five ferromagnetic rings that are divided by four spacer rings. On the cross section of the TF-TSRLM, a stator ferromagnetic ring has six poles with coils winding on. The mover threads through the tubular stator rings. Different from the LF-TSRLM, the interval sleeves which break the mover tooth rings are made by non-ferromagnetic material for isolating any longitudinal flux. When the windings are excited, magnetic lines of force form closed loops through stator poles, air gap, mover tooth ring, and stator yoke. The plane where the surround magnetic flux paths exist is perpendicular to the mover movement direction. Four structures with respectively 2 poles, 4 poles, 6 poles, and 8 poles on the cross section are proposed. The poles of structures with 2 poles, 4 poles, 6 poles, and 8 poles are distributed uniformly at 180°, 90°, 60°, and 45° intervals respectively. The sensitivity analyses were made on some parameters to achieve new dimensions with better thrust performance, such as different stator yoke thickness, different mover cylinder's thickness, different stator pole width, different pole width ratio. In the analysis process, the excitation current is fixed as 15A. After the sensitivity analysis on four important parameters, the final dimensions of proposed TF-TSRLM are determined. The electromagnetic thrust curves of LF-TSRLM and TF-TSRLM with final dimensions are calculated by 3D FEM in 3A, 6A, 9A, 12A and 15A respectively. It is shown that the electromagnetic thrust of transverse flux single-phase tubular switched reluctance linear motor with 6 poles is greater than that of

longitudinal flux single-phase tubular switched reluctance linear motor at the same excited current values.

Submitters Country:

China

Tue-Af-Po2.06 / 883

AC Current Transport Characteristics of HTS Stator Coils in HTS Induction/Synchronous Motor

Author(s): Kenichi Ikeda¹

Co-author(s): Ryohei Nishino¹; Taketsune Nakamura¹; Tomoharu Karashima¹; Masaaki Yoshikawa²; Yoshitaka Itoh³; Toshihisa Terazawa²

¹ *Kyoto University*

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We have been studying on a superconducting motor for highly efficient transportation equipment. Target motor of our study is a High Temperature Superconducting Induction/Synchronous Motor (HTS-ISM). Basic structure of the HTS-ISM is the same as that of so-called squirrel-cage induction motor, and HTS tapes are used in its rotor bars and end rings. Based on experiments and analysis, it has been clarified that the HTS-ISM possesses prominent performances such as high torque density and high efficiency thanks to the steady state synchronous operation. On the other hand, the torque density of the motor depends on the magnetomotive force, which is determined by the primary current. And then, in the case of copper windings, the primary current is restricted by Joule loss, and it is difficult to apply large current. Further, the maximum efficiency of the motor becomes worse due to such loss. Therefore, the HTS-ISM with HTS stator coil is crucial in order to realize higher torque density and higher efficiency. In this paper, we fabricate a three-phase BSCCO HTS stator coils and conducted its DC and AC current transport tests without rotor. We firstly show DC voltage-current characteristics of the HTS stator and show the success of 450 A application test at 77 K. Furthermore, we show one-phase and three-phase AC loss test results, and discuss on the rotation characteristics of the fabricated 50 kW class fully superconducting motor. We also try to reproduce the above results based upon electro-magnetic field analysis. These results would be important in designing highly efficient all superconducting HTS-ISM.

Acknowledgements: This work has been supported by Japan Science and Technology Agency under the program of Advanced Low Carbon Technology Research and Development Program (JST-ALCA) in Japan.

Submitters Country:

Japan

Wed-Af-Po3.12 / 476

AC Loss Investigation on the High Temperature Superconducting (HTS) Coil Under the Action of AC Currents and AC Magnetic Fields

Boyang Shen¹; Jianzhao Geng¹; Chao Li¹; Xiuchang Zhang¹; Tim Coombs¹

¹ *University of Cambridge*

This paper presents the study of AC losses from the High Temperature Superconducting (HTS) coil under various circumstances, such as under the action of AC currents and AC magnetic fields. For some AC systems, superconducting coils could suffer the AC losses from both AC currents and external AC magnetic fields in the meantime. These kinds of AC losses in the dynamic magnetic fields are necessarily important for HTS applications such as superconducting motors and superconducting transformers, as they could potentially affect the efficiency of these devices. Different AC currents and AC magnetic fields have been applied to an experimental HTS coil for varying time intervals. Losses from different cases were measured using electrical method. The equivalent simulations of these AC loss measurements were executed using COMSOL Multiphysics to compare with the experimental results.

Submitters Country:

UK

Wed-Af-Po3.12 / 968

AC Loss Measurement of High-Tc Superconducting Coils Wound by Stacked Conductors under the Various Electro-magnetic Conditions

Shuma Kawabata¹ ; Tadashi Hirayama¹

¹ *Kagoshima University*

In order to elucidate AC loss characteristics of High-Tc superconducting coils wound by stacked conductors, we measured AC losses of Bi-2223 sample coils under the various electro-magnetic conditions by a nitrogen boil-off method. The sample coils were wound by stacked conductors, which were composed of two Bi-2223 tapes. Each tape of stacked conductors was wrapped with the polyimide tape, and two tapes were transposed at the end part of sample coils. The diameter of sample coils is about 50 mm, and the height is about 30 mm. We measured the frequency dependence and the magnetic amplitude dependence of AC losses of sample coils under external sinusoidal magnetic field, and evaluated the magnetization losses and coupling current losses. We also measured AC losses of sample coils under external square wave magnetic field using power electronic circuits. Based on the measured results, AC loss characteristics of High-Tc superconducting coils wound by stacked conductors were discussed.

Submitters Country:

Japan

Wed-Af-Po3.12 / 728

AC Loss Properties of Stacked Multifilamentary REBCO Superconducting Tapes

Author(s): Tetsuya Ito¹

Co-author(s): Masataka Iwakuma¹ ; Akira Tomioka² ; Masayuki Konno² ; Teruo Izumi³ ; Kazuhisa Adachi⁴ ; Takato Machi³ ; Akira IBI³

¹ *Kyushu University*

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For ac applications of superconductors, ac loss is most of the heat load. So it is very important to estimate the ac losses in superconducting windings for the design of cooling system. However the measurement of ac loss takes much time and cost and also needs large facilities. So simple and easy estimation method of ac loss is required. In this study we investigated the ac loss properties of multi-filamentary REBCO superconducting tapes which were made by the IBAD-PLD technique and laser-scribing. The thickness of a REBCO superconducting layer was 3.6 μ m. The length and width of sample tapes was 60mm and 10mm respectively. We measured ac losses of sample tapes with a saddle-shaped pick-up coil applying ac magnetic field perpendicularly to the tape face. Temperature was 30, 40, 50, 64 and 77 K. Number of stacked tapes was 1, 3 and 6. We measured the ac losses in multi-filamentary REBCO superconducting tapes and compared with the ac loss of non-scribed tapes. The number of filament of the laser-scribed tape was 4. When the observed ac losses were normalized by I_{c0} , which was the evaluated critical current at zero field at the respective temperature by using the observed magnetization curve, those agreed with one master-curve regardless of temperature. The ac losses were scaled with temperature whether the tapes were scribed or non-scribed. In addition the ac losses were scaled regardless of the number of stacked tapes. However the dependences of ac losses on the number of stacked tapes for the smaller amplitude than the penetration field, B_p , were different between the scribed tapes and non-scribed ones. In this conference, we will report the observed results and discuss on the simple and easy estimation methods of ac losses.

Submitters Country:

Japan

Tue-Af-Or18 / 1041**AC Loss and inter-tape resistance in various HTS cable configurations**Konstantin Yagotintsev¹ ; Peng Gao¹ ; V. A. Anvar¹ ; Marc Dhallé¹ ; Timothy Haugan² ; Danko van der Laan³ ; Jeremy Weiss³ ; Arend Nijhuis¹¹ *University of Twente*² *U.S. Air Force Research Laboratory*³ *Advanced Conductor Technologies*

To achieve the required current capacity, superconducting cables are composed of numerous HTS tapes. In particular for application in fusion, those conductors have to operate in alternating current and magnetic fields, leading to AC loss and current redistribution. Besides the dimensions and geometry of the composed cable, an important parameter for the mentioned phenomena is the contact resistance between the tapes. The contact resistance affects the ability of current redistribution inside conductor and hence its stability. In this work the AC loss and contact resistance data is presented of HTS conductors manufactured according to three types of cabling methods - CORC (cable on round core), Roebel, and stacked tape including a full-size HTS CICC (cable in conduit conductor) and CroCo (Cross-Conductor) conductor. The AC loss was measured with a calibrated gas flow calorimeter by helium boil-off method and simultaneously by magnetisation with a use of a compensated pick-up coil set. The measurements were done at $T = 4.2$ and 77 K in an AC magnetic field with amplitudes up to 1.5 T. The inter-tape contact resistance was measured for samples at 4.2 and 77 K. We demonstrated that a short heat treatment of a CORC conductor with solder coated tapes activates tape soldering in the whole sample volume and decreases the contact resistance by two orders of magnitude. At the same time no coupling loss component was observed for the heat-treated CORC sample at 4.2 K while AC loss measurements at 77 K clearly demonstrated the presence of coupling loss. The analysis of AC loss and contact resistance data obtained at 4.2 K suggests that a strong shielding effect is present in CORC and Roebel conductors.

Submitters Country:

Netherlands

Wed-Af-Po3.12 / 386

AC Loss of a Quasi-isotropic Strand Stacked by 2G Wires by Numerical Simulation in Cryogenic Temperature

Changtao Kan^{None}

Quasi-isotropic strands made of second generation (2G) wires are regarded as promising cables for large high field magnets in virtue of their high current capacity and well mechanical property. During the charge of the magnet, quasi-isotropic strands in use will subject to magnetic field and inevitably produce alternating current (AC) loss, which has important impacts on the magnet operation. This paper mainly presents the AC loss numerical simulation of a quasi-isotropic strand stacked by 2G wires under high magnetic field in cryogenic temperature. The strand with copper sheath consists of 72 assembled 2G wires. The numerical simulation is based on the H-formulation solved using the finite element method (FEM). The dependence of the critical current density on temperature and magnetic field as well as its orientation to wide surface of 2G wire is used in simulation. The AC loss mainly includes hysteresis losses, eddy-current losses and coupling losses. The angular dependence of AC loss of the strand on magnetic field is also estimated. The simulation results is helpful for overall understanding of the AC loss characteristics of the quasi-isotropic strand in high magnetic field.

Submitters Country:

China

Wed-Af-Po3.06 / 630

AC loss analysis of the armature windings of a fully HTS rotating machine with dual field windings

Author(s): Woo-Seok Kim¹**Co-author(s):** Sang Ho Park²; Seyeon Lee²; Miyeon Yoon²; Seong Eun Yang³; Ji-Kwang Lee⁴; Gye-Won Hong²; Kyeongdal Choi¹¹ Korea Polytechnic University² Korea polytechnic university³ KEPCO⁴ Woosuk university

Although the high temperature superconducting (HTS) synchronous motors or generators has been proposed by lots of research groups, just a small number of them has been proposed a fully superconducting rotating machines with HTS conductors. One major reason for that will be AC loss problem caused by the alternating magnetic field applied to the armature windings. However, a fully HTS rotating machine is to be required to achieve higher electrical capacity for application of wind power generation and so on. We believed that a dually arranged HTS field windings could be the solution of the AC loss problem and suggested a design of a fully HTS synchronous rotating machine with dual field windings. In this paper, the AC loss analysis will be performed for the similar type fully HTS rotating machine. The dually arranged field winding will help to reduce the magnetic field perpendicularly applied to the wide surface of the HTS conductors of the armature winding. As a result, it will not only reduce the AC loss from the armature windings but also increase the critical current of the HTS conductors in it. The results of the analyses will be compared with a conventional synchronous rotating machines.

“This research was supported by Korea Electric Power Corporation (grant number:)”; “This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning (2016R1A2B4013151)”

Submitters Country:

South Korea

Wed-Af-Po3.09 / 162

AC loss distribution in two-layer HTS twisted cable

Author(s): Jun Ogawa¹**Co-author(s):** Satoshi Fukui¹; Tetsuo Oka¹; Tomoya Ogawa¹; Mamoru Sugai¹¹ *Niigata University*

Many investigators have reported the AC loss characteristics in a HTS multi-layered twisted cable. This experimental report describes the whole AC loss characteristics in HTS cable, and the AC loss distribution in each layer of the cable is based on a numerical method only. For this reason, the HTS cable is a twisted structure and a longitudinal magnetic field is generated. A voltage lead loops attached on each layer cannot accurately detect the loss voltage by the longitudinal magnetic field. In this study, we measured the AC loss distribution from a two-layer HTS twisted cable. To measure the AC loss in each layer, we placed the thermo-couples on each tape face with thermal insulations. We measured the influence of the twist pitch, twist direction and balance of the transport current of the outer and inner layers on AC loss characteristic in the two-layer twisted HTS cable. The inner layer is exposed to the longitudinal magnetic field produced by the outer layer, and the outer layer is exposed to a circumferential direction magnetic field produced by the inner layer. The transport current, amplitude and direction of the magnetic field determine the AC loss characteristics.

Submitters Country:

Japan

Tue-Af-Or18 / 890

AC loss evaluation of a 10T class small REBCO coil with conduction-cooled configuration

Author(s): Sadanori Iwai¹**Co-author(s):** Taizo Tosaka¹; Shunji Nomura¹; Tsutomu Kurusu¹; Hiroshi Ueda²; So Noguchi³; Atsushi Ishiyama⁴; Shinichi Urayama⁵; Hidenao Fukuyama⁵; Hiroshi Miyazaki¹; Yasumi Otani¹¹ *Toshiba Corporation*² *Okayama University*³ *Hokkaido University*⁴ *Waseda University*⁵ *Kyoto University*

In order to use a REBCO coil with conduction cooling configuration, AC loss of the coil should be quantitatively predicted and designed under the operating conditions. REBCO-coated conductor is a tape shape and is suited to be composed of a stack of single pancake coils for generating high magnetic field. And various research groups measured and evaluated the ac loss of the REBCO tape; however, there were few reports about the ac loss of the coil which were measured at liquid nitrogen temperature. In this report, the ac losses of the REBCO coil composed of a stack of 22 single pancakes with 50 mm in inner diameter, 132 mm in outer diameter and 105 mm in height, which achieved to generate 13.5 T at 10 K [1], were measured and evaluated with conduction cooling configuration. The experimental results will be compared with the calculated results and discussed at the conference.

H. Miyazaki, et al., IEEE Trans. Appl. Supercond., vol. 27, no. 4, 4701705

Submitters Country:

Japan

Tue-Af-Po2.06 / 212

ANALYSIS AND OPTIMIZATION OF BEARINGLESS FLUX-SWITCHING PERMANENT MAGNET MOTOR

Huangqiu Zhu¹ ; Chenyin Zhao^{None}¹ *Jiangsu university*

For the conventional PM type bearingless motor, the PMs are usually located on or in the rotor which influences the motor's performance due to its relatively poor heat dispersion and mechanical integrity. Moreover, the cost would be higher and the environment may be polluted if the motor adopts the structure of PM fixed on the rotor. In order to make up for the above deficiencies, a new type of bearingless motors with the PMs embedded in the stator, namely the bearingless flux-switching permanent-magnet (BFSPM) motor, is proposed. The BFSPM motor, consisting of doubly salient structure, stator-PM and non-overlapping concentrated windings, combines the characteristics of reluctance motor and bearingless PM synchronous motors, which has the virtues of simple rotor structure, strong robustness, easy thermal dissipation, etc. Hence, the BFSPM motor is suitable for the applications which requires frequent rotor disposal such as pumping of high-purity fluids, e.g. blood during medical operations. In recent years, several structures of the BFSPM motor have been proposed. However, there is no a comprehensive optimization for a 12/10 stator/rotor pole BFSPM motor which is superior to other structures in power and torque density. In this paper, the optimization designs of the stator and rotor parameters are discussed to reduce torque ripple and increase suspension forces based on the simple variable method. The effects of different stator and rotor dimensions, such as the rotor pole width, the PM width and the split ratio on the BFSPM motor characteristics are studied by using finite element analysis. The analysis results show that the torque and suspension force ripple are reduced by 20% and 16%, respectively. And the suspension forces can be increased by 10% with the optimized parameters.

Submitters Country:

China

Tue-Af-Po2.03 / 97

ANALYSIS OF EARLY QUENCH DEVELOPMENT IN JT-60SA TOROIDAL FIELD COILS TESTED IN THE COLD TEST FACILITY

Author(s): Daniel Ciazynski¹**Co-author(s):** Frederic Molinie² ; Laurent Genini³ ; Sylvie NICOLLET¹ ; Walid Abdel Maksoud³ ; Yawei HUANG⁴¹ *CEA*² *DAPNIA*³ *CEA/IRFU*⁴ *CEA Saclay*

The Toroidal Field system of the JT-60SA tokamak is composed of 18 NbTi superconducting coils. Half of them are provided by France within the Broader Approach Agreement. These coils are manufactured by General Electric (ex-Alstom) at Belfort, France. Each TF coil is composed of 6 cable-in-conduit conductor lengths, wound in double-pancakes, carrying a nominal current of 25.7 kA. These coils are being tested in the single coil configuration at the so-called Cold Test Facility (CEA/IRFU Saclay, France). The test program includes for all coils a DC operation for one hour at nominal temperature (4.7 K) and nominal current followed by a progressive operating temperature increase at nominal current up to quench (around 7.5 K inlet temperature). Thanks to the accuracy of the fast Data Acquisition System at 10 kHz sampling rate which is triggered by the quench, but which allows the measurement of the six double-pancake voltage drops up to 10 s before the magnet fast discharge, it has been possible to follow the very early development of the quench at the scale of a few millimeters normal (i.e. non-superconducting) length. In addition, this early quench development over

one conductor length was also simulated using the THEA code with relevant boundary conditions. The paper will report on the analyses of two different quenches which occurred on two different coils: one starting on the central pancake winding which corresponds to the peak magnetic field, the other starting on a side pancake corresponding to a more heated conductor due to heat transfer from the casing. Early quench development and propagation play a major role in quench detection.

Submitters Country:

France

Tue-Af-Po2.02 / 389

Accurate 3D Field Mapping of an Iron Shielded Split Coil Spectrometer Magnet

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The Magnet Section of the Paul Scherrer Institute (PSI) upgraded in 2017 its Hall probe magnet measurement bench with an in-house developed 3D Hall sensor of a distinctive type and of a high accuracy, named Hallcube. The first major magnetic field measurements at the upgraded bench were performed on a split coil magnet with iron housing. This magnet is routinely used on the low energy muons (LEM) spectrometer on the muE4 beam-line at PSI. At the maximal current the main field component in the magnet aperture is 0.35 T and the side field components due to the split coil configuration rise above 0.1 T. Hence, and for the purpose of tuning the muon beam transport and optimising the operation of this worldwide unique facility, accurate 3D field maps of the spectrometer magnet are crucial. To ensure a high relative accuracy of 1E-4, extra measures were taken to cancel out the influence of the earth magnetic field and the lab environment on the measurements. In addition to the magnetic field measurements, the spectrometer magnet has also been modelled in 3D using the Vector Fields OPERA simulation software. A description of the measurement system, detailed analysis of the results and the comparison with the calculation are presented.

Submitters Country:

Switzerland

Thu-Af-Po4.11 / 579

Accurate Measurement of the Superconducting Current in 2G HTS Coil with Rogowski coil in Cryogenic Environment

Shuqian Huang¹ ; Wei Wang¹

¹ *Sichuan University*

This paper presents a Rogowski coil which is utilized to accurately measure the current value in second-generation (2G) high temperature superconducting (HTS) coil in cryogenic environment. We demonstrate the structure and key materials of this Rogowski coil. To ensure the accuracy measurement of superconducting current in cryogenic temperature, this Rogowski coil is fabricated into closed and rigid shape. Foamed plastic is used to fix the 2G HTS wire in the center of Rogowski coil. Silicon nitride ceramic is chosen to build the winding holder due its proper thermal contraction rate and mechanical strength in cryogenic environment. Experiments were carried out to demonstrate

the potentials of the Rogowski coil in accurately measuring the current in 2G HTS coil. The performance of this Rogowski coil was evaluated in liquid nitrogen bath at 77 K. The results show the stability and accuracy of this current measurement method.

Submitters Country:

China

Wed-Af-Po3.12 / 339

Additional AC loss properties of REBCO superconducting two-strand parallel conductors

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REBCO superconducting tapes have great performance in critical current density, J_c , property even at liquid nitrogen temperature. However, it is necessary to enhance a current capacity according to various applications. We proposed the configuration of parallel conductors. The constituent strands of parallel conductors need to be insulated and transposed for even current sharing and low ac loss. In case the transposition points deviate from the optimum ones, shielding current is induced according to the interlinkage magnetic flux of the twisted loop enclosed by the insulated strands and the contact resistances at the terminals. It produces an additional ac loss. Up to now, we have studied in the simple situation where parallel conductors are exposed to a uniform ac magnetic field. However, when parallel conductors are wound into a coil, applied magnetic field varies in space. In this study, we investigated the additional ac losses theoretically in the case that two-strand parallel conductors are located in non-uniform magnetic field. We derived theoretical expressions of the additional ac losses and discussed the dependences of them on the applied field amplitude, B_m , non-uniformity in magnetic field, ΔB , the deviation length of the transposition point from the optimum one, Δl , and so on. The additional ac loss increased in proportion to the square of B_m and Δl when the induced shielding current, I_s , do not reach the critical current, I_c . However, in the case I_s reach I_c , the additional ac loss abruptly increased against B_m . In addition ΔB affects the threshold criterion for $I_s = I_c$ and also the ac loss property itself. In this conference we will report the details of the threshold criterion and ac loss properties.

Submitters Country:

Japan

Thu-Af-Po4.02 / 901

Advanced mathematical model of ITER PF1 coil for manufacture quality control

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A quality control technique is proposed that enables numerical reconstruction of distortions occurred during the manufacture and assembly of the PF1 coil for the ITER machine. The technique utilizes field maps measured near the surface of every pancake and the entire winding pack when the warm coil is energized with a low current. The measured data are used to evaluate parameters of the coil through solving an inverse problem sensitive to accuracy of inputs. This necessitates detailed

description of the geometry for every turn, particularly, such elements as interturn and interlayer joggings. The solution is obtained as the minimized functional of deviations of measured fields from the ideal field distribution. An advanced model has been proposed that describes every PF1 turn in conformity with design documentation. The numerical reconstruction is based on analytical solutions and utilizes the integral formulation. This ensures high accuracy and smoothness of the solution. PF1 is modelled via nearly 1500 arc and linear conductors with square cross-sections. The effect of ferromagnetic components of a shop floor can also be taken into account. The proposed technique has been validated in experiments with the Dummy Double Pancake PF1.

Submitters Country:

Russian Federation

Tue-Af-Pl3 / 1223

Advanced superconductors developed at WSTJianwei Liu¹¹ *WST, Western Superconducting Technologies Co.,Ltd*

WST has been engaged in LTS and HTS since its foundation. WST has finished 210 ton of Nb₃Sn and NbTi superconducting strands for ITER. The experience of the ITER wire production brought great improvement to high-performance LTS as well as HTS for fusion, MRI and accelerators.

Submitters Country:

China

Thu-Mo-Or30 / 1201

Advanced tube type Nb₃Sn conductor and its applications in Hyper TechXuan Peng¹ ; Matt Rindfleisch² ; Michael Tomsic¹ ; Xingchen Xu³ ; JACOB ROCHESTER⁴ ; Mike Sumption⁴¹ *Hyper Tech Research Inc.*² *Hyper Tech Research*³ *Fermi National Accelerator Lab*⁴ *The Ohio State University*

Tube type Nb₃Sn conductor has been being explored by Hyper Tech Research Inc. Our standard conductor with 217 filament arrays have been generated with 12 T non-Cu J_c values of about 2400-2500 A/mm² with filament size of 40 micros at the 0.85 mm strand. We also made 547 filament conductor which has filament size of 25 micros at the 0.85 mm strand without any drawing issue. This conductor exhibited no fabrication problems and was drawn down and tested at a small diameter wire. The standard strand has been successfully applied on the fabrication of helical and planar undulator, both of which reach the fields that are expected in the ILC and Light source industry. It has also been tried in small magnet and the related information will be presented. We are working to improve the non-Cu J_c further by creating artificial pinning centers in the strand which will be presented in this paper.

Submitters Country:

USA

Wed-Af-Po3.07 / 704

Air-gap Control for Superconducting-Hybrid Magnetic Levitation Systems via Linear Matrix Inequality Optimization

Chang-Hyun Kim¹ ; Kyoung-Jin Joo^{None} ; Ju Lee²¹ *Department of Electricity, Vision College of Jeonju, Korea*² *Hanyang University*

Using electric magnetic suspension, magnetic levitation (MagLev) systems have been widely applied in various industries for their great characteristics such as non-contact, noise free, cleanness, high speed transportation, and so on. Especially, superconducting-hybrid electro-magnetic suspension (SH-EMS) is increasingly receiving attention in high-speed transportation because of their property to compensate the instability of MagLev systems. The SH-EMS necessarily requires the fixed apparatus and robustness against the mechanical and electrical disturbances such as sensor noises, current disturbance, levitative force fluctuation in order to prevent quench. Even though the existing robust and optimal control methods have been researched in control engineer, there still exist many challenges on designing and implementing the controller due to their complexity and set-point tracking as compared with conventional proportional-integral-derivative (PID) control. In this paper, we propose the enhanced PID control method with full-order observer, called Kalman filter in order for the noise rejection and good-command following. Composed of Kalman filter and optimal control law, the proposed compensator is tuned for sensor noise rejection and current disturbance reduction. And the total servo controller for tracking the desired air-gap position including the designed compensator matched to the conventional PD controller is determined by convex combination method (CCM) such that the performances of time and frequency domains have the convex properties. The main contributions of the proposed method are summarized as follows: (i) The proposed method provides the intuition to control engineers to apply the traditional controller with disturbance rejection filter and expect the controlled responses of MagLev state in time- and frequency domains by CCM. (ii) The control parameters are explicitly determined by the proposed linear matrix inequality optimization problem to solve CCM. (iii) The proposed multi-loop controller has degree-of-freedom to independently consider various design performances in time and frequency domains.

Submitters Country:

Republic of Korea

Thu-Af-Po4.02 / 246

An Electromagnetic and Structural Finite Element Model of the ITER TF Coils

Author(s): Gabriele D'Amico¹**Co-author(s):** Cornelis Jong² ; Alfredo Portone¹¹ *Fusion For Energy*² *ITER Organization*

The ITER magnet system consists of 18 toroidal field (TFC) coils, a central solenoid, 6 poloidal field coils and a set of correction coils. The TFCs provide the required toroidal field ($\approx 5.3\text{T}$ at plasma radius $R=6.2\text{m}$) mainly needed to confine the plasma. Since the magnets are under manufacturing, non-conformity (NCR) and/or deviation requests (DR) can be provided by the manufacturers. Fast checks on the impact of those design updates on the structural behaviour are needed before accepting their implementation. With this aim a new detailed FE model of the TFCs has been developed. It is a 3D cyclic symmetric model giving a full representation of the 2 types of coils characterizing the TF magnet. It allows computing the magnetic field during the different operating scenario and the related Lorentz forces acting on the TFCs. It also permits to simulate how the TFCs will mechanically behave during operation. Updates of the mesh can be easily implemented since the model

has been built in a modular way, small sub-components of the system can be isolated and geometrically updated. This is the key feature of the model which has allowed to study in a very fast way possible NCR's and DR's. An intensive usage of the ANSYS APDL language has been implemented in such a way that the entire analysis cascade can be ran in a completely automatic way. Due to its versatility, this tool has become the reference TFCs model in the ITER community and it has been extensively used in performing additional studies simulating particular operating conditions to which the magnet can be temporarily subjected during the ITER lifetime. This paper describes the main characteristics of the model, its flexibility and analysis performance, and gives an overview of the main results it can provide considering the 15MA ITER scenario as reference.

Submitters Country:

Italy

Thu-Mo-Or33 / 182

An Engineering Perspective on Ultra High-Field Magnets

Andrew Twin^{None} ; David Warren^{None} ; Joe Brown^{None} ; Neil Clarke^{None} ; Richard Wotherspoon^{None} ; Rod Bateman^{None} ; Roman Viznichenko^{None} ; Steve Chappell^{None} ; Steven Ball¹ ; Ziad Melhem^{None}

¹ *Oxford Instruments Nanoscience*

High temperature superconductors (HTS) have opened up a new experimental space. Commercially available HTS wires and tapes have now been developed with very high critical current densities at high fields. Large bore, high field "outsert" solenoid magnets that use more conventional NbTi and NbSn conductors have been developed to provide background fields in a cold bore of between 150 and 250 mm diameter with an associated central field of 19 and 15 Tesla respectively. This outsert technology is enabling major steps forwards in ultra high field magnet technology. Magnets are under development in laboratories around the world operating at T=4.2K with B fields in excess of 25 Tesla.

We will discuss the challenges which have to be met to provide such background magnets, including quench energy management, coil interactions, mechanical support, eddy current forces and cryogen handling. The challenge of incorporating HTS coils within the ultra high field magnet products of the future is described. We look ahead to further developments and to how this emerging technology may enable wider applications for experimentation in the physical sciences.

Submitters Country:

UK

Tue-Af-Po2.08 / 887

An Experimental Stability Diagram for ReBCO Roebel Cables at 4.2 K and Applied Fields up to 12 T

Author(s): Chris Kovacs¹

Co-author(s): Mike Sumption¹ ; Milan Majoros¹

¹ *The Ohio State University*

A 9-tape, 14 mm wide ReBCO Roebel cable was soldered onto a U-shaped holder. It was determined at 4.2 K with applied fields up to 12 T. At varying I/I_c , different heat pulses resulted in different quench behaviors. For a given sample, these different behaviors were used to construct a stability diagram. Stability diagrams were constructed for samples with different levels of insulation.

Submitters Country:

USA

Thu-Af-Po4.09 / 94**An FPGA-based Quench Detector and Data Acquisition System for Superconducting Insertion Devices**Chun-Yi Wu¹ ; Chih-Yu Liao¹ ; Demi Lee² ; Yung-Sen Cheng² ; Chih-Hsien Huang² ; Jenny Chen² ; Kuo-Hwa Hu² ; Kuo-Tung Hsu²¹ *National Synchrotron Radiation Research Center*² *NSRRC*

A novel quench detector and post-mortem system for superconducting insertion devices are developed. This module consists of two functional components: quench detection and output latch signals for interlock purpose, which is based on field-programmable gate array, and a data acquisition system based on a set of simultaneous sampling ADC modules. The data acquisition system has two concurrent modes of operation: A fast capture mode that is triggered by a user specified of coil quench voltage at sampling rates up to 500 kHz, and a continuous data mode that can real-time monitor data at 10 Hz rate using the same acquisition system. The system was designed with a modular structure using commercially available hardware. This approach makes the new system easily scalable for superconducting insertion devices with coil and lead voltage tap configurations. A detailed description of the system along with test results is presented in this paper.

Submitters Country:

TAIWAN

Wed-Af-Or26 / 696**Analyses of the ITER Poloidal Coil joints cold test results.****Author(s):** Andrei Baikalov¹**Co-author(s):** Byung Su Lim¹ ; Fabrice Simon¹ ; Hua Qing¹ ; Yury ILIN²¹ *ITER Organization*² *ITER IO*

The design of ITER Poloidal Coils contains 88 joints connecting individual conductors. Satisfying restrictions from operating condition, manufacturability and serviceability, these joints were designed as twin-box “shaking hands” concept. To ensure the manufacturing process consistently produces acceptable components, joint qualification tests have been defined for AC losses, DC resistance, heat exchange, critical temperature, etc. Data from each test is aggregated to PASS/FAIL result which qualifies manufacturing process. In present work we attempt to dissect the test data in order to reveal constituents of the final acceptance value. The outcome does not change the qualification results, but could steer us towards more robust manufacturing process by highlighting critical steps. We have studied the data from one failed and 3 passed joint samples with regard to DC resistance tests. In our analysis we consider data from all voltage taps and focus on DC resistance components that constitute the joint acceptance criteria. Measurements were conducted at 0T–5T external magnetic field and 0kA–55kA operating current with voltage taps distributed at various distances from the joint. Joint resistance and cable resistance results have allowed us to study current redistribution between the superconducting strands and the impact of multiple resistive interfaces on overall joint performance. We have dissected the data into inductive, joint-resistive, and cross-strands-resistive components. Study under reverse current polarity has indicated non-symmetric

behavior, most likely originating from mechanical movement of the strands. Cyclic load tests, targeted at joint-resistive component degradation study, have also shown improvement (up to factor of 10 reduction) on the cross-strands-resistive component (outside of the joint).

Acknowledgement: Joints have been provided by F4E and ASIIP through EU and CN Domestic Agencies. Special thanks to SPC SULTAN facility for raw data records.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

France

Wed-Af-Po3.07 / 1081

Analysis and Control of a Multi-Phase Bearingless Permanent Magnet Synchronous Motor

Huangqiu Zhu¹ ; Yuemei Qin¹

¹ *Jiangsu university*

For the virtues of no friction, high-speed, long life, and so on, bearing-less motor have broad application prospects in high-purity and high-speed areas, such as biomedicine, pharmaceutical industry, aerospace, etc.. Meanwhile, multi-phase motor has higher torque/power density, lower torque ripple and superior ability of fault-tolerant operation compared to three-phase motor. Thus, the multi-phase bearing-less permanent magnet synchronous motor (BPMSM) will combine the merits of the two kinds of motors. Although the multi-phase BPMSM with a single set of windings has a simpler configuration, it has many restrictions on the winding distribution and pole-pair allocation. To improve the torque density and decrease the torque ripple of the BPMSM, a five-phase 10-slot/8-pole fractional-slot-concentrated-double-winding (FSCDW) BPMSM is presented in this paper. At first, the harmonic distribution and mathematical model of armature magnetic motive force (MMF) are investigated in detail by adopting the winding function method, and it is verified by finite element analysis (FEA). Then, the permanent magnet shapes are optimized to obtain an ideal rotor MMF. The principle of the suspension force is analyzed in detail according to the interaction between the armature and rotor MMF, and its mathematical model considering the rotor eccentricity is derived based on the Maxwell's stress tensor method. For comparison, a 10-slot/2-pole integer-slot-concentrated-double-winding (ISCDW) BPMSM with the same volume of the proposed motor is designed, and the torque and suspension force of the two motors are computed, compared and analyzed. The dynamic experiments on a prototype are developed finally and the corresponding results reveal that the proposed motor with higher torque density and lower torque ripple can operate stably, and this will provide great significance for further research. Note that the suspension force analysis method of MMFs is little in literature and it is also applicable to other BPMSM with different pole-pair allocation.

Submitters Country:

china

Mon-Af-Po1.07 / 1159

Analysis and Optimal Design of the Transmission Coils for the Wireless Power Transmission System

lantao huang^{None} ; Jianhui Wang¹ ; Jing Zhang¹

¹ *Xiamen University*

With the development of the technology, the wireless power transfer (WPT) which can realize power transmission without wires has attracted much attention in recent years. This technology is promising in the applications of mobile devices charging and biomedical implant powering with the advantages of contactless and flexible. In the WPT system, the transmitting and receiving coils are the core components for the power transmission. It affects the system efficiency and the transmission power directly. In this paper, a comprehensive analysis of the transmitting and receiving coils is conducted based on the circuit and electromagnetic simulation. The effects of the structural parameters and the magnetic core of the coils on the power transfer performance are studied. Finally, aiming at the improvement of the transmission power and efficiency, an optimal design of the coils is carried out according to the characteristics of the WPT system.

Submitters Country:

China

Wed-Af-Po3.08 / 668

Analysis and Optimization of Adjustable Magnetic Fluid Damper in DC Magnetic Field

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Co-author(s): Qingxin Yang¹; Wenrong Yang¹; Bing Guo¹; Lifei Chen¹

¹ *Hebei University of Technology*

Magnetic fluid is a stable colloidal dispersion of single domain magnetic nanoparticles in a carrier fluid [1]. Magnetic fluid can be widely used in various fields [1-2]. Based on the magneto-viscous characteristic, magnetic fluid has many unique advantages as damping medium. This paper presents an adjustable magnetic fluid damper. This damper is composed of an induction coil, a non-magnetic vessel, two non-magnetic springs, and a cylindrical inertia mass. The coil is wrapped around outside of the vessel to provide magnetic field. The cylindrical inertia mass is fixed to the vessel by two springs. The vessel is filled with magnetic fluid and sealed. The different input currents in the coil can generate different magnetic field, which can change the viscosity of the magnetic fluid and adjust the damping parameters of the damper. Based on the Bernoulli equation and the continuity equation, the damping force and equivalent damping coefficient of the damper are obtained. The factors that influence the damping parameters are analyzed, including the viscosity of the magnetic fluid in a magnetic field, the radius and length of the inertia mass, and the size of the gap between inertia mass and vessel. The multi - objective parameters of the shock absorber are optimized by the genetic algorithm. The optimal combination of the performance parameters of the shock absorber is obtained, and then the numerical simulation is carried out. The results show that the adjustable magnetic fluid damper shows high sensitivity and adjustable for the low frequency and small damping vibration.

I Torresdiaz, C Rinaldi, "Recent progress in ferrofluids research: novel applications of magnetically controllable and tunable fluids," *Soft Matter*, vol.10, no.43, pp. 8584-8602, 2014.

N Choudhary and D Kaur. "Vibration Damping Materials and Their Applications in Nano/Micro-Electro-Mechanical Systems: A Review," *J. Nanopart. Res.*, vol.15, no.3, pp. 1907-1924, 2015.

Submitters Country:

China

Tue-Af-Po2.06 / 1138

Analysis and application of discrete Halbach magnet array with unequal arc lengths and unequally-changed magnetization directions

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Compared to radial magnetization, Halbach permanent-magnet (PM) array inherits some attractive features: strong field intensity, self-shielding effect, near-sinusoidal airgap flux density distribution. Due to the difficulty in realizing continuous magnetization direction on single PM annulus, Halbach PM arrays are generally realized by discrete PM segments. In most cases, the magnetization directions of these PM segments change equably, and the arc length of each segment is equal. However, the segment number is limited by the size of machine and some magnetization directions are difficult to produce. These issues limit the application of Halbach PM array in more industry fields. In this paper, both analytical and FEA methods are applied to analysis the flux density distribution produced by the Halbach PM array when changing the arc length and magnetization directions of each PM segment. It is found that with different combinations of arc length and magnetization direction of each PM segment, similar amplitude of main flux density can be produced in the air gap. This knowledge can be helpful to avoiding specific magnetization directions which are hard to process or in danger of demagnetization. In conventional Halbach PM array, the total number of PM segments is integer multiple of pole number. However, this paper shows that by designedly selecting the magnetization direction and arc length of each segment, the specific poles of the magnetic field can be generated by variable number of PM segments with acceptable harmonic components. Therefore, it is more flexible to choose the segment number of Halbach array for different occasions. Moreover, this paper discusses how to produce or reduce multi particular harmonic magnetic fields in Halbach array by designing the magnetization directions and arc lengths. More detailed analysis will be presented in the full paper.

Submitters Country:

China

Thu-Af-Po4.05 / 1027

Analysis of EMF Distortion in Magnetic Geared Machines

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Co-author(s): Dawei Li¹; Ronghai Qu¹

¹ *Huazhong University of Science & Technology*

Magnetic geared machines are widely researched in recent years due to their high torque density, speed separation function, etc.. However, according to flux modulation principle, abundant magnetic field components are produced in 2 airgaps, and they will interact with stator winding and produce back EMF harmonics at even no load condition, hence no load back EMF distortion is caused. No load back EMF distortion of magnetic geared machines has some interesting features. First the back EMF waveform is determined by both the two rotor speeds, hence the distortion degree is also related to them. Moreover, the back EMF waveforms of the three phase windings are unbalanced, which may causes different distortion degrees between phase windings. Thirdly, a tiny variation of the ratio of 2 rotor speeds may cause huge change in the distortion degree, and this is quite different from that of regular PM machine. The three features leads to that it is difficult to analyze back EMF waveform distortion and then improve it while this phenomenon is important for the design and control of magnetic geared machines. In this paper, back EMF distortion analysis of magnetic geared machines is done. Based on flux modulation principle, the origin of this distortion is investigated, and the three distortion features mentioned above are explained and also verified by FEA. Then a distortion index curve method is proposed to evaluate the distortion degree of the EMF waveform in the geared machine, and a comparison between the regular and proposed distortion index is also made to verify the reasonability and conveniences of the proposed method. Moreover, several important design parameters such as slot pole combination, magnet thickness, etc. are optimized based on the proposed distortion index, and the suitable slot pole combination are found, and simulation results are verified by FEA.

Submitters Country:

China

Tue-Af-Po2.07 / 517

Analysis of Interruption Characteristics According to Application Position of Inductor-Combined Superconducting DC Fault Current Limiter**Author(s):** Seonho Hwang¹ ; HyeWon CHOI² ; In-Sung Jeong³ ; NOA PARK³**Co-author(s):** HyoSang CHOI²¹ Chosun university² CHOSUN University³ Chosun University

The existing CSC-HVDC system must compensate for reactive power because of the using thyristors as power conversion switching elements. It is impossible to control active power and reactive power independently. The VSC-HVDC system is receiving attention for solving such a problem. In VSC-HVDC, the study of fault current interruption is necessary to improve the stability and reliability. In this paper, We applied the inductor-combined superconducting DC fault current limiter to interrupt the fault current. This technology can quickly cutoff fault current. Also, It can reduce the burden of the superconducting fault current limiter and the mechanical DC circuit breaker. Using the EMTDC/PSCAD, Our team has designed the VSC-HVDC system and checked the fault current interruption characteristics corresponding to the application position of inductor-combined superconducting DC fault current limiter. As a result, we confirmed that the inductor-combined superconducting DC fault current limiter can be reliably interrupted in the DC link section, back of converter and in front of inverter, of the VSC-HVDC system. And it was confirmed that the burden of the superconducting fault current limiter and the mechanical DC circuit breaker were reduced by 30%. Also, The optimum breaking capacity of the inductor-combined superconducting DC fault current limiter was selected according to the application position.

This research was supported by Korea Electric Power corporation [grant number: R16XA01] This research was supported by Korea Electric Power corporation [grant number: R15XA03]

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 15

Analysis of Magnetic Polarity Distribution for a Dual-rotor Switched Reluctance Machine**Author(s):** Hao Chen¹ ; Tong Xu¹ ; Rui Nie¹¹ China University of Mining & Technology

DR-SRM is a novel structure device which can be evolved from conventional SRMs with a single stator and single rotor by increasing a rotor and changing the structure of stator and rotor. The double mechanical ports and double electrical ports are formed by increasing the number of rotor. This paper presents a model for dual rotors switched reluctance motor consisting of two airgaps, an outer-stator, a middle-rotor and an inner-rotor. This model can optimize structure geometry size parameters and polarity distribution of DR-SRM. The average torque of middle rotor in the outer airgap contributing to the main parts of energy conversion with different geometry size of stator and rotors. The sensitivity of inner-rotor pole-arc coefficient, inner-rotor yoke thickness, outer-stator pole-arc

Analysis of Minimum Quench Energy of ITER NbTi and Nb₃Sn CICC

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¹ *University of Twente*

² *Bologna University*

³ *CEA*

The Cable-In-Conduit Conductors (CICCs) for the ITER magnets are subjected to fast changing magnetic fields during the plasma-operating scenario. In order to anticipate to the limitations of the conductors under the foreseen operating conditions, it is essential to have a better understanding of the stability margin of the magnets. In the last decade ITER has launched a campaign for characterization of several types of NbTi and Nb₃Sn CICCs comprising quench tests. The conductors are subjected to a singular sine-wave fast magnetic field pulse and relatively small amplitude with respect to the ITER plasma operating scenario. The Minimum Quench Energy (MQE) tests, performed in the SULTAN facility, were reproduced and analyzed using JackPot-ACDC, an electromagnetic-thermal model for CICCs, developed at the University of Twente and THEA (Thermal, Hydraulic and Electric Analysis of Superconducting Cables). The experimental results were used to calibrate the numerical models and to reproduce the energy deposited in the cable during the MQE stability tests. The agreement between experiments and models shows a good comprehension of the various CICCs thermal and electromagnetic phenomena. The results provide a good basis for further investigation of conductor stability and extrapolative scaling for different magnetic field pulses with lower ramp rate and higher amplitude.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

Netherlands

Wed-Af-Po3.08 / 744

Analysis of Torque Characteristics according to Gear ratio of Coaxial Magnetic Gear

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Mechanical gears have many applications in industrial machines and power transmission. Because of their contact mechanisms, the associated transmission loss, gear noise and regular lubrication are inevitable. Using coaxial topology and high performance permanent magnets (PMs), it was proposed that magnetic gears could be a valid replacement for the mechanical gear. Using high performance PMs, however, which are caused by noise and vibration generated from the interaction between the modulation pole and the rotor PM. Hence, it is necessary to optimize torque characteristics in coaxial magnetic gear (CMG). In this paper, we analyzed the torque characteristics of according to the gear ratio by fixing the inner permanent magnet of the coaxial magnetic gear to 8 poles and changing the number of poles of the outer PM using a two-dimensional finite element analysis method. In addition, we conducted transient analyses of the torque and torque ripple of the magnetic gears and the rotational speed of the outer rotor for various ratios. The torque ripple are different depending on the gear ratio. When the gear ratio was integer, they confirmed that large torque ripple values were generated. When the gear ratio was half, the torque characteristics were much smaller than the values when the gear ratio was an integer, but torque ripple is can be confirmed that the is finely generated. On the other hand, it is confirmed that the torque ripple is the smallest when the gear ratio is quarter. Therefore, we present the optimal gear ratio and operating characteristics under

the required speed-torque conditions. More detailed analysis results, discussions, manufacturing process and measurements of coaxial magnetic gear will be presented in more detail in the final paper.

Submitters Country:

Republic of Korea

Thu-Af-Po4.02 / 677

Analysis of a protected Loss Of Flow Accident (LOFA) in the ITER TF coil cooling circuit

Author(s): Laura Savoldi¹

Co-author(s): Roberto Bonifetto¹ ; Roberto Zanino¹

¹ *Politecnico di Torino*

A detected loss-of-flow accident (LOFA) in the cryogenic cooling circuit of the ITER superconducting magnets will initiate a series of actions aimed at guaranteeing the protection and the integrity of the magnets. In the case of the Toroidal Field (TF) coils, the protection strategy following a LOFA triggered by, for instance, the stop of the cold circulator, is foreseen to determine an “accelerated discharge” of the coil current, followed by a controlled discharge of the CS and of the PF coils, while the plasma pulse will be terminated and the plasma operation will be stopped until the nominal operating conditions of the magnets are recovered. The suitability of the protection strategy following the detection of a LOFA, and the implications on the heat load to the cryoplant and on the re-cooling time needed to recover to normal operations, still deserve some dedicated analysis. Here we apply the 4C code, a well-established numerical tool for the analysis of thermal-hydraulic transients in superconducting magnets for fusion applications, to simulate the dynamics of a detected LOFA in an ITER TF coil and its cooling circuit, following the event tree as currently foreseen by the coil protection system, with special attention to the temperature margin erosion during the accelerated discharge and to the development of hot spot zones inside the winding pack. The time requested to re-cool the magnet will also be estimated, in order to quantify both the additional thermal load on the refrigerator and the impact of a protected LOFA on the machine availability.

Submitters Country:

ITALY

Wed-Af-Po3.08 / 833

Analysis of deep drawing of stainless steel sheet using electromagnetic forming with a driver sheet

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Various studies have proved that the spring back phenomenon always appears in the deep drawing process of stainless steel sheets using traditional quasi-static metal forming technology, due to the existence of residual stress. To solve this problem, a new forming process combining with the advantages of traditional stamping forming and electromagnetic forming is proposed and analyzed in this work. In this process, a sheet with high electrical conductivity is used to drive the punch under the

action of electromagnetic force, and then to form the stainless steel sheet. The proposed process not only can effectively reduce spring back, but also can ensure the work piece coincide with the die. To validate the feasibility of this new process, numerical studies based on finite element method have been presented to design the forming system and predict the forming behavior of stainless steel sheet, and these results have been compared with experimental studies, both showing that the proposed process could be an effective tool for deep drawing of metal sheets with low electrical conductivity and even nonconductive materials.

Submitters Country:

China

Mon-Af-Po1.05 / 267

Analysis of dynamic deformation and disturbing torque of superconducting spinning rotor

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¹ *Institute of Electrical Engineering, Chinese Academy of Sciences*

Based on the Meissner effect a superconducting hollow sphere rotor is levitated in the vacuum housing. During the high speed rotation, the dynamic deformations caused by the centrifugal force and the temperature variation will generate magnetic disturbing torque on the superconducting rotor. The deformations of the rotor are analyzed and simulated by finite element method, and the deformation laws are obtained. According to the results, an analytical model is presented to calculate the magnetic suspension disturbing torque due to the dynamic deformations. A case study is given to discuss the disturbing torque and the drift error. It has significant theoretical value for the design and optimization of the rotor structure.

Submitters Country:

China

Wed-Af-Po3.04 / 995

Analysis of losses in superconducting magnets based on the Nb₃Sn Rutherford cable configuration for future gantries

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Proton therapy for the treatment of cancers adopts a rotating system called gantry to irradiate the tumor from any direction. The gantry system consists of different beam line magnets that bend the proton beam towards the patient. The use of superconducting magnets allows reducing the size and weight of the last bending section. During the gantry operation, it is necessary to change the magnetic field of the last bending in order to vary the proton penetration depth. The electrodynamic transients in the superconducting strands and cables generate losses that must be computed for a proper design of the cryogenic system. Two main types of losses must be accounted for when dealing with multistrand superconducting cables, related to the magnetization and coupling of the superconducting filaments (intrastrand losses) and to the current loops induced between different strands during electrodynamic transients (interstrand losses). This work describes the methodologies and numerical codes adopted to compute the hysteresis and coupling losses in an innovative magnet system designed by PSI for future superconducting gantries. In this design the superconducting coils are wound using Nb₃Sn Rutherford cables. The validation of the numerical tools versus analytical

results is presented for simplified cases with uniform magnetic flux density applied to the conductor. The results of the loss calculation and the impact of the different contributions are then presented for the actual proposed magnet system configuration.

Submitters Country:

Italy, Switzerland

Wed-Af-Po3.05 / 985

Analysis of magnetic flux density waveform distortion in sensor magnet for rotor position detection

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The sensor magnet is used to detect the position of the rotor in the brushless motor. For accurate position sensing, the sensor magnet must produce a sinusoidal magnetic flux density waveform. However, when the size of the magnet is large and the Hall sensor is positioned on the side of the sensor magnet other than the center, some distorted magnetic flux density waveforms often occur. This distorted magnetic flux density waveform causes an angle error in the calculation of the rotor position in the controller. The angle error degrades the performance of the motor. In this paper, we conclude that the cause of distortion of magnetic flux density waveform of sensor magnet is the shrinkage of block generated in magnet sintering process. That is, since the magnetic domain arrangement is deformed by the shrinkage of the sintering magnet block, the magnetic flux density waveform of the sensor magnet is distorted. This was confirmed by electromagnetic simulation and magnet measurement, and it was possible to fabricate an improved sensor magnet with reduced waveform distortion.

Submitters Country:

South Korea(Republic of Korea)

Thu-Af-Po4.05 / 994

Analysis of the Nonlinear Characteristics of Magnetic Circuit in a Balanced Armature Receiver

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As an inherent nonlinear device, an analysis method of a balanced armature receiver (BAR) considering the nonlinearity, especial the nonlinear magnetic characteristics are important. From literature survey, the finite element method (FEM) could be considered as the most accurate analysis method. Thus, a mass of simulations with 3D FEM analyses are proposed in this paper to analyze the nonlinear characteristics of magnetic circuit in a BAR. The back-EMF can be calculated based on the flux passing through the armature, and the total force is generated based on the flux density in the air

gap. It should be mentioned that, as the flux density in the air gap and the flux passing through the armature changes according to both of the armature vibration displacement and the current in the coil, the back-EMF and the total force can be processed as functions in terms of the displacement and current. Therefore, the nonlinear magnetic characteristics can be obtained: the inductance and speedance can be acquired from the back-EMF, and the cogging force and the force factor can be acquired from the total force. The cogging force is considered as the magnetic stiffness, which acts as negative mechanical stiffness. The modal analysis is implemented with the reduced stiffness of the vibration system by using 3D FE static mechanical analysis. To verify the effects of nonlinear magnetic characteristics, the vibration displacement on the SDP around the area connected with pin should be measured in frequency domain. To eliminate the stiffness effect produced by the sealed air in the back volume and front volume in the BAR, samples with holes punched on both of the upper and lower cover are manufactured. The modeling of simulation and the simulated vibration displacement are followed the measurement, and verified experimentally.

Submitters Country:

Korea

Thu-Af-Po4.01 / 460

Analysis of the Training Behaviour of the MICE Spectrometer Solenoid

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Muon ionization cooling is theoretically well understood but has never been fully demonstrated experimentally. Ionization cooling is regarded as an important technology both in terms of cost and performance for a Neutrino Factory and is absolutely essential for a Muon Collider. The MICE experiment (Muon Ionization Cooling Experiment), based at the Rutherford Appleton Laboratory in the UK, is presently collecting data to prove the concept. Part of MICE are two spectrometer magnets, each consisting of five superconducting large bore solenoids. The spectrometer solenoid is designed for a peak field of 4T. Both spectrometer magnets required about 15 quenches to reach the design current. However, it was discovered that both spectrometers do not remember their training; after a warm-up the spectrometers have to be re-trained, following a very similar training curve. The MICE spectrometer was analyzed using 2D and 3D finite element software to understand the quench and training behaviour; the analysis revealed a clamping mechanism, leading to a stick-slip situation for one of the coils in its coil pocket. This paper summarizes the results and makes suggestions how to improve the design.

Submitters Country:

USA

Mon-Af-Po1.07 / 516

Analysis of the coupling factor according to diameter of superconducting transmitting and receiving coils

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Recently, electronic devices using a wireless charging method are increasing with development of technology. The wireless charging method is free from the space limitation and has an advantage in mobility. However, the wireless charging method has a disadvantage that the efficiency is much lower than the wired charging method. In order to improve the efficiency of the wireless charging method, the coupling factor indicating the degree of coupling between the two coils must be increased. The coupling factor varies depending on the design method of the transmitting and receiving coils.

In this paper, to improve the efficiency of the wireless charging method, the coupling factor according to the diameter of superconducting transmitting and receiving coils was analyzed. To analyze the coupling factor, the diameter of the transmitting coil was fixed and the diameter of the receiving coil was changed to a certain size. As a result, it was confirmed that the coupling factor is the highest when the receiving coil has a specific diameter. Whereas when the receiving coil grew above a certain diameter, the coupling factor could be confirmed to be smaller. Through these considerations, it is possible to get the high efficient wireless charging if the transmitting and receiving coils are designed with the optimal coupling factor.

This research was supported by Korea Electric Power corporation [grant number: R15XA03]. This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (NRF-2015R1D1A1A01059489)

Submitters Country:

Republic of Korea

Tue-Af-Po2.07 / 811

Analysis on AC Loss of DC HTS SFCL Coils due to AC Ripple Current

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Superconducting fault current limiter (SFCL) consisting of high temperature superconducting (HTS) tapes is potential application for direct current (DC) power system, to reduce the amplitude and rise rate of short-circuit fault current in ms-level. Nowadays, with the increase of DC transmission capacity, the magnetic field of fault current limiting component seriously decrease the critical current of HTS tapes and then augment the cost, weakening the advantage of DC HTS SFCL. In order to solve the problem, iron material is used to alter the magnetic field. Inevitably, AC ripple current in DC transmission system leads to the AC loss of DC HTS SFCL coils, which is harmful to the safety and reliability of SFCL. In this paper, two 5 Ω/1 kA DC HTS SFCL coils without and with iron yokes for comparison are designed and investigated by electromagnetic analysis and theoretical calculation in Finite Element Method (FEM) models, given that the amplitude of the AC ripple current is 0~20% of the DC current value. The AC loss in the coil with iron yokes is lower than that without iron yokes, which indicates AC loss due to AC ripple current can be effectively reduced by iron yokes. The result of this paper can provide some reference to the rational design of DC HTS SFCL and corresponding cryogenic systems.

Submitters Country:

China

Tue-Af-Po2.06 / 855

Analysis on Design Sensitivity of Permanent Magnet Motor using Lumped Magnetic Circuit Method

Author(s): Jung Sang-Yong^{None} ; Jin-Seok Kim¹**Co-author(s):** Jae-Hak Lee² ; Yong-Jae Kim³¹ *SUNGKYUNKWAN UNIVERSITY*² *SungKyunKwan University*³ *Chosun University*

In general, Spoke type Permanent Magnet Synchronous Motor (PMSM) has intense air gap flux density due to its magnet arrangement. However, variation of machine performance is severe due to its design variables, such as air-gap length and magnet size. On the other hand, Surface Mounted PMSM (SPMSM) is less sensitive to change of variables that are mentioned above. In this study, we examine the air-gap flux density of SPMSM and Spoke type PMSM with respect to air-gap length and magnet size, in order to identify the sensitivity of performance. It is analyzed numerically based on magnetic equivalent circuit (MEC) method and it is validated through the comparison with FEA results. While establishing MEC, magnetic reluctance, which has different flux path, is considered as component of equivalent circuit element and is defined numerically. For simplicity of the analytical model, magnetic saturation in the rotor and stator cores are ignored, allowing magnetic reluctance of core to be neglected. Thus MEC is composed of air-gap and magnet magnetic reluctance which has low magnetic permeability, and air-gap flux density is calculated numerically in respect to fluctuation of these variables

Considering that air gap flux density of Spoke type motor is varies sensitively to air gap length fluctuation, calculation and analysis is carried out by altering air-gap length from 0.5 mm to 1.5mm with increment of 0.1mm. Moreover, change in air gap flux density considering variation of magnet width is from -1.5 mm to 1.5mm with increment of 0.1mm.

These two types of motor are designed with equivalent condition. In addition, sensitivity of air-gap length and magnet size are compared through both MEC and FEA. As sensitivity of motor can be predicted using MEC, the issue could be avoided in preliminary design stage.

Submitters Country:

South Korea

Mon-Af-Po1.05 / 363

Analysis on end effect and levitation force calculation for radial-type superconducting magnetic bearings

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The levitation force is an important parameter for the design and optimization of superconducting magnetic bearing (SMB). Some attentions have been drawn to the quick and accurate calculation of levitation force. Not only the strongly nonlinear E-J relationship of superconductor, but also the relative movement between superconducting stator and permanent magnet (PM) rotor makes it complicated to model the levitation behaviors of SMB. In this paper, we present a simple and easy way to calculate the levitation force of radial-type SMB. The air-gap magnetic field generated by PM rotor can be obtained applying finite element method. Through the Fourier transformation on the

air-gap magnetic field, a series of sine harmonic travelling magnetic field moving as the rotor speed are exerted on the boundary conditions of solution domain for superconducting stator. Thus the superconducting stator can be modeled using an H-formulation finite element model implemented in commercial software COMSOL easily. Numerical simulations on relationship between the displacement and levitation force in field cooling and zero-field cooling are carried out respectively. The results show a good agreement with experimental data, which verifies the correctness of modeling method. The modeling method of the radial-type SMB is adopted to analyze the end effect caused by finite axial length of superconducting stator and PM rotor. Finite element models of the radial-type SMB bearing with different structure and size for superconducting stator and PM rotor are established. Considering the influence of end effect, magnetic field distribution, induced current density and levitation force are discussed based on the simulation results. The calculation way of levitation force and the influence of end effect may provide a reference for the design and optimization of SMB.

Submitters Country:

China

Thu-Af-Po4.09 / 619

Analytic Study of the Active Quench Detection Method for the HTS Magnet using Resonance circuit

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⁶ *Massachusetts Institute of Technology*

Generally quench detection of high temperature superconducting (HTS) magnet is difficult compared with low temperature superconducting (LTS) magnet. Because normal zone propagation (NZP) velocity of HTS is slower than LTS. In order to detect the quench signal for HTS magnet, signal wires for voltage taps are needed. However, owing to its slow NZP velocity, the quench signal of HTS magnet is hard to detect when the voltage taps are attached on the HTS magnet with short distance. Moreover, HTS magnet have possibility to burn out when the voltage taps are attached both end of HTS tape. Because the hot spot is hardly dissipative and the thermal runaway occurs on the normal zone. In the other hand, inductive voltage can be a noise aspect to the quench detection of HTS magnet. And the larger magnet size, the bigger inductance is. Especially, the effect of inductive voltage get worse as the HTS tape transits from the superconducting state to normal state. Therefore, in this paper, quench detection method is presented for HTS magnet using resonance circuit to detect the quench signal sensitively. The simulation and experimental results show that proposed method can be a feasible technique to detect the quench of HTS magnet.

Submitters Country:

Republic of Korea

Tue-Af-Po2.06 / 727

Analytical Calculation for Rotor Eddy-Current Losses in Permanent Magnet machine

Author(s): Kyung-Hun Shin¹

Co-author(s): Jang-Young Choi ; Han-Wook Cho

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High-speed permanent magnet (PM) machines are used in applications such as machining spindles, generation and storage of energy in vehicles, gas blowers, and other specialized applications. High-speed PM machines exhibit high efficiency, energy density, and dynamic capability. However, in these machines, overheating in rotors due to power loss can lead to problems because, unlike stators, rotors are more difficult to cool. Cooling of rotors is restricted by a small air gap and lack of heat transfer through sleeve materials. Overheating may cause demagnetization of PMs, sleeve failure, or bearing drying. In high-speed PM machines, rotor losses constitute a larger than typical proportion of total losses in the case of conventional low-medium speed machines. Rotor losses are generated by induced eddy currents in rotor materials. The major causes of eddy currents can be divided into the following three categories: (1) No-load rotor eddy current losses caused by existence of stator slots. (2) On-load rotor eddy current losses caused by high magnetic motive force (MMF) winding harmonics. (3) On-load rotor eddy current losses induced by the time harmonics of pulse width modulation (PWM) inverter fed phase current. To maintain the mechanical integrity of a high-speed PM rotor intended for high-speed operation, the rotor assembly is often retained within a carbon-fiber/epoxy composite or metallic sleeve. The sleeve is primarily exposed to magnetic fields produced by a stator from either the slotting or the MMF harmonics that are not synchronous with the rotor. These nonsynchronous fields cause significant rotor losses. As there is no trivial method to remove the heat generated in the rotor assembly including PMs, accurate prediction of these rotor eddy current losses is particularly important. This study addresses the calculation of rotor eddy current losses in high-speed PM machines, based on the subdomain analytical method.

Submitters Country:

Republic of Korea

Wed-Af-Po3.05 / 1093

Analytical Investigation of the On-load Electromagnetic Performance of Magnetic-Geared Permanent-Magnet Machines

Author(s): Kyung-Hun Shin¹

Co-author(s): Han-Wook Cho ; Jang-Young Choi

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Low-speed high-torque machines are being increasingly used in various applications such as electric vehicles, wind-power generation, electric vessels, industrial robots, and home appliances, because they can offer direct-drive operation, which avoids the inconveniences of mechanical gearboxes. The magnetic geared permanent magnet (MGPM) machine, which works similar to an electrical machine coupled with a coaxial magnetic gear, can be used as a substitute for direct drive systems and mechanical gears. The MGPM machine is gaining interest owing to its significant features, such as reduced acoustic noise, maintenance-free operation, improved reliability, precise peak torque transmission capability, and inherent overload protection. In addition, an MGPM machine can further reduce the overall size and weight, compared to the simple combination of gear and electric motor. Despite these advantages, it is difficult to gain insight into the influence of the design parameters on the electromagnetic performance of MGPM machine. Analytical methods are useful for the first evaluation of machine performances and for design optimization, because continuous derivatives, which are obtained from the analytical solutions, are required during most optimization methods. In this paper, an analytical solution based on a Fourier analysis is proposed to compute the on-load electromagnetic performance in magnetic-geared permanent-magnet machines. The analytical solutions are derived by solving the field-governing equations in each simple and regular subdomain, i.e., permanent magnet, air, modulation slot, slot opening, and slot, and then applying the boundary conditions to the interfaces between these subdomains. Based on these solutions, the electromagnetic performance is determined analytically. All analytical results were extensively validated using nonlinear two-dimensional finite element analysis and experiments. Using the proposed method,

we investigated the effect of the slot number on operating characteristics. The proposed method could be very useful in the initial design and optimization of a magnetic-gear permanent-magnet machine.

Submitters Country:

Republic of Korea

Tue-Af-Po2.05 / 611

Analytical Method to Evaluate the Manufacturing Tolerance and the Ferromagnetic Shim-ability of a 400-MHz HTS NMR Magnet.

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This paper describes an analytical method to predict undesirable magnetic field inhomogeneity caused by manufacturing errors and evaluation of the permissible manufacturing tolerance for a high temperature superconductor (HTS) NMR magnet. Recently, HTS magnets have been actively studied for high-field nuclear magnetic resonance (NMR) (>1 GHz) magnet worldwide. Most high-field HTS magnet wound with REBCO tapes are composed of stacks of single or double pancake coils with hundreds of turns per each pancake. Even following ideally homogeneous magnet design, the magnetic field in a certain region of interest (ROI) of an initially manufactured REBCO NMR magnet must be inhomogeneous because of machining tolerance errors, the REBCO conductor's dimensional variation of thickness and width, and human errors during winding and assembling. Also, if the manufacturing-error-induced inhomogeneity exceeds the maximum shim strength of ferromagnetic shim and/or shim coils, the magnet cannot be used for an NMR. In this paper, we present 1) a draft design of 400-MHz/54-mm REBCO NMR magnet; 2) a stochastic modeling and statistical analysis of the magnetic field homogeneity affected by manufacturing errors and 3) evaluation of the maximum manufacturing tolerance under the limit of ferromagnetic shim strength.

Submitters Country:

Republic of Korea

Wed-Af-Po3.06 / 713

Analytical Modeling and Experimental Verification for Electromagnetic Analysis of Permanent Magnet Linear Synchronous Machines with Horizontally Magnetized Permanent Magnets accounting for Flux-Passing Iron Pole

Author(s): Kyung-Hun Shin¹

Co-author(s): Jang-Young Choi ; Han-Wook Cho ; Sung-Won Seo¹

¹ *Chungnam National University*

Permanent magnet linear synchronous machines (PMLSMs) are able to provide thrust force directly to the load without mechanical gears and transmission; therefore, they have significant advantages over rotary machines, such as simplicity and high efficiency. Generally, PMLSM uses vertically magnetized permanent magnets (PMs). However, we proposed a PMLSM with horizontally magnetized PMs, which is very advantageous in terms of weight because there is no back core to make magnetic flux. As is well known that the detailed knowledge of the magnetic field distribution in air gap is vitally important for design and optimization of PMLSMs. Although numerical tools, such as finite element method (FEM), are able to offer precisely field prediction, they can provide neither closed-form solution nor physical insight. Analytical methods are useful for the first evaluation of machine performances and for design optimization since continuous derivatives, which are issued from the analytical solutions, are required during most optimization methods. However, it is difficult to gain insight into the influence of the design parameters on the machine performance of PMLSM with horizontally magnetized PMs through analytical solutions due to magnetically complex PM mover structures. In this study, an exact analytical solution based on a Fourier analysis is proposed to compute the electromagnetic performance in PMLSMs with horizontally magnetized permanent magnets. By using the separation-of-variables technique, we obtain the analytical solutions to Poisson's equations in the PM and slot subdomains (magnetization or current density regions) and Laplace's equation in the air-gap and end subdomains. From these solutions, the electromagnetic performance is also determined. The validity of the analytical method presented in this paper is verified by comparing it with the results of FEM and experiment. The analytical modeling, analysis results, and measurements will be presented in more detail in the full paper.

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 17**Analytical Polynomial Models of Nonlinear Magnetic Flux Linkage for Switched Reluctance Motor**Hao Chen¹; Wenju Yan²; Lei Chen²; Meng Sun²; Zheng Liu²¹ *China University of Mining & Technology*² *China University of Mining and Technology*

In this paper, the flux linkage curve of the second form is analyzed. The characteristic of the flux linkage is presented in the form of a high order polynomial, which makes it easier for data-fitting. The flux linkage curve of the form ψ - θ curves for different i values is analyzed. The flux linkage data of the SRM prototype is obtained on 4 specific rotor positions (0° , 7.5° , 15° , 22.5°). The imitative effect of the flux linkage is not good enough especially when rotor positions are ranging from 0° to 7.5° . It is resulted from the following three reasons: Only 4 specific rotor positions are chosen to get the entire characteristic of the flux linkage. The highest degree of the data-fitting polynomial is three. The derivative of rotor positions ranging from 0° to 22.5° should be greater than 0 when using the least square method. It is easy to find that the error trend of different currents is same with rotor positions ranging from 0° to 7.5° . An error percentage correction coefficient can be introduced into the flux linkage curve for better accuracy when rotor positions changing from 0° to 22.5° . The flux linkage model can also be constructed through $\psi(\text{in}, 0^\circ)$ rapidly. $\psi(\text{in}, 0^\circ)$ is linear to the currents i_k , so the equation for the fast flux linkage model can be obtained by draw into an coefficient matrix when the current is i_k . The torque of the origin model, modified model, and fast model can be calculated by this method. Then make comparison with FEM calculated result to verifies the correctness of the modified model and fast model. The experimental verification is carried out based on the prototype. The results show that the simulation waveforms are consistent with the experimental waveforms, which verifies the accuracy of the model.

Submitters Country:

China

Thu-Af-Po4.05 / 133

Analytical approach to maximize the torque density with size constraints for PMSM

Author(s): KIDOEK LEE¹**Co-author(s):** SEHYUN RHYU¹; JEONGJONG LEE¹¹ *Korea Electronics Technology Institute*

IPMSM is mainly used as the traction motor of HEV and EV, because it has the high torque density and the wide operating range. Especially the size limit of traction motor exists in HEV, because HEV system consist of the engine and the electric propulsion systems at limited space. Many studies have been conducted to maximize the torque of a single air gap IPMSM with the size constraints. In some studies, there are ways to maximize the air-gap flux density by changing the shape and arrangement of the permanent magnet of the rotor with the fixed stator outer diameter, stack length and rotor outer diameter. In some studies, there are ways to add to the cooling structure in order to improve the current density of stator. As a result, the improvements of air-gap flux density by magnet and current density improve the torque density of IPMSM. In this paper, the single air-gap IPMSM was validated by experiments after design for 120kW class traction motor of military trucks with water cooling in order to improve the torque density. In the process of designing, the ratio of stator and rotor that generates maximum torque in given size constraints exists regardless of the shape and arrangement of the permanent magnet. The analytical approach to calculate its ratio was proposed in this paper. And the analytical approach was validated by FEA.

Acknowledgements: This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy (No. 201520201065200)

Submitters Country:

Republic of Korea

Mon-Mo-Or3 / 1077

Analytical investigation in bending characteristic of pre-twisted HTS tapes

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The twisted, stacked-tape cabling method allows developments of high current REBCO cables for various high field applications, such as fusion magnets, magnetic resonance imaging (MRI) devices and accelerator magnets. The single tape performance under applied loads is crucial to understand cable limitations, and important for choosing an appropriate cable geometry. In this paper, we theoretically investigate the effect of twisting morphology on the mechanical properties of HTS tapes by using the Timoshenko beam model. Particular attention is paid to the transverse bending of a pre-twisted HTS tap. The analytical solution is first derived for the deflection of the HTS tap under a uniformly or periodically distributed transverse force. Then, the critical current of a twisted tape is calculated by the integration of the critical current densities corresponding to the strain distribution over the tape cross-section using axial strain data of the pre-twisted tape. The results show that the twisting morphology can significantly improve the resistance of HTS tap to transverse bending, thus reduce the superconducting performance degradation. This study helps understand the electro-mechanical properties of pre-twisted HTS taps and provides theoretical reference for the design of novel HTS cable structures.

Acknowledgments: The authors appreciate the financial supports from the National Natural Science Foundation of China (11572143 and 11421062).

Submitters Country:

China

Thu-Af-Po4.07 / 509**Analytical methodology for efficient design of pulsed electromagnetic blank holding system****Author(s):** Zhipeng Lai¹**Co-author(s):** Quanliang Cao¹; Xiaotao Han¹; Yujie Huang¹; Ning Liu¹; Xiaoxiang Li¹; Meng Chen¹; Fangxiong Deng¹; Liang Li¹¹ *Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology*

Pulsed electromagnetic blank holding system is a new developed facility using pulsed attractive Lorentz force as blank holding force for sheet metal forming process. The system consists of two electromagnetic coils series-connected and a RLC circuit energizing them. The key metrics of the system are the peak value and pulse width of the pulsed blank holding force. In this paper, an analytical methodology was proposed for efficient design of the system. To meet this goal, an analytical model was built to establish an easily-accessible mapping between the design space (i.e., the geometric parameters of the coils, and the electrical parameters of the RLC circuit) and the target space (i.e., the magnitude and pulse width of the blank holding force). In the model, the inductances, resistances and inductance gradient of the coils were analytically expressed in terms of the geometric parameters of the coils. The inductances and the resistances, combined with the RLC circuit parameters, deduce the expression of the discharge current. Then, the calculated discharge current and the inductance gradient were used to calculate the pulsed attractive Lorentz force (the blank holding force). Finite element analysis and experimental measurement have been performed to validate the proposed model, showing well accuracy of the model.

Submitters Country:

China

Wed-Af-Po3.05 / 150**An improved rotating HF signal injection method for PMSM sensorless control****Author(s):** bo xu¹**Co-author(s):** guoding shi²; jian xu²; wei ji¹¹ *Jiangsu University*² *Jiangsu University*

The bearing-less permanent magnet synchronous motor (BPMSM) is being actively researched due to its advantages of high-speed, high efficiency, high torque density etc. Traditionally, the position and speed of the rotor is detected by mechanical sensors. It has several problems on installation, connection and reliability. Therefore, the sensor-less control technology gradually becomes a hot topic in recent years. This paper presents an improved rotating high frequency (HF) signal injection method for sensor-less control of BPMSM. First, the rotating high frequency (HF) voltage vector is added to motor stator winding. Due to the convex polarity of rotor structure of the built-in PMSM, injected HF voltage can drive HF current component with the magnetic pole position information from the stator winding. By using heterodyne and low-pass filter to the two phase HF current signal, the rotor position estimation error signal can be obtained. When the error signal is adjusted to zero, the value of identification will converge to the actual rotor magnetic pole position. Luenberger

observer is used to adjust the error signal to obtain the rotor magnetic pole position. Second, in order to ensure the HF current signal amplitude distortion and phase lag reach to minimum, this paper uses the best approximation linear phase equi-ripple finite impulse response(FIR) filter to extract the HF current signal. The filter has linear phase characteristic, the passband and stopband maximum error is minimal in the same order of other filters. By using this filter, the system tracking ability is improved. At the same time, linear phase compensation is used in the filter to achieve minimum delay of rotor position estimation. Finally, the sensor-less vector control system of BPMSM is set up. Simulation results indicate that the proposed method can accurately estimate the rotor position and speed in the full speed range.

Submitters Country:

china

Tue-Af-Po2.10 / 388

Application of hierarchical matrices to large-scale electromagnetic field analyses of coils wound with coated conductors

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Electromagnetic field analyses of three-dimensional-shape coils wound with coated conductors are necessary for understanding their electromagnetic phenomena, calculating their ac losses, and evaluating their field uniformity and stability. We have been developing a series of models for the numerical electromagnetic field analyses using current vector potentials. In these models, because the coefficient matrix of the linear system derived from the integral equation is dense, the analysis of a large-scale coil requires large amount of memory and long computation time. In this research, we introduce hierarchical matrices (H-matrices) by using the HACApK library in order to reduce both the memory consumption and the computation time: the dense coefficient matrix is decomposed into submatrices, to which low-rank approximation is applied. Memory consumption of the "H-matrix", which is composed of these approximated submatrices, can be smaller than that of the original matrix. In a pancake coil, for example, a thin coated conductor wound with a small separation should be modelled with layered meshes, and each mesh is often elongated along the conductor. Its elongated edges are much longer than the separation between the layered meshes. In this case, it was found that the conventional low-rank approximation does not work well for the submatrices near the diagonal component of the original matrix. We modify the H-matrix-generation algorithm of the HACApK to improve the applicability to the coils wound with coated conductors. The effect of the method with respect to the memory consumption is examined in numerical tests using various shapes of coated conductors such as straight ones, pancake coils, solenoid coils, and racetrack coils. Furthermore, the effect of parallel computations is discussed to accelerate the analyses. This work is supported by JSPS KAKENHI Grant Number JP16H02326.

Submitters Country:

Japan

Tue-Af-Po2.07 / 1209

Application of the superconductive fault current limiter in limiting the transformer inrush current

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A conventional superconducting fault current limiter (SFCL) is usually applied in the electric power system for fault current limitation. This paper, however, attempts to use the SFCL application to reduce the transformer inrush current, which can have large magnitudes and rich harmonics and result in power system problems such as damage and decreased life expectancy of the transformer, or malfunction of the protection relay. Nowadays, there is little effective method to reduce the inrush current. To limit the inrush current, this paper first proposes to expand the scope of the SFCL application in the power system. The power system operator should first determine the proper amount of current-limiting resistance of the SFCL. Therefore, this paper suggests a decision scheme of the optimal insertion resistance in an SFCL application to reduce the transformer inrush current. This scheme and the SFCL model are implemented using the electromagnetic transient program (EMTDC/PSCAD). We determine the optimal current-limiting resistance by PSCAD simulation, and this value is applied to model the SFCL by the PSCAD simulation. The simulation results show the validity and effectiveness of the suggested scheme and the ability of the SFCL to reduce the inrush current.

Submitters Country:

United Kindom

Thu-Af-Po4.01 / 449

Applied metrology in the production of superconducting model magnets for particle accelerators

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The production of superconducting magnets involves tight tolerances and high precision assemblies, in order to achieve the requirements for their appropriate performance. It is therefore essential to have a strict control and traceability over the geometry of each part of the system, and also to be able to compensate possible inherent deviations coming from the production process. The objective of this paper is to present the experience from systematic geometrical measurements and their analysis, using a portable Coordinate Measurement Machine (CMM) at CERN. First, the methodology for the data acquisition and its ulterior analysis is explained. Then, the results obtained during the on-going production of model magnets for the HL-LHC upgrade and other R&D magnets will be commented, mainly focusing on coil and final magnet geometry. The link between coil and fabrication tooling geometry will be also studied, showing the tooling influence on systematic coil deviations. Furthermore, the integrated effect on coil geometry of assembly operations, cool down and powering of the magnet is investigated, looking at measurements before and after cold tests.

Submitters Country:

Switzerland

Wed-Af-Po3.08 / 1040

Applied solenoid coils effects on the ignition experiments of an MPD thruster

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Magneto-plasma-dynamic thrusters (MPDT) are hybrid accelerators with electromagnetic and gas dynamic processes to accelerate plasma which have considerable potential to enhance future deep space exploration and planetary travel missions. MPDT uses the Lorentz force from interacting currents and magnetic fields to accelerate the plasma. In order to provide a desirable magnetic field inside the discharge chamber and so increase the Lorentz force level, the applied-field MPD thruster (AF-MPDT) with solenoid coils was developed. Due to the external source of magnetic field, the AF-MPDT has the advantages over the Self-field MPDT because desirable electromagnetic accelerations are possible for a lower power level. In the paper we have built an experimental vacuum system and an AF-MPD thruster, which has 300 V max charging, 250 A max current flows, 0.25 T max strength of magnetic field. The structure of the AF-MPDT and the test facilities are introduced in detail. The ignition tests were carried on and the effect to the thruster performance of the working parameters were analyzed, which includes the propellant flow rates, the discharge current flows, the strength of magnetic field produced by the coil and so on. Also an effectively thrust measuring method was described to evaluate the performance of the thruster. Langmuir probes are fabricated to diagnose the sheath plasma from the thruster and to provide the plasma data. The thrust curve is measured and its minimum breakdown voltage occurs in the pressure range of 0.1 to 1 Pa. Successful ignitions of the MPDT to its stable operation and the plasma acceleration of applied magnetic field in MPDT are obtained. The average thrust level can reach 70 mN under the Argon flow of 14 mg/s when the input electric power is 12 kW.

This research was supported by Defense Industrial Technology Development Program and The National Natural Science of China.

Submitters Country:

P. R. China

Wed-Af-Po3.01 / 774

Assembly of the Nb3Sn dipole magnet FRESCA2

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The Nb3Sn dipole magnet FRESCA2 has been developed and manufactured within the framework of a collaboration between CEA Saclay and CERN. The aim of the magnet is to upgrade the superconducting cable test station FRESCA at CERN with a Nb3Sn dipole providing a 13 T magnetic field in a 100 mm aperture. The magnet is composed of 4 coils in a block-type configuration with flared ends, 1.6 m long, housed in a bladder and key type mechanical structure. FRESCA2 has been assembled at CERN at the end of 2016 with the 4 first Nb3Sn coils fabricated at CEA Saclay and CERN. The coils were dimensionally measured and electrically tested. Tailored-shims were fabricated and inserted in the coil pack to improve the contact between the different layers. In addition, tests with pressure sensitive films were carried out to verify the uniformity of the loading. In this paper we provide a detailed description of the various steps of the assembly from the impregnated coils to the delivery of the dipole to the test facility, with particular emphasis on the procedures followed and the tooling developed.

Submitters Country:

Switzerland

Wed-Af-Po3.10 / 928

Assessment of electrical insulation of a superconducting magnet winding pack under severe loading conditions**Author(s):** Selanna Roccella¹**Co-author(s):** Gian Mario Polli² ; Antonio Cucchiario¹ ; Valter Cocilovo¹¹ ENEA FSN² ENEA

Electrical insulation of superconducting magnets represents one of the most critical aspects in the manufacturing and operation of these devices. In tokamaks, for instance, the use of superconducting magnets is highly recommended since superconductivity constitutes an enabling technology for fusion plasmas, nonetheless, their capability in withstanding off-normal loading conditions was never assessed. Indeed, accidents during manufacturing or severe out-of-design loadings in operations could compromise the design life of the component. In this respect, since they do not possess plastic properties, when elastic limits are exceeded, insulating materials could be irreversibly damaged. Damages could be cracks or delaminations producing different effects in terms of operational life of the magnets. Whilst a crack could give rise to electrical breakdown during fast discharge after a quench, delaminations might produce local heating due to friction that might induce superconducting quench. The present paper shows the results of the finite element models of two different winding pack mock-ups of a superconducting magnet for fusion applications subject to off-normal torsion and bending conditions. The mock-ups are supposed made of a matrix of superconducting cable in conduit conductors wrapped by 1 mm thick glass fiber resin composites. Through a detailed analysis of stress-strain properties of the insulation and a comparison with available experimental results, the authors give a threshold to the off-normal loading conditions under which the magnet could be safely operated.

Submitters Country:

Italy

Mon-Af-Po1.07 / 487

Asymmetry in wireless power transfer between a superconducting coil and a copper coil**Author(s):** Hui Yu¹ ; Guole Liu² ; Qi Liu^{None}**Co-author(s):** Zhang GuoMin³¹ Institute of Electrical Engineering Chinese Academy of Science; University of Chinese Academy of Science² the Institute of Electrical Engineering of the Chinese Academy³ Institute of Electrical Engineering Chinese Academy of Science

Wireless power transfer (WPT) is of increasing interests today. HTS (high temperature superconducting) WPT has been demonstrated to be more efficient than copper WPT. In our previous work, the efficiency of WPT from a copper coil (as the transmitting coil) to a HTS coil (as the receiving coil) is lower than the efficiency of WPT from the same HTS coil to the same copper coil. Namely, asymmetry exists and degrades WPT performance. In this paper, it is demonstrated theoretically and experimentally that, for WPT between a HTS coil and a Litz coil: asymmetry does exist and influence properties; the root of the asymmetry is the different resistances between the HTS coil and

the Litz coil; the effects of the asymmetry can be eliminated by optimizing the load; the proposed theoretical calculation fit the experimental results well.

Submitters Country:

China

Thu-Af-Po4.04 / 1145

Auxiliary equipment commissioning of the 11.7 T MRI Iseult magnet

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The final commissioning of the 11.7 T Iseult magnet is going to start in the mid of 2017 at NEUROSPIN laboratory. Before that, the dedicated cryoplant, electrical equipment, control-process and instrumentation have already been installed and tested in order to validate all the operation parameters and the component capabilities. Cryogenic tests have been performed to confirm heat loads and cryo-mechanical performances of the cryogenic satellite connected to the helium refrigerator, and the 1.8 K stage was commissioned as well. Power supplies, electrical circuits, Magnet Safety System have been operated up to the nominal current, while electrical insulation has been verified. Finally, the Magnet Control System and its ancillaries have been qualified to ensure a continuous and highly reliable operation of the system.

Submitters Country:

France

Wed-Af-Po3.09 / 28

Axial tensile stress-strain characterization of Bi2212 round wire with different heat treatment

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The China Fusion Engineering Test Reactor (CFETR) is a new tokamak device, whose magnet system includes toroidal field (TF), central solenoid (CS) and poloidal field (PF) coils which are made up of CICC (cable in conduit conductor). The high temperature superconducting material Bi2212 is one of the preferred magnet materials chosen for CICC because it has an outstanding conductor-carrying capacity at 4.2 K in magnetic field. Under heat treatment with high pressure, its performance can be improved much, which could enlarge its application range. However, the differences in thermal contraction of the composite materials in a CICC, combining with electromagnetic load, could cause distributed strain alterations, therefore, could reduce the superconducting transport properties. For some time, there has been an increasing effort to study the impact of strain on the transport properties of superconducting wires. The mechanical properties of wire is important for the analysis. The basic experimental stress-strain data is indispensable at the round wire level for accurate modeling,

analysis and optimizing for cable and magnet design. In this paper, the axial tensile measurements on Bi2212 round wires with different heat treatment were performed at room temperature, 77 K and 4.2 K, respectively. The wires were heat treated under different pressure. One was heat treated with 1atm, and the other was heat treated with 50 atm. Comparing the experimental results of them, we concluded the effect of high pressure on tensile properties of Bi2212 round wire, and got the essential information for future modeling and analysis. A simple 1D model using an independent materials database was also used to simulate the stress-strain characteristic, and compared to experimental results. The SEM of fracture surface for tested samples were also made, and the compared results were given.

Submitters Country:

China

Wed-Af-Po3.02 / 25

Basic Design and Progress of Central Solenoid Model Coil for CFETR

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The Central Solenoid Model Coil (CSMC) project of China Fusion Engineering Test Reactor (CFETR) began in 2014 and the purpose is to develop and verify the related manufacture technology of the larger-scalar superconducting magnet. The CICC (Cable-in-Conduit-Conductor) is chosen for CFETR CSMC as the best conductor type because of 12 T field and 1.5 m inner diameter design requirement. The CFETR CSMC consists of two type coaxial solenoid coils named Nb3Sn coil in the high field region and NbTi coil in the low field region in order to optimize the manufacturing cost effectively. The maximum field of the Nb3Sn and NbTi coil can reach to 12 T and 6.1 T respectively when the operating current is 47.65 kA. In this paper, the basic design aim and operation requirements of CFETR CSMC are summarized firstly. Secondly, the characteristics of superconducting strands and CICCs including the NbTi and Nb3Sn conductor are described in details. Subsequently, the basic structure design and main features of CFETR CSMC are presented in the third part. The DC, AC and stability performance measurement of Nb3Sn CICC sample, as the most important stage assessment, are performed in SUTLAN test facility and some meaningful conclusions are summed up in the last.

Submitters Country:

China

Tue-Af-Po2.07 / 1213

Basic study of superconducting coils in rectifier transformers for railway electrification system

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Recently, the research and development of superconducting cables have been actively advanced all over the world. Particularly in RTRI, the research of superconducting cables for the railway electrification system (DC) is advancing. If the superconducting cables are used as a feeder of the railway

system, the voltage decay could be significantly reduced. Therefore, DC High Temperature Superconducting (HTS) Electrification has many effects. For example, the reduction of transmission losses, the improvement of the regeneration factor, and the reduction of substations. However, since superconducting cables has no resistance, there is a possibility that the fault current such as ground fault or short-circuit is increased. In the rectifier substation, we receive power (high voltage, about 6.6 kV - 77 kV) from AC power system. It is lowered to AC 1200V by the rectifier transformer, and power is transmitted to the train as DC 1500 V by the rectifier. On the other hand, the development of superconducting transformer with current limiting function using a phase transition of the superconductor has been also advanced. It is expected that the fault current can be restrained by applying superconducting transformers as rectifier transformers. In this study, we investigated the basic study of the superconducting coil in the rectifier transformer for railway electrification system.

Submitters Country:

Japan

Mon-Af-Po1.01 / 1032**Beam Trajectory Simulation Considering Each Harmonic Components in HTS Quadruple Triplet****Author(s):** zhan zhang¹ ; Shaoqing Wei¹**Co-author(s):** Sangjin Lee ¹¹ *Uiduk University*

For the quadruple magnets, the harmonic components at reference radius can be used to express the field quality using relative harmonics which is the high harmonics components (order > 2) by 2nd component. Generally speaking, the high harmonics components have negative effects on beam focusing. Therefore, the relative harmonics should be decreased to meet a target value. However, the specific influence of the relative harmonics on beam focusing in three dimensional is difficult to be expressed. In order to estimate the effects of each harmonic component on particle movement, this study presented beam trajectory analysis in three dimensional with respect to harmonic components by SCALA. First, magnetic field distribution was obtained from a given quadruple triplet using Fourier analysis. Then, the harmonic components which compose the field inhomogeneity were removed one by one from the total magnetic field of the given quadruple triplet. Several magnetic field distributions with different harmonic components were generated. Therefore, the beam trajectories can be simulated in SCALA with respect to magnetic field harmonic components. The field quality of quadruple magnets can be expressed by the effects of harmonics components on beam focusing.

Submitters Country:

China

Wed-Mo-Or21 / 1043**Bending of CORC cables, Experiments and Modeling****Anvar Valiyaparambil Abdulsalam**¹ ; **Kirill Ilin**² ; **Konstantin Yagotintsev**¹ ; **Md Shahriar Hossain**³ ; **Danko van der Laan**⁴ ; **Jeremy Weiss**⁴ ; **Timothy Haugan**⁵ ; **Arend Nijhuis**¹¹ *University of Twente*² *U*³ *University Of Wollongong*⁴ *Advanced Conductor Technologies*

⁵ U.S. Air Force Research Laboratory

The CORC cable is composed of several layers of helically wound HTS tapes on a round core with the winding direction reversed in each successive layer. The cable is flexible but the flexibility is limited by the critical strain value when causing breakage of the HTS layer. The cables for magnets in fusion reactors experience large mechanical and electromagnetic loads arising from cabled conductor and coil manufacturing to cooling and operation of the magnet. In order to optimise the manufacture and operating conditions, the mechanical behaviour of CORC cable must be understood for different relevant loading conditions. The complex configuration with many contact interactions between tapes and the non-linear behaviour of the materials during the production and operation conditions requires the use of finite element (FE) modelling. The FE modelling will allow an accurate calculation of the stress-strain state of the cable components under various loads and importantly; avoiding large-scale and expensive experimental optimisation studies. This work presents the results of experimental tests and detailed FE modelling of the 3D stress-strain state in a CORC cable under bending load, taking the temperature dependence and the elastic-plastic properties of the individual tape materials into account, starting from the initial tape processing conditions during its manufacture up to magnet operating conditions. Furthermore a comparison of the simulations with experiments is presented with special attention for the critical force, the threshold where the individual tape performance becomes irreversibly degraded. The FE model appears to describe the bending test of the CORC cable adequately and thus can be used to study other types of loads, parametric research of dependent variables and optimisation of the CORC cable design.

Submitters Country:

Netherlands

Thu-Af-Po4.08 / 303

Bending-peeling method to measure interface strength of YBCO tape

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YBCO superconductor tape adopts a laminated structure wrapped up with Cu stabilizer. This structure helps control the orientation of YBCO and realize a high critical current. Moreover, it can endure high tensile strain of 0.5% without apparent degradation in superconductivity. However, the interface between the laminas is quite weak. Winded tape coil impregnated with resin often suffers from lamination due to thermal mismatch during cooling down from room temperature to working temperature. Therefore it is necessary to study the strength and crack characteristics of the weakest interface in the tape, and how the crack happens during cooling. We designed a new experiment to analyze the interface strength of YBCO tape. A piece of tape is first embedded in a rectangular section beam of epoxy resin, with tape plane parallel to the beam's middle cross section, tape edge at beam surface. The epoxy beam height is bigger than the tape width. Three-point bending is applied to the beam, one point on the opposite side of the tape across the beam and other two points at the two ends. So the interface is tensed during loading. In this way, the interface strength can be determined directly, and the interface energy can be calculated through the force-displacement curve. The crack interface is observed using SEM, and analyzed with EDS technique. The average interface strength is 5.16 MPa. The experiment data is used to further simulate the crack behaviour during the cooling down process. This method is convenient for measuring commercially available tape, and avoids soldering which is usually adopted for interface strength measurement but exposes the tape to the influence of heat.

Submitters Country:

China

Thu-Af-Pl9 / 1233**Best Posters Awards****Tue-Af-Po2.11 / 557****CHARGING 2G HTS DOUBLE PANCAKE COILS WITH THE HTS FLUX PUMP METHOD**Wei Wang¹¹ *Sichuan University*

A novel high temperature superconducting (HTS) flux pump device was built to charge second-generation (2G) HTS double pancake coils (DPC). This device generates a controllable ac travelling magnetic wave based on similar mechanism as a short-stator linear motor, while the wave has been dc-biased by dc windings on the magnetic circuit. A section of YBCO tape (superconducting stator) is placed transversely to the travelling direction of the wave, which output a neat dc voltage. The superconducting stator short-circuited an HTS DPC, with its output dc-voltage charges the DPC to the desired current. This paper describes the construction and operation of this novel HTS flux pump device, which will drastically decrease the cost of the superconducting dc power supply, and has a wide application prospect in HTS magnets and superconducting electric machines.

Submitters Country:

China

Thu-Mo-Or29 / 772**CRYOGENIC ENVIRONMENTS FOR QUANTUM TECHNOLOGIES**Ziad Melhem¹¹ *Oxford Instruments NanoScience*

Superconducting and cryogenic environments are in use and under development for a large variety of Nanotechnology applications and Quantum technologies. Next generation of nanotechnology applications will be dependent on platforms that can probe and manipulate matter at the nanoscale under magnetic field and/or at cryogenic temperatures. This contribution presents an overview of a new class of superconducting systems and cold environments for quantum technologies with particular emphasis on quantum information processing (QIP) and 2D materials measurements for quantum standards and quantum sensing. The new systems are compact in size and realized by exploiting the recent advances in superconducting and cryogenic technologies integrated with advanced measurement systems. These new systems together with Cryofree® technology have opened up a new era in superconducting and cryogenic environments for quantum technologies.

Submitters Country:

United Kingdom

Mon-Af-Po1.11 / 911

CRYOGENIC TECHNOLOGIES OF THE NICA ACCELERATOR COMPLEX

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Since 1992, the largest Russian cryogenic helium complex of the superconducting accelerator Nuclotron with the cooling capacity of 4000 W at 4.5 K has been operating at JINR in Dubna. The construction of this high efficient cryogenic system included a large number of technical ideas that had never been applied before in the world: the fast cycling superconducting magnets, cooling by the two-phase helium flow, parallel connection of cooling channels of the magnets, «wet» turbo expanders, screw compressors with the outlet pressure of more than 2.5 MPa and jet pumps for liquid helium. In the near future it is planned to construct a new accelerator complex, comprising besides the Nuclotron, a superconducting booster and collider to provide collisions of high-intensity beams of heavy ions up to gold Au+79. The helium cryogenics of the NICA complex will be based on the modernized liquid helium plant for the Nuclotron. The main goals of the modernization are: to increase the total refrigerating capacity from 4000 W to 8000 W at 4.5 K; to create a new system of liquid helium distribution; to ensure the shortest time of cooling down three accelerators rings with the total length of about 1 km and the "cold" mass of 290 tons. These goals will be achieved by means of commissioning of a new 1000 l/hour helium liquefier, "satellite" refrigerators of the booster and the collider. Besides, a new closed-cycle 2300 kg/h nitrogen cryogenic system for producing and distributing of liquid nitrogen and re-condensation of nitrogen vapors will be constructed. New technical solutions in the design of the NICA cryogenic systems will be discussed.

Submitters Country:

Russia

Thu-Af-Po4.03 / 1069

Cable-in-Conduit Dipoles for the Ion Ring of JLEIC

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The Ion Ring for the proposed Jefferson Lab Electron-Ion Collider require large aperture with high homogeneity, 1 T/s ramping, and significant beam losses. Two designs have been developed, both utilizing a cable-in-conduit (CIC) winding in which liquid helium flows within the conductor. Two alternative designs are being developed, with the same aperture, having maximum operating field of 3(6) T corresponding to 100(200) GeV/u circulating ion beam energy. Particular features are presented, including the CIC fabrication and validation and the fabrication of a first model dipole.

Submitters Country:

US

Wed-Af-Po3.08 / 761

Capability improvement design method considering eddy current loss reduction of axial-flux permanent magnet coupling with Halbach array structure using 3-D FEM.

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Permanent magnet couplings (PMCs) transmit torque without any mechanical contact. In particular, the axial flux magnet coupling (AFPMC) has the advantage of a compact and flat construction. Furthermore, it can achieve a high torque-to-weight ratio. Owing to the structural characteristics of AFPMC, its analysis requires the three-dimensional finite element method (3-D FEM). Analyzing magnetic torque of AFPMCs with a Halbach array is very important because the operation area of the PMCs is restricted to the maximum allowable torque. By accurately predicting the maximum torque value, the product can be minimized and reduces unnecessary production costs. We will discuss design techniques based on 3D FEM to design AFPMC for high performance. Therefore, the magnetic torque characteristics are predicted according to the design parameters such as the thickness of the iron core, inner PM radius to -outer PM radius ratio, PM thickness, and the number of poles. In order to verify the design results of AFPMC using 3D FEM analysis, we will compare with the result of maximum torque measurement experiment of actual manufactured model. Furthermore, the AFPMC is required an analysis of the eddy current loss. The eddy current may be generated inside the permanent magnet when the torque transmitted to the permanent magnet coupling fluctuates or slip occurs beyond the maximum permissible torque of the permanent magnet coupling. The eddy current induced in the PM lead to losses. When an eddy current is generated in the PM, it is possible to increase the temperature of the PM, which is partly responsible for degradation of PM performance. Therefore, it is important to design a shape that can reduce the eddy current loss. Finally, we will propose some design methods to reduce eddy current loss, which causes maximum torque reduction and is partly responsible for degrading of the permanent magnet performance.

Submitters Country:

Republic of Korea

Mon-Af-Po1.05 / 988

Capacity Allocation of a Superconducting Flywheel Storage System (SFES) in Hybrid Energy Storage System for Wind Generation

Author(s): Rakkyung Ko¹

Co-author(s): Youngwook Kim¹ ; Sung-Kwan Joo¹

¹ *Korea University*

Due to the significant penetration of wind generation, the fast capacity resources are needed to handle the fluctuations caused by the wind generation. Battery Energy Storage Systems (BESSs) could be the solution as resources to back up the unpredictable fluctuation caused by the wind generation. However, the life cycle of batteries deployed in balancing operations could be a lot shorter compared to other capacity resources, caused by frequent charging and discharging operations. The alternative could be a superconducting flywheel storage system (SFES) with virtually unlimited cycle life and a high ramping rate, being able to come up with the fluctuations caused by the wind generation. The capacity of the SFES is relatively limited whereas BESS does not have such problems. The SFES can be synergistically used in combination with BESS to deal with the fluctuations caused by the wind generation. In this paper, a mixed integer linear programming (MILP)-based SFES capacity allocation method for fluctuation compensation in wind farm is proposed. The fluctuation of wind generator is divided into high and low frequency component by lowpass filter to be allocated to SFES and BESS.

Submitters Country:

Republic of Korea

Mon-Af-Po1.12 / 822

Cascaded Multilevel Converter with Floating Capacitors for a small tokamak, PHiX

Author(s): Masamichi Murayama¹**Co-author(s):** Hiroyuki Sugino ; Takayuki Kobayashi ; Shoichi Hatakeyama ; Hiroaki Tsutsui ; Shunji Tsuji-Iio ; Ryuichi Shimada¹ *Tokyo Institute of Technology*

PHiX (Plasma with Helical field initiative eXperiments) is a small tokamak to research MHD phenomena such as restraint of elongated plasma instability and protection of tokamak devices from disruption. The device has 16 toroidal field coils (TF coils) and 10 poloidal field coils (PF coils) magnets. We found that we must drive these coils for more than 5-ms and the response of PF coil current must be less than 1-ms to have clear experiment and control unstable elongated plasma. That is because MHD time scale or the time constant of plasma movement is nearly 1-ms in our device. It is desirable that the TF coil current keep constant during experiments to make it easy to control plasma current, position and shape. To achieve this requirement, we developed a 55kW inverter-driven fly-wheel motor-generator. Advantages of the MG are comparably-long duration, quick power response, and easy implementation of power control compared with conventional capacitor-type power supply. The duration of the current flat-top was extended to 1-s, which is much longer than those of conventional small devices. To control plasma position and shape, PF coil currents must follow the command value within 1-ms and the power supplies must be able to output enough voltage. We manufactured 900-kVA PF coil power supply system that can excite 10 individual coils. To realize enough voltage, we designed the circuits to reconstruct them to cascaded H-bridge multilevel inverters with floating capacitors. These output are connected in series and capacitors are connected to DC-links of some of H-Bridges. This idea enables to heighten output voltages without extra transformers. In our presentation, we report the details of power supplies such as construction, circuits and control and the tokamak experimental progress and result of PHiX.

Submitters Country:

Japan

Mon-Af-Po1.08 / 1089

Changes of superconducting properties due to the unidirectional tensile deformation on bronze-processed Nb₃Sn multifilamentary wires using various Cu-Sn-Zn ternary alloy matrices

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The degradation of transport current property by the mechanical strain on the practical Nb₃Sn wire is serious problem to apply for the future fusion magnet operated under higher electromagnetic force. Recently, we developed various Zn solid solution ternary Cu-Sn alloy (Cu-Sn-Zn) matrices for the internal matrix strengthened Nb₃Sn wires. Zn remained homogeneously into the matrices after the Nb₃Sn layer synthesis, and then Zn substitution in the matrices promoted the synthesis of Nb₃Sn layers. We thought that remained Zn might act as the solid solution strength factor of the matrix after the Nb₃Sn synthesis. We fabricated easily the Nb₃Sn multifilamentary wires using various Cu-Sn-Zn matrices through the conventional bronze process, and also carried out the tensile test under 4.2 K and magnetic field of 15 T on the Nb₃Sn multifilamentary wires using various Cu-Sn-Zn matrices. In the stress-strain curves of Nb₃Sn multifilamentary wires after heat treatment, Young's modulus

was increased with increasing nominal Zn content of Cu-Sn-Zn matrix. In addition, fracture stress of Nb₃Sn wire using Cu-Sn-Zn matrix was relatively higher compared with the conventional bronze processed Nb₃Sn wire. In the case of the sample using Cu-10Sn-10Zn-0.3Ti matrix, the peak tensile stress in the maximum critical current density was remarkably increased, and it obtained to be about 200 MPa. This tensile stress was similar to CuNb reinforced Nb₃Sn wires. In this study, changes of the mechanical properties with different Cu-Sn-Zn matrices were reported. Especially, transport I_c and H_{c2} behavior by the tensile deformation on the Nb₃Sn multifilamentary wire using various Cu-Sn-Zn matrices was also investigated.

Acknowledgements: This work performed to the Fusion Engineering Research Project (UFFF036) in NIFS, and collaborated with the High Field Laboratory for Superconducting Materials, Institute for Materials Research, Tohoku University (Project No.15H0024). And this work financially supported by KAKENHI (Grant-in-Aid for Scientific Research (B), 16H04621).

Submitters Country:

Japan

Thu-Mo-Or31 / 681

Characterisation of HTS insulated coil for high field insert

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High Temperature Superconductors (HTS) are a strong candidate for high field magnets. As their properties are extraordinary especially under high fields and very low temperatures, there are many ongoing projects around the world. The NOUGAT project aims at building a 10 T insert working first inside a 20 T resistive background. Its objectives are not to reach higher field than the already existing resistive magnets but rather to overcome the main issues of using HTS for this kind of applications and pave the way toward full superconductive magnets at lower cost. YBCO was preferred for the NOUGAT insert even if its implementation is still challenging. YBCO tapes display inhomogeneities along their length and this combined with their high thermal stability make them prone to permanent damage when wound. The slow quench propagation also makes the transition hard to detect, so protection remains one of the most challenging issues. Both insulated and metal insulated (MI) coils have been considered for the NOUGAT project. Due to their self-protection behaviour, MI windings have been selected for building the insert but we are still investigating insulated coils for future applications.

We built a fully-instrumented insulated single pancake wound with a 6-mm tape. Voltage taps are set up on each turn to monitor the quench propagation in helium bath under high magnetic field. Results are compared with our quench model, and the MI coils measurements. This study aims at developing our understanding of the windings quench behaviour and testing various quench detection procedures for future large scale insulated applications.

Submitters Country:

FRANCE

Wed-Af-Po3.06 / 295

Characteristic Analysis and Experimental Verification for a Double-sided Permanent Magnet Linear Synchronous Generator According to Magnetization Array

Author(s): Sung-Won Seo¹ ; Jang-Young Choi¹

Co-author(s): Gang-Hyeon Jang¹ ; Jeong-Man Kim¹

¹ *Chungnam National University*

The steady, increase in the demand for linear electrical machines in applications such as industrial robotics, transportation, manufacturing, and electrical power generation has been witnessed in recent times. Linear synchronous machines can be particularly operated without converting rotary motion to linear motion and have significant advantages such as simplicity, efficiency, positioning accuracy, and dynamic performance. Based on these advantages, this paper compares the characteristics of a double-sided permanent magnet linear synchronous generator (PMLSG). Since PMLSGs have significant influence on the manufacturing process and installation environment, it is important to estimate the lowest production cost and mass. Therefore, the analytical model of this paper concentrates on the comparison of the mass and efficiency based on different magnetization arrays while using the same stator. The PMLSG uses the commonly used vertical, Halbach array, which maximizes efficiency, and horizontal array that is easy to fabricate. A previous study highlights the excellence of Halbach arrays by exclusively using these arrays in the design. However, this study compares three magnetization arrays of the same size and rated output power considering the manufacturing cost and mass as mentioned above. As a result, the advantages of the horizontal array can be obtained. To compare the characteristics of the analytical model we use finite element analysis (FEA), which is essential for the electromagnetic analysis of linear generators. The FEA exhibits high reliability and accuracy when characterizing electrical equipment and it is excellent for the characterization of important electrical properties such as magnetic flux density, armature reaction, inductance, and induced voltage. Therefore, we establish the reliability and accuracy of the experimental results of the manufactured model by comparing them with the results of the three arrays obtained through FEA. Detailed analysis results and discussions of derived results will be presented in the final paper.

Submitters Country:

Republic of Korea

Wed-Af-Po3.06 / 1096

Characteristic Analysis for the Influence of Auxiliary Teeth and Notching on the Reduction of the Detent Force of a Permanent Magnet Linear Synchronous Generator

Author(s): Sung-Won Seo¹ ; Jang-Young Choi^{None}

Co-author(s): Min-Mo Koo ; Gang-Hyeon Jang¹

¹ *Chungnam National University*

This study considered the reduction of the detent force of a permanent magnet linear synchronous generator (PMLSG). In general, the PMLSG has a relatively large magnetic air gap. Consequently, in the design of the PMLSG, its structure can be composed of single-sided and double-sided structures. The double-sided structure can produce larger force. The PMLSG also has a slotted-type stator structure, which reduces magnetic energy loss. However, the slotted PMLSG has a detent force caused by the interaction between the permanent magnet (PM) mover and the slotted stator core. This is generally an undesirable effect that contributes to the thrust force ripple, vibration, and noise of the PMLSG. Therefore, in PMLSG design, a method to minimize the detent force is necessary. Various techniques to reduce the detent force of the PMLSG have been reported. In particular, the influence of auxiliary teeth and notching on the detent force has been analyzed and experimentally verified. The detent force should be minimized because it can be a major cause of linear machine vibration. A method for the optimal design of the tooth-slot structure and PM was studied in this paper. The

full manuscript will discuss the analysis procedure for detent force minimization under the no-load condition.

Submitters Country:

Republic of Korea

Thu-Af-Po4.05 / 416

Characteristic Analysis of Novel Outer Rotor Fan-type PMSM for Increasing Power Density

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Co-author(s): Sang-Hwan Ham²; Ju Lee¹

¹ *Hanyang University*

² *Kyungil University*

Rare earth permanent magnet motors are used in many industrial fields because of the advantage of superior output power density. Currently, however, non-rare earth motors have been actively studied due to the instability of rare earth supply and price fluctuations. Example of non-rare earth motors includes a synchronous reluctance motor (SynRM), a wound rotor synchronous motor (WRSM), a spoke-type PMSM and so on. The SynRM is the motor using differences in d-q axis inductance through the barrier structure at a rotor part, and it has only reluctance torque because of not having the magnets. The WRSM is the motor composed of N and S pole using the winding. Finally, the spoke-type PMSM is the motor using non-rare earth permanent magnets with a low residual magnetic flux density instead of rare earth permanent magnets. Therefore, the spoke-type PMSM forms structures that can concentrate the magnetic flux of the permanent magnet in order to improve the output power. However, these non-rare earth motors are mainly inner rotor type motors, and little research has been conducted to replace outer rotor type rare earth permanent magnet motors. Accordingly, this paper suggested an outer rotor fan-type PMSM using the non-rare earth permanent magnets to replace an outer rotor SPMSM which is mainly used as outer rotor type. The outer rotor fan-type PMSM has structures that can concentrate permanent magnet flux similar to the spoke-type PMSM. In order to verify the superiority of the outer rotor fan-type PMSM, this paper includes a comparative analysis of output power and efficiency with the outer rotor SPMSMs. Also, it deals with the analysis of characteristics of the detailed designed outer rotor fan-type PMSM according to the current phase angle. Finally, prototype tests show actual results.

Submitters Country:

Republic of Korea

Thu-Af-Po4.05 / 674

Characteristic Analysis of Permanent Magnet Synchronous Machine Considering Combination of Time Harmonics

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When motor is in operation, harmonic components are inevitably included. Due to the harmonic components, experimental results of motor performance is different from that obtained from FEA analysis, which assumes there is no time harmonic components. However, time harmonic components should be considered in performance analysis process, since time harmonic has effect such as noise and loss. Time harmonic is generated, depending on inverter switching frequency of PWM control, which occurs independently with spatial harmonics. Thus, time harmonic is not considered in motor design process, requiring additional consideration at later stage. Total harmonic, which is combination of spatial harmonic and time harmonic, has effect on performance of the motor. In detail, when time harmonic components are coupled with spatial harmonic components, some of harmonic components are canceled out, as others are intensified due to interaction. Thus, we present analysis and comparison of motor performance, as the combination of time harmonic components are varied. In this study, 3rd, 5th and 7th harmonic is mainly considered because low order harmonic is fundamental component, that has significant effect on the motor performance. With several combinations of the time harmonic components, FEA is carried out, as results for each cases are analyzed and compared. Based on the analyses, this study shows that combination of time harmonic component has effect on machine performance in different ways. Also, with research on spatial harmonic, relation between time and spatial harmonic is analyzed. To verify the relation, motors with different spatial harmonic components are used, to obtain results that are close to experimental results. As a result, this study suggests that FEA should be carried out considering both time and spatial harmonic components based on the analyzed results, as method proposed in the paper is more accurate than the general method, which assumes ideal three-phase input current.

Submitters Country:

Republic of Korea

Tue-Af-Po2.07 / 563**Characteristic analysis of SFCL DC interrupting system in Wind-farm****Author(s):** Jun Beom Kim¹ ; In-Sung Jeong¹ ; Seon-Ho Hwang¹ ; No-A Park¹ ; Dong-Chul Chung²**Co-author(s):** Hyo-Sang Choi¹¹ *Chosun University*² *Korean Institute of Carbon Convergence Technology*

This paper presents a superconductivity fault current limiter(SFCL) DC interrupting system in wind power generation grid. SFCL DC interrupting system is comprised of SFCL and DC circuit breaker. When faults occurs, SFCL operates firstly to limit the maximum fault current and the residual fault current will be vanished by opening operation of dc circuit breaker secondly. To ensure the correct operation and reliable structure, SFCL DC interrupting system and wind power generation grid was designed using the EMTDC/PSCAD. A resistive-type superconducting fault current limiter was used for SFCL. It was modeled on the characteristics of the coil type superconductor in which it belonged to this laboratory. For the DC circuit breaker arc modeling ,Schavemaker model, was considered. To obtain operation characteristics in wind generation grid, DC fault has occurred according to the status of DC interrupting system. The results indicated that burden on the DC circuit breaker was decreased by 30% and also interrupting time has shortened.

This research was supported by Korea Electric Power corporation [grant number: R16XA01] This research was supported by Korea Electric Power corporation [grant number: R15XA03]

Submitters Country:

South Korea

Tue-Af-Po2.06 / 1179

Characteristics Analysis of an HTS Homopolar Motor-Generator Set for DC to DC transformation

Author(s): Woo-Seok Kim¹

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Recently, the concept of DC grid is widely accepted in the electrical power system. DC power systems give better environment for superconducting power devices than AC power systems because of low AC losses. A superconducting high voltage DC cable is a good example. However there is no superconducting device yet for the low voltage and large current, which are the merits of the superconductor. In this paper, we propose a high temperature superconducting (HTS) homopolar motor-generator set (MG set) for low voltage, large current DC to DC transformation. DC power sources with low voltages and large currents are now widely used in the plating industry. Moreover the data centers for IT technology need huge DC currents. The armature current and the magnetic fields are only DC in the homopolar rotating machines, unlikely the conventional DC machines, in which the armature conducts AC currents. We designed an HTS homopolar MG set with low voltage and analyzed the characteristics of DC to DC transformation including the magnetization loss. We will fabricate an HTS MG set with a small capacity based on these design and analysis.

Submitters Country:

Republic of Korea

Mon-Af-Po1.07 / 515

Characteristics of SWPT according to the number of transmitting and receiver coils.

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Co-author(s): HyoSang CHOI²

¹ *Chosun University*

² *CHOSUN University*

³ *Korean Institute of Carbon Convergence Technology*

Recently, The use of electronic devices such as mobile phones and notebooks, tablet PCs, etc. is rapidly increasing. But, There is an inconvenience that electronic devices frequently need to be charged because battery life is short. To solve this problem, The wireless power transfer(WPT) system is drawing much attention. However, WPT system used in real life requires more research for increasing distance. In this research team, transmitter and receiver coils were fabricated using a superconductor for increasing distance and efficiency of WPT system. It was confirmed that the efficiency of wireless power transfer using superconducting coils(SWPT) was increased. In this paper, The characteristics of SWPT according to the number of transmitter and receiver coils was investigated. As the number of coils, the mutual inductance also changed. At this time, We analyzed resonance frequency of SWPT by mutual inductance. As a result, The optimum number and distance of transmitter and receiver coils were estimated with maximum efficiency.

This research was supported by Korea Electric Power corporation [grant number: R16XA01] This research was supported by Korea Electric Power corporation [grant number: R15XA03]

Submitters Country:

South Korea

Wed-Af-Po3.03 / 540

Characteristics of an HTS dipole magnet

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Co-author(s): Toru Ogitsu²; Yusuke Ishii²; Kei Koyanagi²; Shigeki Takayama²; Kenji Tasaki²; Naoyuki Amemiya³

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High T_c superconductor (HTS) could be a key to evolve the magnet technology as it is superior to low T_c superconductor (LTS) in terms of the critical current density, critical magnetic field, and critical temperature. REBa₂Cu₃O_{7-x} (REBCO) coated conductor (CC), which is in common use as the commercially available HTS, is suitable for fabrication of the magnet since it is easy-to-use for winding magnet coils. There is however a concern about application of REBCO CC as exemplified by large shielding currents which could eventually cause a large field error. In addition, one needs to take account of the slow normal zone propagation velocity that HTS owns. Once we solve these issues, use of HTS could be spread across various magnetic devices, including a rotating gantry which provides effective treatment of cancer for the external beam radiotherapy. Indeed, HTS is expected to provide stable operation even in high-field environment and thus enables us to miniaturize the existing huge system such as the gantry for heavy-ion radiotherapy. Verification test of the HTS dipole magnet for the rotating gantry was conducted in collaboration with KEK, Toshiba Corporation, and Kyoto University. Fabrication of the model magnet was complete in 2016, and field measurement was also made in the same year. In conclusion, we found larger field non-uniformity as compared to our numerical calculation, reason of which can partially be explained by misalignments of the coils. After that, we decided to continue the measurement using the model magnet in order for a further investigation into characteristics of the HTS magnet such as temporal variation of the magnetization due to the shielding current and flux jump. In this paper, we report results from the continued measurement with the HTS dipole magnet.

Submitters Country:

Japan

Wed-Af-Po3.11 / 486

Characteristics of current bypassing and transient stability in partial insulation HTS coils

SeokBeom Kim¹; Kentaro TAMI¹; Haruyoshi OKUSA¹; Hiroshi Ueda¹

¹ *Okayama University*

Recently, no insulation (NI) and partial insulation (PI) techniques are proposed and studied for the compact and stable high temperature superconducting (HTS) coils. We have been studied the methods to improve the self-protection ability of HTS coils by removing the turn-to-turn insulation and inserting a metal tape instead of an electrical insulation. The operating current in the NI and/or PI HTS coils would be bypassed into the transverse direction by generated normal region in the HTS coils, and the method to control the current bypassing into the turn-to-turn direction in the NI HTS coil for controlling the effective number of turns was investigated previously. In this study, the characteristics of current bypassing and transient stability in PI HTS coils were studied experimentally. The 20 turns single-pancake PI HTS coils wound with GdBCO coated conductor with/without the stabilizer and co-winding PI HTS coil with Cu tape were prepared and tested experimentally. The thermal properties and current bypassing characteristics due to the normal region created by heaters (Strain gauge) were studied as functions of the number of heater, position of heater, amount of input heating and shape of PI at liquid nitrogen temperature and background magnetic field of 0.6 T. The experimental results including optimized shape of PI and positions of heater to control the current bypassing will be presented.

Submitters Country:

Japan

Tue-Af-Po2.07 / 483

Characteristics of superconducting coil-type DC Fault Current Limiter to increase stability in DC power system**Author(s):** HyeWon CHOI¹ ; InSung JEONG¹ ; JunBeom KIM¹ ; SangYong PARK¹ ; Dong-Chul Chung²**Co-author(s):** HyoSang CHOI¹¹ CHOSUN University² Korean Institute of Carbon Convergence Technology

This paper presents a superconducting coil-type DC Fault Current Limiter(FCL). It has a combination structure of superconducting coils and DC circuit breaker in series. The superconducting coils operate as current limiting element. It was quenched when the fault is generated and limits the maximum fault current. Mechanical DC circuit breaker operates as interrupting element. It cut-offs the primary limited fault current which is limited by superconducting coils. The EMTDC/PSCAD has conducted to design the simulation power system which was designed similarly to real power system and to achieve the characteristic of superconducting coil-type FCL. Also, our research team has made a real power system based on simulation data. Therefore comparative characteristics analysis has conducted with simulation and experimental data. The results indicated that breaking time has reduced 2-times faster than that of the previously proposed DC circuit breaker. In addition, the burdens on the DC circuit breaker were reduced approximately 1.2-times.

Acknowledgment: This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (NRF-2015R1D1A1A01059489). This research was supported by Korea Electric Power corporation [grant number: R16XA01]

Submitters Country:

Republic of Korea

Thu-Af-Po4.08 / 426

Characterization of an internal cooling high temperature composite superconductor with REBCO for large scale energy storage applications**Zhu Jiahui**^{None} ; **Rao Shuangquan**^{None} ; **Chen Panpan**^{None} ; **Zhang Hongjie**^{None} ; **Qiu Ming**^{None} ; **Liu Erwei**^{None} ; **Gong Jun**^{None} ; **He Yuanyuan**^{None} ; **Zhang Huiming**^{None}

High-temperature superconducting magnetic energy storage systems (HTS SMES) have attracted significant attention for fast response and ensure a reliable power supply. However, the current carrying capacity of single superconducting tape often meets limitation for the large scale energy storage for HTS SMES applied in the power grid. Therefore, a composite superconductor with inherent helical cooling tunnel and kA class current carrying ability is proposed for large scale HTS SMES by using REBCO. The magneto-thermal characteristics of this internal cooling composite superconductor are analyzed by using a computer program on the basis of FEM considering the influence of anisotropy in magnetic field. A 1.5 m length, high temperature composite superconductor demo is manufactured in China Electric Power Research Institute (CEPRI). The critical current experimental system with a 3 kA DC current power source and a high-precision Digital Data Acquisition (DAQ) system have been set up to investigate the current carrying ability of a straight and a bending composite superconductor demo in LN₂. The results show that critical current of HTS composite superconductor consisted of 4 REBCO tapes can achieve 830 A at 77K self-field and the experimental I-V

curve of each REBCO tape in the composite superconductor is not uniform because of the influence of anisotropy. When the HTS composite superconductor is bending, its critical current is 93.75% of the straight HTS composite superconductor. And the design method and the proposed experimental system are proved to be effective as well.

Submitters Country:

China

Tue-Af-Po2.09 / 834

Characterization of the Stress Distribution on Nb₃Sn Rutherford Cables Under Transverse Compression

Author(s): Felix Josef Wolf¹**Co-author(s):** Christian Scheuerlein ² ; Daniel Schoerling ² ; Davide Tommasini ² ; Dennis Mosbach ³ ; Florian Meuter ⁴ ; Friedrich Lackner ² ; Katja Schladitz ; Patrick Ebermann¹ *TU Bergakademie Freiberg (DE)*² *CERN*³ *ITWM*⁴ *University of Applied Sciences (DE)*

The coils of high field Nb₃Sn magnets are submitted to large loads during assembly at ambient temperature and during operation at cold. This study addresses the characterization of the stress distribution on reacted and impregnated Nb₃Sn Rutherford cables under transverse compression, at ambient temperature, in a similar configuration as seen during magnet assembly. We performed an experimental campaign on samples prepared in different configurations to measure the local stress distribution on the contact surface of the impregnated cable. Microstructural analysis of the residual sample deformation after the application of the load have also been done with X-ray absorption tomography. The results are presented and discussed in this paper.

Submitters Country:

Switzerland

Tue-Af-Po2.06 / 513

Cogging Force Reduction of Double-Sided Flux-Switching Permanent Magnet Linear Machine

Qiang Liu¹¹ *Jiangsu Maritime Institute*

A double-sided flux switching permanent magnet linear machine (DLFSPM) is presented for direct drives in precision servo applications. The motor is composed of two long stators with plurality of teeth and slots. The mover is designed as two H-shaped and five double H-shaped stacks with six PMs between them. For the reduction of the cogging force, We split the stators for four parts, as, stator I(1), stator II(1) and stator I(2), stator II(2). First, the corresponding stator teeth on both sides, stator I(1) and stator II(1), shift horizontal displacement by $d = (mt)/12$ in one direction, stator I(1) and stator II(1) in other direction. Where m is an odd number, the total cogging force can be expressed as,

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Fig.2 shows the FEM simulation results of cogging force with $d=0$, $d=t/12$, $(3t)/12$, $5t/12$. One can see that the cogging forces have been minimized obviously. But only when $d=t/12$ the thrust force ripples are small than the case of $d=0$. The variation of back-EMFs as well as the thrust forces are well agree with the conventional ones which will be show in the following full paper. The UMF show in Fig.3, one can see that the values are absolutely zero.

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A DLFSPM has been proposed for direct drives in precision servo applications in this paper. The method of DSTAD is introduced to reduce the cogging forces. FEM technique is implemented for the validation of the method. The simulation results were verified by the experiment.

Submitters Country:

China

Tue-Af-Or16 / 260

Coil Dominated Superconducting Multiplets for the HIAF Fragment Separator Using the Canted-Cosine-Theta (CCT) geometry

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The fragment separator of the HIAF (High Intensity Heavy-ion Accelerator Facility) project called HFRS requires quadrupoles with high gradients (11.4 T/m) and large bores (gap width of 160 mm). The iron dominated magnets with superconducting coils have been widely used in the similar facilities such as A1900, BigRIPS, Super-FRS and RISP with the advantages of low request for coils installation precision, simple fabrication and low cost, but they have large cold mass and helium containment, which result in long time cooling-down and big pressure rise after a quench. In addition, due to iron saturation, the field quality is hard to guarantee in the whole field range. A new coil dominated design based on Canted-Cosine-Theta geometry is presented for HFRS, which is expected to overcome these problems. The design superimposes several layers of oppositely wound helical windings to generate high quality quadrupole. Sextupole and steering dipole can also be easily integrated to reduce the length of cryostat. This paper describes the detailed design of HFRS multiplets based on CCT concept and reports on the construction of a subscale prototype.

Submitters Country:

China

Wed-Af-Po3.04 / 632

Cold Tests and Magnetic Characterization of a Superconducting Magnet for a Compact Cyclotron for Radioisotope Production

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⁷ Cells

A superconducting magnet able to provide the required field of 4 T has been developed for a compact cyclotron to produce radio isotopes for medical imaging, in the framework of AMIT project. It consists of two coils in Helmholtz configuration, embedded in a stainless steel casing to hold the Lorentz forces. The cooling scheme is based on a low pressure forced internal flow of two-phase liquid-vapour helium through a narrow channel machined in that casing. This paper reports about the cooling tests. Firstly, liquid helium from dewars has been used to train the magnet and estimate the thermal losses. Afterwards, a custom closed circuit re-condenser – so called Cryogenic Supply System (CSS)- has been tested. It would allow a user-friendly operation of the cyclotron, without external supply of cryogenes. Finally, a custom magnetic measurement bench, developed in collaboration with ALBA/CELLS, has been used to map the magnetic field and shim the iron pole to achieve the required field quality.

Submitters Country:

Spain

Thu-Mo-Or28 / 850

Cold powering test results of the Nb₃Sn FRESKA2 block coil magnet

Author(s): Gerard Willering¹

Co-author(s): Gijs De Rijk¹ ; Marta Bajko¹ ; Maria Durante ; Bernardo Bordini¹ ; Pierre Manil² ; Philippe Grosclaude ; Juan Carlos Perez¹ ; Matthias Probst³ ; Luca Bottura¹ ; Françoise Rondeaux² ; Jerome Feuvrier¹ ; Nicolas Bourcey¹ ; Carlo Petrone¹ ; Etienne Rochepault¹ ; Hugo Bajas¹ ; Franco Julio Mangiarotti¹ ; Paolo Ferracin¹ ; Jean-Michel Rifflet

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The Nb₃Sn block coil dipole magnet FRESKA2 was developed within the framework of a collaboration between CEA Saclay and CERN, in the continuity of the European project EuCARD. With an aperture of 100 mm and a target bore field of 13 T at 10.8 kA, the magnet is aimed at upgrading the FReSCa cable test facility at CERN. The design features four 1.5-m-long double-layer coils wound with a 40 strand, 21-mm-wide cable. In 2017 the first assemblies have been tested. In this paper the performance of the assemblies in terms of training behaviour, detection, protection, magnetic measurements and other cold powering tests will be discussed.

Submitters Country:

Switzerland

Mon-Af-Or7 / 1160**Cold powering tests of the 2 meter Nb₃Sn DS11T model magnets at CERN**

Gerard Willering¹ ; Marta Bajko¹ ; Hugo Bajas¹ ; Bernardo Bordini¹ ; Luca Bottura¹ ; Jerome Feuvrier¹ ; Lucio Fiscarelli¹ ; Christian Hannes Loffler¹ ; Franco Julio Mangiarotti¹ ; Emelie Kristina Nilsson¹ ; Juan Carlos Perez¹ ; Gijs De Rijk¹ ; Frederic Savary¹

¹ CERN

For the upgrade of the LHC a few 15 meter Nb-Ti main dipole magnets are foreseen to be replaced by two 11 T Nb₃Sn dipoles, 5.5 meter long each. A series of model magnets has been produced to verify the design choices that are important for the prototype and series production. A fourth and fifth 2 meter single aperture model and a second double aperture model coil were produced, assembled and tested. In this paper the cold powering tests of the newly tested single aperture models and double aperture model will be presented and the results will be compared with the previous models. Special attention is given to the upper limit of the magnet powering which was found to be in the mid plane for some of the models.

Submitters Country:

Switzerland

Mon-Af-Po1.02 / 1011**Commissioning of the R3B-Glad superconducting dipole magnet**

Bernard GASTINEAU¹ ; Christophe MAYRI¹ ; Roser VALLCORBA CARBONELL¹ ; Christophe BERRIAUD¹ ; Dominique EPELLE¹ ; Quentin GUIHARD¹ ; Frédéric MOLINIE¹ ; Yannick QUEINEC¹ ; Nicolas SOLENNE¹ ; Pascal GODON¹ ; Charles MAILLERET¹ ; Yannick DROUEN¹ ; Jérôme ALLARD¹ ; Jean-Michel JOUBERT¹

¹ *Irfu, CEA Saclay, Gif-sur-Yvette, France*

The R3B-Glad project has already been presented in the previous Magnet Technology conferences. The R3B-Glad magnet is part of a large acceptance spectrometer devoted to the physics of exotic nuclei. This experiment requires a large dipole magnet for analysing the beams of 1 GeV/A protons, neutrons and heavy ion fragments produced in the target. Other features are a field integral of 4.8 T.m and an active shielding ensuring a low fringe field. The detection set-up will allow momentum and angle measurements with an overall resolution of 1/1000. Manufacture and assembly of the 22 tons magnet Cold Mass was completed at CEA-Saclay (France) where it has been tested at 4.6 K and nominal current. After integration in its final cryostat, resulting in a 60 tons dipole magnet, the superconducting dipole has been transported and installed in Darmstadt, Germany, for the current GSI, and future FAIR, facilities. In this paper, we present the commissioning of the R3B-Glad superconducting dipole at GSI up to the thermal and electrical nominal parameters, ensuring the expected magnetic field performances. The command-control system and magnet safety system were also qualified for the magnet operation. After being cooled down during nearly one month by indirect cooling, the cold mass was maintained at 4.6 K by means its two-phase helium thermosiphon loops. Finally the test in current of this large superconducting magnet was performed at nominal value (3584 A), giving 73 A/mm² in the coils and a peak field of 6 T on the conductor, in the presence of significant internal magnetic forces (up to 740 tons per coil and 200 tons per meter).

Submitters Country:

France

Mon-Af-Po1.02 / 457

Commissioning of the Superconducting Magnets for the SHMS Spectrometer at Jefferson Lab

Author(s): paul brindza¹Co-author(s): Amaury PORHIEL²; David RAMAUGE²; Eric SUN³; Frederick Forest⁴; Steven LASSITER³; Vincent SIGALO²; michael fowler¹; morgan DELBECQ⁵; pierre-eric mallard⁵; sylvain antoine⁵¹ jeffersonLab² Sigmaphi³ Jefferson Lab⁴ SIGMAPHI⁵ sigmaphi

The 12 GeV Upgrade Project at Jefferson Lab is complete and all new systems have met their Key Performance Parameters(KPP). The Super High Momentum Spectrometer(SHMS) in JLAB's Hall C is an 11 GeV/c particle spectrometer with a resolution of 0.5×10^{-4} , 4.4 milli Steradian acceptance and a +20 %/-10% momentum bite. All five SC magnets have been delivered, installed, cooled down, tested and all have reached and exceeded the currents required for operation at the nominal settings for 11 GeV/c. Details of the magnet's installation, testing, cryogenics, cool down, quench history and training will be presented. The equipment in Hall C consisting of the SHMS (2017) and the HMS (1994) have operated and demonstrated their Key Performance Parameters(KPP) and performed preliminary data taking experiments to qualify the new equipment. This is the conclusion of a long and very successful project.

Acknowledgement: Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.

Submitters Country:

USA

Thu-Mo-Or31 / 954

Compact, high field coils made with strong, rectangular Bi2212 superconductor wire

Alexander Otto¹¹ Solid Material Solutions, LLC

A Bi2212-based rectangular wire approach has been developed, with up to 500 MPa stress tolerances and useful current densities for building compact solenoid coils that are more problematic to make with wide HTS tapes, and that need to operate beyond the field and temperature limits of low temperature superconductors. We are applying long lengths of this new Bi2212-wire to develop a practical and low cost approach for producing robust HTS insert coils that are capable of boosting the fields of Nb3Sn based magnets to above 30 T levels and that are required to for example advance NMR from its present 900 MHz capability to a targeted 1.2 GHz level. As a first step, we built and qualified a coil winding test bed that we then used to develop wind-and-react coil fabrication techniques by producing short length, multilayer coil samples with different wire, thin insulation and build configurations, followed by reaction and testing. The results were then applied to design and develop techniques for building 5 T to 10 T class, compact field-boosting demonstration coils with configurations and sufficiently strong wire for utilization in the ~ 22T Nb3Sn magnet background

fields and at diameters of interest for use in NMR magnet field boosting. A simple and practical 1 atm heat treatment approach has also been developed to the point where now it can be applied to achieve usefully high current densities in these coils, in place of the more difficult to scale, up to 50 atm over-pressure approach that was initially developed. Techniques for attaching current leads with very low resistance joints have also been qualified, preparing a foundation for producing unique, HTS wire-based, sufficiently-robust, field-boosting insert coils.

Submitters Country:

USA

Thu-Af-Po4.05 / 350**Comparative Analysis of Electromagnetic Characteristics for HTS Motor Considering PWM Schemes in Voltage Source Inverter****Author(s):** Min Hyeok Kang¹ ; Eel-Hwan Kim¹**Co-author(s):** Sang Heon Chae ¹ ; Ji Hyung Kim ¹ ; Chang Ju Hyeon ¹ ; Huu Luong Quach ¹ ; Ho Min Kim ¹¹ *Jeju National University*

The inverter system must be necessary for a high-temperature superconducting (HTS) synchronous motor control in any electric propulsion system such as ship, vehicle, and aircraft. HTS motors for electric propulsion are driven and controlled by pulse width modulation (PWM) input voltage with harmonics, which is made in voltage source inverter (VSI) by a various switching pattern. Therefore, from this perspective, it is important to apply analysis methodology considering the real PWM switching patterns of VSI. In this paper, three PWM schemes such as sinusoidal, third harmonic injection and space vector PWM, respectively were considered for driving a 1.5 MW-class HTS synchronous motor for electric ship propulsion. The various performance characteristics of HTS motor were analyzed by co-simulation method based on ANSYS-Maxwell and Simplerer platform.

Submitters Country:

Republic of Korea

Thu-Af-Po4.01 / 984**Comparative Study of Magnetic Characteristics between Air-Core and Iron-Core High-temperature Superconducting Quadruple Magnet****Author(s):** Jeyull Lee¹**Co-author(s):** Junseong Kim ² ; Zhan Zhang ³ ; Hongseok Lee ⁴ ; Tae Kuk Ko ⁵ ; Sangjin Lee ⁶¹ *Yonsei University*² *Yonsei Univ.*³ *Massachusetts Inst. of Technology (US)*⁴ *Korea National University of Transportation*⁵ *Electrical and Electronic Engineering, Yonsei University*⁶ *Uiduk University*

High-temperature superconductors (HTS) have a much larger thermal margin than low-temperature superconductors (LTS) due to high critical temperature and high upper critical field. It allows HTS magnets to operate stably so as to tolerate very high heat loads due to radiation. Therefore research

on development of HTS quadrupole magnet is progressed widely. The Quadrupole magnets are used for focusing the transporting beams of particles in accelerator. In order to focus the beam, the quadrupole has iron yoke with hyperbolic contour. However the iron yoke induce nonlinear magnetic characteristics due to saturation. Therefore, an air-core HTS quadrupole magnet is proposed to improve the magnetic characteristics. In this paper, we design air-core and iron-core HTS quadrupole magnet. The field gradient and effective length of both magnets is 12.1 T/m and 550 mm, respectively. In order to verify the feasibility of proposed air-core quadrupole magnet, the magnetic field gradient, field uniformity and effective length are analyzed with operating current from 50 to 400 A.

Submitters Country:

Republic of Korea

Tue-Af-Po2.07 / 1001

Comparative Study on Current Limiting Characteristics of Transformer Type Superconducting Fault Current Limiters (SFCLs) with Common Connection Point between Two Secondary Windings

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In this paper, the transformer type superconducting fault current limiters (SFCLs) with common connection point between two secondary windings, which was similar structure to the previously suggested transformer type SFCL with two triggering levels, were proposed and their current limiting characteristics were compared. The suggested transformer type SFCLs consist of the primary winding and two secondary windings with common connection point. However, the current limiting operations through two triggering levels, which can be generally adjusted by the winding direction and the number of turns between two secondary windings, are affected by the application position of two high-TC superconducting (HTSC) elements into the transformer type SFCL with common connection point. To analyze the dependence of the current limiting operation on the application position of two HTSC elements, the short-circuit tests for the transformer type SFCL with two different positions of two HTSC elements were carried out and their current limiting characteristics were compared from the point of view of the power burden and the accumulated energy of two HTSC elements comprising each transformer type SFCL.

Submitters Country:

Republic of Korea

Tue-Af-Po2.10 / 862

Comparative study between in-situ measurements and a 3D efficient model for the computation of magnetic fields in High Field Polyhelix magnets

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The Laboratoire National des Champs Magnétiques Intenses (LNCMI) is a member of the European Magnetic Field Laboratory (EMFL). This is the French facility enabling researchers to perform experiments in the highest possible magnetic fields. The numerical modeling jointly developed with the Center of Modeling and Simulation of Strasbourg (Cemosis) plays an essential role in the understanding and the optimization of such magnets based on the so-called polyhelix technique (a magnet is a set of Copper alloy tubes cut by Electrical Discharge Machining). In the context of this collaboration, a full 3D multi-physics model dedicated to the study of LNCMI resistive high field magnets has been implemented. Applications of this model have shown a 3D behaviour of the magnetic field, specifically in the vicinity of the beginnings and ends of the helical cuts. The effect is greater than what is commonly expected by experts. To validate our model and this unexpected behaviour, dedicated measurement campaigns were carried out both on a real magnet insert and on a low field test bench. In this paper, we will describe the in-situ and low field testbench setups used to perform a 3D mapping of the magnetic field. We will briefly detail the ingredients of our numerical model, especially the parallel algorithm proposed to apply efficiently the Biot and Savart's law for computing the magnetic field produced by magnet inserts and seen by the researchers. Finally we will present the comparative study based on calculations and measurements that confirm the 3D distribution of the magnetic field and therefore validate to some extent our modeling choices. The periodic variations observed are related to the helical cut of the Polyhelix magnets. This study is an important step in the understanding of Polyhelix magnets behaviour.

Submitters Country:

France

Wed-Af-Po3.12 / 519

Comparison between AC loss measurements and analyses in coil assemblies with different geometries and conductors

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When coated conductors are applied to devices whose transport current or applied magnetic field is time-dependent, ac loss in coils is a major issue which needs to be accurately evaluated and addressed. Electromagnetic field analyses are effective tools not only for evaluating and characterizing ac losses in entire coils wound with coated conductors, but also for estimating the ac loss density distribution in coils. The ac loss density distribution depends on the coil structure: namely, the magnetic field distribution in the coil and its superconducting characteristics. In this work, we focus on how the ac loss density distribution is affected by the coil structure, and ac loss measurements and analyses are compared. We built a cross-sectional model for electromagnetic field analyses for the coil assemblies. In this model, the detailed three-dimensional configuration of the coil assemblies was ignored and approximated as axisymmetric. The nonlinear electric field (E)-current density (J) characteristics of each conductor, which depend on both the magnitude and the orientation of the magnetic flux density, are incorporated into this model using a formulation based on the measured E - J curves. In order to compare with the results of the numerical analyses, we carried out ac loss measurements on coil assemblies comprising stacks of double pancake coils (DPCs). The coil assemblies have different number of DPCs and the conductors used for coil windings are from different tape manufacturers. An electrical method was used for the ac loss measurements.

Submitters Country:

Japan

Wed-Af-Or24 / 816

Comparison of HTS Quench detection methods based on Spontaneous Raman and Rayleigh Scattering in Optical Fibers

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In high temperature superconducting (HTS) magnet applications, quench detection is very important to protect magnets before burning out. However, due to a very slow quench propagation of HTS wires compared with low temperature superconducting (LTS) ones, conventional quench detection methods are not suitable for HTS magnet: The method is that continuously measure resistive voltages on voltage taps dispersedly distributed within a magnet. Therefore, quench detection and protection are obstacles to application of large HTS magnet systems, and faces significant challenges. In order to detect incipient quenches with sufficient time, optical fiber distributed temperature sensors (DTS) systems with high spatial and temporal resolution which have been applied to several industrial circles such as petroleum pipeline, bridge structure, power cable, etc. are able to obtain all temperature related information at any location within a magnet. Recent researches indicate that DTS systems based on Rayleigh scattering in optical fibers provide several outstanding results in quench detection experiments. Nevertheless, owing to intrinsic physical characteristics of Rayleigh scattering in optical fibers, photosignal is affected by environmental heat and oscillation together so that avoidless errors exist in this quench detection method. In contrast, Stokes and Anti-Stokes shifts from spontaneous Raman scattering are only depend on the changes of optical fiber temperature thus quenches in magnets can be expressly observed. In this paper, two typical DTS systems with different techniques which are respectively based on spontaneous Raman and Rayleigh scattering in optical fibers are applied for HTS quench detection. More detailed comparison results and optical fiber DTS systems introduction will be discussed and presented in this paper.

Submitters Country:

China

Mon-Af-Po1.10 / 936

Comparison of Measured and Simulated Quench Behaviors of Superconducting Magnets for Jefferson Lab's 11 GeV Super High Momentum Spectrometer

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Super High Momentum Spectrometer (SHMS) of Hall C, part of 12 GeV Upgrade at Jefferson Lab, is tested and complete. We will present the measured quench data and the simulated ones of the Q2/3, and Dipole superconducting magnets using the quench code of Vector Fields' Opera-3D. A multi-channel Tektronix DPO is used to record the signals of the current, voltage of the dump resistor, and other voltages of interest for the Q2/3 and Dipole; the sampling rate used in the tests is 1.0E-4 s. The energy balance method is employed to figure out the energy deposited into the coil during the quench. The deposited energy is correlated with the measured temperatures of the coil. Opera-3D 18.0 is used to model and analyze the quench behaviors of the Q2/3 and Dipole. Material properties of the coils are updated with the real manufacturing data. The measured current decay and measured temperatures of the coil during real quenches will be compared with the simulated quenches from Oper-3D. The differences between the measured and simulated behaviors will be discussed to provide guidance for design of similar superconducting magnets in the future. The training curves of three magnets will be presented also.

Submitters Country:

USA

Mon-Af-Po1.04 / 450**Comparison of output characteristics of PMSM for EV according to water cooling and oil cooling****Author(s):** Soo-Jin Jung¹**Co-author(s):** Kyoung-Jin Joo ; Gang Seok Lee² ; Ju Lee³¹ *LG Electronics*² *Hanyang Univ.*³ *Hanyang University*

Traction motors for EV need to improve the output density, increase the maximum output operation time. In order to satisfy this, it is important to design the cooling system and structure as well as the electromagnetic field design. Generally, the cooling method of (P)HEV is divided into water cooling using cooling jacket and oil cooling using mechanical oil pump connected to the engine. In the case of a battery electric vehicle, there is no engine, so oil is supplied using EOP (Electric Oil Pump) and a thermal exchanger. The water cooling is an indirect cooling method using heat transfer between media. Therefore, it should be designed so that the heat of the end turn of the motor can be efficiently transmitted to the cooling jacket through the media. At this time, cooling jacket should have high heat capacity per unit volume and low pressure loss. The oil cooling method is a direct cooling in which the oil is sprayed or dripped on the stator and the rotor, and the size, number and position of the nozzle to which the oil is injected should be determined. It is also necessary to consider the height of the oil for good cooling performance and turbulence due to rotor rotation. Finally, pressure loss reduction is required and volume of EOP and thermal exchanger should be minimized. In this paper, a 100kW traction motor for EV was designed and analyzed by FEA. In order to compare characteristics according to each cooling method, water cooling and oil cooling are applied to the same active part (stator & rotor) structure. After that, the temperature characteristics according to the operating region were predicted using Computational Fluid Dynamics (CFD) analysis. Finally, the output characteristics of traction motor with water cooling and oil cooling were compared and analyzed through experiments.

Submitters Country:

Republic of KOREA

Tue-Mo-Or13 / 68**Completion and test of the first ITER TF coil winding pack by Europe****Author(s):** Alessandro Bonito Oliva¹**Co-author(s):** A. Devred² ; A. Felipe³ ; A. Moreno¹ ; B. Bellesia¹ ; C. Kostopoulos¹ ; E. Barbero Soto¹ ; E. Boter Rebollo¹ ; E. Thyssen⁴ ; E. Viladiu¹ ; J. Caballero¹ ; J. Cornella¹ ; J. Lucas⁵ ; J. Silva Ribeiro⁶ ; K. Libens¹ ; L. Poncet¹ ; M. Casas Lino¹ ; M. Cornelis¹ ; M. Damone¹ ; M. Jimenez¹ ; N. Mitchel⁷ ; N. Pellicer¹ ; N. Valle⁸ ; O. Dormicchi⁸ ; O. Malpica¹ ; P. Aprili¹ ; P. Barbero⁹ ; R. Batista¹ ; R. Francone⁹ ; R. Harrison¹ ; S. Koczorowski⁷ ; S. Tarrago¹¹ *Fusion for Energy*² *ITER IO*³ *Iberdrola*⁴ *BNG*

⁵ *Elytt*⁶ *CNIM*⁷ *ITER IO*⁸ *ASG*⁹ *SIMIC*

The ITER magnetic system includes 18 Toroidal Field (TF) Coils constructed using Nb3Sn cable-in-conduit superconductor. Each TF coil comprises a Winding Pack (WP) composed of 7 Double Pancake (DP) modules stacked together, impregnated and inserted into a stainless steel coil case. 10 TF coils are being produced in Europe, under the responsibility of Fusion for Energy (the European Domestic Agency (DA)) while the remaining 9 TF coils are being produced in Japan. F4E has implemented a procurement strategy aimed to minimize costs and risks, by subdividing the procurement into three main procurement packages, each foreseeing first an R&D and a qualification phase. One procurement package is related to the construction of 70 radial plates, another to the fabrication of 10 WP and a third to the cold test and coil-case insertion of 10 WP. After 7 years of R&D and qualification activities and of industrial production, the first ITER TF coil winding pack has been completed in Europe. The test, consisting in a combination of leak and pressure drop tests and electrical tests at room temperature and at 78 K, should be completed by middle of 2017. In parallel the series production of the 10 TF coils in Europe is underway. So far, 65 (over 70) radial plates have been completed and delivered, 65 DP have been wound and heat treated and 35 Double pancakes (over 70) have been impregnated and completed. In addition 3 new winding packs are in the final phase of their construction. In this paper we will report on the main phases and results of the qualification, production and test of the first TF winding pack. In addition we will report on the status of the production and on the following phases needed for the completion of the ITER first TF coil.

Submitters Country:

spain

Mon-Af-Or4 / 927**Completion of ENEA's procurement for 9 TF coils of JT-60SA tokamak****Author(s):** Gian Mario Polli¹**Co-author(s):** Antonio Cucchiario¹; Valter Cocilovo¹; Paolo Rossi¹; Giovanni Drago²; Paolo Pesenti²; Franco Terzi²; Enrico Di Pietro³; Valerio Tomarchio³¹ *ENEA FSN*² *ASG Superconductors*³ *Fusion for Energy*

In the framework of Broader Approach program for the early realization of fusion with the construction of JT-60SA tokamak, ENEA has to provide 9 of the 18 TF coils of JT-60SA magnet system. The supply has been subsequently increased to include the procurement of an additional TF coil for spare purposes. The production of the spare coil started in 2016, after the supply to ASG of the corresponding six unit lengths of cable in conduit conductors procured by ENEA through a contract with ICAS consortium in 2016.

The principal milestones of the six year contract with ASG Superconductors are here summarized: at the end of September 2013 the completion, of the engineering phase and of the qualification activities related to winding operations, started production phase. In the course of 2014, the first two winding packs (WP) constituted by 6 double pancakes have been manufactured, impregnated and successfully tested. In 2015, the rest of WP production has been completed and the final integration of the first WP in its casing components set started. In 2016, six WPs have been inserted in their casing components sets and in 2017 the rest of the manufacturing operation are going to be completed. This paper provides an overview of the contract that ENEA signed with ASG Superconductors for this supply. Also main electrical, geometrical and fluidic results of the TFC completed so far are reported in order to give a general assessment of the performances and functionality of the coils.

Submitters Country:

Italy

Wed-Af-Po3.02 / 43

Completion of the French JT-60SA Toroidal Field Magnet Contribution

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¹ CEA

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After agreement on the general and detailed design of the JT-60SA TF coil system by all the Voluntary Contributors in the project, CEA, ENEA and F4E, the manufacturing phase was engaged. The French part including the supply of 9 + 1 spare of the 18 TF winding packs and their integration in casings was entrusted mid-2011 to Alstom (France), now General Electric. Years up to 2013 were devoted to the first phases with manufacturing flow definition, manufacturing drawings and Quality Assurance documentation production as well as qualification of the critical processes on a set of mockups. The procurement and commissioning of the needed tooling was led in parallel and the production was started in January 2014. The first winding pack was ready end 2014. The integration inside the casing started in March 2015 and the coil was completed end 2015. Then the coil was delivered to the Coil Test Facility (CTF) for testing at nominal operation condition ($T=4.5K$, $I=25,7kA$) and for qualifying the coil resilience to quench events. In parallel, the successive coils were engaged in the manufacture process. Up to now, 9 coils have been completed and sent to the CTF and the last coil is now nearly completed. The paper reports the status of the manufacture and gives a feedback on the main issues discovered during the manufacture process and on the technical solutions implemented. A focus is made on the mastering of the manufacturing processes which can be clearly highlighted by the learning curve of the TF coils manufacturing which ultimately reaches the 5 month target even in including the treatment of the unexpected events.

Submitters Country:

France

Mon-Af-Po1.06 / 9

Conceptual Design and Evaluation of a HTS Magnet for a SMES Used in Improving Transient Performance of a Grid-Connected PV System

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¹ Wuhan University

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³ Huazhong University of Science and Technology

Superconducting magnetic energy storage (SMES) enables to offer many technical advantages, such as high energy efficiency, quick response and great controllability, and the SMES applications in distributed renewable energy sources are critical for power systems. This paper suggests a SMES to enhance the transient performance of a 100 kW grid-connected photovoltaic (PV) generation system, and conducts the conceptual design and performance evaluation. Considering the PV fluctuation and transient compensation during a fault, the stored energy of the SMES is designed as 80 kJ, and

the Yttrium Barium Copper Oxide (YBCO) tapes made by the Superpower Company are adopted. The high-temperature superconducting (HTS) magnet uses the single-solenoid structure, and its detailed parameters including critical current, tape length, parallel/perpendicular magnetic field are optimized by the genetic algorithm. In order to achieve a comprehensive performance evaluation, not only the effects of the SMES on the PV generation system, but also the magnetic field, mechanical stress and operation loss of the SMES are assessed in the simulations. From the results, using the SMES can effectively improve the fault ride-through (FRT) capability and smooth the power fluctuation of the PV generation system. During the transient process of the power exchange, the maximum stress of the SMES magnet is within the tolerable allowance, and the mechanical strength of the YBCO tapes can be well ensured. Moreover, the operation loss of the SMES magnet is controlled to an acceptable level, and the joule heat caused by the charging and discharging of the SMES is limitable. The demonstrated design and evaluation will lay a good foundation for the prototype manufacture and experimental testing in the future.

Submitters Country:

China

Tue-Af-Po2.07 / 8

Conceptual Design and Performance Evaluation of a 35 kV / 500 A Flux-Coupling-Type SFCL for Protection of a DFIG-Based Wind Farm

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For the flux-coupling-type superconducting fault current limiter (SFCL) which is composed of coupling transformer (CT), superconducting component (SC) and controlled switch, it can be regarded as a typical application of magnet technology. As the flux-coupling-type SFCL offers many technical advantages, such as higher flexibility, better controllability and lower operation loss, this paper conducts its utilization in improving the transient performance of a 15 MW class doubly fed induction generator (DFIG)-based wind farm. In normal condition, the SFCL shows the non-inductive coupling and does not affect the wind farm. In case of a fault, the electromagnetic properties of the SFCL will be changed, and the current-limiting impedance will be activated and connected in series with the main circuit. In light of the wind power parameters, the conceptual design, electromagnetic analysis and performance evaluation of a 35 kV / 500 A class SFCL are carried out. From the results, the CT achieves the maximum magnetic field in the event of that the fault current reaches to its peak value, and the AC loss of the SC is controlled to a lower level. The demonstrated electromagnetic properties of the SFCL meet the requirements, and using the SFCL in the wind farm enables to limit the fault current, compensate the voltage sag and mitigate the power fluctuation. Consequently, the robustness of the DFIG-based wind farm against the short-circuit fault is well enhanced, and the applicability of the conceptual design of the SFCL is verified.

Submitters Country:

China

Thu-Af-Po4.11 / 923

Conceptual Design of a Large Aperture Dipole for Testing of Cables and Insert Coils at High Field

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¹ SPC² Fusion for Energy³ CERN⁴ LBNL

Advances in the performance of LTS and HTS superconductors enable the development of advanced magnets for a range of applications, including tokamaks for fusion energy, dipoles and quadrupoles for hadron colliders, and solenoids for nuclear magnetic resonance studies. The capability of testing prototype cables and insert coils at high field is critical to these developments. We present here the conceptual design of a test facility dipole with features suitable to support the advanced magnet development efforts of both Fusion and HEP communities. In particular, a background field in the range of 13 to 15 T is provided over a minimum homogeneous length of 700 mm, and the magnet clear bore of approximately 150x100 mm can accommodate large fusion conductors as well as prototype coils for high field dipoles, along with flexible cryogenic and mechanical provisions for sample characterization. Two technical solutions are considered. The first uses a Cable-in-Conduit Conductor and follows the design developed by EFDA for the EDIPO magnet. Preliminary studies show that an increase of the operating field from the original 12.3 T to 13 T is possible by taking advantage of improvements in conductor performance, and further optimizing the cable design. The second approach uses a Rutherford cable and follows a block-coil design similar to the CERN FRESCA2 dipole, and the LBNL HD and LD1 dipoles. Due to increased current density in the coil pack, this approach can provide background fields in the range of 14 to 15 T, depending on the technical features adopted for the magnet and the cryogenics. Following a comparison between the two approaches, we present a baseline design including performance objectives, key parameters, and preliminary magnetic, mechanical and quench protection analysis.

Submitters Country:

United States, European Union

Wed-Af-Po3.03 / 418

Conceptual Design of a Superconducting Magnet Stacked by REBCO Annulus PlatesXi Yuan^{None}

The high temperature superconducting (HTS) magnet has been made progress in high magnetic field with the second generation (2G) HTS wires in recent years. However, the closed-loop operation of the HTS magnet is rarely to be realized at present due to the immature jointing technique. Based on the high n-value of HTS wires, this paper presents a conceptual design of a superconducting magnet stacked of REBCO annulus plates which is magnetized by flux pump. The effects on trapped field characteristics and temporal stability in the superconducting magnet are analyzed by the finite element method (FEM). The design method of REBCO annulus plates and construction details of superconducting magnets are introduced in this paper. This superconducting magnet is stacked of REBCO annulus plates to realize the closed-loop operation of HTS magnet without jointing and it has significance for the stability application of NMR or MRI magnet.

Submitters Country:

The People's Republic of China

Mon-Af-Or6 / 423

Conceptual design of a 16 T cos θ bending dipole for the Future Circular Collider**Author(s):** Vittorio Marinozzi¹

Co-author(s): giovanni bellomo ; Barbara Caiffi ² ; Pasquale Fabbricatore ³ ; Stefania Farinon ³ ; Alessandro Ricci ⁴ ; massimo sorbi ⁵

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After LHC will be turned off, a new accelerator machine will be needed in order to explore unknown high-energy Physics regions. For this reason, the project FCC (Future Circular Collider) has started at CERN, with the target of studying the feasibility of a very large hadron collider with 50 TeV proton beams in a 100 km circumference. The EuroCirCol project is part of the FCC study under European Community leadership. In particular, it has the outcome of producing a conceptual design of the FCC within 2019. One of the main activities is the development of a superconducting dipole able to produce a bore field of 16 T, in order to bend the beams within energy and size constraints. Here we present the conceptual design of a Nb₃Sn cos θ dipole layout, in a double-aperture configuration (LHC style). We show that it is possible to produce a bore field of 16 T with a good field quality, with reasonable assumptions on the conductor features, and with a reasonable amount of cable. A bladders and keys mechanical structure is also presented, proving that the electromagnetic forces can be maintained, keeping the stress within the coils under a safe limit. Finally, we present a preliminary quench study, showing that the magnet can be protected using well-known technologies.

Submitters Country:

Italy

Thu-Af-Po4.01 / 719

Conductor Cost Optimized Idealized Dipole Cross-Sections for Accelerator Applications

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In the design of superconducting accelerator magnets the outline of the coil cross-section is in large part attributed by the minimization of the conductor volume, constrained by the central magnetic field and homogeneity. Such optimizations commonly assume either a Block or Cosine Theta coil type, which is then filled with (pre-determined) rectangular or key-stoned Rutherford cables. By optimizing the positions, angles and number of turns the field quality requirements and cost minimization are then achieved. However, this leaves to wonder what the idealized optimum looks like when such practical constraints are not present. Although in the past such an optimum has always been presented as two intersecting circles, this method results in a non-circular aperture and is thus not fully representative. This paper introduces a method in which organically shaped (non-graded) dipole coil layouts are optimized without any assumptions on the conductor. The resulting layouts are presented as function of overall current density, aperture size and required central magnetic field. The layouts should be viewed as an ultimate limit to what can be achieved to compare real coil layouts against and as an initial guide to find an overall outline for the coil.

Acknowledgment: FP7-EuCARD2 GA 312453

Submitters Country:

Switzerland

Wed-Af-Or22 / 26

Conductor Performance of Nb₃Sn Sample for CFETR CSMC coil

Author(s): Yu WU¹**Co-author(s):** Bo LIU¹; Jinggang QIN¹; Arnaud Devred; Pierluigi Bruzzone²; Arend Nijhuis³; Boris Stepanov; Sedlak Kamil¹ ASIPP² EPFL-CRPP³ University of Twente

The Central Solenoid Model Coil (CSMC) of China Fusion Engineering Testing Reactor (CFETR) is designed to operate max current is 47.65kA and get the highest magnetic field 12 T, the maximum magnetic field rate is designed 1.5 T/s. The CSMC consists of 5 independent coils, the Nb₃Sn Inner and Outer coils, the Upper, Middle and Lower NbTi coils. The Nb₃Sn conductor for the CSMC was manufactured in China and was tested in the SULTAN facility. The cabling was done following the short twist pitch sequence of the ITER CS conductor. The Jacket material is chosen of 316 LN for left leg and JA2LB for right leg. The Tcs test results show that both legs of the Nb₃Sn conductor CSMC have high Tcs performance. Using the electrical method, the Tcs was 6.645 K for the left leg and 6.57 K for the right leg at 45.1 kA /10.85 T in the first test and 6.89 K for left leg and 6.85K for right leg after 9950 electromagnetic load cycles and two times warm up and cool down. Based on the Nb₃Sn conductor sample test results at 47.65 kA and at different fields, the Tcs was extrapolated to the peak field B_{peak}= 12 T and current equal to 47.65 kA. The extrapolated Tcs is 6.538 K for left leg and 6.484K for right leg after 9950 electromagnetic load cycles and two times warm up and cool down. According to the SULTAN test result, the Nb₃Sn conductor for the CSMC is fit the design requirement.

Submitters Country:

China

Wed-Mo-Or20 / 24

Conductor for MRI magnets beyond NbTi

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Magnetic Resonance Imaging, MRI, is a powerful medical diagnostic tool and the largest commercial application of superconductivity. MRI magnet design is determined by competing requirements including functional performance, patient comfort, ease of siting in a hospital, minimum acquisition and lifecycle cost. The increased center field, maximized uniformity volume, minimized field decay and stray field, magnet compactness, optimized refrigeration, improved manufacturability, reliability and serviceability drive the magnet requirements. We consider the conductor requirements for commercial MRI magnets beyond traditional NbTi conductor while avoiding links to a specific magnet configuration. MgB₂, ReBCO and BSCCO conductors are evaluated. From a technical point of view, none of the HTS or MgB₂ conductors meet all of the requirements to commercial MRI magnets at the moment. The following conductor features shall be developed or improved: (1) Conductors specifically designed for MRI applications, with form-fit-and-function which can be readily integrated into present MRI topology with minimum modifications; (2) Conductors with improved quench characteristics, i.e. the conductor ability to carry significant currents without damage in the resistive state; (3) Insulation which is compatible with manufacturing and refrigeration technologies; (4) A dramatic increase in production and long-length quality control, including large-volume

conductor manufacturing technology. The in-situ MgB₂ conductor is, perhaps, the closest to commercial requirements. This conductor still needs significant and lengthy developments including but not limited to development of a stabilized conductor, conductor that does not require processing after winding, reliable long-length conductor. Conductor technology is not the only issue in introduction of HTS / MgB₂ conductor in commercial MRI magnets. Volume-production technologies shall be developed including efficient winding, reliable quench protection, superconducting joints, thermal switches that are compatible with HTS / MgB₂ and can operate at elevated temperature, refrigeration technologies.

Submitters Country:

USA

Mon-Mo-Pl1.1 / 1226

Conference Opening

Submitters Country:

Thu-Af-Po4.03 / 93

Constructing a permanent magnet phase shifter

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A permanent-magnet (PM) phase shifter is constructed for a tandem elliptically polarized undulator (EPU) at TPS. To increase a reproducibility of magnetic field and be installed in a limited space, a robust mechanical structure was designed and constructed. To decrease multipole errors and optimize magnetic field, algorithms of magnet sorting and magnetic field shimming were built and performed. The start-to-end for a construction of a PM phase shifter is discussed and explained in detail herein.

Submitters Country:

Taiwan

Tue-Af-Po2.05 / 254

Construction and Test Results of Coils 2 and 3 of a 3-Nested-Coil 800-MHz REBCO Insert for the MIT 1.3-GHz LTS/HTS NMR Magnet

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We present construction and test results of Coils 2 and 3 of a 3-nested-coil 800-MHz (18.8 T) REBCO insert (H800) for the MIT 1.3-GHz LTS/HTS NMR magnet currently under construction. Each of the

3-nested H800 coils is a stack of no-insulation REBCO double-pancakes (DPs). The innermost 8.7-T Coil 1 (26 DPs) was completed in 2016; the middle 5.7-T Coil 2 (32 DPs) has been fully assembled and tested; and for the outermost 4.4-T Coil 3, its 38 DPs have been wound and preliminary tests performed to characterize the DP at 77 K. In this paper we present first results of Coil 2 and then those of Coil 3. Included in the Coil 2 test results are: 1) 77-K critical current, index number, turn-to-turn contact resistivity, and charging-delay time constant for all DPs; 2) final stacking order of the 32 DPs, optimized to maximize Coil 2's critical current margin and minimize its Joule dissipation from the pancake-to-pancake joints; 3) procedure to experimentally determine and apply a room-temperature preload; 4) 77-K and 4.2-K test results including resistance of pancake-to-pancake joints, before and after each of 64 pancakes was over-banded with 76- μ m-thick stainless steel tape for a total radial thickness of 5 mm. Presented for Coil 3 are 77-K critical current, index number, turn-to-turn contact resistivity, and charging-delay time constant for all DPs.

Acknowledgement: Research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health

Submitters Country:

United States

Mon-Af-Po1.12 / 330

Construction and Test of Three-coil Magnet Power Supply System for High Pulsed Magnetic Field

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High pulsed magnetic field is an important basic research tool, which has been used more and more widely in physics, biology and materials. Higher magnetic field can provide more opportunities for scientist to reveal new phenomena in scientific research. Aiming to achieve a higher magnetic field, Wuhan National High Magnetic Field Center (WHMFC) has designed a power supply system for 100 Tesla magnetic field under existing power supply conditions in April 2015. The magnet of 100 Tesla energized by multi power supply system consists of three coils. The outer coil is energized by a pulsed generator-rectifier connected to battery banks in series. The middle coil and the inner coil are energized by capacitor banks respectively. Coordinated control and stable operation of such complex systems is a great challenge. To ensure safety and reliable operation, control sequence as well as protection system for the power system is designed and developed. A test system with the prototype of three-coil magnet is established at WHMFC. And a series of tests are carried out for hybrid power supply systems, control sequence and protection system. 75 Tesla peak field is reached as the highest magnetic field in the test. Test results presented in this paper show the hybrid power supply system is feasible and operable. And it will be used to energize the magnet for generating 100 Tesla pulsed magnetic field at WHMFC in the summer of 2017.

Acknowledgements: The authors would like to acknowledge the supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Tue-Af-Po2.05 / 695

Construction and Test of a 400 MHz 100 mm Conduction-Cooled NMR Magnet wound with Metal-Clad GdBCO Tapes

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Since 2015, we have been developing a 400 MHz 100 mm no-insulation (NI) high resolution NMR magnet wound metallic cladding (MC) GdBCO tapes. In 2016, a 3 T 100 mm “Demo” magnet was designed and constructed, and successfully generated the target field at the designated operating conditions. In 2017, we move on developing the final magnet of which the design was previously reported. The key design concepts include use of: (1) multi-width GdBCO tapes, manufactured by the SuNAM, to operate the magnet at a substantially higher average current density than that of its single-width counterpart; (2) MC GdBCO tapes to reduce the charging delay of the NI magnet without sacrificing its self-protecting feature; (3) multiple “inner” notches, where inner diameters of selected pancake coils are adjusted to improve the magnet field homogeneity; (4) conduction-cooled operation at 10 – 20 K with a vibration isolator implemented. As a progress report, this paper presents construction details and initial test results of the magnet at 77 K and 20 K.

*This work was supported by KBSI grant (D37611) to S.-G.L funded by the Korea Basic Science Institute (KBSI).

Submitters Country:

south korea

Thu-Af-Po4.01 / 32

Construction and Testing of Curved ReBCO Coils

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In many applications dipole magnets with coils having significant curvature are needed. This is particularly challenging for high temperature superconductors (HTS) as they are brittle. One application for curved HTS coils is the fragment separator dipole magnets for the Facility for Rare Isotope Beams (FRIB). These magnets operate in a high radiation environment and are subject to a high heat load. Removal of heat generated in magnets in this environment using conventional NiTi and Nb3Sn superconductors, which must operate at ~4.5 K, is difficult. However, HTS conductor can be used to permit operation at 40 K where heat removal is significantly more efficient. As these coils are curved, one side of the coils has a reverse curvature requiring the development of special technology to wind the coils. As part of an SBIR/STTR grant to develop and demonstrate a super-ferric design for a 2.2 T magnet two curved coils were fabricated with 12 mm wide SuperPower ReBCO conductor and first tested in liquid nitrogen at 77 K. Afterwards they were installed in a cryostat and cooled to 40 K with cryo-coolers. This paper will present the construction details and test results of these coils.

Submitters Country:

United States of America

Tue-Af-Po2.04 / 1026**Construction and test of the NHMFL 32 T superconducting magnet****Author(s):** H.W. Weijers¹**Co-author(s):** D.V. Abraimov¹; S.R. Gundlach¹; A.V. Gavrilin¹; A.J. Voran¹; W.R. Sheppard¹; D.K. Hilton¹; T.A. Painter¹; T.P. Murphy¹; P.D. Noyes¹; Y.L. Viouchkov¹; B. Jarvis¹; W.D. Markiewicz¹¹ *NHMFL/FSU*

The 32 T project aims to combine a 15 T LTS magnet with two REBCO double pancake coils generating 17 T to create a 32 T user magnet for the MilliKelvin facility at the NHMFL. Both coil sets operate at 4.2 K using two separate power supplies. First, the construction of the REBCO coils and integration with the LTS magnet and cryostat is briefly described. Then, the cool down and performance characteristics of the complete magnet are presented. The effect of screening currents at 77 K and 4.2 K in the REBCO coils is described. Operating modes at 4.2 K include ramping the REBCO and LTS coils separately and synchronized one-hour ramps to full field. A deliberate quench of the REBCO coils using the embedded quench heaters is included in the test protocol. Data from voltage taps, Hall effect and temperature sensors are presented to quantify the performance of the magnet and the magnetic field it generates.

Acknowledgement: This work was supported in part by the U.S. National Science Foundation under Grants No. DMR-0654118, DMR-1157490, DMR-0923070 and the State of Florida.

Submitters Country:

USA

Thu-Mo-Or32 / 925**Contact resistance between REBCO tapes coated with a thin resistive layer****Author(s):** Jun Lu¹**Co-author(s):** Jeremy Levitan¹; Ke Han¹¹ *NHMFL*

No-insulation (NI) REBCO superconducting magnets allow very high engineering current density. Therefore, it can achieve very high magnetic field with a compact design. The considerable charging delay time due to current redistribution between turns in a pancake coil, however, limits its application to magnets that do not require frequent field ramps. Since long charging delay is directly linked to low contact resistance between turns, increasing contact resistance can mitigate the charging delay. On the other hand, very high contact resistance compromises the ability of self-quench-protection which is a crucial advantage of the NI technology. Therefore it is highly desirable to optimize the magnet performance and reliability by adjusting turn-to-turn contact resistance which might be achieved by coating REBCO with a thin layer of resistive material.

In this work, REBCO samples are coated respectively with a layer of nickel, chromium and copper oxide of varying thicknesses. Contact resistance between two coated REBCO tapes is measured at low temperatures as a function of load and load cycles. The results will be discussed in light of its applications in NI magnets.

Acknowledgement: Financial support of National Science Foundation Cooperative Agreement No. DMR-1157490 and the State of Florida

Submitters Country:

USA

Mon-Af-Or5 / 261

Control design of a magnetic catheter navigation system for cardiac arrhythmiasJianhua Liu¹ ; Housheng Wang¹ ; Qiuliang Wang¹¹ *Institute of Electrical Engineering, Chinese Academy of Sciences*

Nowadays, remotely-controlled catheter ablation has emerged as a novel approach to reduce fluoroscopy exposure and provide stable and reproducible catheter movement during in cardiac surgeries for arrhythmias. A remote catheter magnetic navigation system (MNS) which provides real-time navigation of the catheter in the heart is under development in IEE. The catheter navigation system consists of eight magnets aligned spherically, which generate the dynamically shaped magnetic field around the heart of the subject, about 15 cm³ region with a maximal uniform field of 0.2 Tesla. An X-ray generator is mounted underneath the subject's torso while the image detection system is above the subject's torso. Eight four-phase power supplies, which excite the eight magnets to create the needed magnetic field in time, are controlled by a programmed navigation software via a joystick providing the console. Different from CGCI, the magnetic field in our MNS is homogeneous in the navigation region, which only exerts sufficient torque on the ablation catheter tip, while the push/pull of the ablation catheter is carried out by another special device, with a stepping motor to push or pull the catheter. The navigation algorithm, which determines the performance of the system, is the soul of the catheter magnetic navigation system. In this article, how the navigation algorithm works is firstly introduced, and then four navigation algorithms are proposed and compared, and finally a navigation algorithm with simplicity and no dead zone in spherical coordinate system is chosen. Preliminary test results show that this navigation algorithm has good practicability and robustness and thus can be applied to the remote catheter magnetic navigation system.

Submitters Country:

China

Mon-Af-Po1.03 / 638

Controllability of the contact resistance of 2G HTS coil with metal insulation**Author(s):** Myung-Hwan Sohn¹**Co-author(s):** Kideok Sim ¹ ; Beomyong Eom ² ; Hong-Soo Ha ² ; Ho-Yong Kim ¹ ; Kichul Seong ¹¹ *Korea Electrotechnology Research Institute*² *Korea Electrotechnology Research Institute*

Today, researches on the all 2G HTS magnets are actively underway in the field of high magnetic fields. No-insulation coils without insulation between turn-to-turns are very stable against quenching. The characteristic resistance of the no-insulation coil depends on the turn-to-turn contact resistance, which is an important factor determining the current ramping rate. In no-insulation coils, the turn-turn contact resistance is very small and the current ramping rate is very slow. The resistance between these turn-to-turns simply depends on the contact area of one turn and the resistivity and surface conditions of the metal where contact occurs. The metal insulation coil co-wound with stainless steel tape has a higher current ramping rate than the no-insulation coil. The metal insulation coil has two contact interfaces compared to the no-insulation coil, and the resistance of the stainless steel tape is larger than that of the surface material cooper of the 2G HTS wire. So if you can control

the turn-to-turn resistance in the desired HTS magnet, it will be very useful for designing HTS magnets. In this study, we conducted a study to change the contact resistance of metal-insulation coils by coating some metal material on the surface of the co-winding metal tape. The result will discuss the controllability of the contact resistance between the turn-turns of the 2G HTS coils.

Submitters Country:

South Korea

Mon-Af-Po1.11 / 65**Cool-down of LTS magnets by a closed loop helium gas flow**Francesco Dioguardi¹¹ *DH Industries BV*

LTS magnets are typically used and kept at 4K, but when being build or retrofitted they will be at ambient temperature. Cool-down at the factory or installation site can be done using LN2 and LHe, but this is an inefficient process involving a number of operational steps. This paper described how cool-down can be achieved simpler and more efficiently using a closed loop helium gas flow. In this concept no nitrogen gas is introduced in the LHe cryostat, while a temperature of less than 20K will be reached, which will limit the amount of LHe required. The helium gas is cooled by a cryocooler and circulated through the magnet using a high efficiency cryogenic fan. The temperature of this loop will gradually drop from ambient to final temperature. This will give maximum cooling capacity and efficiency of the cryocooler as it is kept at relatively high temperatures as long as possible. The challenge in the design of such a closed loop is the allowed cryostat pressure and connection sizes of each individual magnet design. These tend to be low and small, resulting in high volume flows and large flow losses. In this paper we describe the flow and heat exchange models we have designed to determine the most effective cooling loop for a certain set of parameters for an individual magnet design.

Submitters Country:

The Netherlands

Mon-Af-Po1.11 / 114**Cooling experiment analysis of a prototype thermal siphon system for single crystal ingot growth magnet**Woo Seung Lee¹ ; Kwang Myung Park¹ ; Chu Yong² ; Kwang Pyo Kim²¹ *JH Engineering Corp.*² *National Fusion Research Institute*

Thermal siphon system is a cooling method for a large scale superconducting magnet system by circulating cryogen through cooling channel. In this paper, a small scale prototype thermal siphon system for single crystal ingot growth magnet is designed based on liquid and gas He circulation. The designed system is tested as a part of design method validation process. The cooling performance of the system is analyzed with experiment. The experiment is conducted in different heat input conditions to investigate different magnet heat input conditions such as AC losses. The system is also tested with two different helium levels to analyze the effect of the amount of cryogen. Finally, a revised topology of the prototype system, which is a candidate cooling system of the single crystal growth magnet product, is suggested based on the test results.

Submitters Country:

Korea, Republic of

Thu-Af-Po4.06 / 216

Core Loss Analysis of Permanent Magnet Linear Synchronous Generator with Slotless Stator

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Co-author(s): Min-Mo Koo ; Ji-Hun Ahn ; Jeong-Man Kim ; Gang-Hyeon Jang

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This paper presents core loss analysis of 5kW permanent magnet linear synchronous generator (PMLSG) with slotless stator. PMLSGs are widely used in various applications. Due to the advantages of high efficiency, high power density, and low maintenance cost. Moreover, slotless stator has the advantages of reducing the detent force and magnets barely impact the electrical steel's saturation due to higher air-gap length. Core loss analysis is essential to improve PMLSG's efficiency. Core loss is typically calculated using the classical Steinmetz equation, which only considers hysteresis loss and eddy current loss. However, the use of this equation leads to a significant disparity in the theoretically calculated results and the experimentally obtained results. In order to reconcile this observed discrepancy, modifications to the equation have been proposed in Bertotti's model. Bertotti's model proposes the inclusion of an excess loss parameter that accounts for the loss associated with a material's thickness, cross-sectional area, and conductivity, and a parameter that describes the material's microstructure. This modified Steinmetz equation accounts for hysteresis loss, eddy current loss, and excess loss. In this paper, the hysteresis loss coefficient, the eddy current loss coefficient, and the excess loss coefficient of stator core for the modified Steinmetz equation are derived from the Epstein test data using a curve fitting method. Owing to the core loss occurs in the rotating field is much more than that occurring in the alternating field, we separate the rotating and alternating field and they can be distinguished using the axial ratio of loci. Finally, core loss at slotless stator is calculated using a modified Steinmetz equation that considers rotating field and flux path. More detailed discussions and analysis results will be presented in the final paper.

Submitters Country:

Republic of Korea

Tue-Af-Po2.06 / 717

Core Loss Calculation of Permanent Magnet Machines Using Analytical Method

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Permanent magnet (PM) machines are becoming popular as a key technology for applications such as home appliances, industrial tools, and electric vehicles. This is because of their high efficiency, high power density, and low maintenance costs. It is very important to consider the power losses in the initial design stage itself, because they determine the efficiency of the machine and have a significant influence on its operating cost. More importantly, the power losses determine the operating temperature of the machine, and hence its rating or output power that may be obtained without undue deterioration of the insulation and PMs. The copper losses of the stator winding, rotor loss, and the mechanical losses due to windage and friction are well known. The remaining loss is the core loss of the stator. This is caused by the changing flux densities in various parts of the iron structures in the machine. Some of these core losses can be significant during high-speed

operations. It is imperative to consider the core losses during the design stage. The purpose of this paper is to analytically predict the core loss of the PM machine at the design stage. The process followed in the proposed method is given below.

Step-1: Rearrangement of the core loss data.

Step-2: Deduction of the core loss coefficient by curve fitting.

Step-3: Analytical modeling with a search coil for calculating the flux density.

Step-4: Calculation of the core loss using the obtained core loss coefficients and flux density.

The core loss obtained by the analytical method is compared with those obtained using the finite element method and experiments. In order to verify the core loss results obtained using the proposed method, an experimental system was implemented with a commercial PM machine, power analyzer, and the manufactured test PM machine.

Submitters Country:

Republic of Korea

Thu-Mo-Or33 / 877

Coupled electro-magnetic, thermal, mechanical analysis of a quench in the high luminosity LHC Nb3Sn quadrupole magnet

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Modelling the behavior of a superconducting magnet is challenging due to interdependent, non-linear, multi-domain and multi-scale phenomena occurring during fast transients. A modelling technique based on a lumped-element equivalent system was recently proposed, which efficiently simulates electro-magnetic and thermal transients in a magnet. The model, named LEDET (Lumped-Element Dynamic Electro-Thermal), includes a network of RL loops mutually coupled with the magnet's self-inductance, which simulate the coupling between the magnet and local inter-filament and inter-strand coupling currents developed in the superconductor. The dynamic response of the magnet when subjected to applied voltages, such as during current cycles, fast energy extraction, or CLIQ (Coupling-Loss Induced Quench system) discharges, is correctly reproduced. Furthermore, the heat dissipated as ohmic and coupling losses, exchanged between adjacent conductors, and dissipated to the cryogenic bath are calculated, as well as the conductor temperature variations. Finally, the Lorentz forces acting on each strand are computed. A 2D mechanical model of the magnet was developed in Ansys®, including the coil and its shell-based support structure. The stresses occurring in the coil are analyzed by coupling the LEDET and the Ansys model at a number of selected steps in the time domain. The main contributions to conductor stress are the Lorentz forces and the thermal stress due to the conductor heating. As a case study, the Nb3Sn quadrupole magnet for the LHC upgrade to higher luminosity is considered. Strain measurements performed during magnet cool down, powering, and fast discharge are used to validate the model. Simulation results allow estimating the peak temperature and stress reached in the superconductor during and after a quench.

Submitters Country:

USA

Wed-Af-Or26 / 1048

Coupling loss in prototype CFETR CS conductors with different cable patterns, measurement and modeling

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⁵ *U*

CFETR which stands for “China Fusion Engineering Test Reactor” is a new tokamak device to be built in China as a complimentary to ITER device. Its magnet system includes the Toroidal Field (TF), Center solenoid (CS) and Poloidal Field (PF) coils. The central solenoid consists of 6 coils consisting of Nb3Sn strands to be operated at a maximum magnetic field of about 14 T.

Among several prototype CFETR CS conductors proposed for optimising the cable design, three different pattern variations were experimentally tested and analysed with the JackPot cable model developed at the University of Twente. The conductors were manufactured at ASIPP (Institute of Plasma Physics, Chinese Academy of Sciences) according to the Twente cable design proposed for lower coupling loss with cable twist pitch ratio close-to-one and the new ASIPP cable design with triplet modification in the first stage. The Chinese Central Solenoid Model Coil (CSMC) cable pattern is tested and analysed as well being used as a baseline for comparison since its layout is close to that of ITER CS. The new ASIPP design is aimed at reducing strand deformation as much as possible while increasing the superconducting strand support but keeping similar stiffness as the ITER CS cable to avoid degradation of transport properties. The twist pitch of the two superconducting strands in the initial triplet is increased, reducing the dimple damage from large crossing angles frequently occurring when using short twist pitches. The results from experiments and simulations can be used for optimization of cabling patterns in terms of coupling loss, cabling deformation and transverse load.

Submitters Country:

Netherlands

Thu-Mo-Or33 / 405

Coupling of Mechanical and Magneto-Thermal Models of Superconducting Magnet by Means of Mesh Based Interpolation

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The Finite Element Method (FEM) is used to perform accurate modelling of superconducting magnets for magnetic field design, mechanical design, and calculations of the peak temperature and voltages to ground in the magnet during a quench.

Each design step solves a set of partial differential equations with appropriate boundary conditions, nonlinear material properties, and problem-adapted meshes. For as long as possible, physical problems are dealt with independently and solved with appropriate FEM programs. The study of multiphysics phenomena, however, requires to solve coupled systems of equations, and a monolithic solution using a single tool might not always be desirable. Another approach treats the coupled models independently by means of input and output relations. In this setting, the interpolation of the results obtained with two different mesh definitions has to be carefully addressed. As a result, each model is treated with an optimal tool. Models created for independent studies can be reused for multiphysics analyses, and the overall development time is reduced.

We study the mechanical impact of temperature gradients and Lorentz-force evolution during a quench and subsequent current discharge in a superconducting magnet. The magneto-thermal study is performed with COMSOL Multiphysics and the mechanical analysis is carried out with an ANSYS

APDL. Both models are created through the STEAM (Simulation of Transient Effects in Accelerator Magnets) coupling environment developed at CERN. We use the MpCCI (Multi-physics Code Coupling Interface), which allows for a generic mesh-based interpolation of results obtained with a variety of FEM tools. Integrating MpCCI in STEAM workflows increases in important way the flexibility and reliability of STEAM coupling workflows. The coupling method is illustrated with a simulation of an 11-T dipole magnet for the High-Luminosity upgrade of the LHC. In the study the magnet is protected on a test bench with the CLIQ (Coupling-Loss Induced Quench) technology.

Submitters Country:

Poland

Wed-Af-Po3.10 / 795

Creepage Discharge Characteristics of a Solid Insulation Material for Superconducting Applications

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Solid insulation materials for superconducting applications are required to be robust in terms of both mechanical and electrical performance. The electrical insulation performance of gaseous medium is inferior to that of liquid medium. Also, the characteristics of creepage discharge is inferior to those of penetration breakdown. Therefore, electrical breakdown of a high voltage superconducting apparatus easily occur at current lead part filled with gaseous insulation medium as a form of creepage discharge rather than as a form of penetration breakdown. In this study, dielectric experiments on the creepage discharge characteristics of epoxy resin under various pressures using two kinds of electrode systems are conducted. The first one is for the creepage discharge along the surface of epoxy resin in gaseous and liquid nitrogen. The other is for the creepage discharge along the interface between two different epoxy resins in contact. Dielectric experiments are conducted with respect to various pressures from 0.1 MPa to 0.5 MPa. As results, characteristics of electric field intensity at creepage discharge under AC and DC voltage are deduced as an empirical formula.

Submitters Country:

Republic of Korea

Wed-Af-Po3.10 / 315

Critical Current Properties of Precisely Cation Composition Controlled RE123 Melt-Solidified Bulks

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Thus far, RE123 coated conductors have revealed their promising potential for high field generating materials. On the other hand, RE123 bulks grown by the melt-solidification method, which can trap much higher magnetic field than permanent magnets, have been opening new superconducting applications, such as flywheels, magnetic separation, drug delivery, levitating mixer and compact

NMR. Although J_c of the bulks are more than one order of magnitude lower than that of coated conductors, their engineering J_c values are almost comparable. In both materials, precise control of chemical composition is a crucial factor to determine critical current performance as well as controls of carrier doping state and microstructures. Partial substitution of RE for the Ba-site is known to degrade superconducting properties through structural disorders and a decrease in effective carrier concentration, while the pinning characteristics is improved when the substitution level is low, less than ~1%. In the case of RE123 bulks, the partial substitution of RE is intrinsically prompted even for Y123, because their total composition is RE-rich, which results in poor J_c and low field trapping properties. In the present study, we have attempted to control cation composition of top-seeded RE123 melt-solidified bulks by various methods, such as RE-mixing, starting from Ba-excess composition and introduction of reductive post-annealing process after the crystal growth. All these methods were found to be effective for controlling cation composition of RE123 close to the integral ratio and the J_c -B characteristics of the bulks were largely improved particularly at lower temperatures reflecting the enhanced superconducting condensation energy. Details of synthesis procedure, microstructure and superconducting properties including field-trapping properties of the bulks will be reported.

Submitters Country:

Japan

Mon-Af-Po1.03 / 370

Cryo-free multisection superconducting magnetic system with MgB₂ coil

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Comprehensive studies of the transport and the magnetic properties of MgB₂ wires were carried out at temperatures 4.2-20 K and magnetic field up to 8 T. Cryomagnetic system with MgB₂ coil was designed and constructed based on the received data. Cryomagnetic system is designed to create a permanent magnetic field of up to 5 T in the warm bore of 40 mm in diameter. The operating current of the system is 100 A. The magnetic field is created by a system of three concentric solenoids. The inner coil is composed of a 10 double pancakes wound with the 2nd generation HTS tape produced by SuperOx. Middle coil is made of multifilament MgB₂ wire with a diameter of 1 mm produced by Columbus Superconductors. Middle coil has height of 120 mm, an inner diameter of 80 mm and an outer diameter of 88 mm. The inner and middle coils are connected in series, what allows both sections to operate at temperature range from 4.2 K to 20 K. The external coil of background field is wound of NbTi. It is powered by a separate pair of current leads. The solenoids are cooled by cryocooler through copper bar. The present report describes the design, the manufacture and the test results of the cryomagnetic system.

Submitters Country:

Russian Federation

Mon-Af-Po1.11 / 916

Cryogen Recondensed Cooling System for Electron Beam Ion Source Employing 7 T Superconducting Solenoid Magnet

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¹ *Kyungpook National University*

² *Kangwon National University*

An electron beam ion source (EBIS) is required to fulfill the diverse requirements of proton-beam users facilitating enhanced application. Superconducting magnet is a critical part of EBIS, and cryogenic systems are essential for the design and the operation of the superconducting magnets. Thus, this study demonstrates the development of cryostat of 7 T superconducting solenoid for electron beam focusing in the EBIS system. The proposed cryostat will be used to cool the NbTi coil by using liquid helium. During the full operation of EBIS system, the strong emission of x-ray prevents the easy access to the apparatus. Therefore, through our study, we have realized the development of liquid helium recondensed system. Once the cryostat is filled with coolant, evaporated helium gas will be liquefied again at the recondensing device, which is directly connected to the cryocooler. The design of 7 T superconducting magnet comprises inner and outer diameters of 280 mm and 324 mm, respectively and the height is assigned as 2000 mm. Based on the unique shape of the superconducting magnet, the cryostat also has horizontally long configuration. Cooling margin of cryocooler is precisely calculated to obtain efficient performance of helium recondensation, including heat invasion from conductive and radiative components. Detailed specifications and design considerations of proposed cryostat will be explained through the extended paper.

Submitters Country:

Republic of Korea

Wed-Af-Po3.10 / 1189

Cryogenic Hybrid Magnet with Praseodymium Permanent Magnet

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High-field magnets are often demanded for advanced scientific studies. Although a hybrid coil design comprising Nb-Ti, Nb₃Sn, and HTS (High Temperature Superconductors) are potential candidates for such application, the costs of Nb₃Sn and HTS are expensive compared with Nb-Ti. Permanent magnet can join hybrid magnets. By generating additional field about 1 T by permanent magnets, required amounts of superconducting material may be reduced. Magnetic properties of some magnetic materials have been studied by other work at temperature as low as 100 K. The remanent field of conventional NdFeB magnets decreases at 100 K due to spin reorientation. PrFeB magnets consisting of praseodymium (Pr) instead of neodymium (Nd) do not show such degradation and the coercivity of PrFeB at 100 K is 7 T. The coercivity at 4 K would be estimated as 10 T by a naive extrapolation. Therefore, PrFeB magnets may be applicable as the field booster in the high-field hybrid magnets. In this study, B-H curve, as a primary magnetic property, of a PrFeB magnet sample was measured in the temperature range down to 4 K. Based on the experimental result, magnet configuration for an accelerator dipole magnet is also studied as an example of application.

Submitters Country:

Japan

Mon-Af-Po1.11 / 265

Cryogenic Oscillating Heat Pipe for Conduction-cooled Superconducting Magnets

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The oscillating heat pipe (OHP) is a two-phase flow device used for transferring heat without external mechanical power. In this paper, a cryogenic OHP with neon as working fluid for conduction-cooled superconducting magnet is fabricated. The mock-up magnet is cooled down with the cryogenic OHP. The cooling down process of the mock-up magnet is investigated, and the effect of the liquid filling ratio on the heat transfer characteristics of the OHP is discussed. The result shows that the cooling down process of the mock-up magnet can be significantly accelerated by the presence of neon in the cryogenic OHP. The cryogenic OHP possesses the optimal liquid ratio, which has the maximum the effective thermal conductivity at the same heat input.

Submitters Country:

China

Thu-Mo-Or29 / 1214

Cryogenics Engineering for Superconducting Magnets at DEMACO

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³ *Director*

Cryogenic technology is extensively used at DESY, FERMILAB, ITER, CERN, FAIR and ESS to create and maintain low-temperature conditions for the magnets. In order to operate at high magnetic fields, magnets are cooled with supercritical helium at 4 K (-269°C). They are surrounded by a large cryostat and an actively-cooled thermal shield with a forced flow of helium. Efficient cryogenic infrastructures are needed for the transport and distribution of Liquid He to the cryo-modules and to return helium to the refrigerator plants. There are numerous cryogenic devices used for scientific and industrial application at low temperature. These include cryostats, cryogenic liquid helium transfer lines, valve boxes, cold boxes and others. Every piece of equipment has a function within the cryogenic loop. It is all about flow control and flow conditioning within a vacuum insulated device. Demaco design addresses a number of issues such as the choice of design parameters, design code, system configuration, layout, and safety system assessment. It starts with user technical specifications, piping and instrumentation diagrams, and layouts, and it ends with the design (PDR, FDR, MRR), manufacturing and installation of a functional equipment. In the past, Demaco designed, fabricated and installed the Feed Caps, End Caps and string connection Boxes for the European XFEL project at DESY (Hamburg, DE). Currently Demaco is in the process to deliver the Feed Caps and Transfer Lines for the LCLS-II project at FERMILAB/SLAC (California, USA). Both projects are characterized by complex thermal shields, beam pipe integration, vacuum barriers and many instruments for control of the cryogenic system.

Submitters Country:

the Netherlands

Wed-Af-Po3.04 / 37

Cryostat Design of 230 MeV Superconducting Isochronous Cyclotron for Proton Therapy

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Co-author(s): Atsushi Hashimoto¹; Takaaki Morie¹; Yoshihiko Arakawa¹; Hitoshi Mitsubori¹; Hiroshi Tsutsui¹; Takehisa Tsurudome¹; Yukio Mikami¹

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We have designed a 4 tesla superconducting isochronous cyclotron for proton therapy. Its yoke weight is about 65 tons, which is less than one third of our normal-conducting 230 MeV cyclotron. Application of superconducting wire to cyclotron can contribute to reduction of dimension, initial costs, power consumption and lead time. The superconducting coils using NbTi wire are conduction-cooled by four 4 K Gifford-McMahon cryocoolers. The superconducting coil assembly is supported by four horizontal straps and four vertical columns. We will report cryostat designs of structure, cooling and quench protection.

Submitters Country:

Japan

Tue-Af-Po2.08 / 966

Current Capacity of Cu-sheathed Multi-filamentary Coated Conductors under the Influence of Spatial Variation of Local Critical Currents in Each Filament

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¹ *Kyushu University*

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We have investigated the relationship between local critical current distribution and global current capacity of multi-filamentary RE-123 coated conductor (CC). RE-123 CCs have critical issues on (1) spatial inhomogeneity in local critical current distribution which would become an origin of local burnout of a magnet coil and on (2) magnetization current which affects the spatial and temporal stabilities of magnetic field distribution of a magnet. To compensate (2), striation or slitting of a CC to obtain narrow filaments would become a possible solution. However, (1) will become more serious because smaller defects affect more on it than the case of a wide CC. In other words, the relationship between (1) and (2) have been recognized as a trade-off problem. On the other hand, narrower filaments with electrical coupling will become a promising solution. For example, current in a filament can flow into the adjacent filament avoiding a local defect; this will contribute to the reduction of local heat generation. Furthermore, with the finite coupling resistance, the magnetization current will be confined just in each filament in a steady state; magnetization will be reduced successfully. However, the quantitative impact, which is indispensable for the design of a conductor, has not been clarified yet. We characterized local critical current distribution in each filament of a long multi-filamentary CC based on the experiment by Reel-to-reel scanning Hall-probe microscopy, and then estimated its local heat generation distribution and current capacity. The relationship among (i) inhomogeneity of local critical current distribution, (ii) inter-filament resistance, and (iii) current capacity of the multi-filamentary CC with an appropriate criterion will be summarized systematically. This will become very important information for deciding how homogeneous, how narrow, and how many filaments are needed for an appropriate conductor satisfying the requirements from magnet applications.

This work was supported by "JSPS-KAKENHI (16H02334,16K14216)."

Submitters Country:

Japan

Tue-Af-Po2.03 / 574

Current Center Line Measurement of ITER TF Coil

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Toroidal field (TF) coils are superconductive magnets which create magnetic field to confine plasma in ITER vacuum vessel. In order to confirm TF coil's functionality, magnetic field created by TF coil need to be evaluated and therefore, accurate measurement of current center line (CCL) is necessary. CCL of TF coil is defined as geometrical barycenter of all the conductors and accurate determination of CCL for TF coil is difficult due to two reasons: 1) after some steps through manufacturing, conductor positions within TF coil cannot be measured directly, 2) because each TF coil is composed of 7 double pancakes (DPs); 5 regular DPs and 2 side DPs, it is complicated to measure conductor positions within TF coil. To overcome those complications, a method to determine conductor positions by measuring magnetic fields of each DP, rather than TF coil, at surface of DP was proposed. From magnetic field simulation, magnetic field components are known to range from -0.02 T to +0.02 T at DP surface when direct current of 1 kA is supplied and magnetic field or its derivative takes local extrema above conductor position. In addition, it was calculated that a deviation of 1mm in one of conductor positions results in deviation of 5 μ T in magnetic field above the conductor. Therefore, in order to determine conductor positions of DP with 1 mm accuracy, a system capable of measuring magnetic fields from -0.02 T to +0.02 T with 5 μ T accuracy was developed. From the conductor positions of DP determined with this method, CCL of each DP and TF coil can be calculated very precisely.

Submitters Country:

Japan

Wed-Af-Po3.09 / 794

Current Distribution Calculation of Superconducting Layer in HTS Cable Considering Magnetic Hysteresis by Using XFEM

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The superconducting layers in high temperature superconducting (HTS) cables consist of many twisted superconducting tapes. The number of superconducting tapes, twist angle and twist direction are all different in different layers. The superconducting tapes, of about 4 mm wide and 0.20 mm thick, are twisted and wound on a cylindrical surface of diameter about 30 mm and a pitch of normally greater than 100 mm. Because of the small thickness of conducting layers, it is not possible to study electromagnetic field and current distributions in an HTS cable by the conventional finite element method (CFEM). To overcome these limitations, an improved quasi-3D extended finite element method (XFEM) is proposed. In regions near these interfaces, the magnetic vector potential approximation is enriched by incorporating multiple derivative discontinuous fields such that the interfaces can be represented independent of the mesh. The support of a node or an element can be cut by several interfaces. By this method, the field analysis of an electromagnetic device of multiple nearby interfaces can be accomplished by a coarse low order mesh, and in elements containing multiple nearby interfaces. This paper presents a coupled field-circuit analysis method for the HTS cable considering magnetic hysteresis by using the improved XFEM. The quasi-3D cylindrical coordinate HTS cable model is firstly proposed based on the shell element theory. The quasi-3D meshing elements are used instead of the traditional 3D meshing elements to overcome the difficulties in meshing. A new Preisach type hysteresis model of HTS tapes is firstly combined with the improved

XFEM to determine the magnetic hysteresis inductance. A magnetic field-circuit coupled program for current analysis of superconducting layers is coded. The numerical simulation results of this field-circuit coupled method are reported compared with the experimental test results for the case of an HTS cable with 2 layers.

Submitters Country:

China

Tue-Af-Po2.07 / 1006

Current Limiting Characteristics of Transformer Type Superconducting Fault Current Limiter (SFCL) due to Winding Direction of Additional Secondary Winding

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In this paper, the transformer type superconducting fault current limiter (SFCL) with additional secondary winding, which could limit the fault current through twice quench operations, was suggested. The suggested SFCL includes one primary winding, two non-isolated secondary windings wound on the same iron core, and two high-TC superconducting (HTSC) elements connected with each secondary winding. The advantage of the suggested SFCL is that it can perform the twice current limiting operations due to the transient amplitude of the fault current. Among its designed parameters, the winding direction of two non-isolated secondary windings is expected to affect the current limiting characteristics of the SFCL with twice quench operations. To analyze the dependence of the current limiting operation on the winding direction of the two non-isolated secondary windings, the fault current limiting tests were performed with the suggested SFCL and the current limiting characteristics of the SFCL were discussed.

Submitters Country:

Republic of Korea

Tue-Af-Po2.07 / 1003

Current Limiting and Recovery Characteristics of A Trigger Type SFCL using Double Quench

Sung-Hun Lim¹ ; Seung-Taek Lim¹

¹ *Soongsil University*

The current limiting and recovery characteristics of a trigger type superconducting fault current limiter (SFCL) using double quench, which consists of a power switch, two separated current limiting reactors and two superconducting (SC) elements, were analyzed. The suggested trigger type SFCL can perform two fault current limiting operations (single quench operation and double quench operation) according to the amplitude of the initial fault current. In case of lower amplitude of the initial fault current, the fault current limiting operation of the SFCL can be performed through the occurrence of the single quench in SC1 element connected in series with the power switch. In case of larger amplitude of the initial fault current, the second quench in SC2 element connected in parallel with one of the separated current limiting reactors after the first quench in SC1 element occurs, namely, double quench, is contributed to the larger fault current limiting operation of the SFCL. Through the analysis on the short-circuit tests, the effective current limiting and recovery characteristics of the suggested trigger type SFCL using double quench could be confirmed.

Submitters Country:

South Korea

Tue-Af-Po2.08 / 443

Current Sharing Temperature and Quench Characteristics of REBCO Quasi-isotropic Superconducting Strands in Different Sheaths**Author(s):** Wei Pi¹**Co-author(s):** Xiaochuan Shi¹; Yinshun Wang¹; Jin Dong¹¹ *North China Electric Power University*

Current sharing temperature, minimum quench energy (MQE) and quench propagation velocity (QPV) of quasi-isotropic superconducting strands made of REBCO tape in copper, aluminum and stainless steel sheaths were investigated numerically. The simulation results indicate the types of sheaths have little effect on the current sharing temperature of the superconducting strands. The strands in copper sheath and in stainless steel sheath have the maximum and the minimum MQE respectively. The strands in aluminum sheath and in stainless steel sheath have the maximum and the minimum QPV respectively. The simulation results are very important for the application of this kind of quasi-isotropic superconducting strands.

Submitters Country:

China

Tue-Af-Po2.08 / 317

Current sharing properties of REBCO superconducting parallel conductors wound into a coil**Author(s):** Shintaro Sagawa¹**Co-author(s):** Masataka Iwakuma¹; shotaro Honda¹; Yusuke Fukumoto²; Seiki Sato¹; Teruo Izumi³; Akira Tomioka⁴; Masayuki Konno⁴¹ *Kyushu University*² *Railway Technical Research Institute*³ *Advanced Industrial Science and Technology*⁴ *Fuji Electric*

Operating current of large-scale superconducting magnets needs to be enhanced up to several thousand to several tens thousand amps from the viewpoint of magnet protection in relation to the consumption of stored energy by an external resistor. On the other hand, superconducting magnets for MRI need the uniformity of produced magnetic field within ppm order in time and space. We proposed the configuration of parallel conductors to enhance the current capacity of REBCO superconducting thin tapes. The constituent tapes should be insulated and transposed so as to be inductively equivalent for the even current sharing and low ac loss. However it is usual that the critical current, I_c , and n -value of currently developed REBCO superconducting tapes disperse. We demonstrated in the previous study that the current sharing among the tapes of parallel conductors was influenced by the difference in I_c and n -value even if the tapes were suitably transposed and inductively balanced. Just a little unbalance of current sharing also affects the uniformity of produced magnetic field. In the previous study it was assumed that the applied magnetic field to the parallel conductors wound into a coil was uniform. However, in an actual situation, parallel conductors are subject to the self magnetic field of the respective coils and then the applied magnetic field varies

in space. So, in this study, current sharing properties when 3-strand parallel conductors with the dispersions of I_c and n -value are wound into a coil are investigated taking into account of magnetic field distribution inside the coil with a numerical simulation for an equivalent circuit. Here the I-V characteristics of each tape are expressed by n -power law. In this conference, we will present the details of obtained results.

Submitters Country:

Japan

Mon-Af-Po1.09 / 748

Current transport characteristics of a superconducting joint between REBCO conductors made by a novel method

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¹ RIKEN

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⁶ The University of Tokyo

The superconducting joint technology used for high-temperature superconductors (HTS) is key for realizing persistent operation of HTS magnets. Recently we have succeeded in developing a superconducting joint between REBCO conductors using a polycrystalline intermediate, which has a critical current (I_c) of >100 A at 77 K. A REBCO micro-polycrystalline intermediate was prepared on the surface of the REBCO layer of a conductor and it was transformed into large poly-crystals or single-like crystals as a joint.

We measured the persistent field decay of a small double pancake coil, terminated with this type of joint, at 77 K in a self-field with an operating current of ~ 10 A ($\sim 14\%$ of the calculated coil I_c) for three days. The field decay rate decreased exponentially for the first several hours and then logarithmically, corresponding to a characteristic resistance between $\sim 3 \times 10^{-12}$ to $\sim 5 \times 10^{-13}$ Ω . The logarithmic decay implies that the joint resistance was not constant and might depend on flux creep. The effect of screening current relaxation on field decay and the coil load factor dependence will be investigated.

We also measured I_c -B characteristics of the joint in the temperature range from 4 K to 77 K in a field of <10 T. In a self-field, I_c at 4 K was ~ 7 times higher than that at 77 K. At 4 K, I_c steeply reduced with the field of <1 T and gradually decreased in the range of 1-10 T. The result shows that the joint structure includes a superconducting current path which is weak against a magnetic field. The superconducting current mechanism through the joint device will be discussed based on SEM and TEM observations.

1 T. Nagaishi et al., Presented at 1st Asian ICMC and CSSJ 50th Anniversary Conference, 3A-p02, Kanazawa, Nov.7-10(2016)

This work is supported in part by the MEXT.

Submitters Country:

Japan

Thu-Af-Po4.02 / 121

DEMO Central Solenoid Design Based on the Use of HTS Sections at Highest Magnetic Field

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¹ EPFL - SPC

Previous studies indicated that the use of high-temperature superconductor (HTS) sections in the highest field allows maintaining the magnetic flux in the central solenoid (CS) reducing the outer diameter compared to the nominal size specified by EUROfusion. A reduced outer diameter of the CS coil would provide the possibility to reduce overall size and cost of DEMO. The proposed winding pack design of the CS1 module is based on 10 layer-wound sub-coils using HTS, react & wind Nb3Sn and NbTi conductors in high, medium and low field sections, respectively. The design takes into account the hoop stress in a CS1 module with superconductor grading leading to different overall current densities in each of the 10 sub-coils. In addition, the vertical loads have been estimated for pre-magnetization, where the outer modules were pressed towards the central plane of the CS coil. Both, the hoop stress and the vertical loads have been taken into consideration for the determination of the required stainless steel cross-section in the winding pack. Due to the fact that the hoop stress decreases from the inner to the outer radius of the CS1 module, while the vertical stress depends only weakly on radial position a stainless steel grading is proposed.

Submitters Country:

Switzerland

Wed-Af-Po3.05 / 217

DESIGN CRITERIA FOR HIGH-SPEED PERMANENT MAGNET SYNCHRONOUS MOTORS CONSIDERING ROTOR MAGNET AND SLEEVE MATERIAL

Author(s): Ji-Hun Ahn^{None}; Jang-Young Choi^{None}

Co-author(s): Chang-Woo Kim¹; Cheol Han; Cheol-Hoon Park; Tae-Gwang Yoon

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Recently, high-speed electrical machines are being used at an increasing rate owing to the numerous advantages of high-speed compressors such as high efficiency, simple structure, high power density, and small size. Researchers have proposed various electromagnetic designs for high-speed permanent magnet (PM) machines. However, for high-speed PM machines, mechanical stresses are generated in the rotor when it rotates at high speed. A retaining sleeve is typically installed around PM rotors for protection, and several sleeve materials have been used. The mechanical stresses generated on the surface of the PM when the rotor rotates at a high speed can damage both the PM and the sleeve. Moreover, sleeve thickness, radial interference fit, the material of the PM and the sleeve, all have an influence on the mechanical stress, and ultimately, on the target rotation speed. Therefore, sleeve thickness and radial interference fit, followed by the material of the sleeve and the PM, should be considered in the design stage. In this paper, the influence of four different sleeve materials with two different PM materials on the mechanical stress of a high-speed PM rotor is presented, and the relationship between the sleeve thickness and sleeve material is examined. The proposed method was validated by an actual driving test at 400,000 rpm, and this would be useful for the design of high-speed PM rotors for fast mechanical structures. In addition, the design and manufacturing procedures for high-speed PM rotors could then be greatly simplified since accurate prediction is possible, and it would be possible to develop lightweight motors and generators with smaller volumes. More specific comparison with an accurate initial design method that considers the mechanical structure will be present in the final paper.

Submitters Country:

Republic of Korea

Wed-Af-Po3.04 / 1204

DESIGN STUDY OF AN OCTUPOLE SCANNING MAGNET FOR SPOT SCANNING IN PROTON THERAPY

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Co-author(s): LianHua OuYang¹

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A project to miniaturize the overall size of the proton therapy in Shanghai Ruijin hospital will be launched. One of the greatest challenges of the project is to construct a more compact nozzle for scanning. To this end, we decided to study an octupole scanning magnet to replace these two separate dipole magnets, which are installed in the current nozzle for scanning and occupy excessive space. The octupole scanning magnet, which is completely different from traditional octupole magnet, can generate rotating dipole magnetic field with the change of the loaded sinusoidal current phase. In the paper, we have finished the static optimization, including the length and the shape of the poles, the diameter of the gap, the local and integrated field quality, the pole profile and the shims on the pole edge, both in 2D and 3D. The corresponding relationship between the size of the gap and the good field region is also shown. As to the dynamic behavior, the eddy current effect is relatively serious and has a great influence on the field stability, which is under researching.

Submitters Country:

China

Mon-Af-Po1.05 / 373

Decoupling Control Based on Linear/Nonlinear Active Disturbance Rejection Switching for 3 Degrees of Freedom HMB

Huangqiu Zhu¹ ; Zelong Zhao² ; Chenyin Zhao^{None}

¹ *Jiangsu university*

² *Jiangsu University*

The hybrid magnetic bearing (HMB) is an electromagnetic device which supports the rotor without mechanical contact by using the attractive electromagnetic force and permanent magnet force. Compared with the conventional bearings, the HMB possesses several advantages such as no friction, no lubrication and sealing, high speed, high precision, long service life. Thus, the HMB has a broad prospect of application in the modern rotating machinery, including high-speed machine tool spindle, nuclear energy, flywheel energy storage system, and so on. As the most key part of the HMB system, the controller not only determines the rotor levitation performance, but also directly affects the key indexes of the HMB such as the turning precision of the rotor and bearing capacity. Thus, the design of the controller is particularly important in the design of the HMB system. Active disturbance rejection control (ADRC) is not dependent on the accurate mathematical model of the controlled object, and has characteristics such as high precision, low overshoot, fast convergence speed, and etc. To realize the high precision nonlinear decoupling control of the HMB, a linear/nonlinear active disturbance rejection switching control (SADRC) is proposed in this paper. Firstly, the basic structure of the HMB is introduced in detail, and the mathematical model of the suspension forces is developed by utilizing the equivalent magnetic circuit method. Secondly, a control strategy based on the SADRC is proposed. Then, the PID and SADRC model are designed and compared, and the simulation results show that the decoupling effect of the SADRC is better than that of the PID control. Finally, an experimental setup of HMB is built, and the feasibility and effectiveness of the proposed decoupling control strategy is validated with the results of the experiments.

Submitters Country:

China

Thu-Af-Po4.05 / 369

Decoupling Control of Bearingless Permanent Magnet Synchronous Motor Using ANFIS Inverse System

Huangqiu Zhu¹ ; Wei Du² ; Chenyin Zhao^{None}¹ *Jiangsu university*² *Jinagsu university*

A bearingless permanent magnet synchronous motor (BPMSM) is a new type of motor with the magnetic bearing function applied to the traditional permanent magnet synchronous motor. Besides of the simple structure, high efficiency, and high torque density, the BPMSM can operate with no friction, no wear, high-speed and high-precision, and so on, which show great potential application in many industry fields, such as medical industry, chemical industry, and biotechnology. But the BPMSM has strong couplings among torque and suspension forces, and is a multi-variable and non-linear system. Therefore, dynamic decoupling control is an indispensable condition for the stable operation of the BPMSM, and it is hard to implement for the traditional control methods. A novel decoupling control strategy is proposed in this paper, which applies inverse system based on the adaptive neural-fuzzy inference system (ANFIS). Firstly, invertibility analysis of the BPMSM original system is introduced. Secondly, an appropriate inverse system using the structure of ANFIS is established and trained with sample data. Thirdly, by series connection with the inverse system, the original system is pseudo-linearized, and the rotation and suspension system can realize decoupling control. Then, PID controllers are adopted as closed-loop controllers to realize the stability of the control system. The simulation results show that, comparing with the inverse system, the overshooting value and the setting time of the speed and radial displacement decrease about 40% under the change of parameters and the rotor can realize the full suspension with the proposed control strategy. Finally, the experiment is carried out with a 2.2 kW BPMSM as the prototype and the experimental results validate the effectiveness of the proposed control strategy.

Submitters Country:

China

Mon-Af-Po1.05 / 159

Decoupling Control of Bearingless Synchronous Reluctance Motor Based on Differential Geometry

Xiaoyan Diao¹ ; Huangqiu Zhu¹ ; Chenyin Zhao^{None}¹ *Jiangsu University*

Bearingless motors (BMs) with built-in magnetic bearings are receiving more and more attention. Compared with other types of BMs, the bearingless synchronous reluctance motor (BSRM) has been extensively investigated due to its advantages of simple structure, low cost, low temperature rising and high speed drive. The BSRM is a typical nonlinear multivariable system. There is a strong magnetic coupling among the electromagnetic torque and the radial suspension forces in the x- and y-direction. Therefore, the dynamic decoupling control is of particular importance to realize stable operation of the BSRM. The differential geometry method shows superiority in solving the problem of global linearization and decoupling control. In this paper, a new state feedback linearization method based on differential geometry theory is proposed to realize the decoupling control of the BSRM. Firstly, the mechanical structure and operation principle of the BSRM are analyzed, based on which the mathematical model is established. Secondly, the equation of state is established. The original nonlinear system is transformed to an equivalent affine nonlinear system. By using differential geometry theory and coordinate transformation, the state feedback control law is derived and this affine nonlinear system is transformed to three decoupled pseudo-linear subsystems, and then the closed-loop controllers are designed by using the single-input-single-output linear system theory. Thirdly, the simulation platform based on MATLAB/SIMULINK is developed. The simulation

results show that the presented control algorithm based on the differential geometry theory can realize precise linearization of the original nonlinear system, and that the variables of motor speed, radial displacements in the x- and y-direction are decoupled effectively. Finally, the experimental platform of digital control system is established and experiments are performed. The corresponding experimental results show that the presented control algorithm realizes the stable suspension and rotation of rotor with satisfied dynamic and static performances.

Submitters Country:

China

Mon-Af-Po1.07 / 11

Decoupling Velocity and Thermal Effect in the Electromagnetic Ring Expansion Test

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Electromagnetic forming (EMF) is acknowledged as a potential forming method because of its advantages relative to traditional forming technique. However, the multi-physics coupling process makes it a daunting task to analyze the forming mechanism. It is necessary to decouple the effects of velocity and thermal in EMF. Since the electromagnetic ring expansion is used as a one-dimensional simplification of EMF process, a dual-ring expansion experiment is designed and performed on AA5083 aluminum alloy, in which a copper ring (known as driving ring) is placed between the aluminum ring (also known as workpiece) and the driving coil side by side. Copper rings can shield part of the eddy current in the workpiece, so the thermal effect in the workpiece caused by the eddy current can be decoupled. According to the simulation, while the thickness of copper rings (0.5 mm, 0.8 mm and 1.2 mm) increases, the eddy current in the copper ring and electromagnetic force increases significantly. Then the different deformation strain rates can be achieved. The dual-ring expansion experiment with three different thicknesses driving rings were carried out, and the single aluminum ring expansion experiments were performed comparatively as well. The experiments results show that the average strains to failure at different strain rates appear positive related to the strain rate. The ductility of AA5083 aluminum alloy can be improved from 17% to 25% due to the high strain rate, and from 17% to 30% due to the high strain rate and thermal effect. This study suggests that the forming behavior is influenced by the high strain rate in addition to joule heat caused by the eddy current.

Submitters Country:

China

Tue-Af-Or17 / 62

Defect formation and improved critical current density in YBCO superconducting films by electron beam irradiation

Author(s): Byung-Hyuk Jun¹

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The effects of electron beam (EB) irradiation on the defect formation and critical properties of YBCO thin films were investigated. The YBCO superconducting films were irradiated using an EB accelerator with an energy of 0.2 MeV and a dose of E15-E16 e/cm². The value of the critical temperature (T_c) decreased and the superconducting transition broadened by the EB irradiation. In spite of the

decrease in T_c , the critical current density (J_c) at 20 K, 50 K and 70 K increased at the EB doses of $7.5E15$ e/cm² and $2.2E16$ e/cm². Further irradiation decreased J_c . This indicated that there was an optimum level of EB dose for improving the J_c value of a YBCO film. The X-ray diffraction analysis showed that the c-axis lattice parameter was elongated and the full width at half maximum (FWHM) value increased as the EB dose increased, which is strong evidence of the atomic displacement by EB irradiation. The transmission electron microscopy analysis showed that the amorphous layer formed in the vicinity of the surfaces of the irradiated films. The amorphous phase was often present as an isolated form in the interior of the films. In addition to the formation of the amorphous phase, many striations running along the a-b direction of YBCO were observed. The high magnification image showed that the striations were stacking faults. The J_c enhancement by EB irradiation is likely to be due to the lattice distortion and the formation of defects such as vacancies and stacking faults, which act as a flux pinning center. The J_c decrease at a high EB dose is attributed to the extension of the amorphous region of a non-superconducting phase.

This work was supported by the National Research Foundation grant (NRF-2013M2A8A1035822) from Ministry of Science, ICT and Future Planning (MSIP) of Republic of Korea.

Submitters Country:

South Korea

Mon-Af-Po1.03 / 1005

Defect-Irrelevant Behavior of No-Insulation REBCO Coils at 4.2 K

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High temperature superconductors (HTS) have become a viable option for high field magnets, mainly due to its superior in-field current carrying capacity at greater than 20 T. However, the price of HTS conductors is still high and impedes widespread use. Provided that the need for a defect-free “long” piecelength of HTS conductor is a primary cost driver for most applications. Results previously reported from our defect irrelevant winding (DIW) technique of a no-insulation (NI) pancake coil wound with REBCO tapes containing multiple “defects” was subjected to a temperature of 77 K. A defect is defined as a section of the tape of which the average critical current is less than 80 percent of the lengthwise average over the entire length. The DIW coil performance, such as critical current, field constant, and coil voltage, was barely discernible from that of its “healthy” counterpart. Demonstrating a potential of the DIW technique for significant cost reduction of REBCO devices that may be operated at low current and high operating temperature. This study is to further investigate the validity of the DIW technique in 4.2 K. New pancake coils were wound with REBCO tapes containing multiple defects and tested in a bath of liquid helium at 4.2 K. Key parameters of each coil were measured and compared with simulations by the use of our lumped circuit model containing critical current data of a “healthy” portion of the tape used to build the DIW coils. The DIW coils underperformed at 4.2 K, i.e., the coil critical current was measured to be 60 – 70 percent of that of its healthy counterpart.

Acknowledgement: This work was supported by the National High Magnetic Field Laboratory (which is supported by the National Science Foundation under NSF/DMR-1157490), the State of Florida, and the KBSI grant (D37611) to S.-G.L.

Submitters Country:

United States

Tue-Af-Po2.09 / 997

Degradation of Critical Current in an HTS Tape Considering Curvature of Elliptical Shape under Combined Bending and Torsion

Author(s): Seunghak Han¹**Co-author(s):** jeyull Lee¹; Haeryong Jeon¹; Ji Hyung Kim²; Chang Ju Hyeon²; Ho Min Kim²; Tae Kuk Ko¹; Yong Soo Yoon³¹ *Electrical and Electronic Engineering, Yonsei University*² *Jeju National University*³ *SHIN ANSAN UNIVERSITY*

Degradation of critical current in a high temperature superconducting (HTS) tape under bending conditions had been previously investigated. These investigations were focused on only either bending or torsion. A rotating flux pump is used to study the charging characteristics of HTS synchronous motor. In order to design the rotating flux pump connected in series, the elliptical winding applied together with combined bending and torsion is essential. Therefore, in this paper, the critical current considering curvature of elliptical shape is measured with regard to nine kinds of mandrels. The shapes of mandrels are a tall prolate ellipsoid, oblate ellipsoid and half circle. The diameters of each shape are 20, 30 and 40 mm, respectively. The experiments are mainly composed of four conditions; straight, bending, torsion, and combined bending and torsion. Finally, the experimental observations have been compared with the theoretical predictions.

Submitters Country:

Republic of Korea

Thu-Af-Po4.11 / 965

Delamination Diagnostic Method of REBCO Tapes Using Ultrasonic Waves

Takahiro Tomitsuka¹; Yuta Sakamaki¹; Akira Ninomiya¹; Shinichi Nomura¹¹ *Meiji University*

REBCO coated conductors has a layer structure composed of Cu, Ag, GdBCO, MgO and Hastelloy substrate. Although the REBCO conductors enables high field magnet designs, their critical current properties are sensitive to mechanical stress. Especially, the thermal stresses in the cooling process of the REBCO magnets may cause the delamination of the layer structure of the REBCO conductor. This problem leads to the defectiveness of the superconducting magnets. The objective of this work is to establish the delamination diagnostic method using ultrasonic waves and to estimate the superconducting properties based on the diagnostic results. Since the mechanical stresses between the layers can not be measured directly, the authors try to investigate the relationship between the transfer characteristics of the ultrasonic waves through the layer structure and the critical current properties by using acoustic emission (AE) sensors. Two AE sensors are set on both sides of the REBCO conductor surface. The thickness of the REBCO conductor is 0.2 mm. The one sensor is used as a transmitter which provides 1- μ s width of the pulsed signal with 1-ms interval. The other sensor is used as a receiver which receives the AE signals through the REBCO conductor. In order to delaminate the layer structure, the REBCO sample is partly applied by heat stresses for 5 minutes using a soldering iron. The transfer characteristics of the AE signals are measured in room temperature and evaluated their power spectrum. The resonance frequency is around 366 kHz. From the results, the power spectrum around the resonance frequency at the delamination point is reduced to 40% of that without the delamination point, which fact shows the feasibility of the delamination diagnostic method using AE sensors. In this work, the authors will compare the diagnostic results to the critical current properties with liquid nitrogen cooling.

Submitters Country:

Japan

Wed-Mo-Or21 / 1044**Demonstration Test of Two New 80 kA@12T/4K class ReBCO CORC Cable-In-Conduit Conductors for Fusion and Detector Magnets****Author(s):** Tim Mulder¹**Co-author(s):** Danko van der Laan²; Jeremy Weiss²; Pierluigi Bruzzone³; Alexey Dudarev⁴; Herman Ten Kate⁴¹ *University of Twente (NL)*² *Advanced Conductor Technologies*³ *EPFL-CRPP*⁴ *CERN*

Two new record size ReBCO CORC Cable-In-Conduit-Conductors were designed and manufactured by CERN in collaboration with the CORC strand supplier ACT in Boulder, and tested in cooperation with the Sultan team at PSI. The cables in both conductors are of similar design and use the six-around-one cable layout with six CORC strands. The cables are 2.8 m in length, rated 80 kA at 12T/4.5K and comprise 252 SCS4050 SuperPower tapes with 5 microns copper plating per side. The first conductor is designed for use in large detector magnets featuring conduction cooling and an OFHC copper jacket. The second is intended for operation in large magnets for nuclear fusion facilities with a stainless steel jacket and internal forced flow cooling. The conductors are tested in the SULTAN facility at PSI, Villigen, Switzerland. The facility provides current up to 100 kA, an external magnetic field on the sample up to 10.8 T and a testing temperature from 4.5 to 40 K. Both conductors are tested at the same time as two legs of a hairpin sample. The conductor temperature is controlled by adjusting temperature and flow-rate of the helium gas. A two cooling channel approach allows a temperature difference of a few Kelvin between both legs of the sample, allowing $I_c(B, T)$ measurements to be performed on the individual conductors. Several current and magnetic field cycles are performed to evaluate the mechanical long-term performance of cable and jacket and check for performance degradation due to temperature and load cycling. In the paper details on both CORC Cable-In-Conduit Conductors are provided and the test results are summarized.

Submitters Country:

Switzerland

Wed-Mo-Or20 / 1021**Demonstration of a Wind and React MgB₂ Solenoidal Coil Segment for MRI Applications****Mike Sumption¹; JACOB ROCHESTER¹; Danlu Zhang¹; Chris Kovacs¹; Dave Doll²; Michael Tomsic³; Milan Majoros¹; Ted Collings⁴**¹ *The Ohio State University*² *Hyper Tech Research*³ *Hyper Tech Research Inc.*⁴ *MSE, The Ohio State University*

This work is a contribution to the development of the technology for an MgB₂ based cryogen-free superconducting magnet for a 3T whole body MRI system. Specifically, we demonstrate that a react and wind coil segment can be made using a high-performance in situ route MgB₂ conductor and that the coil could be operated in conduction mode with low levels of temperature gradient. A multifilamentary MgB₂ conductor was used for the winding of a sub-size MRI-like coil segment. The wire was twisted, reacted, and then insulated with s-glass. After insulation, the coil was wound on a 0.9-m OD copper former. The total length of the conductor used was 1km. The coil was instrumented for low temperature testing and then epoxy impregnated. Ten sets of voltage taps and ten thermocouples were used, along with two Cernox sensors, quench disturbance and quench protection heaters, strain gauges, and two hall probes (these latter for field measurements). The coil was installed into a large conduction cooled cryobox for cooldown and testing. After the initial cooldown the coil temperature was increased, and I_c was measured as a function of temperature with decreasing temperature. The radial field of the coil was measured on the former (near the winding) and used to compare coil I_c to short sample I_c via a load line plot. The quench disturbance heater was then used to generate a series of progressively larger normal zones, the growth of which was characterized, and is presented. This was done in a progressive way, pushing from small normal zones which recovered to those which did not, allowing us to investigate an active quench protection scheme devised for the coil, and the results are discussed.

Submitters Country:

USA

Tue-Af-Po2.11 / 201**Design Considerations and Characteristics of Antenna Arrays for Wireless Power Charging System in Superconducting MAGLEV**Yoon Do Chung¹ ; Chang Young Lee² ; Woo Seung Lee³¹ *Suwon Science College*² *Korea Railroad Institute*³ *JH Engineering*

Recently super high speed magnetic levitation MAGLEV using high temperature superconducting (HTS) magnet has been expected as next generation transportation since superconducting magnet can keep mighty levitation force. The superconducting magnet at MAGLEV train should be continually charged with high power in order to keep stronger and stable levitation force. Practically, since conventional power supply unit should be attached to HTS magnet in the MAGLEV, a large thermal loss is indispensably caused by power transfer wires and joints, those have been one of essential obstacles in the superconducting MAGLEV train. As the wireless power transfer (WPT) technology based on strongly resonance coupled method realizes large power charging without any wires through the air, there are advantages compared with the wired counterparts, such as convenient, safety and fearless transmission of power during movement. From this reason, the WPT systems have started to be applied to the wireless charging for various power applications such as transportations (train, underwater ship, electric vehicle). However, it has obstacles to commercialize such as delivery distance and efficiency. To solve the problems, authors proposed the technical fusion using HTS resonance coil in the WPT system since the superconducting wire has merits a larger current density and higher Q value than normal conducting wire. In this study, authors described the design consideration of multi copper antenna (Tx) coils for different sizes corresponding to HTS receiver (Rx) coil. In this paper, the priority characteristics and thermal distributions of multi copper antenna arrays with moving HTS receivers are experimentally compared under radio frequency (RF) power of 370 and 100 kHz below 500 W.

Submitters Country:

South Korea

Thu-Af-Po4.04 / 575

Design Options of a 3-T 900-mm Whole Body MRI Magnet with Selected Commercial MgB₂ Wires

Author(s): Young-Gyun Kim¹ ; Haigun Lee¹ ; Seungyong Hahn²**Co-author(s):** Jiman Kim¹ ; Jimin Kim¹ ; Hyun Hee Son¹¹ *Department of Materials Science and Engineering, Korea University, Seoul, Korea*² *Electrical and Computer Engineering, Seoul National University, Seoul, Korea*

As the global helium crisis continues, the need for liquid-helium-free superconducting magnets continuously increases in the commercial sector of magnetic resonance imaging (MRI) systems. However, the conventional low temperature superconductor (LTS) magnets frequently experience unpredictable premature quenches, resulting in the extra usage of liquid helium before an MRI machine is delivered to its user site. The MgB₂ technology is expected to play an increasingly prominent role in the “next generation”, mainly because of a greater thermal stability of the wires than that of their LTS counterparts, making them essentially immune to the premature quench, as well as with their liquid helium (LHe)-free feature. To date, MgB₂ wires have been routinely produced by a few companies, such as Kiswire Advanced Technology that recently embarked on a collaborative R&D project with Korea University to design, construct, and operate an MgB₂ MRI magnet. This study presents the design options of a 3-T/900 mm MRI magnet employing selected commercial MgB₂ wires with a focus on: (1) conductor design and in-field performance; (2) coil volume and stray field; (3) mechanical stress and its tolerance; (4) cryogenic stability in various conductor options; (5) post-quench behavior and protection; and (6) field inhomogeneity due to manufacturing uncertainties of conductors.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical•electric power equipment].

Submitters Country:

Republic of Korea

Wed-Af-Po3.01 / 908

Design Studies of High-Field Nb₃Sn Dipoles for a post-LHC pp Collider

Alexander Zlobin¹ ; Vadim Kashikhin¹ ; Igor Novitski²¹ *Fermilab*² *FERMILAB*

Cost-effective superconducting dipole magnets with operating fields up to 16 T are being considered for the LHC energy upgrade (HE-LHC) or a Future Circular Collider (FCC). To demonstrate feasibility of 15 T accelerator quality dipole magnets, Fermilab as a part of US-MDP has started the development of a single-aperture Nb₃Sn dipole demonstrator based on a 4-layer graded cos-theta coil with 60 mm aperture and cold iron yoke. In parallel, to explore the limit of the Nb₃Sn accelerator magnet technology, optimize magnet design and performance parameters, and reduce magnet cost, magnet design studies are also being performed based on 3- and 4-layer 50 mm aperture cos-theta coils with and without stress management elements. Results of these studies are reported and discussed in this paper.

Submitters Country:

U.S.A.

Tue-Af-Po2.02 / 568

Design Study of Main Magnets for the J-PARC RCS Energy Upgrade

Author(s): Norio Tani¹**Co-author(s):** Hideaki Hotchi¹; Hiroyuki Harada¹; Masanobu Yamamoto¹; Masashi Shirakata²; Michikazu Kinsho¹; Susumu Igarashi²; Tadashi Koseki²; Yasuhiro Watanabe¹; Yoichi Sato²¹ *Japan Atomic Energy Agency*² *High Energy Accelerator Research Organization*

At J-PARC Main Ring (MR), there have been various investigation carried out at the moment aiming at the beam operation of MW order. As one of the investigations, a study of the Rapid-Cycling Synchrotron (RCS) magnets was implemented. Increase of the extraction energy of RCS was needed to reduce beam loss, as beam loss in the MR injection region was large under influence of the space charge effect at the 3GeV 1MW beam from RCS. Therefore design study of the extraction energy upgrade using dipole and quadrupole magnets of RCS was performed. In this paper we will report the contents of the study for upgrading the extraction energy of RCS magnets and problems found out as a result.

Submitters Country:

JAPAN

Tue-Af-Po2.01 / 1206

Design Study of a Novel, LHC High-Lumi CCT Orbit Corrector.

Glyn Kirby¹; Jeroen Van Nugteren^{None}¹ *CERN*

The Large Hadron Collider (LHC) upgrade, called High Luminosity LHC (HL-LHC) is planned for the next decade. A wide range of magnets and new technologies are currently under development. One of these systems will be a set of twin aperture beam orbit correctors positioned on the approaches to the ATLAS & CMS experiments. This twin aperture magnet system, with large 105 mm clear aperture coils. Each aperture will independently deliver 5 Tm integral field, between apertures the field vectors are rotated by 90° from each other, and individually powered. the base-line magnet design length is forced to be longer than 2.2m due to the cross talk that limits the maximum field to about 2.6 tesla. Above this field errors that are generated in the adjacent aperture exceed the beam optics limit. Within the string of magnets there is limited space between the D2 dipole and the crab cavities. CERN is working on fine adjustment to give extra centimetres of space.

This paper presents a novel solution to reduce the length of this magnet design significantly from that 2.2 m baseline, to a 1.4 m long 4 Tesla design. Utilizing a selection of novel techniques we present a high field design which eliminates totally the adjacent field errors throughout the full bipolar current range. The design uses a set of Canted Cosine Theta 'CCT' air coils with a system of correctors which run in series with each apertures main dipole coils and council totally the errors for both apertures. We present :field quality, quench calculations, assembly structure within the D2 cold mass. The design liberates ~ 1 m of axial space within the D2 cold mass. We also present a comparative cost estimate between the base line design and this CCT air coil design.

Submitters Country:

Switzerland

Wed-Af-Po3.04 / 338

Design Study on High Frequency Magnets for Magnetic Hyperthermia Applications

Shinichi Nomura¹ ; Takanori Isobe²¹ *Meiji University*² *University of Tsukuba*

Magnetic hyperthermia is expected as a thermal ablation cancer therapy. For the induction heating of the nano scale magnetic beads, the required specifications of the high frequency magnet are 0.06 T and 200 kHz of the AC magnetic field with 5 minutes of the continuous or intermittent operation time. However, the magnet system requires the enough bore size for the cancer therapy. Addition to this, due to the skin effect of the conductor, the heating losses and the cooling systems of the magnet should be investigated. Moreover, the number of turns and the operating current should be optimized from the view point of the rated voltage and current of the high frequency power converter system. The objective of this work is to discuss the design considerations of the high frequency magnet for the magnetic hyperthermia applications. As a first step of this work, the authors carry out the design study on the conventional magnet case using copper conductors. The cooling of the magnet is based on the water cooling. The high frequency power converter system is composed of the resonance circuit between the magnets and the series capacitors. From the results of the electromagnetic and thermal analyses, this work shows an optimal magnet design and the coil arrangement including the design of the cooling system and the high frequency power converter system. Furthermore, in order to reduce the size and the heating losses of the magnet, the authors also clarify the technical targets and the problems of the superconducting magnets for the high frequency applications.

Submitters Country:

Japan

Mon-Af-Po1.04 / 784

Design and Analysis of A Novel Modular-Stator Tubular Vernier Permanent-Magnet Machine

Tian Yao¹ ; Wenxiang Zhao¹ ; Fangfang Bian¹ ; Liyang Chen¹ ; Xuhui Zhu¹¹ *School of Electrical and Information Engineering, Jiangsu University*

Currently, the tubular linear permanent-magnet machine has been increasingly adopted for active vehicle suspension, since it has zero net radial force between the armature and stator, no end-windings, and volumetrically efficient. However, it suffers from relatively low thrust force and poor fault-tolerant capability. Thus, a novel modular-stator tubular vernier permanent-magnet machine will be proposed in this paper, which not only improve the force performance, but also significantly enhance the fault-tolerant capability. Both magnets and armature windings are on the stator, while the mover is only consisting of iron with salient teeth which work as modulation teeth. Meanwhile, the modular complementary stator structure is designed to decoupling the adjacent phase windings, hence offering the desired fault-tolerant capability. Moreover, The PMs with two magnetized directions are adopted, namely radially and axially. One is used to produce the main flux, while another can reduce fringing leakage flux, hence increasing the thrust force capability. The electromagnetic performances of the proposed machine is analyzed by using the finite-element method. Thus, it can be known that the back electromotive force of the proposed machine is symmetrical and sinusoidal due to its complementary permanent magnet magnetic circuits. Moreover, the ratio of the mutual inductance to self-inductance of the proposed machine is only 0.90%, revealing that the proposed machine possesses the desired fault-tolerant capability. The average thrust is 720 N when the electric load is 183A/cm, while the thrust ripple of the proposed machine is 8%. Detailed results and discussions will be given in full paper.

Submitters Country:

China

Thu-Af-Po4.06 / 1152**Design and Analysis of Marine Current Power Generation System Based on a Magnetic Gear****Author(s):** Ningjun Feng¹**Co-author(s):** Haitao Yu² ; Rong Guo² ; Tao Xia¹ *Southeast University*² *School of Electrical Engineering, Southeast University*

Marine currents are more predictable than wind and solar power. Because there are only small fluctuations in current speed and stream location with minimal changes in direction, ocean currents may be suitable locations for deploying energy extraction devices such as turbines. The kinetic energy of marine currents can be converted in much the same way that a wind turbine extracts energy from the wind, using various types of open-flow rotors. The potential of electric power generation from marine tidal currents is enormous. Tidal currents are being recognized as a very promising resource to be exploited for a future sustainable scenario of electrical-power generation. Typically a mechanical gear system is used to increase the marine current power generation system (MCPGS) rotational speeds before being coupled to a permanent magnet synchronous generator (PMSG). The gear systems currently being employed suffer from significant long term maintenance and reliability issues. Hence, measures should be taken at the design stage to reduce the frequency and simplify maintenance procedures. The rotational speed of the turbine shaft could be geared up to reach the operational speed of a standard electric generator by a MG. The MG offers many advantages over its mechanical counterpart such as contact free torque production, no gear lubrication and inherent overload protection. Instead of mechanical transmission devices, the advent of magnetic gears means the less routine maintenance, simplifying the task substantially. This paper employs a MG as the speed-increasing device to connect the MCT and the PMSG. The MG is design for a very low speed ocean generation application. An accelerated diffuser is used to improve energy capture coefficient in the MCPGS. We shall describe the main features of the MCPGS based on the MG. The technological solution could lead to a feasible scheme for MCPGS in the future.

Submitters Country:

China

Tue-Af-Po2.06 / 1207**Design and Analysis of Outer-Rotor Permanent Magnet Synchronous Machine With Amorphous Stator Core****Author(s):** yong kong¹**Co-author(s):** mingyao lin ; da xu ; xinghe fu ; liu kai¹ *School of Electrical Engineering, Southeast University*

Efficiency is an important index to evaluate the performance of an electric machine. Core loss takes a big part of the total losses of an electric machine. Amorphous alloy material (AAM) has much lower core loss than that of traditional silicon steel. An outer-rotor permanent magnet synchronous machine (OR-PMSM) with amorphous stator core is proposed in this paper, which exhibits higher efficiency than conventional PM machine. Based on the electromagnetic characteristics of the amorphous alloy material, the general design of the proposed machine is studied, including the structure

parameters and the stator-slot/rotor-pole combinations. The combination principle of permanent magnets and winding turns for OR-PMSM with amorphous stator core is investigated. Based on the 2-D finite element analysis (FEA), the electromagnetic performances of the proposed machine are investigated and compared with an OR-PMSM with silicon steel stator. A prototype is manufactured and tested to validate the FEA results. The design process started from the calculation of the stator and rotor dimensions. Then the numbers of stator-slots and rotor-poles will be choosed after comprehensively considerations of the efficiency goal and the characteristics of OR-PMSM. At last, the winding turns and permanent magnetic flux should meet the requirements of speed range and the power supply voltage limit. To better take advantages of the AAM for reducing the losses, the magnetic loading B_{gap} can be higher owing to the low core loss of AAM. A higher magnetic loading also means a lower electric loading which is proportional to the copper loss. For the OR-PMSM, to reduce outer-rotor yoke thickness, the mutipolar design is adopted. The slots number should be choosed to fit the concentrated windings form in order to reduce the copper loss. The results show that the OR-PMSM with amorphous stator core has a higher efficiency and wide high efficiency operation region.

Submitters Country:

The People's Republic of China

Mon-Af-Or8 / 506

Design and Analysis of a Novel Large Mover Slot Opening Flux-Reversal Linear Permanent Magnet Machine with HTS Bulks

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The flux-reversal linear permanent magnet machines (FRLPMs) have the features of high thrust density, high efficiency and robust stator structure, which make it a suitable solution for linear traction motors, wave energy generators and linear servo motors. But the FRLPMs suffer from the doubly-salient structure and thus it is hard to further improve the flux-linkage and the thrust density of the machine. In this paper, in order to improve the thrust density of the machine, a novel flux-reversal linear permanent magnet machine with consequent-pole permanent magnets and high-temperature superconducting (HTS) bulks is proposed. The permanent magnets (PMs) are mounted on the teeth top of the mover and the HTS bulks are mounted on the stator slot, between every two adjacent stator teeth. Only half of the teeth top of the mover is inset by the PM and all the PMs have the same polarity, which is so-called consequent-pole PMs. The HTS bulks can shield the flux leakage and strengthen the modulation effect of the stator teeth. Moreover, the consequent-pole structure can reduce the usage of PMs and further improve the flux-linkage of the armature windings. In other words, the flux density of the machine can be improved with the combination of consequent-pole PMs and HTS bulks, which results in the improvement of the thrust density. The analytical expressions of magnetic motive force (MMF) excited by the PMs, the air-gap flux distribution and the back electric motive force (back-EMF) will be derived in the paper. Finite element method (FEM) will be employed to verify the superiority of the proposed machine. It can be seen from the FEM results that the thrust density of the proposed FRLPM can be improved by 31% compared to the regular FRLPM.

Submitters Country:

China

Thu-Af-Po4.06 / 391

Design and Analysis of a Transverse Flux Hybrid Field Modulated Linear Generator for wave energy conversion

Author(s): Lei Huang¹

Co-author(s): minqiang Hu ; Haitao Yu ; Tao Xia ; Rong Guo²

¹ *Southeast University*

² *School of Electrical Engineering, Southeast University*

The direct-drive wave energy converter (DD-WEC) system, using linear generator, are widely used for WEC. However, at the low direct-drive speed, how to increase the power density of the linear generator is the main objective of the researchers. Therefore, there are many linear generators have been investigated for DD-WEC. To solve the problem, a transverse flux hybrid field modulated linear generator linear generator is proposed in this paper. Field modulated design can be increase the out put voltage and power density of the linear generator. Transverse flux magnetic circuit is implemented to reduce the eddy loss in the core of stator. The hybrid excited field coil can be used to adapt to the different wave situation and effectively improve the output performance of this kind of generators. By using 3D FEM, a tubular transverse flux hybrid field modulated linear generator is studied on account of the hydrodynamic analysis. The design and optimization of the proposed generator is accomplished. In view of the ratio between stator pole and translator pole pitch being defined, the major component of the cogging force is that caused by longitudinal end effect. The ratio between stator pole and translator pole pitch is optimized to reduce the cogging force. Simulation and comparison have been conducted for the generators with different pole numbers of stator and translator. In addition, the translator is designed to reduce the harmonic of inducted EMF. Lastly, the parameters of the final optimization generator are obtain and listed. The performances of output power, output voltage, and efficiency of the proposed generator with different resistance are compared. From the output performance, it can be seen that the output power of the proposed generator meet the design requirements. And the low output voltage regulation, a higher range of power levels and loading capacity can be obtained.

Submitters Country:

China

Mon-Af-Po1.04 / 612

Design and Analysis of an Arc-teeth Permanent Magnet Linear Synchronous Motor for Direct-drive Application

Author(s): Rong Guo¹

Co-author(s): Haitao Yu¹ ; Xiaomei Liu² ; weibo zhong¹ ; Lei Huang²

¹ *School of Electrical Engineering, Southeast University*

² *Southeast University*

As the core parts of the direct drive transmission mechanism, the permanent magnet synchronous linear motor which has the advantages of high thrust density, high precision, high speed and fast dynamic response ability is widely used in high-grade CNC machine tool and other precision manufacturing equipment. In this paper, a new type of permanent magnet linear synchronous motor (PMLSM) with arc-teeth is proposed used in gantry-type machining center. The stator teeth adopt arc structure and end teeth using semicircle shape as the main scheme of this PMLSM. This structure can significantly reduce the detent force which can meet the requirements of high precision machining. The paper firstly using numerical analysis method evaluation the arc-teeth motor performance. Adopting 2D dynamic magnetic equivalent circuit analytical method for calculated forces. Air-gap permeance between the mover tooth and the adjacent stator blocks is deduced using the flux tube method, the magnetic co-energy are derived with the total permeance, the detent force are calculated based on the magnetic co-energy. Considering the effect of local saturation factor, established the nonlinear dynamic magnetic network model(MNM), thrust force of the motor is derived by this model. Then, Taguchi method based on orthogonal array was used to optimize the end teeth, thrust and thrust ripple in order to obtain the optimal structure of the Arc-PMLSM. Finally, numerical results and different structures are validated and compared by the finite element method, the performance characteristic of different structures are contrasted by comparing the significant data as

flux linkages, back electromotive forces, forces in order to presents the best characteristics in terms of performance. The results illustrate that the proposed arc-teeth structure reduces the detent force more than 70% from conventional structure and have a good electrical performance.

Submitters Country:

China

Thu-Af-Po4.09 / 422

Design and Analysis of an Energy-Extraction System for High Current HTS Magnets

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High temperature superconducting magnets (HTS) suffer from slow quench propagation, have high thermal margin, and consequently require external energy extraction for quench protection. This is especially the case with such accelerator magnets where most of the magnet volume operates far away from its critical surface. Quench heaters and CLIQ, as the most promising quench protection systems (QPS) for low temperature superconductor (LTS) based accelerator magnets, are not effective for HTS magnets and new solutions are needed. Recently two new concepts, ICED and E3SPreSSO, for HTS magnet protection have been presented in the scope of European project EuCARD-2. The principle of ICED is the same as secondary winding for passive energy extraction and E3SPreSSO utilises a series connected bifilar HTS or LTS coil. In this work we present a methodology to design QPS based on ICED and E3SPreSSO for HTS magnets. Then we utilise this methodology to design and analyse the suitability of such QPS for a 20 T HTS accelerator dipole.

Submitters Country:

Finland

Wed-Af-Po3.08 / 284

Design and Experimental Verification of Punching Using a Pulsed Electromagnetic Force

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For the precision work pieces such as vacuum switch contact, the traditional hydraulic press is slow in speed, easy to appear burrs and slivers and for the mechanical press, it is difficult to achieve the large tonnage. So a pulsed electromagnetic punching system consisting of a pulsed magnet driven by a capacitor bank and a conductive driver plate with a male die has been proposed, designed, and verification for precision work pieces. Compared with traditional press, the pulsed electromagnetic punching machine has many advantages, such as, simple construction, small size and weight, low production cost, high speed and large tonnage. A huge pulsed Lorentz force will be generated by the interaction of the pulsed magnetic field with the eddy current induced on the driver plate, which pushes the plate with a male die to punch the work pieces. To verify the feasibility of the system, a series of simulations and experiments were implemented. Results show that the peak value of

generated pulsed electromagnetic force can reach more than 100 tons easily in the simulations and the vacuum switch contact with a thickness of 3 mm can be effectively punched without any burrs and slivers in the experiments.

Submitters Country:

China

Mon-Af-Po1.01 / 894

Design and Fabrication of the 1.9 K Magnet Test Facility at BNL, and Test of the First 4m Long MQXF Coil.

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¹ *Brookhaven National Laboratory*

The future high luminosity upgrade of the Large Hadron Collider (LHC) at CERN will include twenty 4.2 m long Nb₃Sn high gradient quadrupole magnets which will be components of the triplets for two LHC insertion regions. In order to test these and four pre-production models, the vertical superconducting magnet test facility of the Superconducting Magnet Division (SMD) at Brookhaven National Laboratory (BNL) has been upgraded to perform testing in superfluid He at 1.9 K, which is the operational condition at the LHC. This has involved extensive modification of the 4.5 K cryogenics plant, including piping, compressors, and other upgraded components; a new vertical test dewar which can accept larger diameter magnets; a modernized power supply system upgraded with IGBT switches and fast shutoff capability, and that can supply 24 kA to test high field Nb₃Sn magnets; and completely new data acquisition, signal analysis, and control software and hardware, allowing for high precision and large volume data collection. This paper reports on the design, assembly, and commissioning of this upgraded test facility and the first magnet test performed, on a mirror model, which consists of a single coil quadrant and an iron yoke filling the other three quadrants and is designed to have peak fields close to that of the production quadrupoles.

Submitters Country:

USA

Tue-Af-Po2.05 / 661

Design and Implementation of Ferromagnetic Shims for a 3-T 100 mm All-REBCO No-Insulation Magnet

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² *Korea Basic Science Institute*

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This paper presents design and implementation of ferromagnetic shims for a conduction-cooled 3-T 100 mm winding diameter no-insulation (NI) all-REBCO magnet. The initial magnetic field profile was measured by an in-house 3-D field mapper with an NMR magnetometer, from which harmonic coefficients up to 3 order are derived. A ferromagnetic shim design code was developed, which includes an optimization process to minimize target harmonic field errors with a given volume of ferromagnetic shims. For experiment, two designed sets of ferromagnetic shim matrices, which consist of 0.025-25 mm thick iron pieces, were attached on two concentric cylindrical tubes of 54 mm and 60 mm in diameter, respectively, and then installed in a 64 mm room temperature bore of the 3 T magnet. Through recursive mapping and shimming steps, the magnet field uniformity was gradually

improved from ~500 ppm to ~100 ppm. The results imply the first shimming test of all-REBCO no-insulation magnet, which will be a basis for our upcoming high-resolution all-REBCO NMR magnet currently being developed.

This work was supported by KBSI grant (D37611) to S.-G.L funded by the Korea Basic Science Institute (KBSI).

Submitters Country:

Korea

Mon-Af-Po1.04 / 786

Design and Initial Results of a Novel in-situ A.C. loss Measurement in Axial Flux Synchronous Machine

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Electrical aircraft are an important area of modern engineering development to meet the increasing air travel demand while managing a reduction of dependence on fossil fuels. The challenge is exacerbated due to the high sensitivity of aircraft performance with respect to mass and therefore superconducting machines are seen as a possible solution. A key enabler is to reduce the overall size of the system including cooling to lower the mass. Key importance to adoption of superconducting motors is the A.C. loss phenomena which increases the cooling power required to operate HTS systems. In the past several demonstration machines have not measured the in-situ A.C. loss or tested new loss reduction technologies 1. In order to progress the field motor performance as a function of the A.C. loss needs to be understood as well as being able to test A.C. loss reduction techniques resulting from simulation and manufacturing advancements. Therefore, in this paper a novel machine design is presented to enable the measurement of A.C. loss within a machine environment to be built and tested this year and an accurate estimation of the airborne cooling power required is detailed. The novelty of this machine is the enablement of quick and accurate A.C loss measurement of a wide range of superconducting technology including MgB₂, Roebel cables and pancake coils. Along with the new design preliminary simulation and experimental results are outlined which are used to calculate anticipated A.C. loss cooling power required aboard an aircraft using real load demand data supplied by Airbus.

1 Ainslie, Mark, Mitsuru Izumi, and Motohiro Miki. "Recent advances in superconducting rotating machines: an introduction to the 'Focus on Superconducting Rotating Machines'." *Superconductor Science and Technology* 29.6 (2016): 60303-60305.

Submitters Country:

U.K.

Wed-Af-Po3.06 / 371

Design and Magnet Field Analysis of Slotless Linear Generator for Wave Energy Conversion

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³ *Southeast University*

In this paper, an analysis model for the magnetic field by equivalent-magnetizing-current (EMC) method and analytical method is compared with FEM, and a PM slotless tubular linear generator is proposed and analyzed based on the model. Meanwhile, the influence of the main design parameters is investigated, and the main characteristics are compared with those of the slotted structure. Due to theoretical analysis results concordant with the finite-element analysis results, the proposed model and analytical method are correct and effective. The tubular slotless-generator structure consists of a stator with epikote slot topology, and a translator of generator made of steel, where PM rings are mounted on it. For simplification, the dynamic analysis is here restricted to no-load case with a constant speed of 0.4 m/s. The tubular slotless-generator has a symmetric structure along the z-axis, so half section is selected as the analysis region. Assuming that the windings current is zero, PM is the only source to produce the magnetic field. The analysis for the magnetic field is used by EMC method. Some assumptions are adopted to simplify the analysis, such as all regions are extended infinitely in the direction $\pm z$ and the permeability of back iron is infinite. Using the analysis model above and FEM, the amplitude of electromotive force (EMF) and THD of EMF wave form with different α are obtain, where $\alpha = hm / L$, hm and L are the permanent magnet thickness and length respectively. Moreover, the characteristics of the generator are compared with those of the conventional slotted structure. The performance of the slotless linear generator is assessed by magnetic field analysis model and FEM methods. The constructional optimization details are significant for linear generator in energy conversion system.

Submitters Country:

China

Tue-Mo-Or15 / 729

Design and Manufacturing of the First Industrial-Grade CLIQ Units for the Protection of Superconducting Magnets for the High-Luminosity LHC Project at CERN

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The newly developed concept of Coupling-Loss Induced Quench (CLIQ) used in the domain of superconducting magnets quench protection has opened a new path towards efficient magnet protection. Subsequently to the first trials using ad hoc solutions in order to confirm functionality and performance of the method, two pre-series of three units each with different hardware configurations have been recently manufactured at CERN. Starting from the design phase, the hardware realization follows industrial standards and associated quality control. At the same time aspects related to the long term operation of the units have also been addressed. This paper discusses the design and manufacturing issues, the construction details and the decisions made on choices considering their operation in test stations and in a final accelerator environment. The results of the tests of these units before connecting them to a superconducting magnet will be presented and analyzed.

Submitters Country:

Switzerland

Wed-Af-Po3.06 / 569

Design and Operation Performance Research of Brushless Doubly-Fed Generator with Cage Bar Assisted Reluctance Rotor

Author(s): Siyang Yu¹

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Brushless doubly-fed generator (BDFG) is particularly suitable for using in variable speed constant frequency wind power generation system due to its inherent characteristics. The two sets of stator windings with different numbers of magnetic poles are coupled by magnetic field modulation of a special rotor, so the rotor structure directly affects the performance of BDFG. The commonly used rotor structures of BDFG can be divided into cage rotor, wound rotor and reluctance rotor, however, there are still some deficiencies of these structures even after many years of research and optimization. In this paper, a cage-assisted reluctance rotor structure is presented to enhance the rotor coupling capacity and improve the efficiency of BDFG. The design principle and operation performance of the BDFG with cage-assisted reluctance rotor are researched. Firstly, the structure characteristics and design principle of the proposed rotor are illustrated in detail. The cage-assisted reluctance rotor is obtained by adding some short-circuit cages to the non-magnetic layers of the radial laminated magnetic barrier rotor. Secondly, the magnetic field modulation mechanism of the proposed rotor is analyzed by analytical method to reveal the operation principle of BDFG with the proposed rotor. Then the operation performance of the proposed BDFG especially under sub-synchronous and super-synchronous mode is studied. Finally, a 25kW prototype is designed and manufactured to verify the advantages and feasibility of the proposed rotor structure. The experimental results show that the BDFG with the proposed rotor has some advantages such as strong magnetic field coupling ability, high efficiency, superior performance and so on. This paper has also broadened the idea for the development and application of BDFG.

This work is supported by the National Natural Science Foundation of China under Grant 51537007.

Submitters Country:

China

Wed-Af-Or27 / 181

Design and Operation of the Pulsed Magnets at the Dresden High Magnetic Field Laboratory

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The Dresden High Magnetic Field Laboratory (HLD) is a pulsed-field user facility which provides external and in-house researchers with the possibility to perform a broad range of experiments in pulsed magnetic fields. Two independent, modular capacitor banks of 14 and 50 MJ with a maximum charging voltage of 24 kV deliver energy for ten mono-coil and dual-coil pulsed magnets generating magnetic fields up to 95 T available for users. A pulsed-magnet-development program at the HLD targets to increase the peak fields, reliability, and longevity of the pulsed magnets. Another important goal is to decrease the cooling time and the noise level in the pulsed magnets. Since most of the pulsed magnets are stress limited, the inner and outer reinforcement, as well as the choice of conductors plays a crucial role in magnet design and performance. We discuss recent progress, design improvements, and our long-standing experience in the production and operation of the pulsed magnets at the HLD. In particular, we analyze in detail the performance of the dual-coil magnets in the field range of 85 – 95 T. We discuss further prospects for the non-destructive pulsed magnets as well.

We acknowledge the support of the HLD at HZDR, a member of the European Magnetic Field Laboratory (EMFL) and Deutsche Forschungsgemeinschaft via SFB 1143.

1 <http://www.hzdr.de/hld>

Submitters Country:

Germany

Mon-Af-Po1.07 / 355

Design and Optimization of a Multi-pulse Electromagnetic Deep Drawing System

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Electromagnetic forming (EMF) is a high-speed and non-contact forming technology that employed the electromagnetic force to accomplish the forming. Many researches show that this technique can affect the material behavior, improve the forming limit of the metal and reduce the wrinkling and spring-back compared with the conventional forming processes. It provides a promising solution for room temperature processing of complex-shape parts from lightweight, hard-forming materials. However, limited by the energy density of the power, the size of the driving coil and the property of the metal, the application of the conventional electromagnetic forming is difficult in deep drawing. In this work, a new multi-pulse EMF method especially suitable for the deep drawing is developed. The employment of the multi-pulse charging can reduce the requirement of the energy density of the power as well as the complexity of equipment. The multi-field and electromagnetic force acting on the workpieces in the multi-pulse deep drawing process is firstly numerically analyzed. And then a series of experiments are carried out to study the deformation behavior and mechanical properties of the material compared to the conventional electromagnetic forming. Finally, an optimization of the process is conducted based on the research of the metal deformation behavior with different discharging parameters.

Submitters Country:

China

Mon-Af-Or8 / 629

Design and Optimize an external rotor Ironless BLDCM used in a Flywheel Energy Storage System

Kai Liu¹ ; mingyao lin¹ ; xinghe fu¹

¹ *Southeast University*

The flywheel energy storage system (FESS) is a novel electromechanical energy conversion and storage device, whose advantages are long service life, high conversion efficiency, high adaptability and pollution-free, etc.. FESS has enormous application foreground at the Electromagnetic Launch, the aspects of aeronautics and astronautics, distributed generation, power system peak load regulation and electrical vehicles. Based on the application and design requirements of energy storage system, the external rotor ironless brushless DC machine (BLDCM), which is suitable for use in FESS, is designed and further explored. The finite element method is adopted to do computational research on external rotor ironless BLDCM. Performance improvement and loss minimization of the machine are achieved through optimizing the magnetic pole and the winding. The research results show that the copper loss of the machine can be reduced by appropriate selection of magnetic steel thickness even under the condition that the main parameter of the flywheel machine is set. Proper choice of magnetic steel polar-arc coefficient is beneficial to reduce the flux leakage on the surface of the rotor. The width of air gap flux density can be increased by applicable selection of magnetic poles and magnetizing style. The flywheel energy storage machine prototype is fabricated based on the

optimized design of the machine. The experiment results show that the test results almost coincided with the design values.

Submitters Country:

China

Mon-Af-Po1.09 / 553

Design and Performance Results of Optimal Vapor-Cooled MgB₂ Current Leads for a 1.5 T MRI Magnet

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This study presents the design and performance results of a pair of vapor-cooled MgB₂ current leads for a 1.5 T MRI magnet developed by Kiswire Advanced Technology Ltd. in Korea. To reduce the liquid helium (LHe) consumption of the MRI system, the current leads were designed as a retractable type to be detached from the magnet operated under a persistent-current mode. From the cryogenic evaluation, the cold-end heat input of the vapor-cooled current leads was calculated using the LHe consumption measured by a LHe-level sensor and mass flow meter. Furthermore, thermal analysis of the current leads was carried out using the finite element method. During operation tests at various operating currents, the voltage and temperature of the current leads were measured to evaluate the effects of employing the MgB₂ wire on the thermal performance of the leads. In addition, conventional vapor-cooled copper current leads were also examined and the results were compared with the test results of the proposed vapor-cooled MgB₂ current leads.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical•electric power equipment].

Submitters Country:

Republic of Korea

Thu-Af-Po4.07 / 337

Design and Performance Study of a 1 MW Induction Heater with HTS DC magnet

Author(s): Ping Yang¹

Co-author(s): Derong Qiu¹

¹ *Shanghai Jiao Tong University*

The high temperature superconductor (HTS) direct current (DC) induction heater shows a great potential in improving the efficiency and heating quality, which has been studied and validated in some laboratory-scale prototypes. Now, an industrial scale HTS DC induction heater with 1 MW is designed and manufactured in Shanghai Jiao Tong University, China. The heater is designed for aluminum billets with a diameter of 466 mm and length of 800~1500 mm. Two cryocoolers are applied for coil cooling with pluggable sleeve and providing an additional safety margin whose operating temperature is designed to be 25 K. The magnet consists of a large solenoidal coil wound by YBCO tapes from Shanghai Superconductor Technology Company (SSTC), China. More than 18 km HTS tapes are used and the inductance of coil with iron is 98 H. The critical current of the magnet is 213

A and its operating current is set to be 170 A. The magnet is designed to generate approximately 0.7 T DC magnetic fields in its air gap. In the tests, the aluminum billets of 337~632 kg are heated from ambient temperature to 500 °C with 240~720 rpm. The temperature distributions of the aluminum billets are optimized by rotation speed and the distribution of the dc magnetic field in the air gap. The test results show a good agreement with the designed targets. The total efficiency of this industrial scale HTS DC induction heater is about 80 %, which shows a great commercial potentials.

Submitters Country:

China

Mon-Af-Po1.12 / 1211

Design and Preliminary Test Results of the 60T Pulsed High Magnetic Field Facility at Xi'an Jiaotong University

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¹ *Huazhong University of Science and Technology*

² *Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology*

³ *Wuhan National High Magnetic Field Center*

A 60T pulsed high magnetic field facility is designed for the study of magnetic material at Xi'an Jiaotong University. The pulsed high magnetic field facility is energized by two 1.2MJ/3.84mF capacitive power supplies. Each supply consists of 24 capacitor banks, a protection inductor, crowbar circuit, dump circuit. To simplify system configuration, two supplies are equipped with one charge unit, one thyristor switch and one switchgear. The magnet wound with CuNb wire reinforced internally with Zylon fiber composit and externally with stainless steel shell is designed to provide 60T/60ms magnetic field in a bore of 26mm. The control system provide integrated charge/discharge procedure and a remote control terminal. The whole system will be installed in May 2017, and the Preliminary test results will provided in the paper.

Acknowledgements: The authors would like to acknowledge the supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Mon-Af-Po1.11 / 1033

Design and Research of Cryostat for 3W1 SC Wiggler Magnet

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¹ *colleague*

The cryostat with cryocoolers for the Wiggler is capable of keeping helium consumption close to zero (less than 0.03 l/hr in average per year). The wiggler magnet is placed into a bath with liquid helium of 4.2K and all heat emission inside the magnet and heat in-leak outside lead to liquid helium evaporation process. The cryostat chiefly consists of external vacuum housing, 60 K shield screens, liquid helium vessel with a SC multipole magnet inside, vacuum chamber (beam duct) with copper liner inside, four 2-stage coolers with stage temperature 4.2K/60 K. Current leads heat in-leak interception in vacuum using cryocoolers. The helium vessel is suspended with four vertical and four horizontal CFRP(T300) tension rods connected to the external cryostat vessel. These tension rods

pass throughout the 60K shield screens and attach to bolts on the external housing walls and are used for precise alignment of the vertical magnet position.

Submitters Country:

CHINA

Tue-Af-Po2.07 / 482

Design and Test of 10 kV/400 A Flux-coupling Type Superconducting Fault Current Limiting Module

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⁴ *Chinese Academy of Sciences*

The flux-coupling type superconducting fault current limiter (FC-SFCL) is suggested to suppress the short-circuit current in the dc line of VSC-HVDC system. The FC-SFCL could generate larger inductance and smaller resistance at the beginning of current limiting process, but show smaller reactance and very large resistance at the end. One FC-SFCL module with two branches is designed and tested. For the FC-SFCL module, the two branches could use the same or different YBCO tapes. Furthermore the electromagnetic analysis and parameter calculation of the module are performed. In order to study the current-limiting performance of the FC-SFCL under the rapid change of fault current, a dynamic simulation model is established. Finally, the transient properties of FC-SFCL module under 10 ms dc impulse impact are tested.

Submitters Country:

China

Tue-Mo-Or14 / 264

Design and Test of a superconducting levitation system for gravity measurement

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A high precision superconducting levitation system for gravity measurement has been developed which used the levitation of a superconducting sphere by the magnetic field of two superconducting coils. The magnetic levitation is designed to provide independent adjustment of the levitating force and the force gradient. A GM cryocooler is employed to cooldown the system. This article reviews the construction and operating characteristics of the system. The test results show that the system is allowed at least 10-10g sensitivity.

Submitters Country:

China

Thu-Mo-Or29 / 670

Design and Test of the Cryogenic Cooling System for the Rotating Magnetic Validator of the 10 MW SUPRAPOWER Offshore Superconducting Wind Turbine

Author(s): Jiuce Sun¹**Co-author(s):** Holger Neumann² ; Santiago Sanz ; Gustavo Sarmiento³ ; Iker Marino³ ; Ainhoa Pujana³ ; Jose Merino³ ; Matteo Tropeano⁴¹ *KIT*² *Karlsruhe Institute of Technology*³ *TECNALIA*⁴ *Columbus Superconductors Spa*

The SUPRAPOWER consortium, an EU FP7 funded research project, is developing an innovative 10 MW class superconducting generator (SCG) to provide an important breakthrough in the offshore wind industry. It is a partial SCG with MgB₂ wires used in the field coils while conventional copper conductors are used in the armature coils. Due to the requirements of handling, maintenance, reliability of long-term offshore operation, the cooling system of SUPRAPOWER SCG adopts a modular and cryogen-free design. The SCG contains 48 identical superconducting coils and each coil is enveloped in one of the 48 identical modular cryostats. Benefiting from the modular concept, the key challenges of such innovative 10 MW SCG e.g. the modular superconducting (SC) coil and associated cryogenic systems could be validated through a scale-down experiment. This validator consists of two modular SC coils rotating together with the iron poles and yoke to generate the magnetic field. The modular cryostat enveloping the coil consists of a vacuum vessel, an active cooled thermal shield with multi-layer insulation and corresponding supporting structures. In order to achieve the SC coils working temperature of 20 K, a two-stage G-M cryocooler will be installed and linked to the two modular cryostats by means of conductive copper connection. A non-modular cryostat was developed to envelop the cold head of the cryocooler, the thermal link, and three binary current leads to feed electrically the coils while keeping the heat load from ambient as low as possible. A rotary union with Ferrofluid sealing was developed to transfer the helium gas between the rotating cold head and stationary oil-lubricated compressor. In this paper, the design and manufacture of each component will be described, and the assembly and preliminary experimental test of the cryogenic cooling system for the validator will be also presented.

Submitters Country:

Germany

Wed-Af-Po3.03 / 23

Design and analysis of a coaxial-flux superconducting magnetic gear using superconducting bulk in halbach array

Kun dong¹¹ *southeast university*

Design and analysis of a coaxial-flux superconducting magnetic gear using superconducting bulk in halbach array

Submitters Country:

china

Wed-Af-Po3.05 / 1117

Design and analysis of a less-rare-earth PM-assisted synchronous reluctance machine considering tradeoffs of PM flux linkage and magnetic saliency

Wenye Wu¹ ; Xiaoyong Zhu¹ ; Yi Du¹¹ *Jiangsu University*

In recent years, due to the highly variable cost of rare-earth permanent magnet (PM) and requirement for more efficient motor, PM-assisted synchronous reluctance machine (PMAREL) have attracted increasing attention and become one of the research highlights in the motor field. Generally, the PMAREL machines are characterized by a complex rotor structure, where multi flux barriers are set to achieve a high difference between the d-axis inductance L_d and the q-axis inductance L_q , i.e., a large magnetic saliency ratio, which results in a dominant component of reluctance torque. Besides, an amount of PM materials is inserted into the rotor flux barriers, adds a PM flux linkage to q-axis to offset the armature flux linkage $L_q I_q$, which improves the machine's power factor and makes an assisted contribution to the output torque. Thus, it is not easy to determine the proportion of the magnetic saliency and PM flux linkage incorporating into the design of PMAREL machines to yield satisfactory performance. In this paper, a new PMAREL machine adopting less rare-earth PM is proposed, in which an elliptical barrier are set in its rotor pole tip. One purpose is to obstruct the flux along the q-axis, which influences the level of saliency ratio. Another is to divide the magnet flux into two flux streams, achieving reasonable adjustment for the PM flux linkage. By adopting a sensitivity analysis method, the influences of the variables of the elliptical barrier on the machine performance such as power factor, inductance characteristics, output torque and flux-weakening capabilities in high operation are investigated. The results show that the machine performance can be improved by a proper tradeoffs of the magnetic saliency and PM flux linkage. More detailed theoretical analysis and experiment validation will be presented in the full paper.

Submitters Country:

China

Wed-Af-Po3.04 / 138

Design and analysis of a time-varying magnetic field generator for manipulating magnetic particles

Shaozhe Zhang¹ ; Quanliang Cao¹ ; Zhen Wang¹ ; Sheng Feng¹ ; Xiaotao Han¹¹ *Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology*

The use of rotational and oscillating magnetic fields to manipulate magnetic particles has a great importance in the biological and chemical application, such as separation, mixing and assembly. Typically, Helmholtz coil and multipole electromagnet are the two types of field generator. Helmholtz coil has good homogeneity and relatively large working area, while the generated magnetic field can only reach about ten-odd mT. The multipole electromagnet has a complex structure that is difficult to design and its field homogeneity is not good enough. In this paper, a new magnetic field generator consisting of a solenoid coil and an electromagnet with two poles is developed, which is simpler and has better homogeneity of magnetic field than conventional multipole electromagnets. The solenoid coil is placed in the air gap of the electromagnet, it is perpendicular to the plane of the electromagnet. The working area is a cylinder with a height of 10 mm and a diameter of 10 mm inside the solenoid coil. This device can be used to generate rotational and oscillating magnetic fields through altering the configuration of the solenoid coil and the electromagnet. For example, a rotational magnetic field up to 50 mT with a frequency ranging from 0 to 200 Hz can be generated, when sine-wave current excitations with a phase difference of 90 deg are applied to the solenoid coil and the electromagnet simultaneously. Finally, visualization experiments of the behavior of magnetic particles under the generated time-varying magnetic fields are carried out to validate the effectiveness of the proposed

system.

Acknowledgements: We gratefully acknowledge the financial support of the National Natural Science Foundation of China (51577083,51407083).

Submitters Country:

China

Wed-Af-Po3.05 / 1129

Design and analysis of an interior permanent magnet synchronous machine with multi flux barriers based on electromagnetic-mechanical coupling method

Wenye Wu¹ ; Xiaoyong Zhu¹ ; Li Quan¹ ; Yi Du¹

¹ *Jiangsu University*

Interior permanent magnet synchronous machine (IPMSM) have been widely used in many areas compared with the conventional motors for their advantages, such as high torque, high power, widely variable speed range and so on. Theoretically, IPMSM can be designed with an infinite speed range for constant power operation by utilizing flux weakening control method. But practically, in order to achieve a better flux weakening capability, it usually design the rotor with multi flux barriers to extend the magnetic resistance torque and reduce permanent magnetic field, it thus may cause serious mechanical problems to the rotors because the centrifugal force is easily concentrated in thin areas of iron core at high speed operation. Therefore, the rotor design and checking of mechanical strength has become a challenging task due to the conflicting characteristics of improved electromagnetic performance and rotor mechanical strength. Currently, the electromagnetic and mechanical characteristics are often estimated individually and few researches have dealt with the coupling analysis of the two aspects. In this paper, to meet the requirements of high-speed industrial application, a new electromagnetic-mechanical coupling analysis method is proposed to comprehensively evaluate the drive performances of an interior permanent magnet synchronous machine with multi flux barriers, in which sensitivity analysis and multi-objective optimization method are adopted to confirm the optimal parameters of the machine by considering both the electromagnetic and mechanical limits. Results verify the validity of the proposed method and more detailed analysis will be shown in full paper.

Submitters Country:

China

Tue-Af-Po2.02 / 1156

Design and characterisation of tunable high gradient permanent magnets quadrupoles

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The design and the characterization of high gradient permanent magnet (PM) quadrupoles, so-called "QUAPEVA" with variable strength are presented. The quadrupole structure is composed of a Halbach ring in the centre and four PM cylinders around. The central magnet provides a fixed gradient of 160 T/m. The four PM cylinders are used to achieve the gradient tuning range from 100 T/m to 200 T/m thanks to their rotation around their axis. Each tuning magnet can be controlled independently, enabling tuning the gradient without field asymmetry and without magnet centre variation. Seven quadrupoles has been built with different lengths in order to fulfil the integrated gradient requirements (from 3T to 21T). They are now used to focus electrons generated by laser plasma acceleration for a free electron laser application on the COXINEL ERC Advanced Grant Experiment. For this application, high gradient quadrupoles are required due to the large divergence of the electron beam. Furthermore a wide gradient tuning necessary in order to run at different energies can only be achieved with PM technology.

Submitters Country:

France

Thu-Af-Po4.06 / 599

Design and comparative analysis of MgB₂ and YBCO wire-based superconducting wind power generators

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Recently, MgB₂ wire and YBCO wire have been widely used in superconducting generators. However, they have differences in terms of material characteristics, product performance, price, and the relevant cryogenic cooling system, which have a great influence on the design of superconducting generators. Therefore, it is necessary to compare which wire is better for superconducting wind turbine design. This paper deals with design and comparative analysis of direct-driven type superconducting wind power generators according to MgB₂ and YBCO wires. The specifications of MgB₂ and YBCO wires are investigated, and the 3MW superconductor generators using MgB₂ and YBCO wires are designed based on the rated rotational speed of 14 rpm. The magnetic field distributions of the generator are analysed using a 3D finite element method program. The generator designs using MgB₂ and YBCO wire are compared focused on the size, weight, magnetic flux density, operation current value, and required length of the wire. As a result, the weight and volume of the generator using YBCO wire are lighter and smaller than the generator using MgB₂ wire, however, the required length of MgB₂ is shorter than the YBCO wire. When the weight, the volume and the length are considered together, the generator design using the MgB₂ wire is more attractive than the YBCO. This result will be useful for designing a superconducting wind turbine and selecting an appropriate wire.

Submitters Country:

Republic of Korea

Mon-Af-Or7 / 949

Design and construction of the first full-length prototype of the 11T dipole magnet for the High Luminosity LHC Project at CERN

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¹ CERN

The luminosity upgrade of the Large Hadron Collider at CERN requires the installation of additional collimators in the dispersion suppressor regions of the accelerator. Amongst other things, the upgrade foresees the installation of one additional collimator on either side of IP 7 at the location of existing main dipoles that will be replaced by shorter and more powerful dipoles, and of one additional collimator on either side of IP2 at the location of existing empty cryostats. This paper describes the design and the construction status of the first full-length prototype of the 11T dipole magnet, which is needed for IP7. This magnet features a two-in-one structure, like the LHC main dipole, impregnated coils made of Nb3Sn conductor, an inner bore of 60 mm and a magnetic length of about 5.3 m. Two 11 T magnets are needed to replace a 15-m long MB. A by-pass cryostat placed in between the two magnets allows creating a room temperature space for the additional collimators. The magnet is designed to provide the same integrated field as the MB at nominal field. However, due to the difference in transfer function at lower field, a correction by means of a trim current as been considered. A full length prototype is currently under construction at CERN with the goal of developing the manufacturing and inspection procedures prior to launch the series production. For this, new tooling has been developed and optimized during the fabrication of fully representative practice coils. This paper describes the main manufacturing steps and corresponding quality indicators which will be used to monitor the series production. Finally, the production and installation schedule will be presented.

Submitters Country:

Switzerland

Mon-Af-Po1.11 / 986

Design and construction of the magnet-cryostat for the SuperKEKB Interaction Region

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SuperKEKB accelerator consists of 7 GeV electron and 4 GeV positron main rings (HER and LER). The target luminosity of SuperKEKB is 8×10^{35} which is 40 times higher than KEKB. After the Phase-1 commissioning operation of the accelerator, the construction of the superconducting final focus system Construction is progressing on schedule. The magnet-cryostats have being installed into the beam interaction region (IR). The QCSL magnet-cryostat, which is placed in the left side to the interaction point (IP), has 25 superconducting magnets including the superconducting corrector magnets, and the QCSR magnet-cryostat in the right side has 30 superconducting magnets. During the beam operation, the magnet-cryostats will have the electro-magnetic force over 40 kN from the particle detector solenoid field. In this paper, we would like to present the design of the magnet components and the required material in the cryostats from the beam operation and the physics experiment, and the construction conditions and the difficulties.

Submitters Country:

Japan

Wed-Af-Po3.04 / 188

Design and construction of the main magnet for a 230 MeV Superconducting Cyclotron

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For the applications of proton therapy and proton irradiation, and based on the R&D starting from 2009, a construction project of a 230 MeV superconducting cyclotron (CYCIAE-230) has been launched at China Institute of Atomic Energy (CIAE) since Jan 2015. A compact main magnet design with warm iron yokes and a superconducting coil system is adopted to reduce the size, and consequently to lower the construction and operation cost of the cyclotron. In this paper, the physics design, along with the mechanical design of the main magnet, including the structure of the main magnet and the screw lifting system of the main magnet, are described in detail; then the construction progress as well as the BH curve measurement results of the warm iron over the magnetic saturation region are outlined; the R&D of the superconducting coils system and the design of field mapping system are also briefly introduced.

Submitters Country:

China

Thu-Af-Po4.04 / 905

Design and development of conduction cooled MgB₂ magnets for 1.5 and 3.0T full body MRI systems

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Hyper Tech will report on progress that has been made on designing helium-free MgB₂ magnets for 1.5 and 3.0 T full body MRI systems, including mechanical, thermal and quench protection analysis, conductor development, jointing, and prototype test coil characterization and measurements. As an addendum, the development of low AC loss MgB₂ conductors for motors and generator will be presented.

Submitters Country:

United States

Tue-Af-Po2.07 / 143

Design and fabrication of HTS DC bias coil for 500kV saturated iron core fault current limiter

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Saturated iron-core superconducting fault current limiter is a kind of promising device for short-circuit current limiting. During normal operation, large ampere-turns created with DC in the secondary superconducting HTS coil drive the core into saturation. This lowers impedance of the copper coil in the primary AC side near to that of an air-core coil. During a fault, a large fault current demagnetizes the core and drives it from the saturated to unsaturated state (linear B - H region). This increases the primary AC coil impedance. The increased impedance limits the fault current to the desired level. The HTS DC bias coil with Bi2223 and YBCO is developed. Since strongly anisotropic Bi-2223 exhibits an enormous suppression of irreversibility field to the very low value of ~0.2 T at 77K, the second-generation YBCO is used to optimize the magnetic field distribution. The HTS DC coil is composed of 80 Bi-2223 double pancake coils and 8 YBCO double pancake coils, and the rated ampere-turns are 468000 at 72K. The used Bi-2223 tape is produced by Sumitomo, and the critical current is 220A (77K, self-field). The used YBCO tape is produced by Shanghai Superconductor, and the critical current is 100A (77K, self-field). Both of the Bi-2223 and YBCO double pancake coils are fabricated, and the critical current is more than 175A (77K, self-field) for each double pancake coil, which are essentially in agreement with the simulation results.

Submitters Country:

P.R. China

Mon-Af-Or7 / 914**Design and fabrication of a 15 T Nb₃Sn accelerator dipole demonstrator**

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US Magnet Development Program (MDP) is developing a 15 T Nb₃Sn dipole demonstrator for a post-LHC pp Collider. The magnet design is based on 60-mm aperture 4-layer shell-type coils, graded between the inner and outer layers to maximize the magnet performance. An innovative mechanical structure based on aluminum IC-clamps and a thick stainless steel skin was developed to preload brittle Nb₃Sn coils and support larger Lorentz forces at high fields. To study mechanical properties of this structure as well as to optimize the magnet assembly and coil pre-load procedures, the structure was assembled with aluminum cylinders serving as “dummy” coils. These cylinders were instrumented with strain gauges to monitor radial and azimuthal and axial stresses during structure pre-loading. This paper describes the design of the 15 T dipole demonstrator, magnet fabrication status, and mechanical model test results.

Submitters Country:

U.S.A.

Wed-Af-Po3.08 / 559**Design and implementation of a flexible pulsed electromagnetic blankholder system for electromagnetic forming****Author(s):** Yujie Huang¹

Co-author(s): Xiaotao Han ; Quanliang Cao ; Zhipeng Lai ¹ ; Ning Liu ² ; Xiaoxiang Li ¹ ; Meng Chen ³ ; Liang Li ¹

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A flexible pulsed electromagnetic blank holder system consisting of segment blank holder modules has been designed, implemented and tested for electromagnetic forming of large-scale metallic sheet, while each module is consisted of dual-coil driven by capacitor banks. The basic principle is that a high pulsed electromagnetic attractive force is generated between two parallel coils energized by current of the same direction, and then the force can directly transmit to the flange of the work piece as a blank holder force (BHF) to control material flow in the forming process, where the BHF can be flexibly and accurately controlled by adjusting the magnetic energies of each module. In this paper, the distributions of magnetic field and electromagnetic attractive force in single module based on finite element method is analyzed in detail, which provides a theoretical support for the proposed system. Then some key parameters of the system related to coil module and pulsed power supply are designed and optimized. A series of experiments are carried out and the results verify the feasibility and effectiveness of the system for supplying sufficient pulsed BHF to shape metallic sheet.

Submitters Country:

China

Thu-Af-Po4.03 / 1107

Design and magnetic measurements of a hybrid wiggler for SR research program at VEPP-4

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Hybrid wiggler for SR research program at the VEPP-4 was created in the Budker Institute of Nuclear Physics. The wiggler consists of ordinary poles with coils, which generate a spatially periodic magnetic field equal to 1.8 T. Also, permanent magnets are insertion between the poles for increasing magnet field up to 2.05 T. In this paper we present the design, calculations and magnetic measurements for the hybride wiggler.

Submitters Country:

Russia

Thu-Af-Po4.11 / 218

Design and manufacture of Solenoid center deviation measurement device

Xi Wu^{None}

The solenoids are widely used both in conventional magnets and superconducting magnets in the particle accelerators. The longitudinal fields along longitudinal direction of the solenoids are usually measured with the Hall probe measurement system. However, in some cases, the deviation between magnetic center and mechanical center of solenoid is another important parameter and has to be measured accurately. In this paper, a device is designed and developed to measure the center deviation of the solenoid, which can be both used in conventional magnets and superconducting magnets. After the device is finished, some tests are made in the solenoid to check whether the data is correct. For the numerical simulation and analysis of the magnetic field inside the solenoid, the TOSCA code was chosen right from start. The results of the analysis are compared to the result of the tests.

Submitters Country:

China

Tue-Af-Po2.02 / 232

Design and measurement of a 2.4 tesla superbend magnet prototype at SSRF

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Four normal conducting 2.4 tesla “superbend” magnets will be installed in the phase-II beamline project at Shanghai Synchrotron Radiation Facility(SSRF), replacing the current 1.27 T ones. We present the design and the magnetic measurement results of the first prototype magnet in this paper. Also described is a newly-developed field shimming method which has shown its efficiency and simplicity during the shimming of this magnet.

Submitters Country:

P. R. China

Mon-Af-Po1.11 / 1008

Design and performance analysis of a cryostat for pulsed high magnetic field using a small scale helium liquefaction system

Mengyu Liu^{None}; Shaoliang Wang^{None}; Liang Li^{None}

A cryostat for measurements in pulsed high magnetic fields has been designed by employing a small scale helium liquefaction system directly. The helium liquefaction using a 1.5 W @ 4.2 K GM cryocooler can supply more than 800 ml liquid helium per hour. Experimental result shows the sample chamber can be cooled lower to 1.5 K very conveniently and be stable for over 20 minutes. More importantly, the helium liquefaction system is equipped outside the cryostat and away from the magnet which means the vibration of the cryocooler could barely affect the measurements. This cryostat has performed excellently in the electric transport measurement under a 60 T pulsed high magnetic field.

Submitters Country:

China

Wed-Af-Po3.08 / 730

Design and structural analysis of induction type coilgun system

Byeong-Soo Go¹ ; Myung-Geun Song² ; Dinh-Vuong Le¹ ; Minwon Park¹ ; In-Keun Yu³¹ *Changwon National University*² *Hanwha Defense System*³ *Changwon National University*

A multi-stage induction type coilgun system is one of the most important research items. Especially, the capacitor driven induction coilgun, which is almost free from physical contact between the barrels and projectile, has a longer gun lifetime compared to other electromagnetic launchers. Accurate analysis of multi-stage induction coilgun is usually necessary to establish full-size finite element model. Full-size finite element model is accurate and comprehensive, but the model is complex, poor general, computing time increases with the coil from the geometric progression in multiples of increase cannot solve the problem quickly. It is necessary to find a way to ensure both accuracy as well as rapid calculation. In this paper we present design and structural analysis of multi-stage induction type coil-gun system with pulse power module using FEM programs. The fundamental specifications of the induction type coil-gun system were investigated via mathematical analysis model using MATLAB considering pulse power module. The voltage, current, force, velocity, acceleration, efficiency of the multi-stage coil-gun system was analyzed using electromagnetic analysis. Based on the electromagnetic analysis results of the coil-gun system, the structure of the coil-gun system, including the stator (Driving) coil, armature coil, and supporter parts, was defined. The electromagnetic analysis results were compared with mathematical analysis results to confirm the reliability of the FEM simulation model. As the results, voltage, current, force, velocity, and acceleration of the multi-stage coil-gun system were very similar to mathematical analysis results, and the designed coil-gun system has higher efficiency. The stress of the coil structure was less than the allowable stress of the materials, and the increasing temperature was within the permissible range. We therefore recognize that the designed the induction type coil-gun has high efficiency and safe from the force and temperature of the coils.

Submitters Country:

Republic of Korea

Mon-Af-Or5 / 740

Design and technical development of a high-resolution 1.3 GHz NMR magnet

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Japanese researchers succeeded in developing a 1.02GHz NMR (24T) in 2014. The next field target is a 1.3GHz (30.5T) and we have commenced designing a high resolution 1.3GHz LTS/HTS NMR magnet, operated in persistent current (PC) mode. The basic concept and relevant technical problems are identified in this paper.

To reduce the magnet size, high current density HTS coils are used that generate as high as 23T, enabling a compact magnet as small as a 800-900MHz LTS NMR magnet. Two probable designs have been examined so far; one uses reinforced-Bi2223 coils and the other REBCO/reinforced-Bi2223 coils. From a viewpoint of screening current, the former is better; while from a viewpoint of PC mode operation, the latter is preferred. The stress criteria are 350MPa in hoop stress and 50MPa in axial

compressive stress; they are below the tolerance limit of the conductor. Numerical simulations of the screening current induced field are being developed; the magnet design will be modified later based on the simulation results. The RT bore may be enlarged to install stronger RT shims and ferromagnetic shims. The magnet will be self-shielded by a shielding coil for being installed in the NMR facility of RIKEN. 4K pulse tube cryocoolers will be installed to reduce helium consumption. We recently succeeded in developing a new type of superconducting joint between REBCO conductors, which may be available for use on this magnet. However, more investigations must be made in this regard. More details will be presented at the conference.

This work is supported in part by the MEXT. The authors would like to thank members of the HTS Magnet Technology Working Group in a program of the MEXT for their technical comments on the designs. Part of experimental data to be presented was obtained in the S-innovation Program of the JST.

Submitters Country:

Japan

Mon-Af-Or7 / 1157

Design and test results of the Nb₃Sn Canted-Cosine-Theta dipole magnet CCT4

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⁴ *Unknown*

The U.S. Magnet Development Program is developing Canted-Cosine-Theta (CCT) magnet technology for future high field accelerator magnets. The CCT concept prevents Lorentz force accumulation by placing turns within precision-machined grooves that are separated by ribs and a spar that intercept forces, sustainably reducing the stress in the conductor. With other non-stress managed coils, now approaching the 200 MPa limit, some form of force interception like the CCT will eventually be required in future high field magnets. CCT4 is the fourth in a series of CCT dipole magnets that have been designed, built, and tested at the Lawrence Berkeley National Laboratory. The design of this two layer, 1 m long, 90 mm bore, Nb₃Sn dipole is to demonstrate achieving a 10 T bore field plateau. The methods used in fabricating and assembling this magnet will be described and test results presented.

This work was supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Submitters Country:

United States

Wed-Af-Or27 / 430

Design and tests of the 100 T triple coil at LNCMI

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The Laboratoire National des Champs Magnétiques Intenses (LNCMI) is a French host facility for experiments in high magnetic fields. Based on two sites, the LNCMI offers routinely static magnetic fields up to 36 T at its Grenoble site and pulsed magnetic fields up to 90 T using non-destructive magnets and up to 180 T using single-turn magnets at its Toulouse site. Internal research is carried out in the lab and experiment time is allocated to external researchers. LNCMI is a member of the European Magnetic Field Laboratory (EMFL) with the Hochfeld-Magnetlabor in Dresden (HLD) and the High Field Magnet Laboratory in Nijmegen (HFML). The LNCMI develops all the instrumentation required by experiments in high magnetic field, in particular, the electromagnets that generates these high fields.

The main difficulty to generate a very high magnetic field in a non destructive way is to contain the stresses on the magnet conductors due to the Lorentz forces. We will present the design and the first operation of a new type of pulsed magnet consisting of three nested coils energized with three independent capacitor banks. This triple coil, unique in the world, associated with the most powerful generators of the LNCMI, reached a peak field value of 98.8 T in February 2017 and permits to LNCMI to break the European record of non-destructive pulsed magnetic field established at 95.6 T in October 2016 by HLD.

The objective is to go beyond the symbolic limit of 100 T and the world record of 100.75 T kept by the Los Alamos National Laboratory since June 2012. We will describe the next steps toward this goal and some ways to go beyond, keeping in mind that this magnet is before everything else a tool for scientific research, in particular to explore the fundamental properties of the matter.

Submitters Country:

France

Thu-Af-Po4.06 / 204

Design and thermal analysis of an HTS module coil for a 12 MW wind power generator

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High temperature superconducting (HTS) generator is attractively researched with the advantages of high efficiency, and small size compared with conventional generator. One of the big challenge is cooling down the temperature of HTS magnet to ensure the superconducting state. It can take a long time to reach a vacuum because of bulky cooling system. In order to improve the cooling performance of generator, the HTS module coil is designed with the estimation of total heat losses. This paper deals with the design and thermal analysis of an HTS module coil for a 12 MW wind power generator. Heat losses of the HTS module coil include radiation loss, eddy current loss of the structures of the coil bobbins, ac loss of the HTS magnet, conduction loss of the current leads and supports of the magnet, and Joule loss of the current leads and joint with the HTS magnets. The two-stage cryo-cooler of RDK-415D was used to achieve the operating temperature of 20 K. Current leads were designed optimally for reducing the conduction and Joule heat losses. The total heat losses of the HTS magnet module were analyzed using 3D finite elements program. The supports were located in the 1st stage area and 2nd stage area of the HTS module coil. The size of all of supports was calculated to estimate the conduction heat loss from outside to the 1st stage area and from the 1st stage area to the 2nd stage area. The results of heat losses and temperature distribution were confirmed by using FEM program. As a result, the temperature of the magnet was achieved under operating temperature of 20 K, and total heat loss was less than the cooling capacity of the

cryo-cooler. The results will be utilized for structure design of large-scale superconducting generator module coil.

Submitters Country:

Republic of Korea

Tue-Af-Po2.07 / 437

Design and verification test of a flux-coupling type superconducting fault current limiter

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Superconducting fault current limiters (SFCLs) are considered as one of the most technical potentials to limit fault current levels, for that they can suppress fault currents without adding impedance to the circuit during normal operation. In this paper, a small-scale test prototype of the flux-coupling type SFCL (FC-SFCL) is designed and fabricated, and a series of experimental tests are carried out. From the demonstrated experimental results, the FC-SFCL prototype is able to effectively suppress the fault current's steady value to a lower level, and the operation overvoltage is not induced during the current-limiting process.

Submitters Country:

China

Wed-Af-Po3.04 / 360

Design considerations of gantry beamline with fast energy modulation for HUST Proton Therapy Facility

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HUST proton therapy facility is a Major State Research & Development Program supported by MOST, China. This facility is based on an isochronous superconducting cyclotron with two gantry beam lines and one fixed beam line. This paper will discuss the beam optics and main magnetic elements including dipoles, quadrupoles and fast scanning magnets of the gantry beam line. As well as the Energy Selection System (ESS) will be introduced with key features which enable fast energy modulation of proton beam between 70 MeV to 240 MeV.

Submitters Country:

China

Wed-Af-Or27 / 131

Design for an Upgrade of the NHMFL 32-mm Bore Resistive Magnet

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¹ *NHMFL*

The National High Magnetic Field Laboratory (NHMFL) has developed the design of its next generation 32mm bore Resistive Magnet. This magnet upgrade includes enlarging the size of the most outer coil from a 610mm to a 1000mm outer diameter and from a 430mm to a 730mm maximum height. First, a general design optimization was performed to decide on the number, the geometries and the materials of the nested resistive coils. As a result of that analysis, the new magnet will consist of six coils (upgraded from 4 coils) with the innermost two coils electrically connected in parallel and the remaining coils connected in series. Next a series of systematic detailed analysis of the winding pack was iterated coil by coil as well as section by section along each coil axis employing current density grading all aiming to achieve a new world record field near or above 40 Tesla.

Submitters Country:

USA

Mon-Af-Po1.04 / 830

Design method of an ultra-high speed PM Motor/Generator for Electric-Turbo Compounding System

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In various industries, ultra-high speed motor is actively studied and developed for diverse industrial applications like generators/starters for micro gas turbines, turbo-compressor, vacuum pump and turbine generator. Electric Turbo Compounding System (E-TCS), which operates with motor/generator unit at a very-high speed, is the most realistic alternative technology that can respond to fuel efficiency regulation by applying an electrical system to the existing turbocharger. In the low-speed region where the exhaust gas energy in the turbocharger is insufficient, the motor assists the compressor to improve the dynamic characteristics and output of engine, whereas in the high-speed region where the energy of the exhaust gas remains, it operates as a generator and produces electrical energy with excess exhaust gas energy and improves system energy efficiency. This paper presents the design of an ultra-high speed PM motor driven by 10kW at the rated speed 70,000 rpm and the maximum speed 100,000 rpm for applying E-TCS. In this paper, Response Surface Method (RSM) and Finite Element Method (FEM) are used to perform the optimal design of PM motor. For operating at the ultra-high speed, the design of PM motor should be considered the mechanical and structural safety of rotor and losses for the high efficiency. Therefore, the objective function of RSM are the secureness of mechanical and structural safety of rotor and the minimum of losses, occur at the rotor and sleeve. Furthermore, this paper presents the design of the sleeve according to the materials. As the results, the optimal design method of PM motor, using carbon fiber is proposed to not only reduce the eddy-current loss, prominently occur at very-high speed, but also ensure the structural safety. Finally, experiment is performed to verify the validity of the proposed design method and effectiveness of the PM motor, fabricated as a prototype.

Submitters Country:

republic of korea

Mon-Af-Po1.04 / 432

Design of Dual-Channel Switched Reluctance Motor for Safety-Critical Applications Using Two 3-Phase Standard Inverters

Qian Chen¹ ; Guohai Liu¹ ; Jian Wang¹

¹ *Jiangsu University*

Switched reluctance machines are widely used in variety application in automotive, renewable energy, aerospace and domestic appliances sectors, due to its low cost, high torque capacity, simple and robust structure. In order to improve the reliability of SRM further, a dual-channel SRM (DCSRM) was proposed and their fault tolerant capacity was verified. However, the traditional topology of inverter is used, resulting in complicate construction. Meanwhile, the mutually coupled SRM (MCSR) can be excited by sine-wave currents, and then the standard inverter can be adopted. Hence, this paper proposes a novel DCSR using two 3-phase standard inverters. The key of proposed DCSR is two operational models. In first operational model (Model I), it works like one 3-phase traditional SRM supplied by H-bridge inverter, which is drove by square-wave currents. In second operational model (Model II), it can be considered as two MCSRMs which are supplied by sine-wave currents. Model I is adopted for switching fault because the H-bridge inverter is adopt, which can keep the amplitude of the current under power switch fault and just change the direction of the current. Since the reluctance torque is not related with direction but amplitude of the current, the torque output will not reduce when power switch fault happens. Meanwhile, the Model II is employed for phase open-circuit fault. In sinusoids current supply model, when a phase is open, the currents of other two phases in fault channel are forced to be opposite. Then the neutral current is set to be zero. Since only two phases can work, the second and fourth order torque ripple cannot be neglected. In order to compensate the torque loss and torque ripple, the amplitudes of currents in healthy channel are set as a variable. Then, the proposed motor can be used to overcome different fault conditions.

Submitters Country:

China

Mon-Af-Po1.05 / 152

Design of Suspension Force Feedback Control System of Multiphase BPMSM Based on MRAS Inductance Parameter Identification

Huangqiu Zhu¹ ; Yuemei Qin¹

¹ *Jiangsu university*

A multiphase bearingless permanent magnet synchronous motor (BPMSM) has characteristics of multiphase motor and bearingless motor. It can not only operate without mechanical bearings, but also possess the advantages of the multiphase motor. Although the multiphase BPMSM with a single set of windings has a simpler configuration, it has many restrictions on the winding distribution and pole-pair allocation. Compared with the integer-slot concentrated-winding (ISCW) topology, the multiphase fractional-slot concentrated-winding (FSCW) permanent magnet synchronous motor (PMSM) has higher torque density and smaller torque ripple. Thus, a five-phase 10-slot/8-pole fractional-slot concentrated-double-winding (10/8 FSCDW) BPMSM is presented in this paper. Firstly, the suspension principle is elaborated in detail based on the interaction between the stator and rotor MMF. Then, the accurate suspension force mathematical model and inductance parameters are calculated, and the Model Reference Adaptive Method (MRAS) is adopted for the identification of suspension force winding inductance, torque winding inductance, and mutual-inductance coefficient. To improve the convergence speed and robustness of inductance parameter identification, the pole assignment of the inductance parameter identification system is carried out, the feedback matrix is designed, and the validity of the proposed algorithm is verified by simulation. For comparison, a 10-slot/2-pole integer-slot concentrated-double-winding (10/8 ISCDW) BPMSM with the same size of outer stator is designed, the simulation results shows that the average torque and torque ripple of the five-phase 10/8 FSCDW BPMSM are 4 times and 34% of the 10/2 ISCDW BPMSM, respectively.

Although the average suspension force of the former is 94.2% of the latter, it is large enough to realize the rotor suspension. Finally, a prototype of the 10/8 FSCDW BPMSM is manufactured and the experiments of the parameters identification are implemented with the proposed algorithm by the stable and acceleration performance, respectively.

Submitters Country:

China

Mon-Af-Po1.04 / 807

Design of Vernier Motor considering Irreversible Demagnetization in Permanent Magnet

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As demand for motors that are capable of high-torque direct drive operation is increasing, Vernier motor is gaining its importance. Vernier motor is a type of permanent magnet (PM) motor, which is specialized for low speed and high torque operation applications. Unlike conventional PM synchronous motor (PMSM), which generates torque mainly from fundamental flux component, Vernier motor utilizes magnetic flux harmonics to develop additional torque component with harmonic flux component. Moreover, the Vernier motor is also a flux modulation machine, which has operation characteristic analogous to that of the magnetic gear. The magnetic gear ratio of Vernier motor is determined by ratio of the stator winding pole pair number and the rotor pole pair number, which has effect on torque produced by the Vernier motor. For these characteristics, the Vernier motor is regarded as one of possible candidates for future motor applications. However, it is necessary that PM used in the Vernier motor does not suffer from irreversible demagnetization, as it has negative effect on the output performance of the motor. Therefore, it is requisite that analysis on the Vernier motor considering irreversible demagnetization of the PM is carried out, to examine how the motor output performance is influenced. Furthermore, design optimization considering design parameters should be carried out to prevent irreversible demagnetization on the PM, to guarantee performance of the motor. In this paper, the Vernier motor is analyzed under several operation conditions to observe how the motor output performance is affected by irreversible demagnetization of PM. Then, the Vernier motor is redesigned regarding certain design parameters to enhance irreversible demagnetization of PM. Finally, the output performance characteristic of enhanced Vernier motor is compared to that of the base motor.

Submitters Country:

Korea, Republic of (South Korea)

Mon-Af-Or9 / 185

Design of a Magnet Bore Field Mapper Consisting of a Cylindrically Fixed Array of Inexpensive Hall Elements to Probe Low-Order Spherical Harmonics in Real Time

David K. Hilton¹ ; Seungyong Hahn¹ ; Ulf P. Trociewitz¹

¹ *NHMFL-FSU*

Demand continues to be high for high-temperature superconducting (HTS) wires and tapes to wind coils of high field quality for NMR or MRI applications. A magnet bore field mapper of relatively simple design and operation is needed to confirm the low-order spherical harmonics during testing after construction of such coils, irrespective of compensation. Presented here is one probe design of a compact, cylindrically fixed array of inexpensive Hall elements normally used in consumer, industrial, and automotive electronics. At most, the probe is only 50.8 mm in diameter and 124 mm in height. The several (i.e., 20) gallium arsenide (GaAs) Hall elements required are incorporated into this probe only after careful and systematic calibration of each at room and low temperatures (i.e., at 298 K and 4.22 K), and moderate magnetic fields (i.e., from 0.0 T to 9.0 T by 0.25 T), in this case, using a Physical Property Measurement System (PPMS) manufactured by Quantum Design. Furthermore, because the array is fixed rather than rotating, the low-order spherical harmonics from the magnet bore may be probed in real time. Thus, the severe magnetic distortions generated by induced screening currents in anisotropic (RE)BCO coated conductors (e.g., in no-insulation pancake windings) may be followed with respect to time.

This work was funded by the National Institutes of Health (NIH) under Grant 5-R21GM111302-03, by the National Science Foundation (NSF) under Cooperative Agreement DMR-1157490, and by the State of Florida. The content of this work is solely the responsibility of the authors.

Submitters Country:

United States of America

Mon-Af-Or6 / 439

Design of a Nb₃Sn 16 T block dipole for the Future Circular Collider

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In the framework of the EuroCirCol project the high field accelerator magnet design work package 5 focuses on double-aperture dipole magnets made of Nb₃Sn conductors and providing a field of 16 T in a 50-mm aperture. Three options are considered: block-coils, common-coils and cosine- θ , the workload being shared between several research institutes. All options are explored and compared based on the same assumptions, in particular in what regards the conductor performance, operating temperature and margin. This work describes the status of the block-coil design. A 2D electromechanical analysis in a double aperture configuration is presented as well as a 3D investigation in a single aperture configuration towards the manufacturing of a prototype.

Submitters Country:

France

Wed-Af-Po3.01 / 428

Design of a Nb₃Sn 400 T/m quadrupole for the Future Circular Collider

Author(s): Clement Lorin¹

Co-author(s): Maria Durante ; Helene Felice ¹ ; Tiina-Mari Salmi ² ; Daniel Schoerling ³ ; Damien SIMON ⁴

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³ CERN⁴ CEA

For the Future Circular Collider (FCC), a 100 TeV post Large Hadron Collider machine, 750 main quadrupoles with a gradient of around 400 T/m are required. This paper presents an electromagnetic design optimization of a double aperture Nb₃Sn quadrupole fulfilling the specifications, and, a structural design of a single aperture configuration towards a prototype.

Submitters Country:

France, Finland, Switzerland

Thu-Af-Po4.05 / 126**Design of a Non Rare Earth Spoke Type Permanent Magnet Motor for Considering Magnetization after Assembly****Author(s):** Jung-Ho Han¹**Co-author(s):** Jae-Kwang Lee² ; Ju Lee³¹ LG Innotek² hanyang university³ Hanyang University

Recently, due to the rising issue of environmental pollution, secure process of rare earth material with high efficiency is increasing world wide. However, the price of the rare earth material has increased significantly by restriction of rare earth production in China, where more than 90% of rare earth material is produced. Therefore, non rare earth material, for replacing of rare earth material has been interested and interests on a Spoke type permanent magnet motor has been increased. However, it is not easy to magnetize due to the structural problem of the Spoke type permanent magnet motor. In this paper, multiple magnetization method was proposed for considering magnetization after assembly of a Spoke type permanent magnet motor by using non rare earth material. First, 10 poles 12 slots combination was designed for considering simple production, low cost, torque and vibration. And requirements of the model were set up by considering number of turns, width of permanent magnet, air-gap flux density, stack length. Finally, the multiple magnetization method was selected for optimizing this model. The 3 times partial multi-magnetization was selected for considering mass production, magnetic reduction of permanent magnet and magnetization ratio of the permanent magnet. Magnetization after the assembly method was selected due to the problem of repulsive power and suction power of the permanent magnet. The magnetization yoke was designed for testing magnetization yoke design. The magnetization requirements of non-rare earth permanent magnet was determined based on the result of simulation. Therefore, the proposed 3 times partial magnetization method was verified. Finally, the design was analyzed and investigated by applying to the Spoke type permanent magnet motor.

Submitters Country:

South Korea

Tue-Af-Po2.06 / 759**Design of a Novel Double-Stator Flux Reversal Machine with Hybrid HTS and PM Excitations**Yuting Gao¹ ; Ronghai Qu² ; Dawei Li¹¹ Huazhong University of Science and Technology

² School of Electrical and Electronic Engineering, Huazhong University of Science and Technology

Flux reversal machines (FRMs) have a stator with permanent magnets (PMs) mounted on the surface each teeth and a reluctance rotor. As the flux field excited by the PMs is almost constant, the magnitude and phase of the stator current are often adjusted to realize the flux-weakening operation, but it usually sacrifices the output torque. As we know, HTS wound field machines can easily adjust the airgap field and realize wide speed range. Therefore, in this paper, a double-stator hybrid excitation FRM, which utilizes the merit of HTS wound field machines with adjustable d-axis flux, is proposed and analyzed. As the change of airgap flux can be enhanced or weakened by controlling HTS field winding current, the proposed HEFRM can improve both low speed overload torque and high speed flux-weakening capabilities. The proposed machine has two stators and a sandwiched rotor. The outer stator has three-phase windings and consequent-pole PMs mounted on each stator teeth. The inner stator is a conventional stator with HTS field windings and semi-closed slots. The rotor is a simple reluctance rotor. The proposed machine can be regarded as a superposition of two machines, i.e. a single-stator consequent-pole PM FRM and a double-stator HTS FRM. The operation principles will be analyzed and the feasible slot-pole combinations will be summarized. Then, in order to get maximal torque density, the proposed machine will be optimized in terms of several key parameters including slot-pole combination, split ratio and slot opening ratio. Moreover, through comparisons to a conventional FRM, it is found that the proposed FRM has much larger torque density and wider speed range.

Submitters Country:

China

Thu-Af-Po4.03 / 91

Design of a Short Period Permanent Magnet Helical Undulator

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Co-author(s): Cheng-Hsing Chang¹; Ting-Yi Chung¹; Jyh-Chyuan Jan¹; Ching-Shiang Hwang¹; Cheng-Hsiang Chang¹

¹ NSRRC

The design of helical permanent magnet undulator with a period length of 24 mm for the production of circularly and linearly polarized radiation will be discussed. The helical permanent magnet undulator consists of four pairs of helically shaped Vanadium Permendur poles located between Neodymium Iron Boron magnet blocks. This magnet arrangement is expected to produce helical fields in the cylindrical gap along the longitudinal axis. The helical fields were calculated using the 3-D OPERA computer code. The helical undulator produces in phase vertical and horizontal peak fields of 0.57 T for a 24 mm period length within a bore diameter of 10 mm. The sizes and location of end poles were optimized for optimum control of the first and second field integral. Furthermore, the on-axis independent horizontal or independent vertical magnetic fields can be generated by shifting the relative position of diagonal pairs of helical magnet arrays in this device. It leads to the generation of circularly and linearly polarized radiation in undulator. The gap width and the phase shifter of the undulator can be controlled by mechanical changes to adjusting field strength and for the purpose of tuning the helical and linear photon energy. This work describes the magnetic field simulations and mechanical design of the short period helical permanent magnet undulator.

Submitters Country:

Taiwan

Thu-Af-Po4.01 / 469

Design of a cosine-theta dipole magnet considering influence of shielding-current-induced field on field quality

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Co-author(s): Naoyuki Amemiya¹

¹ *Kyoto University*

Magnets wound with coated conductors are attractive for the applications to accelerator systems because of high magnetic field generation and easy cooling by using cryocooler. In accelerator systems, the time-dependent and precise magnetic fields are sometimes required. However, large magnetization in wide coated conductors deteriorates field qualities of magnets, and the temporal behavior of magnetization could be complicated. We have been developing a model for electromagnetic field analyses of a multilayered cosine-theta dipole magnet wound with coated conductors with iron yoke. In this model, the influence of iron yoke is considered as the image currents in the iron yoke. We conducted the electromagnetic field analyses using this model for a dipole magnet designed based on specifications for a rotating gantry of carbon cancer therapy and evaluated the time-dependent shielding-current-induced field (SCIF). The temporal profile of magnet current was determined referring to that of the magnets in a rotating gantry. Using the calculated field affected by SCIF, we redesigned the arrangement of the coated conductors in the magnet and adjusted the temporal profile of the magnet excitation in order to reduce the influence of SCIF on the field quality. This work was supported in part by JSPS KAKENHI Grant Number JP16805140.

Submitters Country:

Japan

Wed-Mo-Or19 / 694

Design of a dipole with longitudinally variable field using permanent magnets for CLIC damping rings

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⁵ *CERN*

The latest CLIC damping ring lattice is based on magnets with longitudinally variable dipole fields in order to achieve ultra-low beam emittance, while keeping the ring circumference small. These magnets need to provide a focusing gradient of 11 T/m as well. The good field region radius is 5 mm. The field harmonics shall be in the order of 1E-4 of the main one. Since only a small variation of the field is requested, permanent magnets are the most cost-effective solution. Beam dynamics calculations have provided idealized field profiles and magnetic calculations have been performed to check their feasibility. FEM electromagnetic computations are complicated because the cross-section of the magnet is not constant. Therefore, iron poles cannot be modeled by extrusion and only 3-D computations are meaningful. Mechanical calculations have been also realized to evaluate the forces and design the support structure. Finally, this paper shows that small variations of field strength are possible by using moving parts.

Submitters Country:

Spain

Mon-Af-Po1.12 / 652

Design of a hybrid power supply for the 65 T high-stability flat-top pulsed magnetic field

Hongfa Ding¹; Yongheng Huang¹; Jun Zhou²; Zhangfei Zhao³; Tieqiang Ren¹; Yiliang Lv^{None}; Huan Li¹¹ Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology² Huazhong University of Science and Technology³ Wuhan National High Magnetic Field Center Huazhong University of Science and Technology

With the increasing applications in physics, biology, chemistry and many other basic scientific fields, high-stability flat-top pulsed magnetic field is demanded for a higher field intensity and a lower ripple. To meet this demands, this paper proposes a hybrid power supply to generate a high-stability flat-top pulsed magnetic field at the Wuhan National High Magnetic Field Center. The hybrid power supply which is adopted to energize a dual-coil magnet, consists of an 11 MJ/25 kV capacitor power supply and a 100 MVA generator-rectifier power supply. A coupling transformer is adopted in the circuit to compensate the influence of the mutual coupling between the two coils. To protect the system from the damage of a short circuit fault occurring between the first turns of the inner coil and outer coil, which will produce oscillation voltage with a high peak value and high frequency (45 kV and 776.6 kHz) on the rectifiers, a protection circuit consists of an R-C branch, a diode array and a metal-oxide arrester is presented. The self-adaptive PI controller with the coefficients corrected by back propagation neural network is adopted to reduce the ripple of flat-top. The MATLAB/SIMULINK is used to model and simulate the proposed system, and a 65 T/100 ms high magnetic field with a ripple less than 160 ppm is generated. Acknowledgements: The National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Wed-Af-Or22 / 61

Design of a laser-driven kiloTesla magnetic bottle

Author(s): Francesco Schillaci¹**Co-author(s):** Massimo De Marco ²; Lorenzo Giuffrida ²; Daniele Margarone ²; Georg Korn ²¹ Institute of Physics Czech Academy of Science, ELI-Beamlines² ELI-Beams

The possibility to trigger the proton-boron nuclear fusion reaction ($p + 11B \rightarrow 8.5 \text{ MeV} + 3\alpha$) by using a nsec class laser has been recently demonstrated. This is of high interest since such reaction does not produce any neutrons but just three alpha-particles, which could be used for applications in different fields. The possibility to confine the plasma fuel generated during laser-target interaction through an ultra-intense magnetic field would allow to enhance the rate of the generated alpha-particles. In last decades it has been experimentally proved that a small coil-target energized with a long pulse (nsec-class), high energy (several hundreds of J) laser can produce a quasi-static (over one nsec) magnetic field of the order of 1 kT. The combination of several laser beams with the dual purpose of producing a plasma responsible of the fusion reaction and, using a proper synchronization, energizing two multiturn coils would enhance the alpha particle rate by confining ions up to few MeV/u in a small region (less than 1mm^2 in diameter). We propose the design of an innovative magnetic bottle-like trap made of two multiturn coil targets able to produce a magnitude field of several kT, which is ideal to confine the plasma for a relatively long time (few nsec), thus increasing the number of p-B collisions and, hence, the fusion reaction rate. A complete study of the trap is here reported including magnetic field analysis, electric, thermal and mechanic behavior and also the confinement efficiency using particle tracking code simulations. A preliminary experimental setup will also be proposed.

Submitters Country:

Czech Republic

Mon-Af-Po1.12 / 324**Design of an active ripple compensator for the 50 T high-stability flat-top pulsed magnetic field**Yongheng Huang¹ ; Hongfa Ding¹ ; Jun Zhou² ; Zhangfei Zhao³ ; Xiao Fang¹ ; Qingjian Wang¹ ; Tieqiang Ren¹¹ *Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology*² *Huazhong University of Science and Technology*³ *Wuhan National High Magnetic Field Center Huazhong University of Science and Technology*

High magnetic field technology has played an important role in basic scientific researches. High-stability flat-top pulsed magnetic field can meet the demands of high field intensity and high stability in modern scientific experiments. The higher stability of flat-top magnetic field would be the more benefit to the observation of experimental phenomena (such as specific heat measurement and NMR experiment). In order to reduce the ripple of flat-top magnetic field, an active ripple compensator is presented in this paper for the 50 T dual-coil magnet system at the Wuhan National High Magnetic Field Center. The compensator is composed of a compensation coil and its power supply. The compensation coil, which is put inside the 50 T dual-coil magnet coaxially, is used to generate a magnetic field to compensate the ripple generated by the 50 T dual-coil magnet. The energy to operate the coil is provided by a 16 V/500 F super capacitor. To accommodate the needs of this coil, a PWM full-bridge circuit with variable output and bidirectional energy flow, is designed as the discharge circuit. The active ripple compensator has the advantages of modularization, flexibility and low energy consumption. The simulation model including the generator-rectifier power supply is established on the MATLAB/SIMULINK platform. The ripple of 50 T magnetic field is reduced from 1000 ppm to 100 ppm, which verifies the feasibility of the scheme. Acknowledgements: The National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Thu-Af-Po4.11 / 1105**Design of dipole magnet integral measurement system for HTPTF****Author(s):** Jun Yang¹**Co-author(s):** Hui Liang¹ ; Wei Chen¹ ; Bin Qin¹¹ *Huazhong University of Science and Technology*

A new proton therapy facility (HTPTF) is under construction in Wuhan, China. The dipole magnet integral measurement system was designed for the beam transport system of the HTPTF. The design goal is to build a reliable, precise, automatic measurement system, and it is accurate enough to characterize the magnetic field quality of the dipole magnets in the beam transport system. The integral measurement system consists of a long coil, precision motion stages, data acquisition and control system. The design of the whole system and the measurement method is described in this paper. The design and fabrication of the long coil are also discussed, and the errors from the geometric frame of coil and electronic equipment are analyzed.

Submitters Country:

China

Wed-Af-Po3.07 / 1094

Design of hybrid thrust magnetic bearing for heavy rotating shaft considering self-weight compensation according to axial load**Author(s):** Ji-Hun Ahn^{None} ; Jang-Young Choi^{None}**Co-author(s):** Cheol Han ; Chang-Woo Kim¹ ; Cheol-Hoon Park¹ *Chungnam National University*

Hybrid thrust magnetic bearing(HTMB) for heavy rotating shaft should be considered axial load at initial design stage since as the load increases, the force is generated asymmetrically. Therefore, the force acting on the upper part and the force acting on the lower part must necessarily be designed in different ways. In the case of a vertically driven shaft with a heavy impeller mounted vertically, because of the axial weight always acts as a load in the downward direction, the forces acting in the same air gap cannot be balanced, and the greater the weight of the shaft, the greater the imbalance of the axial force of the HTMB. Therefore, the position of the axial collar has to move further upwards or downwards in order to maintain the balance between the upper directional force and the lower directional force. The thrust collar must be located at position that the force of the upper and lower parts is in equilibrium for flexible control, but the closer the thrust collar is to the upper and lower core, the smaller the mechanical air-gap and the shaft may be damaged, or a lot of HTMB loss occurs since the current for HTMB control increase when the magnetic bearing force is imbalanced. In this paper, The first part focuses on the design of HTMB which use a finite element method (FEM), deals with a general design that does not consider self-weight according to axial load. The second part is based on the validation of the initial designs by experiments using a manufactured HTMB, and deals with the influence of self-weight that changes according to the axial load. Finally, redesign of HTMB for compensation self-weight with axial load, and validation of the results by the two-dimensional FEM, and then by experiments using a manufactured model.

Submitters Country:

Republic of Korea

Mon-Af-Po1.07 / 716

Design of maximum power density of TVC driving motor for space launch vehicle considering space environmentHyun-Woo Jun¹ ; JONGSUK LIM² ; Gang Seok Lee³ ; Ju Lee¹¹ *Hanyang University*² *Hanyang university*³ *Hanyang Univ.*

The most important point in electromagnetic design for the drive motor design of an electric TVC(Thrust vector control) system for space launch vehicle is the right choice of the maximum allowable current density considering the heat transfer condition of the vacuum environment and light weight design through high output density design. Thermal-electromagnetic interaction analysis considering the heat transfer conditions of the system's environment is performed, where the heat flow between the system components is determined by the specific heat and the heat transfer coefficient. In the heat transfer method, the heat transfer coefficient is determined by the kind and area of the material and the temperature difference in case of conduction and radiation, but in the case of convection condition, the conduction coefficient changes according to the pressure. The thermal conductivity

coefficient was calculated considering the operating environment of the system in the stratosphere, and the maximum allowable current density of the TVC system could be calculated through this calculation. The output density is usually expressed as a volume-to-volume output, which is a criterion for how efficiently a motor can produce large forces. In the situation where the allowable voltage and the limit drive speed are determined, the achievement of the maximum output density can be achieved through the electromagnetic improvement design. An analysis of how much TRV(Torque per unit rotor volume) has been increased compared to the existing design through the application of various latest high power density design techniques.

Submitters Country:

South Korea

Wed-Af-Po3.04 / 331

Design of prototype magnets for HUST Proton Therapy beam-line

Author(s): Wei Chen¹ ; Xiaoyu Fang¹ ; Zhikai Liang¹ ; Xu Liu¹ ; Kaifeng Liu¹

Co-author(s): Bin Qin¹

¹ HUST

A proton therapy project HUST-PTF (HUST Proton Therapy Facility) based on a 250 MeV isochronous superconducting cyclotron was under development in Huazhong University of Science and Technology (HUST). In this paper we reported the main design considerations of the beam line in HUST-PTF project. As well as two prototype magnets (one quadrupole and one dipole) were designed. Two-dimensional contour optimization and pole-end chamfer iteration were used to minimize the systematic harmonic errors. Finally, Both the field uniformity and harmonic errors achieved the precision requirement and were presented in the paper in detail.

Submitters Country:

China

Mon-Af-Po1.07 / 191

Design of the Conduction-cooled YBCO Magnet for a MW Class Induction Heating System

Author(s): Dong Zhang¹

Co-author(s): Liye Xiao² ; Naihao Song³ ; Xiaoyong Wang³ ; Liwei Jing³ ; Guomin Zhang³ ; Liangzhen Lin³

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³ *IEE, CAS*

Abstract—With the power conversion device proposes greater efficiency and higher power, the new HTS induction heating equipment shows a wide application prospect in the future in the field of metal material through heating treatment. Efficiency analysis for the traditional induction heating and new structures for the HTS induction heating are studied in this paper. Calculation models for induction heating system electromagnetic field and billet region temperature field analysis are established. The MW class conduction-cooled YBCO magnet system is designed. The magnet consists of an iron core and HTS coils wound with the spliced YBCO-coated conductors. The magnet system is cooled by two AL325 GM refrigerators with the pluggable structure and the operating temperature

is 20~30 K. Furthermore, the prototype YBCO coils with the same thickness are fabricated and tested to evaluate the performance of conduction-cooled YBCO magnet. In this paper, test results of the prototype magnet are presented.

Submitters Country:

China

Wed-Af-Po3.05 / 219

Design of the high power density permanent magnet synchronous linear motor with water cooling structure in the end windings

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Permanent magnet linear motors (PMLMs) are increasingly applied in computer numerical control machine tools, rail transportation, linear generators, etc. owing to the advantages of simple structure, convenient control, high positioning accuracy and high efficiency characteristics. Besides, it is urgent to exploit the high power density electric machine (HPDEM) to meet the increasing requirements for producing the PMLM miniature, high energy efficiency, and cost-effective. While the first task on the road to research the HPDEM is the dissipation, the heat dissipation problem is related to the safety operation of high power density electric machine, which is important in the process of designing and improving motor's efficiency and working capacity. The increased current density will increase more loss, and the temperature rise will be more higher. At present, the rated current density of PMLM is about 5A/mm² with natural air cooling structure. In this article, a permanent magnet linear motor (PMLM) with current density of 12A/mm² is designed and a water-cooling structure of end windings is proposed. Different from the existing water cooling structure in the back iron of the primary, the proposed water cooling structure in the end windings can not only improve the dissipation capacity of the end windings, but also afford another heat dissipation channel for the coils in the slot, where is the most vulnerable component. In this article, the cooling performance of the proposed water-cooling structure is compared with the existing cooling structure in the back iron of the primary based on the finite element method (FEM). The results show that the cooling structure in the end windings is more useful; besides, this structure is simple and easy to implement.

Submitters Country:

China

Mon-Af-Po1.09 / 225

Design of the internal embedded joints for the EU DEMO TF coils

Author(s): Aldo Di Zenobio¹; luigi affinito¹; Alessandro Anemona²; Mohammed Arabi²; Sandro Chiarelli¹; Valentina Corato¹

Co-author(s): Luigi Muzzi¹; Simonetta Turtu³; Antonio della Corte¹; Riccardo Righetti²; Luigi Morici¹

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Within the frame of the R&D activities carried out in Europe for the Toroidal Field (TF) Coils of the nuclear fusion device DEMO, different proposals have been given so far. All of them rely on superconducting (SC) Low Tc wires (Nb3Sn). The present paper deals with a Wind & React solution based on Cable-In-Conduit Conductors (CICCs). The TF coil is a graded layer one, with varying SC, Cu and SS quantities every 2 layers, thus permitting an optimized distribution of the materials and consequent cost savings. The whole Winding Pack (WP) is formed by 6 Double Layers (DLs), each wound over the previous one. This solution makes the internal joints connecting two different DLs a crucial topic for a sound performance of the coil. Basing on previous successful experiences, as for instance the EDIPO and the NAFASSY Nb3Sn coils, our team is designing a proposal for such intermediate joint so to possibly "embed" it in the WP. This is feasible only if the whole junction is kept within the same external dimension of the two joined conductors. A complete description of the joint design for each connected DL is given here, along with hints about the manufacturing of a SULTAN sample, foreseen to be tested in order to confirm the joint electrical performances, both in terms of ohmic resistance and AC losses under variable magnetic field and temperature.

Submitters Country:

ITALY

Mon-Mo-Or2 / 357

Design of the resistive insert coils for the HFML 45 T Hybrid Magnet

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In 2007 the Nijmegen High Field Magnet Laboratory has embarked in a programme to design and construct a 45 T hybrid magnet to provide the highest magnetic field available to its user programme. We present the final design of the resistive insert coils for this hybrid, which will operate in the 12.3 T background field of the superconducting outsert magnet. The insert magnet has an outer diameter just shy of 600 mm and consists of five Florida Bitter coils, with the Nijmegen cooling hole optimisation. The coils will operate at 38 kA, with the innermost coils (A1 and A2) powered in parallel, and generate an on-axis field of 33.0 T. The power consumption is restricted to 21 MW to accommodate, if necessary, additional power to compensate for variations in Bitter disk thickness or deviations in cooling properties. Construction of the stamping tools for the disks has started and the first disks will be produced in the spring of 2018.

Submitters Country:

The Netherlands

Mon-Af-Po1.04 / 421

Design principle of WFSM for Electric Vehicle based magnetic-thermal equivalent circuit

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INTRODUCTION: Following to the recently emerging environmental regulations and energy depletion, HEV and EV draw attention as future cars. And there are many studies carried out for traction motor design. This study is about a design algorithm which can make wound field synchronous motor design easier and faster. Because main flux path is sensitive to magnetic saturation and heat problem is caused in a rotor by copper loss, basic design considering that problems is necessary especially in case of high torque density application. Non-linear magnetic equivalent circuit is constructed to calculate non-linear design parameters of motor exactly and a thermal equivalent circuit is also made to select accurately current density. This paper proposes the basic design algorithm based on the non-linear magnetic and thermal equivalent circuits and accuracy of equivalent circuits is verified by a comparison with FE analysis. A basic design of 140kW-class wound field synchronous motor is done with the proposed basic design algorithm. And a test results of final model design will be added in the full paper.

Submitters Country:

Republic of Korea

Tue-Af-Po2.06 / 738

Design strategy of interior permanent magnet synchronous motor for maintaining torque performance at flux weakening region

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Recently, various types of electric motor are applied to vehicle traction field because of strengthened environmental law. In general, Interior Permanent Magnet Synchronous Motor(IPMSM) has high power density and efficiency due to reluctance torque by adopting permanent magnet. By these advantages, IPMSM is widely used in Electric Vehicle(EV) traction motor. In case of EV traction motor, operating region varies from low speed region to high speed region. IPMSM has different performances at flux weakening region due to its center of voltage limit ellipse. In this paper, design method for maintaining torque performance of high speed region is proposed.

IPMSM of analyzed model has 8 pole and 72 slot. Hairpin winding is adopted for increasing power density by augmentation of slot fill factor. d and q axis current and phase angle of IPMSM is decided by its limitations not to exceed voltage limit. In flux weakening region, torque is continuously decreases by increasing rotating speed. By applying design method, torque of flux weakening region is maintained.

There's several methods for maintaining torque performance at flux weakening region. By changing various design parameters can improve torque performance of flux weakening region. For maintaining input condition, control factors of models are stator outer and inner diameter, air gap length and slot area. If portion of back yoke and teeth changes, also the torque of flux weakening region changes. If the length of stator teeth is decreased, magnetic flux density of MTPA region is increased and as a result, torque is decreased. But in flux weakening region, magnetic flux density is increased to proper level and torque performance is improved.

Submitters Country:

South Korea

Mon-Af-Or5 / 675

Design study of an HTS magnet with REBCO coils for heavy ion beam-line experiments

Author(s): Kei Koyanagi¹

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² *JAEA*

³ *KEK*

⁴ *Toshiba Corporation*

⁵ *QST(NIRS)*

⁶ *Kyoto University*

A project to develop fundamental technologies for accelerator magnets using REBCO coated conductors is currently underway funded by the Japan Science and Technology Agency (JST).

In this project, an FFAG (fixed field alternating gradient) accelerator for the carbon cancer therapy system is one of the primary applications. In the first step of this project, REBCO coils with complicated winding shapes were fabricated and a reduced-size test magnet was developed to verify the winding technology required for the HTS accelerator magnets. In the following stage, there are plans to develop another experimental REBCO magnet for the performance evaluations in the beam line of the HIMAC (Heavy Ion Medical Accelerator in Chiba) at NIRS (National Institute of Radiological Sciences). This development has two main objectives; demonstration of beam guiding characteristics and stability verification of the magnet against beam loss. For these experiments, a cryocooler-cooled magnet with REBCO coils has been developed to generate dipole field in the room temperature bore. The magnet consisting of multiple REBCO pancake coils with racetrack shapes was designed. The coils were designed to generate a peak field of 2.3 T at the beam orbit and also designed to meet the target value of the field accuracy. A cryostat structure and a layout of the coils have been studied to verify the stability against beam loss as compared with the Monte Carlo simulation. In the experiments, magnetic field distribution in a beam duct will be also evaluated to reveal the effect of the magnetization behavior of coated conductors. This paper describes design and fabrication results of the REBCO coils, magnetic field calculation, and simulation of ion beam transport in the dipole field.

Acknowledgements

This work was supported by the Japan Science and Technology Agency under the Strategic Promotion of Innovative Research and Development (S-Innovation) Program.

Submitters Country:

JAPAN

Thu-Af-Po4.01 / 865

Design, Assembly and Use of a Device to Eliminate Earth Faults Caused by Foreign Metallic Debris in the LHC Main Dipole Circuit

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The superconducting dipole magnets of the Large Hadron Collider operate in a superfluid helium bath at 1.9K. As a part of the magnet quench protection system, each dipole magnet is equipped with a by-pass diode located in the helium bath. The connection between the superconducting magnet and the cold by-pass diode is made through a clamping system called “half-moon”, located at the lowest point of the cold-masses. This area is prone to receiving metallic debris residual from the assembly technological processes. The metallic debris might move and create an earth fault during helium flows that occur not only during the flushing of the cryogenic installation but also during magnet quenches at high currents. In the case of appearance, the earth fault is detected by the protection system of the circuit and the current is ramped down to zero as a consequence. Subsequently, with the circuit current already at zero, the fault can be eliminated using a device denominated Earth Fault Burner (EFB). The fault elimination must follow a strict procedure as it is not fully risk-free. This paper describes the details of such an earth fault elimination, including preliminary diagnostics and necessary hardware. Two examples from the LHC operation are described and discussed.

Submitters Country:

Poland

Thu-Mo-Or31 / 972

Design, Construction and Operation of a 13 T 52 mm No-Insulation REBCO Insert for a 20 T All-Superconducting User Magnet

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⁵ Seoul National University / National High Magnetic Field Lab.

To date, quite a number of no-insulation (NI) REBCO magnets have been designed and constructed, and all of them successfully generated their target fields. Some magnets experienced a quench at their full fields and survived without damage. The results have shown a potential of the NI REBCO winding technique for high field user magnets. Motivated by the recent progress, a 20 T all-superconducting user magnet project was launched in early 2016 at the National High Magnetic Field Laboratory, where a 13 T 52 mm NI REBCO insert has been designed and constructed with support from the University of Florida to purchase the REBCO conductors. The insert will be installed in a cold bore of a 7 T low temperature superconductor background magnet to complete the 20 T all-superconducting system. The insert consists of a stack of 24 double pancake coils wound with multi-width (MW) REBCO tapes manufactured by the SuNAM, Co., Ltd. It is expected to generate a target field of 13 T at an operating current of 213 A that corresponds to a current density of the narrowest-tape-wound coil of 433 A/mm². We plan to apply the active feed-back control method, recently proposed by our team, to precisely control the steady-state field generation as well as to reduce the charging time delay. This paper presents design and construction details of the 13 T insert and operation results and user feedback of the complete 20 T system.

ACKNOWLEDGMENTS: This work was supported by the National High Magnetic Field Laboratory (which is supported by the National Science Foundation under NSF/DMR-1157490), and by the State of Florida.

Submitters Country:

USA

Thu-Mo-Or28 / 1111

Design, Construction and Test of HTS/LTS Hybrid Dipole

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This paper presents the design, construction and test results of a hybrid dipole magnet built with inner coils made of High Temperature Superconductor (HTS) and outer coils of Low Temperature Superconductor (LTS). This is believed to be the first significant HTS/LTS hybrid R&D dipole magnet to be built and tested. The dipole is based on the common coil design with simple racetrack coils. The interest in HTS/LTS hybrid dipoles has risen recently as a way to provide very high fields for future high energy colliders such as the Future Circular Collider (FCC). The HTS "insert" coils were made with ReBCO tape and the LTS outer coils with Nb3Sn Rutherford cable. The outer coils were made over a decade ago for a magnet that reached 10.2 T at 10,800 A. The HTS and LTS coils were independently powered and protected using different power supplies. The HTS coils were quenched many times with no degradation in performance observed. HTS coils were independently ramped to 800 A and the LTS coils to 10,000 A. The hybrid field reached was ~8.6 T, limited by the stable operation of the LTS coil leads at 8000 A. With improved leads and instrumentation, this hybrid dipole is expected to produce over 13 T when the HTS coils are primarily aligned parallel to the field. One major purpose of this program was to perform magnetization studies in the coils made with the HTS tape. These measurements were performed at 77 K with the field either parallel to or perpendicular to the wide face of the HTS tape. In addition, measurements were also performed at 4 K in different background fields provided by the outer Nb3Sn coils. This paper will summarize the magnetization measurements and present the quenching experience of the HTS coils in this hybrid magnet system.

Submitters Country:

USA

Thu-Af-Po4.02 / 1170

Design, Construction and Testing of Reduced Insulation Solenoids for Fusion

Yuhu Zhai¹

¹ Princeton Plasma Physics Laboratory

Princeton Plasma Physics Laboratory is currently developing a targeted superconducting magnet R&D program in support of its leading design studies of Fusion Nuclear Science Facility (FNSF) and Pilot Plant using the most promising magnetic confinement configurations including Spherical Tokamak and Stellarator. An innovative magnet design approach is required to ensure success of the FNSF, focusing on capabilities to close the gap between rapid advances in High Temperature Superconductor (HTS) and the maximal fusion energy extraction from ITER-like burning plasma development. Irradiation damage to organic insulation in the coil winding pack is a critical issue for the next step fusion reactors where orders of magnitude higher neutron fluence than that in ITER are expected. On the other hand, slow current charging time is an issue in a fully non-insulation coils. We present design, construction and cryogenic testing of mid-level field in-house built Nb3Sn solenoid coils with a novel design of significantly reduced organic insulation in the coil winding pack. Coil behavior during current charging and discharging will be investigated for flux swing needed from the FNSF CS magnet design.

Submitters Country:

United States

Wed-Af-Or25 / 763

Design, Fabrication, and Test Results of an 18 T Metal Cladding GdBCO Magnet for Axion Detector**Author(s):** Jaemin Kim¹ ; Yungil Kim² ; Kang Hwan Shin¹ ; Sangwon Yoon¹ ; Kyekun Cheon³ ; Hunju Lee¹ ; Seung-Hyun Moon¹**Co-author(s):** JongHee Yoo⁴ ; Ji-Young Lee⁴ ; Ahn Moohyun⁴ ; Dong Lak Kim⁴¹ *SuNAM Co., Ltd.*² *SuNAM Co.,Ltd*³ *SuNAM*⁴ *Center for Axion and Precision Physics Research, IBS*

An 18 T 70 mm cold bore high temperature superconducting (HTS) magnet was developed for axion detector system of Center for Axion and Precision Physics (CAPP) research center in Institute for Basic Science (IBS) in the Republic of Korea. No-insulation (NI) technique with metal cladding (MC) HTS tape was adopted for preventing damage from quenches. However, a NI magnet shows field lagging behavior due to leakage current flowing in the radial direction. In 2015, we proposed a new type of HTS tape as a name of "metal cladding" to reduce field charging time in NI magnet. Metal cladding HTS tape is surrounded by high resistive metal, and its NI magnet has high resistance between turns. Thus, field charging time could be remarkably reduced. We chose stainless steel (316L) as a cladding material because of its electrical and mechanical properties. A key parameter for axion detector magnet is to generate high and longitudinally uniform magnetic field in RF cavity. Magnetic field strength on $-100 \text{ mm} < z < 100 \text{ mm}$ in coil bore space should be larger than 90 % of it at magnet center. Total 44 double pancake (DP) HTS coils are assembled and wound by HTS tapes of various widths of 4.1, 5.1, 6.1, 7.1, and 8.1 mm (multi-width). In this presentation, we report the magnet design, fabricating process, and test results in liquid nitrogen and liquid helium.

Submitters Country:

South Korea

Wed-Af-Or25 / 466

Design, Manufacture and Testing of a Pair of Superconducting Solenoids for the Upgrade of the Neutron Spin-Echo Spectrometer J-NSE at the Research Reactor FRM II (Munich)**Author(s):** Cristian Boffo¹**Co-author(s):** Stefano Pasini² ; Olaf Holderer³ ; Tadeusz Kozielowski² ; Michael Monckenbusch² ; Achim Sendner⁴ ; Jochen Steinmann⁴ ; Eckhard Theisen⁴ ; Wolfgang Walter⁴¹ *Babcock Noell*² *Forschungszentrum Jülich GmbH*³ *Forschungs-Neutronenquelle Heinz Meier-Leibnitz*⁴ *Babcock Noell GmbH*

A Neutron Spin-Echo (NSE) -spectrometer measures small velocity changes that neutrons undergo upon scattering at a sample. The velocity changes are encoded/decoded by the neutrons spin precession in large magnetic field before and after the sample. In order to achieve maximum sensitivity

and efficiency, both a high value and a high precision of the magnetic field integral before and after the sample, which determines the resolution of the instrument, are required. FZJ has decided to substitute the water-cooled copper coils of the J-NSE installed at the research reactor FRM II in Munich with a fully symmetric pair of large superconducting coil-systems to allow for a higher magnetic field integral. Each coil-system consists of 10 individual coils in a cryostat to achieve a field shape with minimal intrinsic field integral inhomogeneity over the beam cross section. Each system contains about 59 km of NbTi strand and a cold mass of 2 tons conduction cooled by two pulse tube cryocoolers. The resolution of the J-NSE will be extended significantly by the application of these new coils. This document presents the engineering results and design as well as manufacture and acceptance testing of the superconducting coil-systems.

Submitters Country:

Germany

Mon-Af-Po1.09 / 227**Design, Testing and Commissioning of 25.7 kA HTS Current Leads**Guido Consogno¹ ; Michael Boersch¹ ; Pascal Erni¹ ; Walid Abdel-Maksoud² ; Laurent Genini³¹ WEKA AG² CEA³ CEA/IRFU

Superconducting high field magnets use the principle of superconductivity of the material, thus working with very high current density in thin cables. The cables are cooled down to cryogenic temperatures inside of a vacuum insulated cold box. In order to feed the high current into the cold box, it is important to cool down the conductors progressively. The less coolant is needed for current unit, the more efficient is the system. Hybrid current leads, using the properties of BSCCO 2223 (High Temperature Superconductor), have an almost-zero resistivity already at higher temperatures around 50 K and are a very efficient way to reduce the consumption of cooling energy. This philosophy has been applied to a pair of 25.7kA current leads, aimed for a magnet test facility of CEA Saclay for verifying the Toroidal Field Coils of the Tokamak JT-60SA. This contribution describes the design features and parameter and its confirmation through the first commissioning results.

Submitters Country:

Switzerland, France

Thu-Af-Po4.01 / 112**Design, fabrication and test of a 2 T superconducting dipole prototype by using tilted solenoids**Yuquan Chen^{None} ; Wei Wu^{None} ; Yu Liang^{None} ; Beimin Wu^{None} ; Enming Mei^{None}

A novel scheme of the superconducting dipole magnet which superposes two concentric and oppositely titled solenoids with respect to the bore axis is described. A designed dipole magnet prototype consists of four tilted solenoids by using a 7-strands NbTi superconducting cable and will produce a 2 T magnetic field with operating current of 3 kA. The bore diameter is 50 mm. The detailed magnetic field design by the software of OPERA is presented. The fabrication and test of the magnet prototype are also reported in detail.

Submitters Country:

China

Wed-Af-Po3.08 / 804

Design, fabrication, and test of a dual-coil system for electromagnetic sheet forming

Author(s): Ning Liu¹**Co-author(s):** Zhipeng Lai²; Quanliang Cao; Yujie Huang²; Xiaoxiang Li²; Meng Chen; HanChen Xiao; hang zhang²; Liang Li¹ *Huazhong University of Science and Technology*² *Huazhong University of Science and Technology*

In electromagnetic sheet forming(EMF)process, the driving coil structure and strength play a crucial role in the magnetic field distribution and corresponding electromagnetic force acting on the work-piece, which determines the forming performance. In this work, a new EMF system with a dual-coil was proposed to investigate coil strength and the effect of electromagnetic force distribution on the deformation behavior of the work-piece. Different from the traditional EMF coils, the dual-coil system has two coils which are energized by two independent power sources, respectively. Hence, the discharge energy and timing of the two coils can be flexibly controlled for adjusting the temporal and spatial distributions of electromagnetic force. To validate the feasibility of the dual-coil system, numerical simulations and a series of experiments have been presented and results show that the structure strength of the dual-coil has an obvious improvement and the forming performance of an aluminum alloy sheet with a diameter and thickness of 300mm and 2mm can be effectively improved, compared with the conventional single-coil system. Meanwhile, it has been found that, the discharge sequences of the two coils have an obvious influence on the forming performance.

Submitters Country:

China

Mon-Af-Po1.09 / 1184

Design, manufacture and test of 20 kA binary current leads for the HFML 45 T hybrid magnet

Andries den Ouden¹; **Matthias Hoffmann**²; **Chris Wulffers**³; **Gideon Laureijs**⁴; **Frans Wijnen**⁵; **Jos Perenboom**³; **William Marshall**⁶; **Iain Dixon**⁷; **Mark Bird**⁸; **Nigel Hussey**³¹ *Radboud University, Nijmegen, The Netherlands*² *Radboud University Nijmegen-High Field Magnet Laboratory,*³ *Radboud University Nijmegen - High Field Magnet Laboratory*⁴ *Radboud University Nijmegen-High Field Magnet Laboratory-*⁵ *Radboud University Nijmegen*⁶ *National High Magnetic Field Laboratory*⁷ *NHMFL-FSU*⁸ *FSU*

The High Field Magnet Laboratory has designed, manufactured and tested a pair of 20 kA binary vapour cooled/superconducting current leads for the superconducting outsert magnet of its 45 T hybrid magnet system, in close collaboration with the National High Magnetic Field Laboratory (FL, USA). The resistive section of each lead consists of 22 parallel copper plates cooled by a flow of nitrogen vapor evaporating from a level controlled liquid nitrogen reservoir. As shown during the test at the HFML of similarly cooled 20 kA binary leads for NHMFL's Series Connected Hybrid this cooling scheme ensures a very stable temperature of about 77 K at the transition from the resistive section to the warmest part of the HTS section. The HTS section is made up of 60 pre-soldered stacks of 4 Ag/Au sheathed Bi-2223 tapes. The ese stacks are soldered simultaneously into machined

slots of a stainless steel cylinder and onto both the 77 K copper interface and the 5 K copper bus bar connector block. The dedicated test facility at HFML provides the required current, a level controlled liquid nitrogen supply, and a closed-loop supercritical helium supply at 5 K and 5 bar. A test assembly is made, including the pair of current leads, an actively cooled jumper made from an aluminum stabilized NbTi Rutherford type of cable, instrumentation and mounting hardware. In this paper we present details of the design and manufacture of the current leads and the test facility and report results from the powering tests including measurement of the temperature, current and field safety margins for the HTS section and the response to loss of coolant.

Submitters Country:

The Netherlands

Mon-Af-Po1.02 / 203

Design, manufacturing and testing of a unique coil collaring system for the Jefferson lab's large superconducting magnets SHMS Dipole and Q2Q3 quadrupoles

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⁵ *Jefferson Lab*

Three large superconducting magnets have been designed and built by Sigmaphi (France) for the Jefferson Lab's 11 GeV/C Superconducting Spectrometer. These SHMS Dipole and Q2/Q3 quadrupoles use the same collaring system based on aluminum force rings designed to ensure coil integrity and avoid conductor motion. The coil properties have been determined thanks to mechanical tests at room temperature and at 4.2K. Conclusions of the FEA analysis performed by Sigmaphi have been verified thanks to strain measurements on a collaring prototype and during final collaring. Final acceptance tests done at JLAB are also presented.

Submitters Country:

FRANCE

Wed-Af-Po3.07 / 1114

Detailed analysis of conduction-cooled MgB2 for use in superconducting magnetic density separation

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Co-author(s): Chao Zhou²; Dorus Dijkstra¹; Giovanni Grasso³; Herman ten Kate²; Jaap Kosse¹; Marcel ter Brake¹; Matteo Tropeano⁴

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Superconducting MgB₂ wire is characterized to analyze the optimum working point of a magnet system for magnetic density separation (MDS) in terms of the magnetic field and operating temperature. MDS is an innovative recycling technology that selectively separates particles in a waste stream based on their mass density by suspending them in a ferro-fluid that flows through a strong vertical magnetic field gradient. Application of superconducting MDS on an industrial scale will require a user-friendly conduction-cooled magnet system. With its relatively high critical temperature and relatively low cost, MgB₂ is a prime candidate material to realize such a magnet. Since the separation forces depend on the product of the magnetic field and the ferro-fluid magnetization, the optimal design of a superconducting MDS system has to balance magnet cost (CAPEX, higher field implies a more expensive magnet) against the ferro-fluid price (OPEX, higher field allows for a more dilute fluid) and cooling requirements (OPEX, lower temperature implies higher power consumption). To be able to achieve this optimal balance, the critical surface of MgB₂ wire produced by Columbus Superconductors SpA is measured in detail and used as starting point to calculate the most adequate operating point of an MgB₂-based MDS system. This work is part of the research programme "Innovative Magnetic Density Separation for the optimal use of resources and energy" with project number P14-07, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

Submitters Country:

Netherlands

Mon-Mo-Or1 / 451

Detailed magnetic and mechanical design of the nested orbit correctors for HL-LHC

Author(s): Jesús Angel García-Matos¹ ; Fernando Toral¹

Co-author(s): Ezio Todesco² ; Pablo Abramian¹ ; Javier Munilla¹ ; Jesús Calero¹ ; Juan Carlos Perez² ; Jose Luis Gutierrez¹ ; Luis Garcia-Tabares¹ ; Nicolas Bourcey² ; Pablo Ramón Gómez¹ ; Susana Izquierdo Bermudez² ; Daniel López¹ ; Paolo Fessia²

¹ CIEMAT

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Nested orbit correctors magnets so-called MCBXF are needed for the upgrade of the LHC, in the framework of the HL-LHC project. There are two versions (A and B), with different physical lengths, respectively, 2.5 and 1.5 m, which share the same cross section to decrease the fabrication cost. These magnets have a large aperture of 150 mm. Due to the high radiation dose, a mechanical clamping is necessary to hold the large torque between both dipoles.

Magnetic and mechanical conceptual design is described elsewhere. This paper describes the final magnetic design, with special attention to 3-D electromagnetic calculations and the different operation scenarios. It also includes the results of a number of mechanical FEM models, which analyze the stress distribution and deformations at several load steps: assembly, cooling-down and energization. Finally, a mechanical model has been designed, fabricated and tested to show the feasibility of the proposed clamping structure. This paper also describes other tests performed to improve the accuracy of the FEM models, such as the measurement of the Young modulus of stacks of impregnated cables.

Acknowledgments: This work has been partially funded by CERN contract KE-2292 and the Spanish Ministry of Economy, Industry and Competitiveness under projects ref. FPA2013-47883-C2-2-P and Resolution on May 24th, 2016.

Submitters Country:

SPAIN

Tue-Af-Po2.12 / 607

Determination of Threshold Electric Field for PPLP Specimen in Liquid Nitrogen Based on the Measurement of Electrical Conductivity

Author(s): Bang-Wook Lee¹

Co-author(s): Ik-Soo Kwon²; Kuniaki Sakamoto²; Jin-Yong Na²; Jae-Hong Koo²

¹ *Division of Electrical Engineering*

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AC electric field distribution in composite insulation materials is mainly determined by their permittivity. However, DC electric field distribution highly depends on the electrical conductivity of the insulating materials, and this electrical conductivity exponentially increases with externally applied electric field in cryogenic environment. Therefore, we should not only obtain the accurate electrical conductivity according to externally applied electric field but also necessary to find out the threshold electric field of each insulation material for the desirable insulation design of dc power apparatuses. Accurate determination of the threshold electric field at which charge injection from the electrodes increases is the important matter for the reliable electric field analysis. Due to the presence of space charge in the insulation material, it could lead to the electric field enhancement, resulting in degradation and early failures of the insulation material. Therefore, in this paper, we tried to measure the electrical conductivity of the Polypropylene Laminated Paper (PPLP) specimen in liquid nitrogen (LN₂) and find out the threshold electric field. PPLP was widely known as insulating layer for dc High Temperature Superconducting (HTS) Power cable and the examination of the electric field characteristics of PPLP is very important for the reliable insulation design of dc HTS power cable. For the verification of the experimental results, the simulation works were performed using COMSOL Multiphysics in HTS cable model for the comparison of the electric field distribution depending on whether the threshold electric field were considered or not. Consequently, it was possible to deduce the threshold electric field for PPLP was around 10.34 kV/mm, and this value could vary the dc electric field distribution of HTS cable.

Submitters Country:

Republic of Korea

Mon-Af-Or5 / 718

Development Progress of a 9.4 T 100 mm Metal-Clad No-Insulation All-REBCO High-Resolution NMR Magnet Cooled by Conduction

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Since 2014, the Korea Basic Science Institute (KBSI), the Korea Institute of Machinery and Materials, the National High Magnetic Field Laboratory, and the SuNAM Co., Ltd. have been on international

collaboration to develop a 9.4 T (400 MHz ^1H frequency) 100 mm winding-diameter metal-clad no-insulation all-REBa₂Cu₃O_{7-x} (REBCO, RE = Rare Earth) high-resolution NMR magnet cooled by conduction. Once successfully completed in 2019, the magnet will be installed at the KBSI to serve as a new 400 MHz solid-state NMR user magnet. Prior to completion of the 400-MHz NMR magnet, a 3 T 100-mm metal-clad no-insulation all-REBCO "Demo" magnet was fabricated and tested, demonstrating that the approach of "metallic cladding" enables significant reduction in charging delay of a no-insulation magnet without losing its self-protecting feature and thus faster field shaking that is efficient for mitigation of screening current induced field. This paper presents the recent progress in development of the 9.4 T NMR magnet.

This work was supported by KBSI grant (D37611) to S.-G.L. funded by the Korea Basic Science Institute (KBSI).

Submitters Country:

Republic of Korea, USA

Tue-Af-Po2.04 / 59

Development and Performance of 65 T Fast-cooling User Magnet with Long Service Life

Author(s): Tao Peng¹

Co-author(s): Fritz Herlach ; Liang Li

¹ *Wuhan National High Magnetic Field Center*

Since the accomplishment of the pulsed magnetic field facility at the Wuhan National High Magnetic Field Center, a few types of pulsed magnets, such as the 40 T helical magnet, 65 T monolithic-coil magnet and 90 T dual-coil magnet, have been developed and are now in operation for scientific research. As the workhorse, the 65 T user magnets show excellent cooling performance and long service life. These user magnets have typical bore size of 21 and 23 mm. They are energized by 2 or 3 MJ capacitor bank for 50 ~ 80 ms pulse duration with crowbar circuit. For magnetization measurement, shorter pulse duration of 12 ms for field waveform with symmetrical rising and falling edge can also be produced with 1.25 MJ high reversal voltage capacitor bank.

In each of these magnets, a 5 mm axial cooling channel for flow of liquid nitrogen is fabricated. The cooling time between every two 60 T pulses ranges from 30 to 50 minutes depending on the magnets and the field waveform. Since 2013, six fast cooling user magnet have been manufactured. Two of them have failed after 616 and 916 pulses with the magnetic field above 60 T. The other three have delivered 34, 618 and 817 pulses above 60 T and are still in operation. The design and experimental results of these fast-cooling magnets will be reported in this paper.

Submitters Country:

China

Mon-Af-Or6 / 1012

Development and test of REBCO canted $\cos\theta$ dipole coils with CORC[®] wires

Andy Lin¹ ; Daniel Dietderich¹ ; Danko van der Laan² ; Diego Arbelaez³ ; GianLuca Sabbi³ ; Gueorgui Velez⁴ ; Hugh Higley¹ ; Jeremy Weiss² ; Joseph DiMarco⁵ ; Lucas Brouwer¹ ; Marcos Turqueti¹ ; Maxim Marchevsky³ ; Shlomo Caspi⁶ ; Soren Prestemon³ ; Stephen Gourlay³ ; Tengming Shen³ ; Thomas Lipton¹ ; William Ghiorso¹ ; Xiaorong Wang¹

¹ *Lawrence Berkeley National Laboratory*

² *Advanced Conductor Technologies*

³ *LBNL*⁴ *FNAL*⁵ *Fermi National Accelerator Laboratory*⁶ *Lawrence Berkeley national laboratory USA*

The US HEP Magnet Development Program is developing accelerator insert coils based on REBCO coated conductors. These insert coils will operate in high dipole or quadrupole background fields and enhance the field generated by the outsert coils made of Nb₃Sn or NbTi conductors. The inserts are of canted $\cos \theta$ (CCT) design configuration, which effectively intercepts the accumulation of azimuthal stress that can potentially damage the conductors. Through the collaboration with Advanced Conductor Technologies, we use the CORC® round wire due to its potential to offer high engineering current density in a mechanically and magnetically isotropic conductor form. The design and fabrication of the CORC® CCT dipole insert coils is presented. These coils were also tested at 77 K and 4.2 K in self-field, and we report on the coil performance including quench current and magnetic field measurements in the coil aperture.

Submitters Country:

U.S.A.

Wed-Mo-Or20 / 163**Development of 3 T high-temperature superconducting magnet for MRI**

Masayoshi Oya¹ ; Tetsuya Matsuda¹ ; Tatsuya Inoue¹ ; Tomohiro Morita¹ ; Ryo Eguchi¹ ; Syunsuke Otake¹ ; Toshinari Nagahiro¹ ; Hajime Tanabe¹ ; Shoichi Yokoyama¹ ; Akihiro Daikoku¹ ; Taketsune Nakamura² ; Yasuyuki Shirai² ; Daisuke Miyagi³ ; Makoto Tsuda³

¹ *Mitsubishi Electric Corporation*² *Kyoto University*³ *Tohoku University*

The new HTS application project supported by New Energy and Industrial Technology Development Organization (NEDO) started on July 2016 in Japan. One of the targets of this project is to demonstrate the half-scale magnet resonance imaging (MRI) system using high-temperature superconducting (HTS) magnets with REBCO coils. In the first phase of this project (2016 – 2018), a three-tesla magnet with active-shield coils will be manufactured. The room temperature bore of the magnet is 480 mm in diameter. The magnet will be cooled to less than 20 K with a G-M refrigerator and the MR imaging will be performed to evaluate the uniformity and stability of the magnetic field.

Submitters Country:

JAPAN

Tue-Af-Or17 / 1045**Development of 300 to 500 A/mm² at 10T/4.2K class ReBCO-CORC Round Wires****Author(s):** Tim Mulder¹**Co-author(s):** Danko van der Laan² ; Jeremy Weiss² ; Marc Dhallé³ ; Alexey Dudarev⁴ ; Herman Ten Kate⁴¹ *University of Twente (NL)*

² *Advanced Conductor Technologies*

³ *University of Twente*

⁴ *CERN*

Thinner substrate ReBCO tapes, nowadays produced by SuperPower, make it possible to wind thin CORC based ReBCO wires of 3 to 4 mm diameter. The reduction of the tape's substrate thickness from 100 via 50 to 30 micron leads to a significantly reduced minimum bending radius of ReBCO tapes. The 30 micron substrate tapes can now also be manufactured with a width of only 2 mm. Thinner substrates and narrower tapes allow production of CORC wires with more flexibility and a high current density. This technique of thin and round CORC wires opens up their general application in high field magnets and insert coils operating at 4 K as well as magnets operating at elevated temperature in the 20-50 K range, a range uniquely served by ReBCO. CORC wires with various tape layouts were tested in common effort of CERN, ACT and the University of Twente to develop this and potentially break-through technology. The 3.0 to 4.5 mm diameter CORC wire samples are tested in transverse magnetic field of up to 11 T as small solenoids at 4.2 K and in self field at 77 K. The tests demonstrate the ease of use and high performance of the new CORC wires. In addition the tests provide feedback needed to optimize wire manufacturing and joint terminal production.

Submitters Country:

Switzerland

Mon-Af-Po1.09 / 1056

Development of 52 kA HTS Current Leads for the ITER CS Magnet Test Application

Kaizhong Ding¹; Tingzhi Zhou¹; Kun Lu¹; Xiongyi Huang^{None}; Qingqing Du²; Qingxiang Ran¹; Chenglian Liu³; Yuntao Song¹; Piec Zbigniew⁴; Schaubel Kurt⁴; Liuwei Xu¹; Bo Li¹; Sikui Yu¹; Jun Li¹; Ke Zhang¹; Kaiming Jing¹; Quan Han¹; Jun Wang¹

¹ *Institute of Plasma Physics, Chinese Academy of Sciences*

² *ASIPP*

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⁴ *General Atomics*

Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) was contracted by General Atomics Company to develop a superconducting feeder system containing a pair of 52 kA high temperature superconducting (HTS) current leads for ITER Central Solenoid CS magnet test. These HTS current leads are majorly based on the previous ITER lead design experiences. However, the vertical assembly design which is different from ITER horizontal assembly causes the water leakage in the insulation flange during the initial phase. Some improvement was recognized and avoids the potential risk for further prototypes and series production of ITER leads. Some development experience will be shared in the paper. The HTS current leads contain BiSCCO AgAu tapes to minimize the heat load to 4.5 K end. Its resistive part is cooled by 50 K helium. The HTS part is cooled by conduction. The HTS current leads were integrated in the feeder system to perform 4.5 K full current test. The factory acceptance test was implemented to verify the high voltage and thermodynamic performances. The maximum current was achieved at 55 kA. The test indicates the helium mass flow consumption is 3.3 g/s per lead, and loss of flow accident (LOFA) time is close 10 minutes at the nominal current with the stoppage of 50 K helium. The insulation flange passed the high voltage test of 15 kV with less than 1 micro Ampere leakage current after the improvement. More detailed test results will be shown in the paper. The development of the whole feeder system for CS magnet test will be contributed on the different paper presented at this conference.

Submitters Country:

China

Thu-Af-Po4.01 / 910

Development of 7 T superconducting solenoid magnet for Electron Beam Ion Source

Su-Hun Kim¹ ; Se-Hee Lee¹ ; Seyong Choi²¹ *Kyungpook National University*² *Kangwon National University*

A proton accelerator requires a wide range of beam properties such as beam energy, beam current, beam repetition rate, and beam pulse width. The electron beam ion source (EBIS), which can perform short pulse operation up to 1 μ s, can meet the diverse requirements of users by facilitating enhanced utilization efficiency and broad application area. Therefore, the purpose of this study is to develop a superconducting solenoid magnet in order to focus electron beams, and to achieve a stable operation of EBIS system. A superconducting solenoid magnet plays a key role in the EBIS system for the production of short pulse beams. The electron beam extracted from the electron gun is accelerated till it reaches tens of keV. The electron beam is then focused by using a superconducting magnet. To increase the electron beam quality and utilization efficiency, a focusing radius below 1 mm is required. For achieving this criterion, the solenoid coil should be designed with the peak magnetic field of 7 T at the center. The solenoid coil needs highly uniform magnetic field along the axial and radial directions. Hence, a magnetic field analysis should be performed considering the characteristics of NbTi multifilament wire by using the finite element method. From the conceptual design result, the inner and outer diameters of the superconducting magnet are obtained as 280 mm and 324 mm, respectively. To satisfy the design requirements, the height of the coil is determined as 2000 mm. Furthermore, to prevent the mechanical deformation in the solenoid due to the Lorentz force distribution, the mechanical stress in coil is calculated by using the structural analysis. Detailed design parameters and numerical analysis results will be explained through the extended paper.

Submitters Country:

Republic of Korea

Tue-Af-Po2.08 / 637

Development of Analyzing Capability of React and Wind Process based on Strand Trace and Inter-Strand Resistance Measurement System for Cable-In-Conduit Conductor

TSUYOSHI YAGAI¹ ; Hayato Shoji¹ ; Kentaro Shimomura¹ ; Taro Morita² ; Hideki Kajitani³ ; Daisuke Miyagi⁴ ; Makoto Tsuda⁴ ; Tetsuhiro Obana⁵ ; Shinsaku Imagawa⁵ ; Toshiyuki Mito⁶¹ *Sophia University*² *Sophia University*³ *National Institutes for Quantum and Radiological Science and Te*⁴ *Tohoku University*⁵ *National Institute for Fusion Science*⁶ *National Institute for Fusion Science (NIFS)*

ITER project has been running in decades and has started after complications. While it is now under construction, design activity for new fusion device called "DEMO" has already taken place, in which the superconducting magnet system will be much larger than that of ITER. In the present project, the magnets are made of Nb3Sn superconducting material, hence heat treatment is needed to generate Nb3Sn intermetallic compound. In terms of fabrication process of large scale magnets, the heat treatment is applied after making coil shape, which is called "Wind and React" process because the Nb3Sn is sensitive to bending strain after heat treatment. Since we need to construct the huge electric heating furnace, introducing the process is one of the biggest problem with respect to the

cost and high requirements of its dimensional tolerance for making large scale magnets. In terms of designing DEMO magnets which are much larger scale than that of ITER magnets, more simple process, winding after heat treatment of conductor has been discussing in recent years, so called "React and Wind" process. Although it looks reasonable to make huge magnets, there is no research to evaluate the expected strains when we choose the conventional Cable-In-Conduit (CIC) conductors. To clear the applicability of the conventional conductors to the React and Wind process, we have been developing direct measurement system of all strand traces and inter-strand contact resistance as well as strain analyzing tools based on structural mechanics and complicated electrical network calculation. We will report the progress of proposing system at the upcoming conference.

Submitters Country:

Japan

Wed-Mo-Pl4 / 1224

Development of Carbon-Ion Radiotherapy Facilities at NIRS

Iwata Yoshiyuki¹

¹ *National Institute of Radiological Sciences (NIRS)*

Cancer therapy using high-energy carbon beams from the Heavy Ion Medical Accelerator in Chiba (HIMAC) has been carried out at NIRS since June 1994, and more than 10,000 patients were treated by now. With the prospective clinical results for the first ten years, we designed a compact accelerator facility for carbon-ion radiotherapy (CIRT), and performed related R&D works for widespread use of CIRT since 2004. Based on this design, three compact facilities for CIRT were constructed and are in treatment operation, and two facilities are being constructed in Japan. To further develop the sophisticated CIRT, we constructed a new treatment facility at NIRS. This new facility is equipped with three treatment rooms; two of them have both horizontal and vertical fixed-irradiation-ports, and the other is a rotating-gantry port. For all ports, fast 3D raster-scanning irradiation technology was employed. The rotating gantry equips ten combined-function superconducting magnets, and can deliver carbon ions having the energy of between 430-58 MeV/u to an isocenter with irradiation angles of over +-180 degrees. The superconducting magnets with optimized beam optics allowed a compact gantry design with a large scan size at the isocenter. Construction as well as installation of the superconducting gantry was completed by the end of September, 2015. Beam commissioning was successfully carried out, and treatments using the gantry are being conducted. Presently, we are further designing a next-generation compact superconducting gantry as well as a superconducting synchrotron as a future project. In this talk, an overview of carbon-ion radiotherapy and development of heavy-ion accelerators including a superconducting rotating-gantry as well as the future project will be presented.

Submitters Country:

Japan

Wed-Af-Po3.08 / 576

Development of Conduction-cooled Superconducting Split Coil for Metal Melting by DC Induction Heating

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Co-author(s): Shigeo Nagaya²; Naoki Hirano³; Satoshi Fukui⁴; Mitsuho Furuse⁵

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⁴ Niigata University

⁵ National Institute of Advanced Industrial Science and Technology

We already reported the capability of DC induction heating with the superconducting magnet to supply melting metal of required amount in a short time to the die-casting, in 2015. Many of complex geometries of aluminum profiles for automotive, transportation and industrial equipment are formed by the die-casting, and highly efficient metal melting technology for die-casting is required. We performed a metal melting experiment with the small examination equipment, which consisted of a motor, a heat insulation structure, a rotating shaft, a specimen holder, a frame and incidental devices, using a large low-temperature superconducting magnet, then. About 0.77 kg aluminum pipe was rotated in a DC magnetic field, ranging from about 1 T at the nearest point to 0.4 T at the furthest point, by the examination equipment. Aluminum melting in the sample holder was observed after the rotation of 1,200 rpm in 90 second. In order to obtain better distributed and stronger magnetic fields, the superconducting split magnet, using REBCO coated conductors, was designed and manufactured. The magnet contains six rectangle shaped double pancake coils with the short and long side of about 260 mm and 330 mm. The inductance of each coil was about 200 mH. Then the superconducting coils were cooled by the conduction cooling and generate the magnetic field for the aluminum heating examinations. The detailed design and the performance of the magnet for aluminum melting will be discussed.

Submitters Country:

Japan

Tue-Af-Po2.05 / 1166

Development of HTS bulk NMR relaxometry with ring-shaped iron rings

Author(s): SeokBeom Kim¹

Co-author(s): Hiroshi Ueda¹; Susumu Fukada²; Ryouta Nomura¹

¹ Okayama University

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The unique magnets for compact NMR relaxometry device consisted of the stacked high temperature superconducting (HTS) bulk annuli trapped by a field cooling (FC) method are suggested and studied. The magnetically charged HTS bulk magnet for NMR relaxometry device is cooled by liquid nitrogen and no more need a power supply. The strength and homogeneity of the magnetic field required for the NMR relaxometry device are 1.5 T and 150 ppm/cm respectively, these values are much lower than those of a conventional NMR device. The superconducting magnet (JASTEC, Inc.) wound with low temperature superconductors, and have a 100 mm room temperature bore size and 10 T was used in our experiments. The field homogeneity of our superconducting magnet is 610 ppm in the center region along the 10 mm axial direction. It is relatively easy to obtain a magnetic field of 1.5 T using suggested HTS bulk magnet at liquid nitrogen temperature. However, it is hard to obtain 150 ppm/cm field homogeneity using our superconducting magnet, and the field compensation methods are required. So, in this study, the passive field compensation method using the ring-shaped irons was studied, and the size and position of the iron rings were optimized to obtain the target field homogeneity by 3-D FEM based analysis. The obtained analytical and experimental field properties against the developed HTS bulk magnet with optimized iron rings and measured NMR signals using the fabricated NMR probe will be presented.

Submitters Country:

Japan

Tue-Af-Po2.01 / 174

Development of MQYY: a 90 mm NbTi double-aperture quadrupole magnet for HL-LHC

Author(s): Helene Felice¹

Co-author(s): Jean-Michel Rifflet ; Arnaud Pascal Foussat ² ; Laura Vida ZARAGOZA ³ ; Ezio Todesco ² ; Pawel Krawczyk ⁴ ; Fernando Toral ⁵ ; Isabel Bejar Alonso ² ; Marcello Losasso ² ; Hector Garcia Gavela ⁶ ; Damien SIMON ⁷ ; Michel Segreti ⁸ ; Juan Carlos Perez ²

¹ CEA/IRFU, Centre d'étude de Saclay Gif-sur-Yvette (FR)

² CERN

³ CIEMAT

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⁶ Universidad de Oviedo (ES)

⁷ CEA

⁸ CEA/Saclay

In the context of the HL-LHC project, a NbTi double aperture quadrupole magnet called MQYY is being developed. This 90 mm aperture quadrupole magnet has a magnetic length of 3.67 m and an operating gradient of 120 T/m at 1.9 K. Its development is done along two parallel paths: 1) the design, fabrication and test of a short model, 2) the design and fabrication of two full scale prototypes in industry within the H2020 EU Pre-Commercial Procurement project QUACO implemented by CERN, CEA, CIEMAT and NCBJ. We report here on the short-model design choices, the status of its fabrication and the preparation of the tests. In particular, we describe the magnetic and mechanical design relying on self-supporting collars, the protection aspects and the assembly process. In addition, we present the unusual scheme of the QUACO project leading to the prototypes fabrication. The QUACO project has received funding from the European Union's Horizon 2020 PCP programme under Grant Agreement no. 689359

Submitters Country:

France

Thu-Mo-Or30 / 920

Development of Nb3Sn strands and Rutherford Cables for 16 T Accelerators Magnets

Emanuela Barzi¹ ; Pei Li¹ ; Daniele Turrioni¹ ; Xingchen Xu² ; Alexander Zlobin¹ ; Vito Lombardo³

¹ Fermilab

² Fermi National Accelerator Lab

³ Fermi National Accelerator Laboratory

Fermilab, as part of US MDP, is conducting Nb3Sn wire and cable R&D, with the goal of improving key properties and providing conductor specifications and data for design and construction of SC accelerator magnets for a future very high energy pp collider. SC wire R&D focused first on optimizing the regular Restacked-Rod Process Nb3Sn conductor by Bruker OST. Then, efforts were intensified on research to improve Nb3Sn inherent flux pinning by producing artificial pinning centers in the Nb3Sn phase, which refines grain size to 30 nm. In parallel, Fermilab is collaborating with industry to develop Nb3Sn wires with increased specific heat to improve conductor stability and reduce sensitivity to external perturbations. Rutherford cable development includes heat treatment studies to boost performance of existing cables, and innovative design ideas for larger cables, which are preferred for 16 T magnets with appropriate operational margin. This paper will give an overview of the various SC R&D activities at Fermilab and their associated results.

Submitters Country:

U.S.A.

Mon-Af-Po1.10 / 446

Development of Quench Antennas for Quench Detection in Nb₃Sn Magnets

Author(s): Gerard Willering¹**Co-author(s):** Matthias Probst² ; Marta Bajko¹ ; Lucio Fiscarelli¹ ; Franco Julio Mangiarotti¹ ; Carlo Petrone¹ ; Hugo Bajas¹¹ CERN² KIT - Karlsruhe Institute of Technology (DE)

Detailed localisation of the quench start in Nb₃Sn accelerator magnets by voltage measurements requires a large number of voltage taps, which is less feasible in long prototype coils. Localisation with quench antennas is a proven concept for longitudinal quench localisation in full length accelerator magnets. Quench antennas are also excellent vibration detection tools, and give important information on the cause of the quench. Dedicated quench antennas were produced using state of the art flexible printed circuit boards. The quench antennas were tested at the CERN based SM18 superconducting magnet test facility in Nb₃Sn model magnets; the results were validated with voltage measurements and compared with numerical model predictions.

Submitters Country:

Switzerland

Mon-Af-Po1.12 / 645

Development of Real-time Monitoring System of the 100 MVA/100 MJ Flywheel Pulse Generator System

Yun Xu¹ ; Taiqiang Sun¹ ; Zhangfei Zhao¹ ; Tieqiang Ren¹ ; Hongfa Ding¹ ; Liang Li¹¹ Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology

A 100 MVA/100 MJ flywheel pulse generator system with the characteristics of high energy density and good control performance has been developed to energize the pulsed magnet at the Wuhan National High Magnetic Field Center (WHMFC). To realize the flexible, accurate, real-time and safe remote monitoring of the pulse generator system, a set of monitoring system using the total control plus sub-control mode was proposed so that the two sets of 12-pulse rectifier system can be used alone or together. Programmable Logic Controller (PLC) suitable for the industrial control was chosen as the central control system of the total control cabinet, which collected real-time operating parameters of rectifier transformer, direct current sensor, pure water cooler and other supporting facilities, and realized interlocking, protection and other function of electrical rules. High-speed and high-performance Digital Signal Processing (DSP) was chosen as the main controller of the sub-control cabinet to improve the accuracy of the firing angles. In addition, introducing the Complex Programmable Logic Device (CPLD) technology integrated the peripheral digital circuit of microprocessor into a piece of chip, which reduced the complexity of the system external wiring, improved the integration and reliability of the system. The host computer was realized by Monitor and Control Generated System (MCGS) based on OLE for Process Control (OPC) technology, which solved the problem that PLC protocol is not open. The proposed monitoring system has controlled the pulse generator system to energize the 50 Tesla magnet and the outer coil of the 100 Tesla magnet. The result shows that this monitoring system is stable, reliable, and easy to use, and can meet the security, flexibility and visualization requirements of the control system applied to pulsed magnetic high field facility.

Submitters Country:

China

Tue-Af-Or16 / 122

Development of SECRAL II superconducting magnet

Tongjun Yang¹ ; Wei Wu¹ ; Li Zhu² ; Enming Mei¹ ; Mingzhi Guan² ; Shijun Zheng² ; Wenjie Yang³ ; Liangting Sun² ; Lizhen Ma⁴

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² *Institute of Modern Physics, Chinese Academy of Sciences*

³ *Institute of modern physics, Chinese academy of sciences*

⁴ *Institute of modern physics,CAS*

A superconducting magnet has been developed for SECRAL II ion source at IMP. The design of this magnet is based on SECRAL, with sextupole coils external to the axial solenoids to reduce Lorentz force between sextupole coil's end and solenoids. The magnet consists of a set of sextupole coils and three solenoids to generate a confinement magnetic field. All the coils use a NbTi conductor and are bath-cooled in liquid helium. The challenges of the magnet are the sextupole coils' winding and cold mass's assembling. Thus, some modifications related to coil fabrication, cold mass assembling and cryostat have been adopted to improve the performance or simplify the process. The cold mass assembly was complete and tested in July 2014. Then the magnet was integrated into cryostat and finally trained to design current after several quenches. This paper will present the design, construction and test results of the magnet.

Submitters Country:

China

Tue-Af-Pl3 / 1220

Development of Superconductors at Furukawa Electric GroupHisaki Sakamoto¹

¹ *Furukawa Electric Co., Ltd.*

Half a century of development activities on superconductors, such as NbTi, bronze-processed Nb3Sn and REBCO, at Furukawa Electric Group will be presented. Plans for the future will be presented as well.

Submitters Country:

Japan

Thu-Af-Po4.07 / 525

Development of Test Device for Aluminum Metal Melting by Electromagnetic Induction Heating Using HTS Coils

Satoshi Fukui¹ ; Ryohei Ono² ; Jun Ogawa² ; Takao Sato² ; Tomonori Watanabe³ ; Shigeo Nagaya³ ; Naoki Hirano³ ; Mitsuo Furuse⁴

¹ Niigata University

² Niigata University

³ Chubu Electric Power Co., Inc.

⁴ National Institute of Advanced Industrial Science and Technology

The development and of magnetic billet heating with high temperature superconductor (HTS) coils provided energy benefits to the aluminum extrusion process, compared with conventional technologies. The magnetic billet heating technique by rotating aluminum rods in a magnetic field achieved large heating capacity with high efficiency in short time for an extrusion. Recently, in an industrial aluminum casting technology such as production of automotive parts, high efficient and high speed melting technology is required. Aluminum metal melting by induction heating using HTS coils is one of candidates. In our former study, we have verified the capability of induction heating using DC superconductor coils for aluminum metal melting in the casting process. In this study, the test device for aluminum metal melting by the induction heating using HTS coils was designed using the numerical electromagnetic and thermal analysis. Based on the numerical result, the 1/5 scale test device using REBCO HTS coils was designed and fabricated. In the presentation, the design and fabrication process of the test device, and the results of the preliminary experiment using the test device are reported.

Submitters Country:

Japan

Mon-Af-Po1.09 / 477

Development of Vapor-cooled Current Leads for LTS magnet in the EMPS

Myung Su KIM¹ ; Yeon Suk Choi¹

¹ Korea Basic Science Institute

The development of the Electro-Magnetic Property measurement System (EMPS) is underway at the Korea Basic Science Institute (KBSI). The EMPS is the equipment for measuring the electrical, thermal and magnetic properties of specimen in variable magnetic field and temperature using the low temperature superconducting (LTS) magnet. To energize the LTS magnet in the EMPS which operate at liquid helium, the vapor-cooled current lead (VCCL) is proposed. The LTS magnet is thermally connected to the power supply at room temperature through the pair of current leads, so the heat invasion is occurred through the current leads and it is one of the large factor of the entire heat invasion to the magnet. Therefore, optimized design and evaluation of current lead for the LTS magnet are necessary to minimize the heat invasion and liquid helium consumption. The VCCL for the LTS magnet is designed and fabricated, and the test of current leads in liquid helium cryostat is carried out. The LTS magnet is charged with the current up to operating level of the LTS magnet and the liquid helium boil-off rate with respect to the supplied current is measured. The boil-off rate due to the VCCL is corrected since other loads such as gas conduction and thermal radiation affect the amount of boil-off. The effect of vacuum level in liquid helium cryostat on the boil-off rate is also discussed. The experimental boil-off rate of liquid helium through the current leads agrees well with that of the design and the current leads will be applied to the EMPS.

Submitters Country:

South Korea

Mon-Af-Po1.11 / 872

Development of a 1.5 Tesla whole-body MRI Magnet with a very low helium inventory

Author(s): Adam Johnstone¹ ; Simon Calvert¹

Co-author(s): Michael Simpkins² ; Simon Chorley² ; John Teah² ; Jonathan Noys² ; Peter Dietz² ; Marcel Kruijff² ; Adrian Bampton²

¹ *Siemens Healthcare*

² *Siemens Healthineers*

We present a recent successful program to develop a 1.5 Tesla MRI magnet with a maximum helium inventory of less than 50 litres. The Magnet Technology Demonstrator was fully evaluated in a Siemens MRI system and found to deliver comparable imaging performance to a conventional bath-cooled magnet. As well as the development of the novel magnet technology, other key enabling technologies were developed. These included an automatic ramp-down system for protection against power outages and methods for cooling the magnet both within a manufacturing facility and on site. The program culminated in the successful demonstration of key technologies required to realise the next generation of whole-body MRI magnets with much reduced dependency on scarce and increasingly expensive helium.

Submitters Country:

United Kingdom

Thu-Af-Po4.02 / 733

Development of a 2D simplified tool for the analysis of the cooling of the ITER TF winding pack

Author(s): Francesca Cau¹ ; Ruggero Forte²

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³ *Fusion for Energy, F4E*

The cooling of the ITER Toroidal Field (TF) coils winding pack is guaranteed by the circulation of supercritical Helium (He) in 134 Nb3Sn Cable in Conduit Conductor (CICCs) and in 74 channels devoted to the cooling of the Stainless Steel (SS) case supporting the winding pack. A simplified tool aimed at computing the temperature distribution and the He temperature in the cooling channels of the TF winding pack has been developed. The advantage of this tool, which is based on 2D FE thermal analyses and has been entirely developed inside ANSYS with the APDL language, is that is able to provide in a relatively fast time the temperature reached by He during plasma operation. The heat load that has been considered is the volumetric nuclear heating computed with the MNCP code in 32 poloidal segments in which each TF coil has been divided. For each segment, a FE model has been built and a thermal analysis carried out by applying the corresponding heat load. The Heat Transfer coefficient (HTC) of the He flowing in the CICC and in the cooling pipes of the SS case is calculated with Dittus Boelter correlation, taking into account the pressure drop computed with the Katheder correlation. The He is assumed to enter the coil at 4.2 K in the lower terminal junction. Several steady state analyses have been done considering the baseline pancake wound configuration, and two ideal layer wound configurations. In these analyses the bulk temperature in all the CICCs in each of the 32 segments is calculated by means of enthalpy balance between segments, taking into account the actual direction of He circulation. In a second step, transient analyses of the pancake-wound and layer-wound configurations have been also carried out, considering the actual ramp up and ramp down of the nuclear heating.

Submitters Country:

Spain

Tue-Af-Po2.05 / 628

Development of a REBCO innermost coil for a persistent 400 MHz (9.39 T) LTS/REBCO NMR magnet

Author(s): Takeshi Ueno¹**Co-author(s):** Hideaki Maeda²; Kazama Yamagishi¹; Kentaro Kajita¹; Kotaro Ohki³; Takashi Yamaguchi³; Tatsuoki Nagaishi³; Tomoaki Takao¹; Yoshinori Yanagisawa²; renzhong piao²¹ *Sophia University*² *riken*³ *SEI*

We are starting the development of a persistent 400 MHz (9.39 T) LTS/REBCO NMR magnet as a first step towards a 1.3 GHz (30.5 T) LTS/HTS NMR. The 400 MHz magnet consists of a layer-wound REBCO innermost coil and an LTS outer coil which are operated in individual persistent circuits. The system requires the following technical developments; (a) a REBCO-REBCO superconducting joint, located above the REBCO coil, with a current capacity of >130 A at 4 K in a field of <1 T, (b) a reasonably fast 4 K REBCO persistent current switch (PCS), operated below a heat input of <10 W and (c) the design and fabrication of the REBCO innermost coil. We measured the transport properties of a new REBCO-REBCO superconducting joint 1, at 77 K and 4 K. The lift factor of the critical current from 77 K to 4 K and n-index at 4 K were 6.6 and 60, respectively. The assumed resistance based on the power-law V-I characteristics is much lower than the permissible resistance estimated from the required field decay rate of a NMR magnet. We developed a 4 K PCS with a resistance of 7 mΩ at 5 W and on/off times of <5 s and ~50 s, respectively. The performance of the PCS fulfills the operation requirement of the present magnet. The major challenge in the fabrication of the REBCO innermost coil is to avoid degradation of the performance of the terminal conductors connected to the PCS terminals since the REBCO conductor is easily degraded by handling and electromagnetic forces. We will present the results of persistent operations at 77 K and 4.2 K.

1 T. Nagaishi et al., Presented at 1st Asian ICMC and CSSJ 50th Anniversary Conference, 3A-p02, Kanazawa, Nov.7-10 (2016)

This work is supported by the MEXT NMR Platform Program.

Submitters Country:

Japan

Thu-Af-Pl7 / 1219

Development of a Superconductive Wind Power Generator within the EcoSwing project

Juergen Kellers¹¹ *ECO 5 GmbH*

The EU-funded EcoSwing project aims at demonstrating world's first superconducting low-cost and lightweight wind turbine drivetrain demonstrated on a large-scale wind turbine. This prototype generator is planned to operate in the second half of 2017. The main design considerations for this synchronous generator will be explained. Further the focus is on the superconductive coils made of 2G superconductor and the cryogenic infrastructure.

Submitters Country:

Germany

Thu-Af-Po4.07 / 609

Development of a low temperature superconducting magnet with MgB2 wire for a 10 kW DC induction furnace

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Generally, Nb₃SN and NbTi wires are used widely in superconducting applications. However, these wires are expensive and have low critical temperature (T_c of Nb₃SN=18 K, T_c of NbTi=9.8 K). To maintain the low-temperature condition, liquid helium is required continuously for cooling the wire and this causes lots of maintenance cost. However, MgB₂ wire has higher critical temperature than Nb₃SN and NbTi wires as 39 K. The MgB₂ wire does not need liquid helium and is able to make under the critical temperature condition using cryogen free cooling system such as conduction cooling system. Also, MgB₂ wire has an advantage of low price. Therefore, if we adopt MgB₂ wire to superconducting applications, we get advantages such as operating temperature, price, and cryogen free cooling system. In this paper, the authors develop a low temperature superconducting (LTS) magnet with MgB₂ wire for a 10 kW DC induction furnace. Firstly, a MgB₂ magnet is designed and analyzed using finite element method for a 10 kW DC induction furnace. Secondly, the magnet is fabricated using dry-winding method with metal insulation. Finally, MgB₂ magnet is assembled into the 10 kW DC induction furnace to evaluate its performance and characteristics. As a result, the MgB₂ magnet guarantees a satisfactory performance with low price and highest critical temperature among LTS wires. The low temperature as 20 K, which is the operating temperature of the MgB₂ magnet, can be achieved by a conduction cooling system. This study will be effectively utilized for a 300 kW DC induction furnace and other superconducting magnet applications.

Acknowledgements: This work was supported by the Power Generation & Electricity Delivery Core Technology Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 20142020103940)

Submitters Country:

Republic of Korea

Mon-Af-Or4 / 455

Development of a new generic analytical modeling of AC coupling losses in cable-in-conduit conductors (CICCs).

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Co-author(s): Alexandre Torre¹ ; Anna Chiara Ricchiuto² ; Arend Nijhuis³ ; Bernard Turck⁴ ; Daniel Ciazynski⁵ ; Frédéric Topin⁶ ; Ion Tiseanu⁷ ; Jean-Luc Duchateau¹ ; Louis Zani¹ ; Marco Bianchi² ; Marco Breschi² ; Tommaso Bagni³ ; V. A. Anvar³

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The determination of coupling losses induced in cable-in-conduit conductors (CICCs) when subject to time-varying magnetic field is a major issue commonly encountered in large fusion tokamaks

(e.g. JT-60SA, ITER, DEMO). The knowledge of these losses is crucial to determine the stability of CICC's but is yet difficult to achieve analytically in a satisfying way given the specific and complex architecture of these conductors: superconducting and copper strands twisted together in several helical cabling stages. Numerical modeling however, by THELMA and JACKPOT, already provided solutions. In an attempt to ease the resolution of this problem, we have previously presented a theoretical generic study of a group of strands twisted helically together (representative of a single cabling stage of a CICC) and analytically derived the expressions of coupling losses using the electrical and geometrical properties of the conductor. We have now up scaled this analytical study to a two cabling stages conductor and derived the expressions of its time constants and partial shielding coefficients which, in the Multizone Partial Shielding (MPAS) model, are used to model coupling losses and determined experimentally (e.g. JT-60SA TF conductor). We derive these coefficients as functions of the effective electric and geometrical parameters of the conductor and present an iterative method to model coupling losses in a N cabling stages CICC. In a second part, the real strand trajectories of JT-60SA TF conductor obtained via X-ray tomography are used to find the effective geometrical parameters needed in our modeling, and the experimental coupling losses of this conductor determined from tests within Sultan facility enables us to apply our modeling on a real case to discuss its validity. Furthermore, we compare our results to these of THELMA and JACKPOT numerical modelings on specific geometries. This modeling opens new perspectives for the study of CICC's (e.g. stability and dimensioning).

Submitters Country:

France, Italy, Netherlands, Romania

Mon-Af-Po1.12 / 96**Development of a new high stability of power supply in the superconducting system****Author(s):** Bao-Sheng Wang¹ ; Chen-Yao Liu¹ ; Kuo-Bin Liu¹ ; yongseng wong¹**Co-author(s):** Yuan-Chen Chien ¹¹ NSRRC

This paper studies the use of a novel high stability of power supply used in superconducting system, this power supply with high stability, low output current ripple characteristics. Also, the slope slew of raising and failing were be change through the firmware in order to satisfy the operation of the system. The superconducting coil wingding has a total length magnetic period of 56.56cm, total magnet length of 478.9cm and vertical (horizontal) magnetic field of 18.7T. The operation principle and steady-state analysis of the proposed converter were discussed. Finally, a hardware prototype system with output current of 320 ampere was constructed in a superconducting laboratory of Taiwan Photon Light Source.

Submitters Country:

Taiwan

Mon-Mo-Or1 / 89**Development of a short model of the superconducting separation dipoles D2 for the High Luminosity Upgrade of LHC****Pasquale Fabbricatore**¹ ; **Andrea Bersani**² ; **Barbara Caiiffi**³ ; **Roberto Cereseto**³ ; **Stefania Farinon**¹ ; **Arnaud Pascal Foussat**⁴ ; **Ezio Todesco**⁴¹ *Universita e INFN Genova (IT)*² *INFN*

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⁴ *CERN*

The luminosity upgrade of the Large Hadron Collider requires that the new separation/recombination dipoles D2 shall deliver a field integral of 35 Tm. A design has been developed of a twin dipole generating a magnetic field as high as 4.5 T in apertures of 105 mm and 7.78 m magnetic length. The magnetic field direction is identical in both apertures causing a not negligible magnetic cross talk, which could be highly detrimental for the field quality. In order to minimize the cross talk effects a design based on asymmetric coils has been developed in the past years. Recently the design has achieved a level of maturity allowing the starting of a second phase of development involving the construction of a short model and, later on, of a prototype. The short model (1.6 m long) has been designed in all aspects and it is presently under construction in industry. The contribution is focused on the design of the short model with emphasis on the mechanical aspects, which include a novel approach to the integration of coils in the mechanical structure through the use of Al-alloy sleeves. General aspects related to the integration of the D2 in the IR are discussed as well.

Submitters Country:

Italy

Mon-Af-Po1.02 / 1243

Development of conductors for thin solenoids for ultra radiation-transparent detector magnets

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In the frame of the ongoing design study of the Future Circular Collider (FCC), new options for detector magnets are being developed. In the current concept, the first phase of the FCC may be the FCC-ee, an electron-positron collider operating at energies up to 350 GeV in a 100 km long tunnel. As second phase it may be replaced by a 100 TeV hadron-hadron collider (FCC-hh). The particle detectors and their superconducting magnets are required to provide sufficient resolution. For FCC-hh, for example, this requires 4 T over 20 m in a 10 m diameter free bore. In current general-purpose detector systems, the magnetic field not only encloses the inner tracker where the magnetic field is actually needed, but also the electromagnetic and hadronic calorimeter. Essentially because current high field detector magnets are insufficiently radiation transparent. This implies a waste of magnetic field, stored energy and financial resources. A proposed solution is to build an ultra-thin, particle transparent solenoid, which only covers the inner tracker, similarly to the ATLAS Central Solenoid. The idea is to build a thin coil (<1 radiation length), which is able to provide thermodynamic stability and quench protection. This requires a conductor with a RRR of > 500. In addition, the conductor has to act as mechanical reinforcement to handle the magnetic pressure leading to hoop stress of about 300 MPa. Advanced doped Aluminium alloys are most promising given their density to strength ratio. The development of such a conductor is approached from different sides. One is to look for a multi-material reinforced sandwich like alloy with high RRR and sufficient tensile strength at 4.2 K. Second is to create a hybrid conductor from micro-alloyed Aluminium providing electro-thermal stability to the superconductor, reinforced by welding to an ultra-high yield strength Al-alloy of the 7000 series, or a mixed option.

Submitters Country:

Switzerland

Mon-Af-Po1.07 / 144

Development of high-temperature superconducting magnet for 1MW induction heater

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High-temperature superconducting (HTS) DC induction heater is a kind of promising device for aluminum, copper and brass extrusion billets with high efficiency. The HTS DC magnet with its refrigeration system is placed concentric with the middle iron-core limb. The magnet consists of three solenoid coils wound with YBCO produced by Shanghai Superconductor, and the critical current of the tape is 90A (77K, self-field). The inner and outer diameters of the YBCO magnet are $\Phi 1960\text{mm}$ and $\Phi 2009\text{mm}$, respectively. The magnet is a cryogen free system cooled by two AL325 cryo-refrigerators, and the rated operating temperature is about 25K. The rated current is 130A at 25K, and the magnetic field in the middle of the billet is 0.75T. Some model coils are fabricated and tested to evaluate the performance of the conduction-cooled YBCO magnet.

Submitters Country:

P.R. China

Wed-Af-Po3.04 / 1237

Development of highly saturated dipole magnets for the SAPT booster

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² *SINAP, CAS*

Eight highly saturated dipole magnets have been developed for the Shanghai Advanced Proton Therapy booster. The field reaches 1.77 T at the design current of 1200 A. The homogeneity of the integrated field is better than 0.001 within a good field region width of 100 mm. The integrated field consistency for the 8 dipole magnets is better than 0.003. The design and the measurement results for the dipole magnets are presented in this paper.

Submitters Country:

China

Mon-Af-Or5 / 336

Development of liquid nitrogen cooled RE-Ba-Cu-O magnet for NMR use

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We have developed RE-Ba-Cu-O (REBCO; RE=rare earth) superconducting magnet operated in sub-cooled liquid nitrogen (68 K). The superconducting magnet is a stack of six double pancake (DP) coils. Each DP coil was made of a REBCO coated conductor. The conductor was insulated by polyimide tape wrappings. The width and thickness of the insulated conductor were 4 mm and 0.2 mm, respectively. The outer diameter, inner diameter, and height of the coil stack are 107 mm, 57 mm, and 68 mm, respectively. The number of turns was 770. Ferromagnetic SS400 flanges were used on both ends of the magnet to improve performance, because they changed the field profile to reduce radial component of the magnetic field, which corresponds to perpendicular component for conductor. The magnet generated 1.6 T at 67 K for 1 hour stably. It generated 2.1 T at 66 K for 1 minute. Temperature dependence of the coil performance, the effect of ferromagnetic flanges, and applicability for NMR will be discussed.

Acknowledgement: This work was supported by JSPS KAKENHI Grant Number JP26288012.

Submitters Country:

Japan

Tue-Mo-O10 / 46

Development of low resistance splicing between Nb₃Sn and NbTi wires to make superconducting wigglers on the base of Nb₃Sn superconductor

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During the last decade nine multipole superconducting wigglers were manufactured in BINP on the base of NbTi superconductor. These wigglers are operating in various synchrotron radiation centers worldwide. High magnet design parameters were achieved by using the NbTi wire of high NbTi/Cu ratio, up to a factor of 2, and by grading current density in coils. So, further increase in the magnet parameter is limited by the properties of NbTi conductor. Also important peculiarity of the BINP wigglers is the design of the magnet where superconducting coils were separately manufactured and connected with splicing resistance well below of 0.1 nOhm at operating current about 1 kA. It benefits in significant decrease of heat load on cryocoolers because the total amount of splicing in one wiggler is more than 200. There are demands in superconducting wigglers and undulators for higher magnet parameters that can be realized by using the Nb₃Sn wire. The ultimate aim of the current work is to make an Nb₃Sn superconducting wiggler with separate coils which terminals will be connected with NbTi wires with low splicing resistance, below 0.1 nOhm. During assembling of such wiggler these coils will be connected via NbTi terminals by existing in BINP technology. This presentation reports on first results of testing of five samples of Nb₃Sn-NbTi connection. Experimental setup will be described. The samples represent a two turn loops made of Nb₃Sn and NbTi wires. The loops were charged by currents up to 500 A, and the resistance of these superconducting wire connection was evaluated by the current decay via a Hall sensor. All samples have demonstrated very low resistance, estimated as several fOhm, because during several days no current decay was detected by voltmeter in the range of several hundreds micro volts with sensitivity of 1 micro volt.

Submitters Country:

Russia

Wed-Mo-Or19 / 105

Development of prototype high gradient small aperture quadrupole magnets for HEPS-TF

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A test facility for storage ring based high energy photon source with a beam energy of 6 GeV, a circumference about 1300m, and an emittance about 59 pm•rad (HEPF-TF) is now under construction in china. Small aperture high gradient quadrupole magnets are important magnets in HEPS-TF. The design and manufacture of two prototype high gradient small aperture quadrupole magnets are finished. The bore diameters of the prototypes are both 25mm, and the field gradient is 80T/m and 90T/m, respectively. The field quality requirement of the prototypes is stringent, but the pole width is constrained by the requirement of the minimum gap between adjacent poles of 11mm. A lot of effort was spent to obtain an optimized pole shape which is convenient to be machined, and to avoid serious magnetic saturation in the iron. The detailed 2D and 3D magnetic design, field simulation and field error analysis of the two prototypes are presented, and preliminary field measurement results are also described and compared with the field simulations.

Submitters Country:

China

Tue-Af-Po2.07 / 468

Development of round flexible HTS CORC® wires for fault current limiting applications

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Next generation electric power systems require higher capacity, efficiency, and stability to meet the demands of increasingly complicated grid systems. High-temperature superconductors (HTS) provide unique solutions to stringent operating requirements, including the ability to protect electric power apparatus and systems from large currents that can develop during a fault. The extensive development of Conductor on Round Core (CORC®) cables and wires has resulted in round, multi-filament, REBCO conductors with critical current densities beyond 200 A/mm² at 77 K. The inherent fault current limiting capabilities of a short kA-class CORC® wire of less than 4 mm thickness are demonstrated in liquid nitrogen, developing nearly instantaneous voltages in excess of 20 V/m that increased to about 70 V/m within 15 ms of applied over-currents up to 250% of the critical current. Enhanced current sharing between tapes enabled by the CORC® cable topology appears to mitigate the issue of hot-spots caused by inhomogeneities on the HTS tape level by providing several alternate superconducting routes for current to bypass low I_c sections of the tapes. Operation of the CORC® FCL conductor in stand-alone operation and operated as part of a hybrid-cable system, in which the overcurrent is redirected to a normal conducting path outside of the cryogenic environment, are demonstrated without any degradation of the CORC® wire performance. The results show that highly flexible CORC® wires with record current densities are able to function as fault current limiters in which they develop record voltages per unit length of any HTS FCL cable without the need for resistive laminates.

Submitters Country:

United States of America

Tue-Af-Po2.08 / 98

Development of small diameter HTS Cross Conductors for Fusion Magnet Application

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Co-author(s): Nadja Bagrets¹; Reinhard Heller¹; Christian Lange¹; Alan Preuss¹; Klaus-Peter Weiss¹; Michael J. Wolf¹

¹ *Karlsruhe Institute of Technology, Institute for Technical Physics, Karlsruhe, Germany*

Karlsruhe Institute of Technology (KIT) developed the HTS Cross Conductor (CroCo), a round twisted stacked REBCO strand with outer Cu envelope, optimized for high current density and easy long length fabrication. First generation of HTS CroCos were built from 6 mm and 4 mm wide REBCO tapes with critical currents $I_c \sim 3$ kA (77 K / s.f.) and $I_c > 8$ kA (4.2 K, 12 T). Due to the continuously increasing REBCO tape performance, I_c of HTS CroCo is now > 10 kA at 4.2 K / 12 T. This HTS CroCo diameter will be used for a high current power transmission cable demonstrator with LN₂ cooling in the 35 kA range. For the planned use in large fusion magnets, smaller HTS CroCos would be preferable, because improved bending properties are beneficial. Therefore, the HTS CroCo fabrication technique was extended to smaller HTS CroCos.

HTS CroCos were fabricated from 3 mm and 2 mm wide REBCO tapes. Straight samples were measured at 4.2 K / 12 T in the FBI facility and bending experiments at 77 K, s.f. were performed with similar samples, too. First results from measurements of straight and bended HTS CroCos will be presented and compared with expectations.

Submitters Country:

Germany

Tue-Af-Pl3 / 1229

Development of superconductors for future large scale applications

Amalia Ballarino¹

¹ *CERN*

Particle accelerators have been an important driver of superconductor development, and Nb-Ti technology has enabled, in the last thirty years, fundamental discoveries in high energy physics. While the Large Hadron Collider continues delivering data and investigating the experimentally achievable domain, the quest for new sub-nuclear phenomena, beyond the Standard Model, has generated studies on future 100 TeV-scale synchrotron machines based magnets capable of delivering fields of 16 to 20 T. Nb₃Sn is to date the baseline superconducting technology of the Future Circular Collider (FCC). A key technological challenge of the FCC study is the R&D aimed at exceeding present state-of-the-art performance in a cost effective Nb₃Sn superconductor, and a world-wide effort on conductor development has recently been launched by CERN. In the last decade, the landscape of superconducting materials showing potential for accelerator technology has significantly enlarged. Nb₃Sn will be used in the High Luminosity LHC (HL-LHC) upgrade; REBCO conductors, with superior performance, have become commercially available from several companies; BSCCO 2212 has demonstrated in-field capability; on a longer term perspective, encouraging fundamental properties of MgB₂ and iron-based materials motivate studies for understanding and improving their in-field characteristics. For electrical transmission, LHC and HL-LHC rely respectively on BSCCO 2223 and MgB₂. The challenges and potential of both low-temperature (LTS) and high-temperature superconductors (HTS) are presented, with close attention being paid to the requirements driven by future high energy accelerators. Considerations on targets of performance and cost of Nb₃Sn and HTS superconductors, which could enable their adoption in large scale applications, are discussed.

Submitters Country:

CERN hosted in Switzerland&France

Wed-Af-Or27 / 676

Development of the 100 T Pulsed Magnet at the Wuhan National High Magnetic Field Center

Tao Peng¹ ; Liang Li^{None} ; Shuang Wang² ; Fan Jiang^{None} ; Yiliang Lv^{None} ; Fritz Herlach^{None}¹ Wuhan National High Magnetic Field Center² Huazhong University of Science and Technology

The 100 T pulsed magnet was designed and manufactured at the Wuhan National High Magnetic Field Center (WHMFC). The magnet consists of three coils. The inner coil consists of 8 layers of 2.8 mm × 4.3 mm CuNb micro-composite wire developed in China. The middle and the outer coils were wound from 8 layers of 3.55 mm × 9.5 mm and 12 layers of 5 mm × 10 mm soft copper, respectively. The inner and middle coil will be driven by a 1.6 MJ/5.12 mF capacitor bank and by eighteen 1 MJ/3.2 mF modules, respectively. As the big volume of the outer coil consumes lots of energy, it will be driven by the 100 MJ pulsed generator/rectifier system installed at the WHMFC. The objective is to obtain 100 T peak magnetic field with contribution of 45, 35 and 20 T produced by the inner, middle and outer coils. In this paper we present the details of the design, manufacture and preliminary test of the three-coil magnet.

Submitters Country:

China

Wed-Af-Po3.01 / 747

Development of the Mineral Insulated High Temperature Superconducting Magnet for Future High Intensity Muon Beamline

Ye Yang¹ ; Masami Iio² ; Makoto YOSHIDA³ ; Kento Suzuki⁴ ; Michinaka Sugano⁴ ; Tatsushi Nakamoto⁴ ; Toru Ogitsu⁴¹ Kyushu University² High Energy Accelerator Research Organization (KEK)³ KEK⁴ High Energy Accelerator Research Organization

The high intensity muon beam line is required for the next-generation experimental search for the muon-to-electron conversion, such as PRISM project and the muon collider for the NuFact project. Currently, a muon beam line for COMET experiment is under construction, and the pion capture solenoid system faces the radiation issue. Radiation exposure (neutron fluence: 5×10^{21} n/m²/200 days and 3 MGy/200 days) for the COMET pion capture solenoid causes the degradation of the coil cooling capacity by the conduction cooling method and mechanical property of magnet materials. A Mineral insulated magnet with High Temperature Superconductor (HTS) is one of the candidate to solve the radiation issue for the pion capture solenoid. Due to the tritium production from the nuclear reaction, the conduction cooling is best option for designing the superconducting coil at high radiation environment. Therefore, we are aiming to study and develop the HTS magnet with mineral insulation and conduction cooling. To confirm the deterioration of the critical electric current (I_c) of HTS by the irradiation, commercial REBCO coated conductors are studied with the neutron fluence up to 10^{22} n/m² using the joint research program of the International Research Center for Nuclear Materials Science of the Institute for Materials Research (IMR), Tohoku University. The I_c of the irradiated HTS tape is measured with 15.5 Tesla external magnetic field at IMR. Trial surface treatment with ceramics to commercial REBCO coated conductors and magnet materials is currently in progress. In this contribution, the results of the irradiation test of HTS and development status of the mineral insulated HTS magnet will be presented.

Submitters Country:

Japan

Wed-Af-Po3.08 / 316

Development of three stage electromagnetic forming facility and its timing control system

jianfeng Xie¹ ; liang Li¹ ; qunliang Cao¹ ; xiaotao Han¹¹ *Huazhong University of Science and Technology*

a Space-Time-Controlled Multi-Stage Pulsed Magnetic Field (Stic-Must-PMF) forming and manufacturing technology is introduced in Wuhan National High Magnetic Field Center, the technology is based on spatially strategically placed multiple coil systems and each coil can be addressed individually by its associated power supply with precise timing control. Such well-designed space-time distribution of electromagnetic force could lead to the forming and manufacturing of sheet and tube parts and components with controlled materials properties. Based on Stic-Must-PMF a Three Stage Electromagnetic Forming Facility is developed. The designed facility is composed of three capacitor power modules. The total energy of each power module is 1 MJ, 200 kJ, and 14.4 kJ, respectively. The power modules can be freely selected or utilized for driving multi-stage coils under its timing control system. The precise timing control system is designed for power modules configuration and discharge control. By generating precise and synchronous triggering signals according to the requirement of forming, the multiple power modules could be discharged to multi-stage coils synchronously or in a preset time sequence. With the application of the designed and fabricated triple-stage electromagnetic forming system, an approach of radial Lorentz force augmented electromagnetic forming is proposed to realize the deep drawing with large drawing ratio. The forming depth of aluminum alloy sheet (1060-H24) has been dramatically increased from 8.44 mm to 20.28 mm .

Submitters Country:

China

Thu-Af-Po4.10 / 304

Diffusion process of screening current in REBCO coil wound with copper-plated multi-filamentary REBCO tape

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High-field magnets wound with REBCO tape and their application to NMR have undergone considerable research and development. NMR coil systems require a highly accurate field; i.e. homogeneous and temporally stable field. However, in case of REBCO coils, the screening current induced magnetic field spatially and temporally deteriorates the field quality.. The filamentization of REBCO tape enables us to reduce the screening current induced magnetic field in REBCO tape coils. The multi-filamentary REBCO tape is usually plated with copper for mechanical strength and thermal stability. In this case, the coupling currents are induced between filaments in REBCO tape during changing the magnetic field. Therefore, the screening current passes through the filaments with a characteristic length and flows along the winding tape. Therefore, the behavior and diffusion process of screening current depend on the geometry of the coil winding and the effective transverse resistivity between filaments in REBCO tape. In our previous study, we have developed the numerical simulation code to calculate the spatial and temporal behavior of screening current distribution in REBCO coil. This simulation code is taking into account the three-dimensional geometry treatment

of the coil winding and the electromagnetic interaction among tapes. In this study, we numerically investigate the diffusion process of screening current for a layer wound REBCO coil and a double pancake; both coils are wound REBCO coil with copper-plated multi-filamentary REBCO tape. The numerical simulation result was compared with the experimental result presented elsewhere 1. We will discuss on the current distribution in REBCO tape, the characteristic length of coupling current and time constant of magnetic field diffusion.

1 T. Ueno et .al. "The coupling time constant for a multi-filamentary REBCO coated-conductor solenoid", Applied Superconductivity Conference 2016, 3LPo1L-05.

Submitters Country:

Japan

Thu-Af-Po4.05 / 367

Direct Control of Bearingless Permanent Magnet Slice Motor Based on Flux Linkage Observer Using Phase-locked Loop

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¹ *Jiangsu university*

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A bearingless permanent magnet slice motor (BPMSM) has compact structure and high efficiency, which can realize the rotor magnetic suspension at five degrees of freedom. The rotor magnetic field oriented strategy can realize the decoupling control of torque and suspension force, but it is difficult to meet the high performance requirements of torque and suspension force. The theory and method of direct torque control are applied to the BPMSM in this paper. With the reference of the direct torque control, a double-closed-loop control system of rotor displacement and radial suspension force is designed. Meanwhile, aiming at the low-accuracy stator flux linkage estimation and complex control structure of the traditional direct control, a stator flux linkage observer based on the phase-locked loop is proposed and implemented to improve the accuracy and performance of the BPMSM control. Firstly, the mathematic models of torque and suspension force are deduced. Secondly, a flux linkage observer based on the phased-locked loop is designed, and the principle of the flux linkage estimation and the control algorithm of the direct control are analyzed. Thirdly, the direct control system of the BPMSM is constructed. The correctness of the mathematic model and control algorithm are verified by Matlab/Simulink. The simulation results indicate that the start-up time is reduced by 20%. Finally, the proposed strategy is applied to a 4kW prototype. The peak value of displacement vibration is decreased by 25% when the BPMSM operates stably in no load and the recovery time of displacement in the x-direction is reduced from 100ms to 50ms when a 10N interference force is added in the x-direction. The experimental results show that the robustness of the system is effectively improved, as well as the dynamic and static performance.

Submitters Country:

China

Mon-Af-Po1.03 / 687

Direct current decay in a closed YBCO No-insulation coil under external AC magnetic field

Jun Ma¹

¹ *Cambridge University*

The high temperature superconducting (HTS) No-insulation (NI) coils have the self-protecting ability and good thermal stability because of the absence of turn-to-turn insulation. HTS coils carrying a

direct current is supposed to suffer a non-negligible loss when they are exposed to an external AC magnetic field. And the trapped magnetic field of NI coil will decay when the stored magnetic energy is decreasing. Although this phenomenon is well-known, no study is concerning the direct current decay of NI coil under external AC magnetic field and its angular dependence. To investigate the direct current decay of NI coil under external AC magnetic field, experiments have been performed and results will be present later.

Submitters Country:

United Kingdom

Wed-Af-Po3.07 / 873

Direct simulation of interactive motion of magnetic particles in an oscillating magnetic field

Author(s): Quanliang Cao^{None}

Co-author(s): Zhenhao Li ; Xiaotao Han ; Zhen Wang ; Liang Li

Manipulation of magnetic particles with the aid of dynamic magnetic fields including rotating and oscillating fields has been recently increased in various applications, such as mixing, separation and steering. In these processes, the motion behavior of particles is mainly dominated by the competition between magnetic force and induced hydrodynamic drags, and therefore both the inter-particle interactions and the particle-fluid should be considered in the simulations. In the previous studies, magnetic dipole-dipole interaction models are usually adopted in which each magnetic particle is assumed as a point with dipole moment responding to the external magnetic field, which cannot precisely capture the real dynamics of closely spaced particles. The aim of this work is to develop a coupled fluid-structure model based on the direct numerical scheme to investigate the dynamical behavior of magnetic micro-chain under the influence of an oscillating magnetic field, taking into account magnetic and hydrodynamic interactions between particles in a fully coupled manner. In the simulations, the Arbitrary Lagrangian-Eulerian method is used for dealing with the movement of the particles, and forces acting on particles are calculated based on the Maxwell stress tensor and hydrodynamic stress tensor. The simulation results are compared with the existing experiment studies and show good qualitative agreements. These results could provide an efficient way to predict the motion behavior of magnetic particles under dynamic magnetic fields in various applications.

Submitters Country:

China

Mon-Af-Po1.04 / 767

Direct-Control Strategy for Bearingless Permanent Magnet Synchronous Motor

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A bearingless permanent magnet synchronous motor (BPMSM) is a new-type special motor received extensive attention in the field of special drive/transmission. Because of its advantages, such as high efficiency and power factor, no mechanical contact, non-wear, compact structure and so on, has a broad application in centrifugal pumps, contamination-free ventricular assist devices, high purity pharmaceutical mixing devices, rotating stages and flywheels. However the BPMSM is a strong-couples nonlinear system, which leads the difficulty in the motor control. Therefore, the performance of its control system is the guarantee for the stable operation. In this paper, firstly, the

operation principle of the BPMSM is analyzed and the mathematical models of radial suspension forces and torque are deduced. Secondly, with reference to the idea of direct torque control in the traditional motor, the direct-control strategy for the BPMSM is proposed, and based on voltage space vector pulse width modulation (SVPWM), the torque control system and the levitation force control system are designed with double closed-loop structure respectively. Then, the control model is built using MATLAB, and simulation results show that the designed direct-control system can realize dynamic decoupling between the torque control system and the levitation force control system, which proves the validity of the direct-control strategy. Finally, based on DSP TMS320F2812, the experiment platform of the BPMSM and the corresponding software and hardware system are designed, and the suspension experiments are carried out. The test results also show that the proposed direct-control method is correct, and the BPMSM has good static and dynamic performances.

Submitters Country:

China

Wed-Af-Po3.05 / 136

Double-Stator Permanent-Magnet Vernier Linear Machine With PMs Surface-Mounted on the Mover

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¹ *School of Electrical and Information Engineering*

PM linear machine is an important category of PM machine, which is suitable for rail transit. The existence of the end effect will cause the unbalanced back-EMF, which can enlarge the ripple of the thrust. A novel linear vernier mover-PM (LVMPM) machine will be proposed in this paper. It is economical to be used in long distance. The characteristics of the proposed machine are analyzed by finite element method (FEM). In the LVMPM machine, the mover is sandwiched between the two stators. The stator is composed of silicon steel sheet with equidistant straight teeth, which work as modulation teeth. On the mover, the PMs are mounted on the top of teeth and windings are placed in slots. The magnetic circuit of the permanent magnet of the two side of the mover is connected in series with each other. Besides, due to the vernier effect, the proposed machine has the advantage of high thrust density. However, linear machines have end effects; thus the thrust ripple is higher than general vernier machine. The waveforms of back-EMF are sinusoidal and the amplitude of three-phase is equal. This can effectively reduce the thrust ripple of linear machine. In linear machine, the detent force is composed of cogging force and end force. The peak-to-peak value of detent force is about 46N, while the value of cogging force and end force are about 32.6 N and 20.9 N, respectively. The average thrust is 906 N when the electric load is 137 A/cm, while the thrust density is about 219.26 kN/m³. However, the thrust ripple of proposed MPMLV machine is up to 23.7%, which is higher than general vernier machine. Some design approaches may be done to reduce it. All details will be given in the paper.

Submitters Country:

China

Mon-Af-Po1.12 / 1133

Driving and protecting superconducting hybrid magnets

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Co-author(s): Dimitrios Papathanasiou¹

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The 45 T hybrid magnet project is developed by High Magnetic Field Laboratory in Nijmegen, Netherlands from an existing 22 MW power supply for its resistive magnet and a new 20 kA current source for the outer superconducting magnet. With 10 V load voltage it requires half an hour to charge to full current. The current source is fed from the 400 V mains and consists of a 12-pulse topology (4x3 pulse) with passive filtering. This will be further detailed in the paper. The new current source will feed the magnet through safety devices that will mostly prevent the superconducting magnet from quenching. These devices will contain redundant DC circuit-breakers opening the current path from the current source and transferring the load current into the parallel connected dump resistor. Further parallel connected with the load is a series connection of dump resistor, DC circuit breakers and semiconductor make switch: the slow dump circuit. Various abnormal and fault scenarios can be dealt with. Coordination in the control of the switches at certain fault levels in one of the power supplies and its protective action will therefore be mandatory to avoid the risk of a possible quench to be minimized. At a positively detected quench or such cases the load current will be transferred within 8 ms into the fast dump resistor at 2.5 kV maximum avoiding any possible damage to the part of the superconductive cable that became normal conductive. A slow dump facility is connected parallel to the load to more slowly reduce the current to zero at 50 V reverse avoiding quenching. Closing the thyristor make switch while opening the fast dump breakers will initiate the load current transfer to the slow dump resistor. In the paper several above mentioned scenarios will be explained.

Submitters Country:

Netherlands

Thu-Af-Po4.03 / 310**Dynamic Behaviour of Laminated Magnets with Solid Tension Bars**Thomas Zickler¹¹ CERN

An important criterion for the design of fast-ramping accelerator magnets is their field distribution in the time-transient regime. Eddy current effects in different components of the magnet become more or less significant depending on the field level, the ramp rate, the magnet geometry and the materials used. In this work, we focus on eddy currents in solid tension bars of laminated, iron-dominated magnets and quantify their effects based on finite-element simulations of a dipole model magnet. Several configurations are studied to derive empirical laws for the dynamic behavior of the magnets. The simulation results are validated with magnetic measurements.

Submitters Country:

Switzerland

Mon-Af-Po1.05 / 275**Dynamic Responses of Stacked coated conductor tapes Levitated above a Permanent Magnet Guideway****Author(s):** Kun Liu^{None}**Co-author(s):** Chang-Qing Ye ; Xiang Li ; Wen-Jiao Yang ; Tian-Yong Gong ; Guang-Tong Ma

For the superconducting magnetic bearings (SMB) employed with stacked high-temperature superconducting (HTS) tapes, rotational or linear, its static and dynamic performance are essential for engineering application. Up to now, most works reported on the HTS tapes of SMB were focused on experimentally or numerically studies on levitation and guidance forces under quasi-static conditions. However, the dynamics of SMB has not been investigated primarily. In this work, a linear

magnetic bearing composed of a stacked HTS tapes and a permanent magnetic guideway was built up for maglev application and its response on pulsed excitation was investigated. Three identical stacked HTS tapes with each 120 layers were used to form an assembly-sample which was exposed to the magnetic field produced by permanent magnet guideway of Halbach array. A force imposed on the sample was excited by a hammer with replaceable head. The laser displacement sensor (LK-G80) and uniaxial piezoelectric acceleration sensor (4507-B-004) were used to measure the response of sample at different field-cooling heights and amplitudes of impulse, the decay curves of displacement and velocity were obtained. Additionally, the resonant frequency of the levitation system was determined by spectrum analysis. Definitely, this work is of great value for better understanding the dynamics of SMB and promote its application.

Submitters Country:

China

Mon-Af-Po1.06 / 979

Dynamic performances analysis for HTS SMES Used in Power Grid Based on a Novel Field-Circuit Coupled Method

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High temperature superconducting magnetic energy storage (HTS SMES) is expected to be utilized in power grid for dynamic power compensation with low losses and high energy storage density during steady-state operation. Under transient operating conditions, especially in the case of fast power switching process, AC losses of the SMES will occur and lead to changes in equivalent resistance, total inductance, and critical current distribution throughout the magnet. In this paper, the dynamic performance of a 150kJ SMES has been analyzed based on a co-simulation model of MATLAB and COMSOL. The SMES element is a customized module by self-code S-Function in MATLAB. A magneto-thermal finite element model based on the PDE and Heat Transfer Modules of COMSOL is built in the module. Thus, the operating states of the SMES such as the distribution of the AC losses, magnetic flux density, critical current, maximum temperature increment, and the fluctuation of inductance and equivalent resistance have been comprehensively monitored in the power switching process.

Submitters Country:

China

Tue-Mo-Or15 / 825

Dynamic strain characteristics and responds in a LTS sextupole magnet during excitation and spontaneous quench

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The dynamic strain/stress characteristics and responds of a low temperature superconducting (LTS) sextupole magnet during excitation, pre and post spontaneous quench are investigated in the present work. The strains are measured by using a half-bridge circuit composed of a cryogenic strain gauge

and dummy resistances. The strain gauges are directly embedded within the magnet structure, which are located between the superconducting windings and the stainless steel. A fast data acquisition system with wireless and a resolution of 1ms is used for the strain measurements of the SC magnet during excitation and spontaneous quench. The results show that the strong turbulence and high value of measured internal strains are always detected in advance compared to the transport current, magnetic field and temperature signals recorded when a spontaneous quench occurs. It indicates that the transient internal strain measured in the SC magnet can capture the quench feature timely. To better understand the dynamic strain histories in the SC magnet during the excitation, initial and post quench processes, a spectrum analysis of the measured strain signals is conducted. It is indicated that several spectral peaks are always observed at the onset of a quench. When the current is increased, the amplitudes of these spectral peaks for the pre quench are weakened and the corresponding frequencies are enhanced. The observations indicate that the accumulated disturbance energy from the deformation or movement of SC wires inside the magnet may be dominant for occurrence of a quench. By means of quench training, the movement inside of coils is gradually constrained resulting in the structural frequency being increased.

Submitters Country:

China

Tue-Af-Po2.03 / 742**Dynamical Cryodistribution Model of the JT-60SA Toroidal Field Coil in Cold Test Facility****Author(s):** François BONNE¹**Co-author(s):** Walid ABDEL MAKSOUD¹ ; Daniel Ciazynski² ; Benoit LACROIX¹ ; Christine Hoa³ ; Jacques Nicollet⁴ ; Sylvie NICOLLET¹ ; Quentin Le Coz²¹ CEA² CEA-IRFM³ CEA SBT⁴ CERN

This paper deals with the simulation of the JT-60SA tokamak toroidal field coils test facility in CEA Saclay. To have a better understanding of the thermohydraulic behavior of the coils, a model of the cold test facility cryodistribution coupled to a model of the coils has been developed. Each of the 12 Pancakes is modelled by a 1-D thermohydraulic tube of Simcryogenics code representing the Cable-In-Conduit Conductor (CICC) of the coil, with each its own parameters, in particular heat loads from coil casing. This paper presents more in details, the external cryogenic distribution circuit which is modelled with the Simcryogenics library comprising the pump, a heat exchanger, control valves, quench relief valves and a quench tank. This paper focuses on the cryodistribution model made with Simcryogenics and the associated simulation results obtained during the coil test. The experimental test until quench initiation is performed and has been simulated, representing the increase of inlet helium temperature up to 7.46 K leading to the quench, followed by the safety current discharge. The simulation results are compared with the test measurement signals and other simulations performed with THEA and SimCryogenics coupled model, in particular the helium temperature, pressure and mass flow at the extremities of the conductors and coil. This work shows that this Simcryogenics simulation can predict the behavior of a coil coupled to a cryodistribution system until quench initiation, leading to possible future analysis and recommendation for operation of future (JT-60SA) tokamak cryogenic systems (determination of temperature margin with other operating conditions: helium mass flow and casing heat loads).

Submitters Country:

france

Wed-Af-Or24 / 754

E3SPreSSO: A Quench Protection System for High-Field High-Temperature Superconducting Magnets

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For reaching very high magnetic fields in fully superconducting magnets beyond 20T the use of High-Temperature Superconductors (HTS) is unavoidable. Due to the high Minimum Quench Energy in HTS, when operating in the temperature range of 4-20K, these coils are not very likely to quench. A nice twist of fate is, however, that it is the same stability that makes these coils much more difficult to protect against quenches using conventional methods such as quench heaters or Coupling Loss Induced Quench (CLIQ). Although it is possible to use a dump resistor on a short HTS magnet, extracting the energy externally, this does not provide a solution for longer magnets or magnets operated in a string, because the extraction voltage becomes unacceptably high. Here a method named E3SPreSSO is proposed that allows for fast energy extraction in HTS magnets. The \espr comprises units with a near-zero self-inductance superconducting circuit, connected in series with the main magnet. When the protection is triggered, these devices are turned resistive, using quench heaters, over-current or CLIQ, causing them to absorb the energy of the system. The units can be located outside the main magnet and do not generate magnetic field. Therefore it is possible to use relatively cost-efficient and robust Nb-Ti or possibly MgB₂. However, when a resistor is added in parallel, also non-stabilized HTS tapes can be considered. Multiple E3SPreSSO units can be used between magnets operated in a string or between the layers of a large coil in order to avoid high inductive voltages. This causes the operating current of the magnet to no longer depend on the protection system, reducing cost and complexity of testing and operation. This paper introduces the concept and provides an analytical analysis weighing the different options for designing the E3SPreSSO units themselves.

Acknowledgment: FP7-EuCARD2 GA 312453

Submitters Country:

Switzerland

Mon-Af-Po1.12 / 364

EMC tests at the location of the DCCT and ADC calibration laboratory at FAIR project

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The requested beam precision of the Facility for Antiproton and Ion Research (FAIR) requires the regular calibration of the main components of the current control system such as the Zero-Flux Direct Current-Current Transducer (DCCT) and the analogue-to-digital converter (ADC) module at a level of 1ppm or better. To reach this goal, a dedicated calibration laboratory is designed and prepared for construction. Due to the requirement to use a power converter in the vicinity of calibration arrangement and the limitation of available space, the calibration laboratory is to be located in the building where the power converters of the beam transfer lines are installed. In order to determine the spurious electromagnetic emissions from these power converters and the associated power distribution system, EMC tests were conducted. On the basis of the results, requirements for the electromagnetic shielding and other EMC mitigation measures were defined. As expected, typical inductive components such as transformers were identified as relevant sources of low frequency magnetic field. Unexpectedly, significant levels of low frequency magnetic field were identified in the planned calibration laboratory when all power converters were turned-off (including their supply cables and filters). This launched a further investigation which led to the conclusion that the

400V supply system in a TN-C (Terre Neutre Combiné) or TN-C-S (Terre Neutre Combiné Séparé) configuration is an additional source of low frequency magnetic disturbances. The paper presents the approach of the EMC investigation, the EMC test results and the conclusions. Measures to reduce electro-magnetic interferences for sensitive instrumentation systems are presented. The authors would like to highlight to the accelerator community the significance of a structured EMC assessment of the EM environment including the design of the power supply configuration in order to minimise the effects of electromagnetic interference in sensitive and complex instrumentation systems.

Submitters Country:

Germany

Thu-Af-Po4.04 / 858

ENLARGED BORE 11.74T MAGNET FOR BRAIN RESEARCH APPLICATION

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Ultra-high field magnets are becoming fundamental in brain research in order to satisfy the higher requirements in tissue contrast, spectral resolution and signal to noise ratio. ASG is putting a lot of effort to be competitive in this sector. After a 7 T conceptual design (1), now ASG is working on an 11.74 T MRI magnet for the Gachon University GIL Hospital. In this project, ASG has the responsibility of the complete magnet design, of the manufacturing and of the installation. A wax impregnated Nb-Ti superconductive compensated solenoid configuration has been selected to reach the ultra-high field value. In order to compensate the field inhomogeneity, additional superconductive coils are installed to perform active shimming, while to respect the fringe field restrictions a passive shield system has been optimized. Lorentz forces and coil interactions produced by the magnet have been calculated in order to verify mechanical structure and stresses on the coils. The whole magnet is working in helium bath and the radiation load is reduced using several thermal shields, cryocooler cooled. The system overall length of 3 meter is reached with an overall weight less than 60 tons. Compared to the actual head MRI magnets, a larger bore (700 mm) will characterize the developing magnet. This feature can make the patient access more comfortable and make higher the comfort level.

(1) S. Cuneo, A. Capelluto, R. Marabotto, G. Masullo and G. Salvitti, "Design of a compact 7T Nb-Ti superconducting magnet for MRI application" MT24, 2015.

Submitters Country:

Italy

Tue-Af-Po2.10 / 586

Eddy Current Loss Analysis of Surface Mount High Speed Permanent Magnet Motor Base on Multi-physics Fields

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Co-author(s): Fengge Zhang¹ ; Guangwei Liu¹ ; Shi Jin¹

¹ *Shenyang University of Technology*

In recent year, the demand for high speed permanent magnet(HSPM) motor is increasing in various fields due to its high efficiency and high power density. The research and application of high speed permanent magnet motor meets the needs of economic development of energy conservation and emission reduction. However, there are some studies have found that the rotor heating is very serious, which is due to the existence of eddy current loss, and high temperature will lead to demagnetization. In this paper, the eddy current loss of HSPM motor is analyzed based on electromagnetic field, stress field, and temperature field. Through the analysis, it is found that the eddy current loss is not only exists in the permanent magnet, but also exists in the protective sleeve, at the same time, the influence of different protective sleeve on eddy current loss is different, the eddy current loss will directly affect the rotor temperature. Through the finite element analysis of electromagnetic field, stress field and temperature field, it is proved that the eddy current loss is related to the conductivity of the material and the length of the air gap. Reasonable choice of rotor material will ensure the strength of the rotor to meet the requirements, and the appropriate air gap length will ensure the ventilation cooling, which is helpful to reduce the temperature of the rotor. Therefore the analysis of the eddy current loss should be integrated by the electromagnetic field, the stress field and the temperature field. The analysis of eddy current loss is of great significance to the research of high speed permanent magnet motor.

Submitters Country:

China

Thu-Af-Po4.03 / 319

Eddy currents analysis of dipole magnets of booster ring at HIAF project

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The High Intensity Heavy-ion Accelerator Facility (HIAF) is a new major scientific infrastructure at the Institute of Modern Physics of Chinese Academy of Science (IMPCAS), which is expected to accelerate heavy ions to 12.0 GeV/u. To improve gradually heavy-ion beam energy, booster ring which is an important accelerator between i-linac and HFRS, is established for confine and deflect the heavy ion at HIAF project. As an important deflection component, a pulsed room temperature dipole magnet in booster ring is proposed. The aim of the present work is to characterize the behaviors of eddy current in the iron yoke and vacuum pipe and its effects on the quality of magnetic field during a fast-pulsed mode. For purpose of precise, 3-D numerical modeling for the pulsed room temperature dipole magnet, the iron yoke and vacuum pipe were performed to calculate their eddy current. Maxwell's equations considering eddy current effects have been dynamically solved by means of finite element method. The influences of the ramping rates, materials and dimension of vacuum pipe on the eddy current profile and magnetic field distribution are also discussed in details. According to our analysis results, the paper provides some meaningful suggestions for the design of magnet and vacuum pipe at HIAF project.

Submitters Country:

China

Thu-Af-Po4.08 / 400

Effect of Background Magnetic Field on the Critical Current Degradation under Tensile Fatigue Loading for YBCO Tapes

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YBCO tapes are subjected to various stresses such as tension, compression, bending, twisting and fatigue in practical application. The influence of mechanical fatigue on the critical current decay behavior has been studied by several research teams. The impact of background magnetic field on the critical current degradation under tensile fatigue loading, however, has been rarely investigated. In this work, strain controlled fatigue behavior including strains up to 0.746% and strain ratios of 0.3, 0.5 and 0.7 will be studied. In addition, the effect of mechanical fatigue strain on critical current under background magnetic field was evaluated at different field angles and fields.

Submitters Country:

China

Mon-Af-Po1.04 / 283

Effect of Multi-phase Winding on Surface Permanent-Magnet Machine with Low Space Harmonics for Electric Steering Gear

Junqiang Zheng¹ ; Wenxiang Zhao¹ ; Jinghua Ji¹

¹ *Jiangsu university*

Surface permanent-magnet (SPM) machines with a fractional-slot concentrated winding (FSCW) present several advantages, such as high copper packing factor, short end-winding length, low cogging torque, small volume and good fault-tolerant capability, because of which SPM machines have been increasingly applied in aerospace applications. However, the key challenge of utilizing FSCW is abundant magneto-motive force (MMF) harmonics. These MMF harmonics result in high rotor eddy-current loss, acoustic noise and vibrations. In this paper, an analytical equation is derived to present the relationship between MMF harmonics and phase numbers. Finally, a 24-slot and 22-poles SPM FCSW machine is designed, adopting three, six and twenty-phase for validation, respectively. The slot-pole combination of 24-slot and 22-pole is selected. And the FCSW is adopted to improve copper utilization rate and reduce copper loss. In order to maximize torque density, the SPM rotor topology is employed and entire stator structure has been optimally designed. Besides, the machine adopts three, six and twelve phase, which is able to cancel some MMF harmonics with increased phase number. At the same time, the shape, size and pole-arc coefficient have been optimally designed to obtain better electromagnetic performance. Analytical method is adopted to derive the relationship between MMF harmonics and phase number. And finite-element analysis is employed to verify the electromagnetic performance of the designed SPM machine. The 1th, 5th and 7th harmonics are sub-harmonic, while 13th, 35th and 37th are the main slot harmonics. By using the multi-phase winding, the sub-harmonics are completely almost eliminated compared with those of three-phase winding. Also, the greatly decrease of the MMF harmonics, contributes to significantly reduce the PMs eddy-current loss. Besides, the unbalance magnetic force of nine-phase winding is smaller than that of three-phase winding due to the absence of sub-harmonics.

Submitters Country:

china

Mon-Af-Po1.04 / 768

Effect of Pole and Slot Combination on Vibration of Spoke-Type Permanent Magnet Motors

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Vibration characteristics of two spoke-type permanent magnet motors with different pole and slot combinations were investigated. Motor A has 12 slots and 10 poles, and Motor B 12 slots and 8 poles. The two motors have identical torque of 0.2Nm, rotating speed of 15660rpm, and outer dimension of 55mm by 55mm. vibration were measured on the outer surface of each stator. The two motors had identical size and shape, leading to approximately identical vibration characteristics. Natural frequencies and corresponding modal shapes were numerically calculated and validated by actual impact hammer tests. It was found that they had oval-shape vibrating modes approximately at 1600 Hz and 2500 Hz. Acceleration was measured on Motor A to peak at 2610 Hz, which is ten times of its rotating speed. Motor B had its highest peak at 2088Hz, which is eight times of its rotating speed. The peak from Motor A was observed to be much higher than Motor B. This is because the fundamental frequency of an excitation force of Motor A was closer to its resonant frequency, 2500Hz, than Motor B. Due to the difference in pole and slot numbers, the distributions of excitation forces along air gap were turned out to be significantly different between the two motors. Motor A with two symmetric periods had two large force peaks rotating along its air gap, while Motor B had four. Motor A excited its stator with the two peaks, thusly leading to higher vibration amplitude at its oval modal vibrating mode. Based on experimental and numerical analysis results, it was observed that the combination of pole and slot numbers affect significantly the force distribution along the air gap, leading to the different vibrating behavior. It was therefore concluded that vibration and noise can be minimized by selecting an optimal pole and slot combination.

Submitters Country:

Korea, Republic of

Thu-Mo-Or30 / 1053

Effect of strand diameter, magnetic field and injection length on the current entrance length of internal tin strand

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The current entrance and current transfer length (CTL) of prototype DEMO superconducting Nb3Sn internal-tin strands has been investigated in terms of strand diameter, magnetic field and current injection joint length. Knowledge of the current entrance effect of Nb3Sn strands provides insight on current distribution among strands in cables. In particular for large cable-in-conduit conductors (CICC) the strands are subjected to electromagnetic and thermal loading causing strand deformations like bending. Since bending causes a current redistribution between filaments, the current transfer length is essential for CICC performance and stability. Strands subjected to periodic bending will degrade more when having a longer CTL.

Voltage-current measurements were performed on strands having identical internal layout produced by Western Superconducting Technologies Co., Ltd., China (WST) with diameters of 0.83, 1.00 and 1.50 mm. Various current injection lengths and magnetic fields were used at 4.2 K. The results have been analyzed with analytical formulae and also with the 3D numerical strand model developed at the University of Twente. The measured entrance effects were compared with the determined CTL of the strands. As a result, the entrance effect is stronger in strands with a larger diameter due to their higher transverse resistance. The transfer length is also longer for lower magnetic fields due to higher absolute currents and for samples with shorter current injection length. The measurement method, the experimental results and analysis are presented.

Submitters Country:

Netherlands

Tue-Af-Or18 / 106

Effect of striating coated conductors on reducing shielding-current-induced fields in pancake coils exposed to normal magnetic fields

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The large magnetization caused by shielding current in coated conductors can deteriorate the field qualities of magnets. One of the counter measures of this large magnetization is the striation of a coated conductor to divide its superconductor layer into multifilaments. A striated coated conductor was fabricated by Furukawa Electric Co., Ltd. and SuperPower Inc. The superconductor layer of a coated conductor was cut into four filaments by laser, and, then, which was plated with copper. Plating copper results in the finite transverse conductance between filaments. Pros of this finite transverse conductance is the current sharing between filaments which is preferable from the viewpoint of stability and protection. The cons is electromagnetic coupling between filaments. In order to confirm the effect of striation, a pancake coil was wound with this striated coated conductor and was placed in a cusp magnetic field, which was normal to the coated conductors. The temporal change of the magnetic field near the pancake coil was measured by using a Hall sensor to look at the effect of the striation to decay the shielding current rapidly. Another pancake coil was wound with a reference non-striated coated conductor, and the similar experiment was carried out. Numerical electromagnetic field analyses were made while considering the finite E-J characteristics of superconductor layer and the transverse resistance between filaments, which was determined through the coupling loss measurements of short samples. The electromagnetic behaviors of the striated coated conductor was clarified by the electromagnetic field analyses. The effect of the striation was confirmed through the comparison between numerical and experimental results.

Submitters Country:

Japan

Tue-Af-Po2.07 / 1113

Effectiveness of Superconducting Fault Current Limiting Transformers in Power Systems

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Superconducting devices have emerged in many applications during the last few decades. They offer many advantages including high efficiency, compact size, and superior performance. However, the main drawback of these devices is the high cost. An option to reduce the high cost and improve the cost-benefit ratio is to integrate two functions into one device. This paper presents the superconducting fault current limiting transformer (SCFCLT) as a superior alternative to normal power transformers. The transformer has superconducting windings in both primary and secondary sides and also provides fault current limiting capability to reduce high fault currents. The performance of the SCFCLT was investigated considering the thermal behaviour of the superconducting windings. It works as a low impedance transformer in normal conditions and as a resistive-type fault current limiter during fault periods. A detailed model of the SCFCLT was developed based on the different

states of superconducting tapes according to the critical current and temperature rise of the tapes. These values were determined based on the transformer current ratings and the number of turns on each side. The SCFCLT is tested in two power system models: a 7 bus wind farm based model simulated in PSCAD and on the 80 bus simplified Australian power system model simulated in RTDS. Various conditions were studied to investigate the effectiveness of the fault current limiting transformer. Results illustrated the ability of the SCFCLT to limit high fault currents from the first cycle effectively. Also, the several scenarios proved that adding SCFCLT at strategic locations in a power system improves stability.

Submitters Country:

United Kingdom

Thu-Af-Po4.09 / 1181

Effects of metallic coatings on the thermal sensitivity of optical fiber sensors at cryogenic sensors

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One promising new application for optical fiber sensors is in monitoring superconducting magnets that are, inevitably, operated at cryogenic temperatures. In fact, Rayleigh backscattering interrogated optical fibers have been shown to be a viable alternative to voltage taps in quench detection of high temperature superconductors. The cryogenic thermal sensitivity of commercially available optical fibers is depressed by the low coefficient of thermal expansion of the constituent materials. Here, single mode, telecommunication-grade optical fibers are coated with different metals to alter their sensitivity to thermal perturbation at temperatures as low as 4.2 K. Commercially available fibers with acrylate coating are compared to fibers with only metallic coatings, those with and acrylate-metal composite coatings, in terms of their sensitivity to thermal perturbations in the temperature range from 4.2 to 61 K. All the metallic coatings are deposited in house with a dedicated coating method. The metals considered include Sn, PbSnAg and InBi, both on cladding and on an acrylate primary coating. Results show that the 4.2 K thermal sensitivity can be enhanced significantly by a composite coating approach.

Submitters Country:

United States

Thu-Af-Po4.11 / 180

Electrical Field Generation by Hall Effect in High Field No-Insulation REBCO Pancake Coils

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A no-insulation (NI) winding technique is very promising to conduct a practical use of REBCO pancake coils by greatly enhancing the thermal stability. Many applications using the NI technique have

been developed or constructed, such as a magnetic separation, a 1.3-GHz NMR, an over 40-T magnet, etc. So far, a lot of measurement data proved a high thermal stability of test magnets through overcurrent experiments. When an NI REBCO magnet transitions into a normal state, an operating current radially bypasses from a joint to another joint across turns. This mechanism enhances a thermal stability of NI REBCO pancake coils, and the bypassing currents avoid the coils from burning out. However, since the bypassing currents flow under a high magnetic field, an electrical field is generated in the circumferential direction, according to the Hall effect. The electrical field generated by the Hall effect is linearly proportional to a current density and a magnetic field. The radial bypass current flows through the stabilizer edges of REBCO tape so that the current density in the radial direction increases under a high magnetic field in the axis direction. Consequently, a high electrical field is generated along the REBCO tape winding. When an NI REBCO magnet is operated under a high background field, the electrical hall-effect field would be not negligible. Therefore, we try to estimate the electrical hall-effect field in simulations, and investigate the influence of the electrical hall-effect field on the stability of NI REBCO magnets. In future, since NI REBCO magnets will be installed into very high background fields, it is necessary to grasp a hall-effect phenomenon not only after quench but also during charging magnets.

Submitters Country:

Japan

Thu-Af-Po4.06 / 312**Electrical analysis for 15MW REBCO designed wind turbine generators**Kiwook Yun¹ ; Masataka Iwakuma² ; Katsuhito Tamura¹ ; Yoshiji Hase³ ; Teruo Izumi⁴ ; yuichiro Sasamori⁵¹ *Kyushu university*² *Kyushu University*³ *fujielectric*⁴ *Advanced Industrial Science and Technology*⁵ *Fujielectric*

Number of offshore wind farms is still increasing all over the world. The offshore wind power is greater than that on land. In addition there is no restriction of site and road for construction. However the offshore wind farm is expensive. Therefore the capacity in electricity per a wind turbine needs to be much larger than those on land and onshore. Especially, in Japan, there is so little shoal that not traditional fixed-bottom wind turbines but floating wind turbines are required. So the capacity in electricity per a single turbine for offshore wind farms should be larger than 10 MW or 15 MW. Furthermore the most troubles in the present wind turbine systems occur in the multiplying gear. Hence the trend of the development of wind turbine systems is the direct drive without gear. In case of normal conductive generators which are composed of copper windings and iron core and teeth, the weight of generators becomes huge. In this study we studied the optimum electrical design of 15 MW fully superconducting generators with REBCO superconducting tapes. We first investigated the electromagnetic properties of currently developed REBCO superconducting tapes. To reduce the ac loss in REBCO superconducting tapes, we intend to adopt the ac loss reduction technique which was applied to construct a 3phase-66/6.9kV-2MVA superconducting transformer. It is the combination of scribing and special winding. Using the observed and theoretically estimated properties, we conceptually designed 15 MW fully superconducting generators with the magnetic field at the gap and the operating temperature as a parameter. The diameter of superconducting rotor was supposed as 4.5 m. For each case we investigated the weight of generator, the required length of REBCO superconducting tapes, ac loss of the tape, efficiency and the construction cost by numerical simulation using the software on the market.

Submitters Country:

JAPAN

Tue-Af-Po2.04 / 302

Electrical and Mechanical Interactions between Component Coils of Multi-Plex Pulsed Magnet Systems

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To distribute the mechanical load and to reduce the driving voltages, ultra-high field pulsed magnets are usually designed as a group of nested, concentric coils driven by separated power sources. Since the magnet operated in a fast transient mode, there will be strong and complicated electromagnetic and mechanical couplings between the component coils. The high eddy currents generated in the reinforcement shells of those component coils during the pulses also strongly affect the couplings between them. The total Lorentz forces on a component coil will be zero if it is installed so that its field center is perfectly aligned with the field centers of other coils. However this condition is extremely difficult to be achieved in reality. Therefore understanding the electromagnetic and mechanical couplings between the component coils will allow safer and more optimized operation of our magnets. This presentation will focus on our finite element modeling and experimental results for the electromagnetic and mechanical interactions between the component coils of the 100 T nondestructive magnet and 80 T duplex magnet at our facility.

Submitters Country:

USA

Mon-Af-Po1.09 / 88

Electrical joints of pure aluminum stabilised sc conductors

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In the facility Ma.Ri.S.A. of INFN in Genova there is a long experience in measuring the critical current of pure Al stabilised S.C. conductors involving a transformer method, which implies to shape the conductor as rings with low resistance joints. Since the measured values of I_c can fall in the range 10 kA-100kA the value of the electrical resistance of the joint is crucial. From a practical point of view an electrical resistance less than 0.5 nOhm at 5 T is required for limiting the Joule dissipation to few watts. The joints are usually made with a soft soldering technique at temperatures not higher than 225 C. This approach allows an easy integration of the sample into the sample holder and at the same time avoids degradation of the critical current. In order to optimize the techniques to develop low resistance electrical joints a study has been recently performed for understanding the chemical modifications of the pure Al and Al-alloys stabilisers in the joint region, due to used methods.

Elemental and morphological analysis were performed on joints and correlated with measured electrical resistance measurements.

Submitters Country:

Italy

Wed-Af-Or26 / 697

Electro-mechanical measurements of mechanical lap joint of HTS STARS conductors

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Co-author(s): Tatsuki Nishio¹; Nagato Yanagi²; Yoshiro Terazaki²; Nadezda Bagrets³; Michael J. Wolf⁴; Hitoshi Tamura²; Klaus-Peter Weiss⁴; Hidetoshi Hashizume¹; Akio Sagara²; Walter Fietz⁵

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Segment-fabrication of high-temperature superconducting (HTS) coils has been proposed for huge and complex superconducting magnets. In Japan, the LHD-type helical fusion reactor, FFHR, designed by National Institute for Fusion Science, adopts the segment-fabrication for its helical coils as the challenging option. The fabrication method is called “joint-winding”, in which the HTS helical coils are wound by connecting Stacked Tapes Assembled in Rigid Structure (STARS) conductors with an appropriate length. The STARS conductor consists of simply stacked rare-earth barium copper oxide (REBCO) tapes embedded in copper and stainless steel jackets. Insulating material is situated between the copper and the stainless steel jackets. At the joint section, REBCO tapes are connected by bridge-type mechanical lap joint, developed by Tohoku University. Indium foils are inserted between joint surfaces, then the copper jacket and insulator are set, and the stainless steel jackets are welded. In this study, a mechanical lap joint of a 10-kA-class STARS conductor with a cross-sectional diameter of 20 mm was fabricated. The conductor has five layers of 10-mm-wide copper stabilized REBCO tapes and each layer is connected by the mechanical lap joint with an indium foil with a joint length of 15 mm. The stacks are embedded in a copper jacket, glass-fiber-reinforced plastics layer, and a stainless steel pipe. After pre-evaluations of critical current and joint resistance at 77 K, self-field in Tohoku University, the conductor is to be transported to Karlsruhe Institute of Technology. We plan to perform electro-mechanical measurements of the joint by means of the FBI (F: force, B: magnetic field, I: current) measurement facility at a temperature of 4.2 K, a DC current up to 10 kA, a magnetic field of up to 12 T and a tensile force up to 100 kN. The details of the results will be presented at the conference.

Submitters Country:

Japan

Mon-Af-Po1.04 / 16

Electromagnetic Analysis on Dual-Stator Switched Reluctance Motor

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¹ *China University of Mining & Technology*

The dual-stator switched reluctance motor (SRM) is based on the traditional SRM and increases one electrical port with two stators and a rotor. The outer-stator adopts salient pole structure of 12 poles, the inner-stator adopts 6 poles, the middle-rotor is doubly salient with 8 poles. The outer-stator and inner-stator have concentrated windings. That is to say, the outer motor is three-phase 12/8 structure machine, and the inner motor is three-phase 6/8 structure machine. Different inner-stator pole-arc, coefficient, different outer-stator pole-arc coefficient, different rotor teeth pole-arc coefficient, different rotor yoke thickness, different outer-stator yoke thickness, different inner-stator yoke thickness are analyzed for enhancing the average electromagnetic torque. The rotor teeth and the inner-stator pole-arc width are equal in order to avoid that the rotor inner teeth pole-arc width

effects the inner stator pole-arc coefficient. The rotor of dual-stator SRM has no windings, the each teeth of the stator has a central coil, and diametrically opposed two coils are connected in series. According to the series in different ways, it can be divided into positive and negative distribution. When the stator windings are energized in one direction, the stator teeth have a pair of NS poles and two pairs of NN poles, and the layouts of windings are different too. According to its positive and negative distribution and different layouts, the motor windings have 12 kinds of layouts. First, when the outer-stator winding layout is NNNNNNNNNNNN, the stator windings can be SSSSSS, SSSNNN, SNSNSN and NNNNNN, four kinds. When the outer-stator winding layout is NNNNNNSSSSSS, the stator windings have SSSSSS, SSSNNN, SNSNSN and NNNNNN, four kinds of distributions. When the outer stator winding layout is NSNSNSNSNSNS, the stator windings have SSSSSS, SSSNNN, SNSNSN and NNNNNN, four kinds of layouts. The NSNSNSNSNSNS with SNSNSN is selected for enhancing the torque by FEM calculation.

Submitters Country:

China

Wed-Af-Po3.08 / 810

Electromagnetic Deep Drawing of Aluminum Cylindrical Cup with High Depth-diameter Ratio

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Deep drawing of metal sheet is one of the most widely used forming technology. However, it's usually difficult to avoid failure which causes the current bottleneck problems of deep drawing with high depth-diameter ratio. To solve this problem, the common way is to draw the work piece by multiple steps. Another novel way is to introduce a radial inward Lorentz force (Fr) in the flange region of work piece by electro-magnetic coils. The Fr can effectively improve material flow, thus increasing the limiting forming depth. In this paper, a novel improved electromagnetic deep drawing method is proposed to manufacture aluminum cylindrical cup. The system consists three electro-magnetic coils (Coil_1, Coil_2 and Coil_3). During deep drawing process, Coil_1 is placed above the cavity to generate axial Lorentz force to shape the work piece into the die cavity. Coil_2 is placed above the flange region while Coil_3 is placed at the periphery of the flange. Coil_2 and Coil_3 are used to generate Fr to enhance the material flow. At the beginning of forming process, Fr is mainly generated by Coil_3, since the work piece end is close to it. And then, with the distance between Coil_3 and the work piece end increasing, Fr is mainly generated by Coil_2, thus increasing material flow and improving the efficiency in generating Fr. In comparison with traditional electromagnetic deep drawing with radial Lorentz force, Fr on the flange region can be significantly increased, especially when there is material flow at the flange end. Therefore, higher depth-diameter ratio of aluminum cylindrical cup may be manufactured, which validates the effectiveness of the proposed method.

Submitters Country:

China

Thu-Mo-Or31 / 263

Electromagnetic Design of HTS insert for NMR Magnet in Consideration of Screening Currents

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A 25 Tesla superconducting magnet for NMR will be fabricated in the Institute of Electrical Engineering, Chinese Academy of Sciences. The magnet consists of HTS insert and LTS outsert with the central field contribution of 10 T and 15 T, respectively. Based on the features of HTS insert with respect to winding geometry and screening current, an electromagnetic design method is proposed. High homogeneous central field can be obtained after the lock of the screening current distribution in the HTS tape. It makes the shimming work afterwards much easier with no attempt of elimination of the screening current.

Submitters Country:

China

Wed-Af-Po3.01 / 521

Electromagnetic Design of a Twin-Aperture Quadrupole Magnet with Common-Coil Configuration

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Conventional superconducting quadrupole magnets are designed with $\cos 2\theta$ configuration which helps to provide a perfect quadrupole field in the aperture. But for brittle superconductors like Nb₃Sn wires and ReBCO tapes to be used in quadrupole magnets, they will face the risk of severe J_c degradation in the coil ends because of the small bending radius determined by the magnet aperture. To solve this problem, a novel conceptual design of a twin-aperture quadrupole magnet has been carried out with common-coil configuration based on flat racetrack coils. The coil bending radius depends on the distance between two apertures and it is much larger than the conventional quadrupole magnets. The two apertures with the diameter of 60 mm are obtained with the top (bottom) coils bending outward and the center coils bending inward. By optimizing the straight section and the coil ends, high magnetic field gradient of 300 T/m is achieved within 2/3 of the aperture with a good field quality. The detailed magnetic analysis and the main characteristics of this concept will be presented.

Submitters Country:

China

Wed-Af-Po3.05 / 1076

Electromagnetic Performance Analysis of Less-rare-earth Stator-partitioned Multi-excitation Flux-switching Machine Considering Multi-operation Conditions

Yunyun Chen^{None} ; Xiaoyong Zhu¹

¹ *Jiangsu University*

Rare-earth permanent magnet (PM) machines have been widely recognized as a promising candidate for EV propulsion due to their merits of high power density and high reliability. In recent years, the price of rare-earth PM materials have been experienced significant increase and fluctuations which increased the manufacturing cost of rare-earth PM motor obviously. In this paper, a new less-rare-earth stator-partitioned multi-excitation flux-switching machine is proposed, where the two types of excitation sources of rare-earth NdFeB-PM and non-rare-earth Ferrite-PM are skillfully integrated into a stator-partitioned flux-switching machine. Considering the potential different operation conditions of heavy load climbing, rated load operation and high speed flux-weakening operation, a special design of auxiliary DC field windings are also adopted to protect the low-energy Ferrite-PM from the irreversible demagnetization. The corresponding electromagnetic performances of the proposed machine at multi-operation conditions are analyzed and simulated in details. In proposed machine, the PMs are separated from the armature windings and inserted in the inner stator, the space conflict between armature windings, PMs and electrical field windings can be relieved significantly. With the special arrangement of multi-excitation, the proposed motor can not only realize the effective reduction of rare-earth PMs volume and cost, but also achieve relatively high output torque. And with the protection of DC field, the capability of anti-demagnetization in Ferrite-PMs can be improved significantly. It indicates that the auxiliary DC field provides a significant protection for the ferrite PMs and the proposed motor possesses high anti-demagnetization capabilities. In order to verify the feasibility of the motor topology and the correctness of theoretical analysis, an experimental prototype is fabricated, and more theoretical analysis and experimental verification will be provided in the full text.

Submitters Country:

China

Mon-Af-Po1.05 / 139

Electromagnetic Performance Optimization Design of 5-phase BPMSM Based on Third Harmonic Injection

Author(s): Yuemei Qin¹

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¹ *Jiangsu university*

For the virtues of no friction and abrasion, high-speed and high-precision, long life, and etc., bearingless motors have wide application prospects in high-purity and high-speed areas. Meanwhile, multi-phase motors are superior over three-phase motors for their higher torque density and lower torque ripple. For a five-phase motor, the torque density can be further increased when the third-order harmonic current is injected. However, the rotor MMF produced by square-shape surface-mounted permanent magnets (SMPMs) contains abundant harmonic resulting in large torque ripple. Although the torque ripple can be decreased by optimizing the SMPMs into sine-shape, it has adverse effect on output torque. To balance the contradiction mentioned above, a five-phase 10-slot/8-pole bearingless PMSM (10/8 BPMSM) with PMs shaping is proposed in this paper. The mathematical model of stator MMF is established in detail based on the winding function method. By optimizing the SMPMs into the saddle-shape, the rotor MMF mainly contains the fundamental and third-order harmonic. The optimal ratio of the third-order harmonic of saddle-shape PMs is deduced and verified by finite element analysis (FEA) to obtain the maximum average torque. In addition, the variable edge thickness of PMs is analyzed to compensate the inter-pole flux leakage. Accordingly, the production principle of suspension forces is elaborated based on the harmonics interaction between stator and rotor MMFs. The SMPMs in sine-shape and square-shape are designed respectively for comparison. The simulation results show that the average torque and suspension force increase about 13% and 6% when PMs are saddle-shape compared with the one with sine-shape, while the torque and suspension force ripple decrease about 16.1% and 6.7% compared with the one with square-shape,

respectively. Finally, the motor with saddle-shape SMPMs are prototyped and experimented to validate the analysis.

Submitters Country:

China

Mon-Af-Po1.04 / 773

Electromagnetic Performances and Noise Analysis of IPMSM according to the Control Method under Flux-Weakening Region

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In this research, we designed Interior Permanent Magnet Synchronous Motor (IPMSM) type traction motor for 130kW Electrical Vehicle (EV). In addition, we analyzed its electromagnetic characteristics related to Permanent Magnet (PM) such as eddy current loss of PM, demagnetization, electromagnetic force especially radial magnetic force, and performed the noise analysis using the noise map in accordance with input control method, both SVPWM and six-step control under high speed and flux-weakening region. IPMSM has broad applications in domestic, automotive and marine field, and motor vehicle electrical system due to its high efficiency, power density and environmental issues. In the case of IPMSM, a voltage saturation problem is a major drawback in the high-speed region (over base speed) due to a back-electromotive force and the limited inverter voltage. The EV traction motor system requires various operating points and wide driving speed region to substitute role of the planet gear system. To satisfy its performance specification, the flux-weakening control is inevitable for IPMSM, generally. In terms of the flux-weakening control, the magnetic flux cannot be directly controlled because it occurs from PMs. Therefore, the stator current of d-axis, which is the direction of magnetic flux, must flow to generate magnetic flux in the direction opposite to the one of the PM to reduce the effective magnetic flux magnitude of the air-gap. It allows IPMSM to operate wide operating region under the limited input voltage condition. In the flux-weakening region, however, high speed and the magnetic flux from d-axis current bring about more harmonic components in air-gap flux density, ideally regarded as sinusoidal wave. We analyzed these harmonic components effect on PM eddy current loss, demagnetization, and radial force which leads to noise and vibration depending on the input control method by the coupled analysis of finite element analysis, FFT, and Simulink.

Submitters Country:

Republic of KOREA

Tue-Mo-Or12 / 1004

Electromagnetic Quench Propagation and Self-Protecting Behavior of a Stack of No-Insulation REBCO Double-Pancake Coils

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⁵ *Seoul National University / National High Magnetic Field Laboratory*

No-insulation (NI) high temperature superconductor (HTS) winding approach has been progressing as a promising technique to produce compact, reliable and robust magnets, and has demonstrated electromagnetic quench propagation and self-protecting nature. Comprehensive distributed network simulation models have been used to understand the mechanism of the self-protecting behavior in a qualitative manner. However, the electromagnetic responses of actual NI magnets consisting of a stack of multiple coils have not been fully understood. Our approach uses previously described "lumped circuit model," where each NI sub-coil in a magnet is modeled as an inductor and a resistor connected in parallel. Combined with an adiabatic lumped thermal analysis, the model reasonably well simulates the electromagnetic quench propagation among magnetically coupled sub-coils, much faster than the comprehensive distributed approach. Yet, some time-varying variables including transient responses of individual pancake voltages showed substantial discrepancy between measured and simulated results. The goal of this research is to investigate this discrepancy and improve our code for more precise simulation. An NI magnet comprising a stack of 3 double-pancake coils was constructed with REBCO tapes of which the lengthwise critical current over the entire length and the angular dependency of critical current of a short sample had been measured before construction of the coils. Fast ramping and over-current quench tests of the magnet were performed in a bath of liquid nitrogen and liquid helium, and the results were compared with simulated ones based on the inverse calculation approach. This allows us to investigate the validity of our code in a more controlled manner and better understand the electromagnetic behavior of an NI magnet more accurately. Acknowledgement: This work was supported by the National High Magnetic Field Laboratory (which is supported by the National Science Foundation under NSF/DMR-1157490), the State of Florida, and the KBSI grant (D37611) to S.-G.L.

Submitters Country:

United States

Tue-Af-Po2.07 / 820

Electromagnetic analysis and Optimized Design of a noval hybrid type DC Superconducting Fault Current Limiter

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Co-author(s): Yuejin Tang¹

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With increase of direct current (dc) transmission voltage and capacity, large dc fault current becomes an important issue due to the bottleneck of the capacity of the dc breaker. In order to reduce the fault current, we proposed a noval hybrid type DC superconducting fault current limiter (DC-SFCL) in our published papers, whose principle of limiting current was verified by a small scale experimental prototype. In this paper, some improvements are made to the novel hybrid type DC-SFCL for application in a 200kV/1kA HVDC system. The target is to limit the short-circuit current to less than 35% when the dc short-circuit occurs. However, the cost and stability of DC-SFCL in high-power dc system are being challenged, which weakens the advantage of the noval hybrid DC-SFCL. Therefore, in consideration of cost and stability, combined with the transient characteristics of the DC-SFCL, an analysis method consisting of electromagnetic theory, electric circuit theory and thermal analysis is used to promote the utilization efficiency of YBCO coated conductors. A finite element model is established to simulate and evaluate the critical current, stress and energy loss of superconducting coils in the DC-SFCL. Concluding the corresponding results, a method is developed for optimized design of the DC-SFCL.

Submitters Country:

China

Tue-Af-Po2.01 / 755

Electromagnetic analysis of a superconducting bus-bar for SIS100 particle accelerator at FAIR

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Sections of the superconducting magnets of SIS100 particle accelerator (under construction at GSI, Darmstadt) are going to be connected with by-pass lines used to transfer electric current and liquid helium. Each by-pass line will contain four pairs of Nuclotron-type superconducting cables (bus-bars) used to supply the different types of magnets with electric current. Since the accelerator is going to be powered with fast-ramping currents, some interactions between the bus-bars are expected. In this work the electromagnetic behaviour of the line is considered. The distribution of the magnetic field around a superconducting cable is analysed and used to find some electrical properties of the line - its electric capacity, self-inductance and mutual inductances between the bus-bars. Inductances are then applied in the calculation of cross-talk currents. Knowledge of these currents is crucial for the operation of the accelerator. The disturbance in the amount of supplied current can lead to the deformation of the magnetic field generated by the superconducting and in turn the decrease of luminosity or even the loss of particle beam.

Submitters Country:

Poland

Mon-Af-Or7 / 353

Electromechanical Design of a 16-T CCT Twin-Aperture Dipole for FCC

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The CCT (Canted Cosine Theta) Technology has been studied for its suitability for an FCC main dipole in terms of magnetic and mechanical performance, electro-thermal protectability, as well as efficiency. In this paper we present lessons learnt from our search for efficient CCT solutions by means of 2-D magnetic and mechanical simulations, discuss the 3-D periodic mechanical model, as well as 3-D electromagnetic analysis of the end regions. Temperature and voltage distributions during a quench under simplifying assumptions are discussed. Eventually, we present quench propagation in CCT-type high-field magnets, and how it may impact quench detection when compared to classic cosine-theta coils. Several new insights into efficient CCT design could be gleaned from these types of analyses and are summarized.

Submitters Country:

Switzerland

Wed-Af-Po3.08 / 529

Embedded flexible Fe-Si-Al powder composite-film inductor for a Low Power DC-DC Converters

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An embedded flexible inductor constructed using Fe-Si-Al powder composite films and a low power DC-DC converter using this inductor are proposed. Composite films, with a μR of 40, are composed of mixed Fe-Si-Al flaked powders and ethylene propylene diene monomer (EPDM) rubber. The embedded flexible circuits have etched spiral copper traces with 18 turns for two layers. The copper trace is patterned with a 30- μm thickness, 100- μm width, and a 100- μm pitch. With respect to the performance, the simulated inductance and copper resistance using a Maxwell 3D tool are 5 uH and 0.77 Ω , respectively, whereas the measured results are 5.0 uH and 0.72 Ω , respectively, for the proposed embedded flexible inductor. The performances are also simulated by folding the fabricated flexible inductor (to 0°, 45°, 90°, and above 90°) using the Maxwell 3D tool. Additionally, it is confirmed that the inductance of this flexible inductor has a good linearity at high frequencies of a few-MHz. To verify its usefulness, the flexible inductor with dimensions of 10 mm x 7 mm x 0.3 mm is applied to a DC-DC Boost converter fabricated on a flexible printed circuit board, 10 mm x 23 mm x 2.42 mm. The specifications for the fabricated DC-DC converter include an output power of 2 W (5 V/400 mA) and a switching frequency of 1.2 MHz. The fabricated DC-DC Boost converter is tested by folding the fabricated flexible inductor (to 0°, 45°, 90°, and above 90°); the results are highly similar and a maximum efficiency of 84% was obtained.

Submitters Country:

KOREA

Tue-Af-Po2.04 / 465

Energy and material efficient non-circular bore Bitter magnets

Andrey Akhmeteli¹ ; Andrey Gavrilin²¹ *LTASolid, Inc.*² *Florida State University, Florida, USA*

There exist a number of experiments/applications where the second dimension of the bore of Bitter magnets is not fully utilized and thus not really needed. Using an analytical solution for elliptical bore coils, as well as finite-element analysis for elliptical and racetrack bore coils, we show that reducing one of the dimensions of the bore can lead to a considerable decrease in consumed power and/or coil material; the gains are quantified. At the same time, the benefits carry the penalty of higher stress in non-circular bore coils because of the bending moment. The results of finite-element analysis of stress suggest that this penalty can be significantly decreased. Additionally, the potential of two-phase cooling is reviewed based on recent advances in technology. So far all the results are theoretical rather than practical.

Submitters Country:

USA

Wed-Af-Po3.07 / 157

Energy-Shaping Control Strategy of SMES

Xiaodong Lin¹; Yong Lei¹

¹ *Sichuan University*

The precise control strategy is the basis of the practical application of superconducting magnetic energy storage system (SMES), which has non-linear dynamic characteristic. In this paper, a novel nonlinear control strategy of SMES is proposed. Mathematic models of SMES and the port-controlled Hamiltonian (PCH) models of VSC converter and DC chopper of SMES are established. Through the analysis of passivity proof of SMES, the energy-shaping control strategy of SMES based on the structure of feedback interconnection are designed in terms of control objective analysis, desire equilibrium assignment and energy matching equation solution. The simulation results show that SMES based on the proposed energy-shaping control has good tracking ability for power instructions and it can quickly stabilize the DC-side voltage of the converter. Simulation results also indicate the validity of the energy-shaping control strategy and it has better robustness and convergence than the typical PI closed-loop control strategy.

Submitters Country:

China

Mon-Af-Po1.08 / 351

Enhanced critical current densities in Nb₃Sn superconducting strands prepared by bronze process

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¹ *Western Superconducting Technologies Co. Ltd.*

In the past much of the emphasis in the development of Nb₃Sn superconducting strands has been on improving the non-Cu critical current density (J_c). Different design Nb₃Sn strands were manufactured by the bronze route artificially doped with titanium in bronze. The influences of bronze to Nb volume ratio, filament diameter and Ti content were studied. Bronze to Nb volume ratio affected J_c largely for the different Nb₃Sn volume formed after heat treatment. The study of filament diameter on J_c indicates that J_c increases small with the filament diameter increases. Ti diffused into Nb filament when temperature is higher than 340°C and no Ti element has been found in the Cu-Sn matrix after heat treatment. Results shows that Ti content had weak influence on J_c. Microstructure images show that residual Nb core can be seen in each filament. The Nb₃Sn grains are almost equiaxed and uniform in size.

Submitters Country:

China

Thu-Af-Po4.08 / 301

Enhancement of crystallinity and critical current properties of fluorine-free MOD processed YBCO films by introduction of oxyhalide Ba₂Cu₃O₄X₂ (X = Cl, Br)

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The fluorine-free metal organic decomposition (FF-MOD) is one of the most promising methods for preparing REBa₂Cu₃O_y (REBCO, RE: rare earth elements) coated conductors because the simple chemical reaction to form textured REBCO phases is completed in a short time without any necessity of vacuum chambers or high power laser devices. However, reproducibility is not always high due to generation of misaligned grains inside the film. Therefore, coated conductors with long length have not yet been developed by FF-MOD method. Our recent study revealed that halogen-addition to the starting solution resulted in generation of oxyhalides, Ba₂Cu₃O₄X₂ (Ba₂342), where only Cl and Br can be the candidate for X of Ba₂342 composition. The Ba₂342 crystal is a layered compound where [Cu₃O₄]²⁻ layers and [Ba₂X₂]²⁺ layers are alternately stacked. It should be noted that the size of Cu₃O₄ plane is almost same as that of CuO₂ plane in YBCO crystal. We have found that Ba₂342 precipitates helped biaxial alignment of YBCO due to the perfect lattice matching, and hence highly textured YBCO films were obtained with high reproducibility by introduction of Ba₂342. Also, co-doping of Ba₂342 and impurity metal such as Hf and Zr is significantly effective to enhance flux pinning properties of FF-MOD processed YBCO films. Various interesting effects of oxyhalides on microstructures and superconducting properties will be discussed.

Submitters Country:

Japan

Thu-Af-Po4.08 / 987

Enhancement of in-field critical current density of BaZrO₃ added (Y, Gd)BCO coated conductors by reduced once-coat-layer-thickness in multi-coating TFA-MOD method

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The trifluoroacetate metal-organic decomposition (TFA-MOD) process is a non-vacuum process. Therefore, this process for REBa₂Cu₃O_y (RE: rare earth) coated conductors (MOD-REBCO) is useful from a cost point of view. Recently, it has been reported that the critical current density (J_c) in liquid nitrogen temperature can be increased effectively by reducing once-coat-layer-thickness in the multiple coating process of BaZrO₃ (BZO) doped MOD-YGdBCO coated conductors. In this study, we have investigated the J_c properties of the BaZrO₃ doped YGdBCO coated conductors obtained from the multi-thin-layer-coating process over a wide magnetic field and temperature region and an analytical expression for the J_c as a function T and B has been derived by using percolation transition model. We prepared two samples for comparison with the similar total thickness of 0.53 μm and 0.75 μm with the once-coat-layer-thicknesses of 30 nm and 170 nm, respectively. Transport critical current density was measured by the four-probe method with a micro-bridge by the photo lithography. The typical micro-bridge is about 70 μm wide and 500 μm long. The critical current density was determined using the criterion of E=1 μV/cm. We measured the in-field critical current density up to 27 T at temperature from 4.2 K to 77 K. The sample using the 30 nm once-coat-layer-thickness shows superior in-field J_c in the all measured conditions than that of the standard coating using 170 nm thick layer for each coating. Moreover, we found that the minimum J_c, which estimated from

magnetic field angle dependence, shows even higher value than that of PLD processed EuBCO up to 5 T of magnetic field at 65 K and up to 3 T at 77 K. From these results, the new MOD-YGdBCO process using the thin once-coat-layer-thickness is very promising for the magnet applications. Acknowledgments: This work was supported by the “JSPS: KAKENHI (16H02334)”

Submitters Country:

Japan

Tue-Af-Po2.12 / 409**Enhancement of the magnetic coupling by using Superconductors/Ferromagnet heterostructure**Zhou Pengbo¹¹ *Southwest Jiaotong University*

Superconductor/Ferromagnet (SC/FM) heterostructure has shown its great potential in the utilization of transferring and cloak magnetic field from static to quasistatic. In this work, we tried to expand the application of the magnetic field control by using SC/FM heterostructure to higher frequencies region, we verified such a concept by experimentally comparing the performance of a simple transformer with and without the SC/FM heterostructure, the results of which show that the magnetic coupling between the primary and secondary windings has been greatly enhanced by adding the SC/FM heterostructure, which is mainly due to the reduction of the magnetic flux leakage. Moreover, a FEM model by COMSOL based on the experimental setup has been built, the analysis of the field patterns help us to straightforward understand the underlying mechanism of the SC/FM heterostructure, meanwhile, a further study has been carried out to investigate the superconducting ac losses as a function of the applied frequency. The results presented in this work may provide a reference to the design of the SC/FM heterostructure in high frequencies magnetic coupling applications like contactless energy transfer system.

Submitters Country:

China

Mon-Af-Po1.07 / 268**Enhancement of trapped magnetic field using a large-size REBCO bulk in a desktop type superconducting bulk magnet**Kazuya Yokoyama¹ ; Atsushi Katsuki² ; Atsuro Miura¹ ; Tetsuo Oka³¹ *Ashikaga Institute of Technology*² *Ashikaga Institute of Technology*³ *Niigata University*

We have developed a desktop-type superconducting bulk magnet using a Stirling cryocooler with the aim of miniaturizing the magnet system. As a result of cooling and magnetizing tests using a GdBCO bulk material 45 mm in diameter and 15 mm thick, the lowest achieved temperature was 51.3 K, and the maximum trapped field was approximately 2.8 T at the center of the bulk surface in the applied field of 7.0 T. For this paper, we remodeled the bulk magnet system in order to attach a large bulk 60 mm in diameter and 20 mm thick for the purpose of enhancing the total magnetic flux. This was based on the idea that a total magnetic flux was increased if the volume of the bulk was expanded, while we were anxious about the reduction of the trapped field due to the low cooling capacity of the refrigerator and a high ultimate temperature. When cooling and magnetizing tests were carried out using 60-mm GdBCO bulk, the sample was cooled from room temperature to the

ultimate temperature of 55.6 K for approximately 6.5 hours, and the total magnetic flux was 2.0 mWb, which was about twice that of 45-mm bulk, indicating that the aim of this study was achieved. Moreover, the maximum trapped field was 3.0 T in the applied field of 6.2 T, which was the maximum value in the pulsed-field magnetization using a large bulk at temperatures beyond 50 K.

Submitters Country:

Japan

Thu-Mo-Or33 / 7

Errors and optics study of a permanent magnet quadrupole system

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Laser-based accelerators are gaining interest in recent years as an alternative to conventional machines. Nowadays, energy and angular spread of the laser-driven beams are the main issues in application and different solutions for dedicated beam-transport lines have been proposed. In this context a system of permanent magnet quadrupoles (PMQs) has been realized by INFN researchers, in collaboration with SIGMAPHI company in France, to be used as a collection and pre-selection system for laser driven proton beams. The definition of well specified characteristics, both in terms of performances and field quality, of the magnetic lenses is crucial for the system realization, for an accurate study of the beam dynamics and the proper matching with a magnetic selection system already realized. Hence, different series of simulations have been used for studying the PMQs harmonic contents and stating the mechanical and magnetic tolerances in order to have reasonable good beam quality downstream the system. In this contribution is reported the method used for the analysis of the PMQs errors and its validation. It will be also shown that the method is totally general and can be extended to any kind of magnet and/or error sources. Finally, the experimental characterization of the PMQ system, using real laser-accelerated beams, will be shortly presented.

Submitters Country:

Czech Republic, Italy

Thu-Af-Po4.04 / 826

Estimation method of optimal amount of overshooting current for temporally uniform magnetic field in a conduction-cooled Re-BCO coil for MRI applications

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The variation of the magnetic flux density due to shielding current attenuation causes negative influence on temporally stable magnetic flux density required at the center of high-resolution MRI magnets. We have already clarified the relationship between the maximum current in an overshooting process and the shielding magnetic flux density attenuation and established the estimation method of the optimal amount of the overshooting current for suppressing the shielding magnetic flux density

attenuation in a ReBCO coil cooled by LN₂. This estimation method, however, cannot be applied to MRI applications because the repeated measurements are required for estimating the optimal amount of the overshooting current in the ReBCO coil. In this paper, we investigated an estimation method of the optimal amount of the overshooting current for suppressing the shielding magnetic flux density attenuation by only one-time excitation of the ReBCO coil cooled by a refrigerator. We investigated the operating temperature and current load factor dependency of the variation rate of the shielding magnetic flux density just after the overshooting process. Regardless of the operating temperature and the current load factor, the variation rate of the shielding magnetic flux density decreased with the amount of overshooting current and changed from a positive value to a negative value. The ratio of the optimal overshooting current to the critical current of the ReBCO coil against each current load factor became almost the same independently of the operating temperature. Based on these results, we devised a suitable excitation current waveform in the overshooting process for suppressing the shielding magnetic flux density attenuation in the ReBCO coil cooled by the refrigerator. Using this current waveform, we could suppress the shielding magnetic flux density attenuation by only one-time excitation.

Submitters Country:

JAPAN

Tue-Af-Po2.06 / 633

Estimation of Flux Regulation Capability of a Hybrid PM Axial-Field Flux Switching Memory Machine Considering the Effect of Temperature

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PM memory machines applying the low coercive force (LCF) magnets for flux regulation have attracted great attention due to the novel flux regulating concept. Unlike high coercive force (HCF) magnets in the conventional permanent magnet synchronous machines, the magnetization state of LCF magnets in memory machines can be changed by the magnetization state control current to realize flux controllability. However, magnetic properties of the PMs are temperature-dependent, meaning that the flux regulation characteristics and torque may be significantly affected. Moreover, magnetization state variation may occur due to the magnetic field produced by load current instead of magnetizing current at some temperatures. Therefore, this paper presents the temperature-dependent demagnetization model for determining the accurate flux regulation characteristic which can be used for accurate flux control.

LCF magnets such as Alnico offer excellent stability with respect to temperature while HCF magnets such as NdFeB are highly sensitive to temperature changes. Thus, it is acceptable that only the remanence and intrinsic coercivity of HCF magnets are treated with temperature coefficients. The temperature-dependent demagnetization model of the HCF magnet is adopted and then incorporated into the 3-D FE analysis of a hybrid PM axial-field flux switching memory machine (HPM-AFFSMM). The electromagnetic characteristics of the machine are evaluated at different temperatures. It can be seen that working points of hybrid PM are lowered as temperature increases. As a result, flux regulation capacity decreases up to 20% at 100 degree. The worst working points of hybrid PM at different temperatures and load current are calculated and the maximum allowed load current is determined.

The results show that the flux regulation characteristic of hybrid PM memory machine is extremely sensitive to temperature. The effectiveness was verified through FEM analysis and experimental evaluation. In the full paper, more detailed characteristics of the HPM-AFFSMM will be given and analyzed.

Submitters Country:

China

Wed-Af-Po3.12 / 888

Estimation of Losses in the (RE)BCO Two-coil Insert of the NHMFL 32 T All-superconducting Magnet

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(RE)BCO commercial coated superconductors have gained an increasing interest for its use in high magnetic field magnets. The leading project is the 32 T DC user magnet to be commissioned soon at the National High Magnetic Field Laboratory, Florida, USA. This state-of-the-art high field all-superconducting magnet, bath-cooled at 4.2 K, is comprised of a two-coil insert pancake-wound with (RE)BCO tapes supplied by SuperPower Inc. and a multi-coil LTS outsert. To ensure the reliable operation of such a complex magnet, it is important to estimate the hysteresis losses which arise in the insert during ramping operations. Such an estimate will allow implementing safe operational procedures to avoid premature quenching of the magnet and, in the worst case, the failure of the insert. The insert coils are assembled from tens of pancakes and thus have thousands of turns, with notable variations in the critical current throughout the pancakes. Therefore, estimating the losses in such a large and complex superconducting magnet presents a significant challenge that requires an efficient strategy without compromising the accuracy of calculations. We propose here a new approach relying on a multi-scale scheme to achieve a high computational efficiency. This new method is flexible enough to simulate different sections of the entire insert with the right level of detail while providing a larger computational speed than other approaches using the finite element method. Estimates of the hysteresis losses in the 17 T insert for a ramping operation sequence are presented.

Submitters Country:

México

Mon-Af-Po1.04 / 307

Estimation of Permanent Magnet Temperature using d-axis Current for IPMSM

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Permanent magnet (PM), such as NdFeB, in the interior permanent magnet synchronous motor (IPMSM) used to be irreversibly demagnetized when the motor operate at high temperature. Therefore, the motor is designed considering irreversible demagnetization of PM. However, it is difficult to optimize motor design because we can't forecast the exact temperature of PM when the motor operate. In addition, it is difficult to measure the temperature of PM using thermocouple because of rotating the rotor. So, this paper proposes the method which it estimates the temperature of PM

using reduction of d-axis current to know irreversible demagnetization of the PM. The estimated the temperature of PM is first obtained using experiment and then it is compared with the simulation data, such as d-axis current and torque, to verify the correlation between simulation and experimental results design.

Submitters Country:

Republic of KOREA

Tue-Af-Po2.08 / 501

Evaluation of Electrical Characteristics for a Twisted Soldered-Stacked-Square (3S) HTS Wire with 1 mm Width

Author(s): Zhuyong Li^{None}

Co-author(s): Yongkang Zhou ; Daomin Hu ; Dongmin Xi ; Chao Guo ; Jiachen Liu ; Zhijian Jin ; Zhiyong Hong

In the superconducting applications for large current and strong magnetic field, a twist structure between superconducting wires can prevent generation of loop current and reduce AC loss. However, the twist structure is difficult to achieve for high temperature superconducting (HTS) tapes because of their high width-thickness ratio. In order to apply twist process more easily, a novel soldered-stacked-square (3S) HTS wire, whose cross-section is a square shape of 1 mm width, has been proposed and tested. Based on previous results of 3S wire, in this paper, a direct twist structure between 3S wires will be tried firstly and studied in detail. For the twisted 3S wires, we will investigate their electrical characteristics of critical current and AC loss under various magnetic field and mechanical environment. Moreover, a three-dimensional finite element method (FEM) model considering the twist structure of 3S wire will be developed, and result of AC loss and twist effect calculated from this model will be compared with the measured ones. More detailed evaluation results and FEM model introduction will be discussed and presented in this paper.

This work was supported in part by the National Natural Science Foundation of China (Project 51577119).

Submitters Country:

China

Tue-Af-Po2.03 / 71

Evaluation of Voltage between Conductors for Resonance Phenomenon and Transient Response in JT-60SA Central Solenoid

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The central solenoid (CS) of JT-60SA is composed of the four electrically independent modules, and 6 octa-pancake coils and a quad-pancake coil are assembled vertically in one module. The CS module is supplied with current through the room temperature busbar and current feeder of the superconductor. The withstand voltage for the insulation between the conductors is one of the most important parameters for the magnet system. The maximum voltage between the CS module terminals is designed to be 10 kV, the voltage between the layers under ideal conditions is then about 0.38 kV because the CS module has 52 layers. The actual voltage between the conductors can become larger

than the voltage under ideal condition due to the resonance phenomenon and transient response to supply voltage. Therefore, there is a possibility that the insulation between conductors is damaged. In the previous works, from the experimental and analytical results of the real size preproduction quad pancake coil, the circuit simulation model of the 12-layer pancake coil that is part of JT-60SA CS was created, and the influence of resonance phenomenon on voltage distribution was investigated. Based on the results of the previous works, the circuit simulation model of the CS module (the 52-layer pancake coil) was created. Moreover, the circuit simulation model includes the room temperature busbar, the current feeder and the structures around the CS module. We evaluated the behavior of the voltage between conductors for resonance phenomenon and the transient response to the supply voltage in the CS module by using the simulation model. As a result, it can be concluded that the influence of resonance phenomenon and transient response is negligible small under the operating conditions. These results therefore represent important information for the safe operation of the JT-60SA.

Submitters Country:

Japan

Mon-Af-Po1.08 / 698**Evaluation of thermal strain induced on components of Nb3Sn strand during cool down****Author(s):** Tomone Suwa¹**Co-author(s):** Tsutomu Hemmi¹; Toru Saito²; Yoshikazu Takahashi¹; Takaaki Isono²; Vladimir Luzin³; Hiroshi Suzuki⁴; Stefanus Harjo⁵¹ *National Institutes for Quantum and Radiological Science and Technology*² *QST*³ *Australian Nuclear Science and Technology Organization*⁴ *Japan Atomic Energy Agency*⁵ *JAEA*

Practical Nb3Sn superconductive strands of composite material were utilized for a cable-in-conduit conductor (CICC) for ITER central solenoid (CS) which consist of 576 Nb3Sn strands, 288 Cu strands and a stainless-steel jacket. During the manufacture of CS, heat treatment up to 923 K is applied to the CICC for reaction of Sn and Nb in Nb3Sn strands. the CICC is cooled down to approximately 4 K to operate ITER magnets. Thermal strain on Nb3Sn filaments of the strand is induced by large temperature difference and different coefficients of thermal expansion among components of the strands and the jacket. Strain dependence of critical current, which is used for prediction of the conductor performance, is influenced by thermal strain. Therefore, it is important to understand mechanism of the inducing thermal strain on the Nb3Sn filament. To distinguish contributions of the Nb3Sn strand components and the jacket to thermal strain on Nb3Sn filaments, internal strain measurement of the Nb3Sn strand was carried out by using neutron diffraction during cool down from 300 K to 12 K. As the results of the measurement, it was found that compressive thermal strain on Nb3Sn filaments was -0.1% at 300 K and -0.2% at 12 K in axial direction. In this paper, stress-strain state of components of the Nb3Sn strand during cooldown is discussed.

Acknowledgement: We acknowledge the support of the Australian Centre for Neutron Scattering, Australian Nuclear Science and Technology Organisation, in providing the neutron research facilities used in this work.

Submitters Country:

Japan

Wed-Mo-Or21 / 1039

Evolution of AC loss, inter-strand resistance and mechanical properties in prototype EU DEMO TF conductors during 30,000 load cycles

Konstantin Yagotintsev¹ ; Sander Wessel¹ ; Ruben Lubkemann¹ ; Arend Nijhuis¹

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Two prototype Nb₃Sn cable-in-conduit (CICC) conductors were designed and manufactured for the Toroidal Field (TF) magnet system of the envisaged European DEMO fusion reactor. Though both conductors were designed to operate at 82 kA in a background magnetic field of 13.6 T, they reflect a different approach with respect to the magnet winding pack assembly. The first approach is based on React & Wind (RW) technology while the second approach is the more common Wind & React (WR) technology. Each conductor was tested first for AC loss in its virgin condition without any additional handling. The impact of Lorentz load during magnet operation was simulated using Twente Cryogenic Cable Press. The AC loss, contact resistance and mechanical properties of two sample conductors were tested in the press under cyclic load up to 30,000 cycles in LHe at 4.2 K. A summary of the results is presented for AC loss, contact resistance, conductor deformation, mechanical heat production and conductor stiffness evolution during cycling of the load. The results of cyclic load tests on DEMO TF conductors is compared with ITER TF samples tested previously. Both DEMO TF conductors showed similar mechanical behaviour show quite different AC losses. It is shown that in comparison with ITER TF samples, both DEMO TF conductors have much lower contact resistance, which results in high coupling loss. At the same time, load cycling has lower influence on DEMO TF conductors properties compared to ITER TF conductors.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

The conductor samples were kindly provided by P. Bruzzone, EPFL/SPC, 5232 Villigen, Switzerland and L. Muzzi, ENEA, 00044 Frascati, Italy.

Submitters Country:

Netherlands

Thu-Af-Po4.07 / 977

Excitation Effect Analysis of a Novel HTS Controllable Reactor with Orthogonally Configured Core Based on dynamic Inductance

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The controllable reactor is one of the most effective methods for compensating reactive power. A novel high temperature superconducting (HTS) controllable reactor with orthogonally configured core has been proposed, analyzed, and developed. However, for the controllable reactor with dynamic inductance, the excitation analysis based on field circuit coupled method is inefficient and the excitation parameters optimization is more difficult. In this paper, an excitation system containing voltage source converter (VSC) and Buck-Boost converter is established. The reactor is built as a self-defined nonlinear element in system model based on the dynamic inductance. The inductance matrix, core saturation, leakage magnetic field at HTS winding, and total magnetic flux in the excitation core are included in the self-defined element. The parameters of the excitation system have been optimized easily. The simulation result of the output characteristic of the reactor is consistent with the experimental observations of the prototype. The dynamic inductance method is proved to be fast and effective.

Submitters Country:

China

Tue-Af-Po2.11 / 625

Experimental Analysis of Charging Characteristics of an HTS Field Coil with Contactless HTS Excitation Device Considering Various HTS Loads

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High-temperature superconducting (HTS) synchronous motors conventionally require current leads to inject the large DC currents into HTS field coils. However heat losses are generated on these current leads due to mechanical connection between the HTS field coils and power supply. For that reason, rotary HTS flux pump is used to remove the physical connection. However, HTS flux pump has spatial limitation due to the size of the HTS synchronous motor. Therefore, in this paper, the charging characteristics of HTS field coils are experimentally analyzed to verify the efficient method for charging the HTS coils when a contactless HTS excitation device (CHED) is used. The CHED is composed of eight HTS strands which are connected in series and eight neodymium permanent magnets (N50). The magnetic field of N50 is about 0.3 T. Air gap between the HTS strand and N50 is 8 mm. In order to verify the proper charging method, two cases of experiments are performed. First, the HTS loads are connected in series and they are charged by eight HTS series-connected strands of the CHED. Second, the HTS loads are connected in parallel and each coil is charged by four HTS series-connected strands of the CHED. In those experiments, the current flowing through the HTS load is measured with rotor speed range, from 100 to 300 rpm.

Submitters Country:

Republic of Korea

Mon-Af-Or8 / 198

Experimental Evaluation and Numerical Simulation of a HTS Linear Synchronous Motor for High Speed Railway

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A HTS linear synchronous motor prototype that could be used as the traction system of high speed railway was demonstrated in our laboratory. The stator was made of traditional ferromagnetic yoke and three-phase copper windings. To control the three-phase travelling magnetic field of the stator, a frequency-variable convertor was applied to the system. Different from the permanent magnet mover of traditional synchronous motor, the secondary was assembled by YBCO-coated conductor which has powerful ampacity to create high-intensity magnetic field. The YBCO coils were electrically connected in series and were injected dc currents to behave as magnets. To take a comprehensive study of the developed HTS linear synchronous motor, a finite-element model was established to simulate its thrust and normal force which are the key factors for traction. To validate the simulation model, we have developed a three-dimensional force-measuring system. A three-dimensional force sensor was used to observe the thrust and normal force of the HTS linear synchronous motor

under different conditions. As the key parameters, the trust and the normal force of the linear synchronous motor play an important role in the traction system because the speed and the load-ability are the key factors for railways. In this paper, the combination of the finite element method (FEM) and experiments presents the mechanical properties of the HTS linear synchronous motor prototype and provides some references for optimizing.

Submitters Country:

China

Wed-Af-Po3.12 / 494

Experimental Research of AC Ripple Losses in A High Temperature Superconducting Current Lead of A Magnet

Author(s): Hongwei Liu¹

Co-author(s): Guosheng Song¹ ; Wengang Feng¹

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In the circumstances of the bulk transport of current lead in a magnet, HTS DC cables used as current leads for the magnets have great advantages. However, the AC loss is one of the important parameters of HTS DC cable and it has a strong effect on its stability and operation cost. For this research, a cold dielectric HTS DC cable, consisting of one conductor layer, one insulation layer and one shielding layer, was fabricated using YBCO coated conductor. We measured the AC ripple losses of the HTS cable, and concluded on the relation between AC losses and power frequency.

Submitters Country:

China

Thu-Af-Po4.08 / 526

Experimental Research on Out-of-plane Bending Characteristics of Critical Current for 2G Tapes

Yinshun Wang¹

¹ *North china Electric power University*

Second generation (2G) high temperature superconducting (HTS) tapes have been commercialized in the form of thin tape and promising for the application of high field magnets in low temperature and high current cables in liquid nitrogen temperature. Bending 2G tapes is always essential in fabrication of practical devices, which possibly causes the degradation of critical current. Although there are several studies on easy bending and hard bending characteristics, out-of-plane bending characteristics with different bending orientations are still seldom. The effects of out-of-plane bending with different bending angles relative to in-plane bending, that is easy bending, on the critical currents and n values of 2G HTS were experimentally investigated in self-field and 77 K. Experiments showed that degradation behavior of n -value has a similar agreement with degradation behavior of the critical current.

Submitters Country:

China

Mon-Af-Po1.10 / 507

Experimental Study of Quench Performance for Superconducting Coil with YBCO Coated Conductors

Panpan Chen¹ ; Jiahui Zhu²¹ *China electric power research institute*² *China Electric Power Research Institute*

When the high temperature superconducting power devices run in the power system, the superconducting tapes may quench due to power system fault. Therefore, quench characteristic is one of the most important characteristics of superconducting electric equipment. In this paper, the quench characteristics of the YBCO coil module have been investigated. Firstly, YBCO experiment coil is developed which has heating wire to be placed. Then, based on AC voltage source, the experiment system is established with data acquisition and control system. To obtain electrical and thermal behaviors of the coils, quench experiments are carried out under different thermal disturbance and operation current conditions. Special attention has been paid to the current decrease and joule heating. Influence of heating power on operate current are discussed. Results in this paper could be helpful to investigate quench and fault current limiting characteristic of the YBCO coil.

Submitters Country:

China

Tue-Af-Po2.08 / 399

Experimental Study on AC Loss of a Quasi-isotropic Strand Fabricated by 2G HTS CCs in AC Magnetic Fields

Author(s): Yan Li^{None}**Co-author(s):** Yinshun Wang ; Yanbing Hou

AC loss of the superconducting composite conductor is one of the important factors for the application of superconducting power devices since it determines the stability and operation cost. In recent years, a variety of models have been successfully developed to simulate HTS coated conductors (CCs), while the calculation of AC loss focused on superconducting strands based on REBCO CCs is relatively less. Moreover, systematic analysis on hysteresis loss is relatively mature, much efforts need to be made to carry out the research on the eddy-current loss and coupling loss because they are also crucial part of AC loss. In this paper, we analyze total AC loss including eddy-current loss and coupling loss as well as hysteresis loss of a quasi-isotropic strand consisting of symmetrically stacked 2G HTS CCs and present a new calorimetric method for measuring AC loss of the strand by optical fiber Bragg grating (FBG) in liquid nitrogen temperature. The experimental results are in agreement with the calculations.

Submitters Country:

China

Tue-Af-Po2.08 / 898

Experimental Study on the Magnetization Losses of Tri-axial CORC Cable used in All-Electric Aircraft

Zixuan Zhu^{None} ; Yawei Wang¹ ; Min Zhang¹ ; Jie Sheng¹ ; Weijia Yuan¹

¹ *University of Bath*

A high temperature superconductor tri-axial CORC cable has been designed for all-electrical aircraft. This paper is to study the magnetization loss of this tri-axial cable under time-varying external magnetic field. This cable is wound by ReBCO tapes from SuNAM, Korea. An experimental platform is built to measure the magnetization loss using the calibration-free method. The tri-axial cable is operated at 77 K in liquid nitrogen. Magnetization loss is measured under two situations, with and without transport current. Under the same external field, the cable with transport current generates higher magnetization loss than that without transport current. The influences of field amplitude and frequency on the magnetization loss are also studied in this paper. The magnetization loss increases dramatically with the field amplitude. A 3D finite element method (FEM) model based on T-A formulation is built to calculate the magnetization loss. The results from measurement are well agreed with expected value. Then the distribution of the magnetization loss on different layers of the cable is analysed by modelling. Less magnetization loss is observed on the inner layers of the tri-axial cable, due to the field shielding of the outer layers.

Submitters Country:

UK

Tue-Af-Po2.09 / 909

Experimental Study on the Mechanical Stress Effect on the Degradation of High Temperature Superconducting Coils

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High temperature superconducting (HTS) conductors are expected to improve small sized high field magnets. However, the mechanical stresses lower the critical current properties of the HTS tapes. The objective of this work is to clarify the relationship between the critical current properties and the total tensile stresses caused by the winding tension during the coil winding process and the electromagnetic forces during the coil excitation process. As a previous work, the authors carried out the short sample tests using YBCO coated conductors with 0.22 mm of the thickness. From the results, when the YBCO tape is bending with 30 mm of the flatwise curvature radius, over 200 MPa of the applied tensile stress lowers its critical current property. In order to compare the mechanical stress effect of the YBCO coils with the short sample test results, the authors carry out one turn coil tests using YBCO tapes. The one turn coil radius is 30 mm. In order to evaluate the winding tension effect on the critical current, the authors develop a winding machine which can control the winding tension from 0 N to 1 kN. Using a 10-T cryogen free superconducting magnets with 150 mm of the bore diameter, the authors will carry out the excitation tests of the one turn coil with liquid nitrogen cooling and evaluate the hoop stress effect caused by the induced electromagnetic forces. From the one turn coil test results, this paper summarizes the mechanical stress restriction which causes to the degradation of the YBCO coils.

Submitters Country:

Japan

Mon-Af-Po1.10 / 1203

Experimental and numerical analysis of quench characteristics on a HTS coil by fault disturbance in HTS generator

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For the high temperature superconducting (HTS) coils supplied by DC powers, a thermal disturbance may cause local temperature rise and irreversible damage because of constant current. In contrast, when a thermal disturbance occurs, the current flowing in a closed-loop HTS coil operated in persistent current mode (PCM) will decrease correspondingly. In this paper, a closed-loop single-pancake HTS coil energized by persistent-current switch (PCS) is tested to obtain the minimum quench energies (MQEs) and normal zone propagation velocity (NZPV), which we use to describe thermal stability, as well as an unclosed one. A FEM model coupling with PDEs and thermal module is built to reveal the mechanism. The experiment results coincide with the simulated ones and show that the closed-loop coil has larger MQEs and better thermal stability.

Submitters Country:

China

Mon-Af-Po1.01 / 913

Experimental and numerical investigation on losses in electrodynamic transients in a Nb₃Sn prototype race-track coil

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The detailed calculation of the current and losses distribution during the electrodynamic transients is of great importance for the design of superconducting accelerator magnets made of Rutherford cable. On the one hand, the current distribution affects the field harmonics generated by the superconducting magnet; on the other hand, the loss computation is necessary for the design of the cryogenic system. This paper presents the analysis of current distribution and losses in a prototype race-track coil configuration, the so-called Short Model Coil (SMC), developed at CERN in the frame of a test campaign of possible cable candidates for the HL-LHC project of CERN. The SMC 11 T was wound with a 40 Nb₃Sn strand Rutherford cable in two layers, with 35 turns per layer. The loss measurements were performed at CERN by means of an electrical approach to analyse different transport current cycles. The THELMA model of the Rutherford cable, which represents the conductor at the strand level, was used for the analysis of the current distribution and losses in the coil during the transport current ramps. In this way, the inter-strand current diffusion and the corresponding time constants could be analysed in detail. In the paper, the comparison between the numerical and the experimental results is presented, together with the relevant information on contact conductances between strands, current distribution and losses.

Submitters Country:

Italy

Wed-Af-Po3.07 / 812

Experimental and numerical investigations on the separation behavior of magnetic particles under an alternating gradient magnetic field

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Magnetic particles are known to align and aggregate into multi-particle clusters in an applied magnetic field, and this aggregation phenomenon has been widely used in various biological and chemical applications. However, it will give rise to the separation difficulty of multiple types of magnetic particles with different sizes in traditional magnetic separation process. In this work, an alternating gradient magnetic field is designed and applied to solve the aggregation problem between particles, which is based on the fact that the inter-particle interaction force changes with the external field direction. By varying the magnetic field direction periodically in the region of interest, intermittent repelling forces acting on the particles lead to the disaggregation of clusters for better separation. To validate the feasibility of this method, the aggregation and separation behavior of magnetic particles with different sizes (10 μm , and 5 μm) is numerically investigated, showing that the two types of particles could be separated effectively under the dynamic field, while they are easy to form a chain and move together under the static field. These results are corroborated by microscopic visualizations of magnetic particles in the experiments.

Submitters Country:

China

Thu-Af-Po4.09 / 760

Experimental evaluation of computer-aided quench detection for the KSTAR CS Coil

yong chu^{None}

The KSTAR CS coil needs an active quench detection system, where the primary one is the resistive voltage detection. The system should operate with two basic requirements, which are almost infallible quench detection and minimization of fake quench alarms. However, the inductive voltage, which is generally much higher than the resistive voltage caused by quench, can trigger the fake quench alarm frequently if it is not properly compensated. Co-wound Voltage Tapes (CVT) and bridge circuits are used to reduce such inductive voltage. However, they do not perfectly cancel out the inductive voltage due to mutual inductances between coils. In order to effectively compensate the inductive voltage, all inductances between coils should be considered, where the real quench detection voltage is made by subtracting all inductive voltage components of the other coils from the measured voltage of a coil. By taking all the complexity into account, its implementation can be done only by a microprocessor. The computer-aided quench detection system was designed and tested for the KSTAR PF 1 coil. In this paper, the design of di/dt measurement devices and pre-compensation circuits are presented with the test results carried out in 2016 KSTAR campaign. The design considering plasma dynamics is suggested to further reduce the inductive voltages caused by plasma.

Submitters Country:

South Korea

Tue-Af-Po2.08 / 746

Experimental study on the effect of twisting on critical currents of Nb3Sn cable-in-conduit conductors

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Cable-in-conduit (CIC) conductors made of Nb₃Sn wires have been developed for use in large high-field magnets. A “wind, react and transfer” method has been established to avoid the degradation by excess strain after reaction of Nb₃Sn and to adopt organic insulator. However, the “react and wind” method is preferred for a helical coil for a helical fusion reactor, because the “transfer” process is difficult to be adopted after being wound into the three-dimensional configuration. In this concept, a CIC conductor is heated for reaction of Nb₃Sn on a bobbin with the same equivalent radius of the helical coil, and transferred to a reel that revolves through the helical coil. Next, the conductor is pulled aside, that is, twisted, and wound in a coil case. According to the experimental study with a model CIC conductor, the tensile strain is induced in the wires by twisting the conduit in the same direction as the wire twisting direction, as expected. In this experiment, the amounts of change of longitudinal normal strain in the wires are in the order of 1/10 of the highest normal strain in the conduit. The change of strain in the wires is considered to be lessened by slippage of the wires to the conduit. Since the compressive strain in the wires can be slightly lessened by twisting the conductor, the react-and-wind method is expected to be applicable for the helical coil without degradation or with slight improvement of the conductor performance. In order to confirm this effect, small CIC conductor samples in spring-shape are prepared. The torsion strain is induced on the conduits by changing the length of the spring, and the change of the critical current is measured in liquid helium with a background field. The first experimental results are presented.

Submitters Country:

Japan

Tue-Af-Po2.07 / 821

Experimental tests on a superconducting hybrid DC circuit breaker

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High Voltage Direct Current (HVDC) transmission systems using Voltage-Source Converters (VSC) are widely recognized as having significant potential for long distance high power delivery, particularly for offshore wind farm connections. The US Navy has also proposed a Medium Voltage DC (MVDC) distribution architecture for the all-electric shipboard power systems. NASA is also evaluating turboelectric aircraft propulsion systems using MVDC electrical networks to meet the N+3 / N+4 emission targets. DC circuit breakers are a critical technology for managing faults in multi-terminal DC networks. DC current breaking however is much more challenging compared to that for AC systems because there is no natural zero-crossing of the current to isolate the fault. A superconducting hybrid DC circuit breaker consisting of a superconducting coil, a mechanical switch, one (or more) semiconductor(s) and varistor(s) has been proposed and patented. A low voltage superconducting hybrid DC circuit breaker prototype has been built and has demonstrated interrupting 500 A DC within 4.5 msecs. The superconducting coil for this prototype used a multi-strand MgB₂ round wire with a stainless steel sheath. This paper will focus on the operation of the superconducting hybrid DC circuit breaker and the design of each component. The paper will also include a detailed analysis of the test results and the implications for practical design of the superconducting hybrid DC circuit breaker. This paper will attempt to show that a hybrid superconducting coil can be used to produce an option that represents a competitive candidate DC circuit breaker for MVDC networks.

Acknowledgment: This work was funded as part of the UK EPSRC, FCL/CB: An Integrated VSC-HVDC Fault Current Limiter/Breaker project, EP/L021552/1.

Submitters Country:

United Kingdom

Mon-Af-Po1.10 / 601

Experiments and Numerical Model of Quench Process Generated by Magnetic Disturbance in 2G HTS Tapes

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Second generation (2G) high temperature superconducting (HTS) tapes are now capable of carrying very high transport current and promising for a wide range of applications. One of the most important things considered in the development of applications is the stability of HTS material. Because of various disturbances, such as heat disturbance and magnetic disturbance, HTS tapes may experience severe quench, which can be damaged. So the study of quench behavior is very necessary and important. Many studies have been performed to investigate the quench generated by heat disturbance, but the quench generated by magnetic disturbance has rarely been reported. In this study, we apply a magnetic disturbance on a HTS sample to quench it, and the minimum quench magnetic field and normal zone propagation velocity are measured. The quench and recovery characteristics are compared with that generated by heat disturbance. Moreover, a numerical model is built to verify the measured results. The detailed results about the experiments and the numerical analysis are presented and discussed in this paper.

Submitters Country:

China

Mon-Af-Po1.02 / 1029

FCC-hh Detector Magnet Cryostats and Cold Mass Suspension system

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¹ *CERN*

The baseline design of the FCC-hh detector magnet system with 14 GJ stored energy and providing 4 T for particle tracking, comprises 3 large size superconducting solenoids. The main solenoid is 20 m long and has a 10 m free bore, while the so-called forward solenoids have a free bore of 2.6 m and a length of 4.2 m. The designs of the cryostats take into consideration not only vacuum and cold mass weights of 1.05 kt and 0.048 kt respectively, but also those specific for the detector such as the high weight of 4.6 kt of the calorimeters and trackers resting on the bore tube. A specific challenge in the design is to choose the type of cold mass supports since these entails an important mechanical local load on the cryostat. The choice of materials and their properties has significant impact on both heat load by conduction and strain in the tie rods. The design of both vacuum vessels and suspension systems of these very large magnets will be presented. Also an estimate of the various heat loads seen by the cold masses are provided.

Submitters Country:

Switzerland

Wed-Af-Po3.01 / 708

FEA Model and Mechanical Analysis of the Nb₃Sn 15 T Dipole Demonstrator

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Nb₃Sn magnets with a nominal operation field of 15-16 T are being considered for the LHC energy upgrade (HE-LHC) and a post-LHC Future Circular Collider (FCC). To demonstrate the feasibility of 15 T accelerator quality dipole magnets, the US Magnet Development Program (MDP) is developing a single-aperture 15 T Nb₃Sn dipole demonstrator based on a 4-layer graded cos-theta coil with 60 mm aperture and cold iron yoke. The main design challenges for 15 T accelerator magnets include large Lorentz forces at this field level. To counteract them, an innovative mechanical structure based on a vertically split iron yoke, locked by large aluminum IC-clamps and supported by a thick stainless steel skin, has been developed at Fermilab. To study the performance of the structure a parametric multi-physics FEA model has been set-up by FEAC. This paper describes the numerical model as well as the results of a sensitivity analysis of the effect of geometrical tolerances and assembly parameters.

*Work is supported by Fermi Research Alliance, LLC, under contract No. DE-AC02-07CH11359 with the U.S. Department of Energy

Submitters Country:

GREECE

Thu-Af-Po4.04 / 939

FEM Modelling Studies of 3 T Cryogen Free MRI Magnet based on MgB₂ conductor

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This work describes magnetic, mechanical, and thermal Finite Element Modeling (FEM) studies in support of a whole body 3 T MRI magnet based on conduction cooling. As a strand, both 1G and 2G MgB₂ conductors were considered. An optimization code to design the main coil segment layout and winding size was used. Thermal FEM modeling was used to estimate the temperature gradient on the coils in order to determine the critical surface of magnet operation. Mechanical and thermal FEM modeling was used to determine stresses, thermal expansion of different materials as well as required cooling power and cooling time of the magnet. Material parameters and their temperature dependencies used as inputs in the modeling were taken from experiments performed in our laboratory or taken from available material data bases. We used a Wire In Channel (WIC) design for the conductor to have a well-protected system, and also perform quench and protection studies on the magnet system (in this case at the individual coil level). Coil sizes, field homogeneities, temperature gradients, and coil protection are discussed. The influence of 1 G vs 2G conductor choice is also discussed.

Submitters Country:

USA

Tue-Af-Po2.02 / 252

FIELD QUALITY FROM TOLERANCE ANALYSES IN EIGHT-PIECE QUADRUPOLE MAGNET***Author(s):** Jie Liu¹**Co-author(s):** Rogue Dejus¹ ; Aric Donnelly¹ ; Chuck Doose¹ ; Animesh Jain¹ ; Mark Jaski¹¹ *Argonne National Laboratory*

Quadrupole magnets are used extensively in particle accelerators, synchrotrons, and storage rings all over the world. Excellent field quality in these quadrupole magnets is needed at these facilities, which requires machining the magnet parts to high precision with conventional magnet designs. An eight-piece quadrupole design and assembly method are developed that produce the desired magnetic field quality by accurately positioning the pole tips in a quadrupole magnet. In this magnet, all the parts need to be machined only within standard machining tolerances. This paper presents the magnetic and mechanical tolerance analyses of this eight-piece quadrupole magnet. We performed mechanical tolerance stack-up analyses using the Teamcenter Variation Analysis software 1 to evaluate the relationship of part-level machining tolerances to final magnet assembly errors. We then performed finite element analyses using OPERA 1 to estimate the effect of assembly errors on magnetic field quality and in turn to set the acceptable machining tolerances for parts to achieve the desired magnetic performances. We conclude from our tolerance analyses that 20 microns symmetry in pole tip gaps can be achieved with 50 micron standard machining tolerances, resulting in improved field quality. The analysis results are compared to magnetic measurements of the R&D eight-piece quadrupole magnets.

Submitters Country:

USA

Tue-Af-Po2.06 / 213

FLUX-REGULATION PERFORMANCE FOR RADIAL SUSPENSION FORECES OF BEARINGLESS FLUX-SWITCHING MOTOR**Huangqiu Zhu¹ ; Chenyin Zhao^{None}**¹ *Jiangsu university*

Conventional bearingless PM motors usually suffer from the problems of mechanical integrity and thermal instability due to their PMs located in the rotor, which lead to a discount of the maximum electric loading performance. In order to solve the problems, the bearingless flux-switching permanent magnet (BFSPM) motors appear in recent years. BFSPM motor combines the characteristics of conventional FSPM motor and bearingless motor, which has the virtues of large torque capability, high radial suspension forces, simple rotor structure, strong robustness, easy thermal dissipation, etc. This structure of magnet-free rotor is favorable in application which requires frequent rotor disposal such as pumping of high-purity fluids, e.g. blood during medical operations. However, since the open-circuit air-gap flux is produced by the stator-magnets solely, it is difficult to be regulated. So the radial suspension force and torque can't be predicted accurately. Hence, in this paper, the flux-regulation capability of the BFSPM motor with four PM locations, namely PM-Full, PM-Top, PM-Middle and PM-Bottom are compared based on finite element analysis (FEA). According to the PM locations, four typical topologies of BFSPM motors are emerged, namely PM-full, PM-Bottom, PM-Middle, PM-Top, respectively. Based on these configurations, their flux-regulation performances for radial suspension forces are analyzed and compared by FEA. The analysis results show that the

magnitude of radial suspension forces can be double at the PM-Bottom location if the PM length is halved when NdFeB is adopted. The PM-Middle and PM-Top configurations have almost the same magnitude of radial suspension forces. And the magnitude of radial suspension forces of PM-Middle has little difference from the PM-Top. The cause of this phenomenon will be discussed and analyzed in the full paper.

Submitters Country:

China

Thu-Af-Po4.01 / 953

Fabrication and Measurement of New Inflector for g-2

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¹ *Fermilab*

The new FNAL g-2 experiment is based on the muon storage ring previously used at BNL. The 1.45 T dipole magnetic field in the storage ring is required to have very high (1 ppm) homogeneity. The muon beam injected into the ring must be transported through the magnet yoke and the main superconducting coil cryostat with minimal distortions. The old inflector magnet shielded the main dipole fringe field inside the muon transport beam pipe, with an outer NbTi superconducting screen, and did not disturb the field in the area of circulating beam. Nevertheless, this magnet had coils with closed ends in which a large fraction of muon beam particles were lost. A new magnet has been designed and fabricated at FNAL, utilizing new end geometry with open ends to allow improved beam transport. The magnet has been fabricated and undergone warm measurements prior to installation in the experiment.

Submitters Country:

United States

Mon-Af-Or5 / 508

Fabrication and Testing of Bi-2223 Insert Coils for High Field NMR Magnets

William Marshall¹ ; Mark Bird² ; David Larbalestier¹ ; Dustin McRae¹ ; Patrick Noyes³ ; Adam Voran¹ ; Robert Walsh¹

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² *FSU*

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In 2005 the Committee on Opportunities in High Magnetic Fields (COHMAG) issued a challenge to develop a 30 T high-resolution NMR magnet. In response, the National High Magnetic Field Laboratory (NHMFL) is investigating all three commercially available high-temperature superconductors (HTS) including REBCO, Bi-2212 and most recently, a reinforced Bi-2223 conductor supplied by Sumitomo Electric, designated Type HT-NX. Recent investigations of Type HT-NX conductor at the NHMFL and by others suggest that operation at stress above 400 MPa, and strain above 0.7% may be feasible. The next steps in our program are reported here, and include fabrication of coils made with conductor piece lengths above 300 meters and testing of those coils at their stress limit at 4.2 K in a 16 Tesla background field. Findings from experience developed during fabrication and testing of these coils are reported. Some details of the coil technology development are presented, including continuous layer winding, splice joints and reduced current density 'notch' windings. For long-term operation, the conductor needs to tolerate repeated cyclic loading. Results from cyclic

fatigue measurements of the conductor, and of a test coil are reported, along with estimations made of load and cycle limits.

Submitters Country:

United States

Wed-Af-Or23 / 606

Fabrication and assembly performance of the first 4.2 m MQXFA magnet and mechanical model for the Hi-Lumi LHC Upgrade

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The LHC Accelerator Research Program (LARP), in collaboration with CERN and under the scope of the high luminosity upgrade of the Large Hadron Collider, is in the prototyping stage of the development of a 150 mm aperture high-field Nb3Sn quadrupole magnet called MQXF. This magnet is mechanically supported using a shell-based support structure, which has been extensively demonstrated on several R&D models within LARP, as well as in the more recent short MQXF model (1.2 m magnetic length) program. The MQXFA magnets are each 4.2 m magnetic length, and the first mechanical long model, MQXFA1M (using surrogate aluminum coils), and MQXFA1 prototype magnet (the first prototype with Nb3Sn coils) have been assembled at LBNL. In this paper, we summarize the tooling and the assembly processes, and discuss the mechanical performance of these first two structures, comparing strain gauge data with finite element model analysis. Additionally, magnetic measurements will be discussed along with alignment and fiducialization data of these structures, and their implications on the long MQXF magnet program.

Submitters Country:

United States

Wed-Af-Po3.09 / 309

Fabrication of grain aligned Bi2223 thick films with high critical current properties

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The Ag-sheathed Bi2223 tapes have been extensively used for practical applications, while it is thought that the J_c properties of the Bi2223 polycrystalline materials were severely limited by the weak grain coupling originated in short coherence length with large anisotropy. Although control of the microstructure is known to be effective to improve critical current properties, J_c of the tapes is approximately two order of magnitude lower than that of the single crystalline film. In our previous studies, the grain coupling of the Bi2223 materials was found to be improved by introduction of post-annealing process under moderately reducing atmosphere to control the nonstoichiometric cation compositions. Recent our studies revealed that sintering in reducing atmospheres with low oxygen pressure (PO_2) below 5 kPa enabled us to obtain Bi2223 with almost single phase by sintering for a short time less than 10 hours, resulting in small grains of Bi2223 and impurity phases. In Bi2223 thick film materials, the grains easily form well-aligned microstructure and high J_c properties can be achieved by integration of these guidelines. Based on these backgrounds, we have attempted to fabricate grain aligned Bi2223 thick film materials with high critical current properties. In addition to the investigation of heat treatment conditions, we have optimized the fabricating processes including the constituent phases of the precursor powder and the designed film thickness in terms of enhancement in J_c . Thus far, intergrain- J_c at 77 K has been improved up to approximately 5 kA cm⁻². Applications of thick film materials as for current leads and magnetic shielding will be discussed.

Submitters Country:

Japan

Mon-Af-Po1.01 / 961

Fabrication of the 7.2 m long coils for the prototype of MQXFB, the Nb₃Sn low-b quadrupole magnet for the Hi-LHC

Friedrich Lackner¹ ; Paolo Ferracin¹ ; Ezio Todesco¹ ; Stephane Triquet¹ ; Marc Pozzobon¹ ; Juan Carlos Perez¹ ; Christian Scheuerlein¹ ; Eugenio Cavanna^{None} ; Thibault Genestier^{None} ; Rosario Principe¹ ; Giorgio Ambrosio² ; Frederic Savary¹

¹ *CERN*

² *Fermilab*

The High Luminosity LHC Project target is to reach an integrated luminosity of the LHC of 3000 fb⁻¹, corresponding to a factor 10 increase in number of collisions with respect to the current accelerator. One major improvement foreseen is the reduction of the beam size at the collision points. This requires the development of 150 mm single aperture quadrupoles for the interaction regions. These quadrupoles are under development in a joint collaboration between CERN and the US-LHC Accelerator Research Program (LARP). The chosen approach for achieving a nominal quadrupole field gradient of 132.6 T/m is based on the Nb₃Sn technology. The coils with a length of 7281 mm will be the longest Nb₃Sn coils fabricated so far for accelerator magnets. The production of the long coils was launched in 2016 based on practice coils made with copper cable. This paper provides a status of the production of the coils made with low grade and full performance Nb₃Sn cable and will describe the production process and applied quality control. Furthermore an outlook for the prototype assembly will be provided.

Submitters Country:

Switzerland

Thu-Af-Po4.03 / 77

Fast Cycling Superconducting Quadrupole

Author(s): Sergey Kozub¹**Co-author(s):** Evgeny Kashtanov¹; Igor Bogdanov¹; Leonid Shirshov¹; Leonid Tkachenko¹; Pavel Slabodchikov¹; Peter Shcherbakov¹; Valery Pokrovsky¹; Veniamin Sytnik¹¹ *Institute for High Energy Physics*

FAIR (Facility for Antiproton and Ion Research), planned to be built at the site of GSI, will include the 300 Tm fast-ramping heavy ion synchrotron SIS300. In the frame of collaboration in FAIR project IHEP has developed, produced and tested two prototypes of a SIS300 fast cycling superconducting quadrupole. The main parameters of the quadrupole are: 45 T/m central gradient, the gradient ramp rate of 10 T/m/s, the superconducting coil inner diameter of 125 mm, 1 m length of the magnet. These prototypes had one layer coil which was wound by a cored cable with 19 wires. The superconducting wire of the second prototype had improved characteristics which have allowed to reduce the AS losses in the magnet. The paper presents measured characteristics of the quadrupole prototypes.

Submitters Country:

Russia

Tue-Af-Po2.04 / 840

Fast cooling high field pulsed magnet with distributed mini cooling gaps

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Enhancement of the repetition rate of high field pulsed magnets is significant for the efficiency of the experiments under pulsed high magnetic field. Adding a liquid nitrogen cooling gap of 3-5 mm has been proven to be a feasible method to increase the cooling efficiency and improves the repetition rate of pulsed magnets. Study indicated that the cooling efficiency increased with the number of the cooling gaps. But the radial dimension of the cooling gaps has to stay rather small in order to limit their influence on the maximum field and coil efficiency, especially when we tried to set a cooling gap adjacent to every layer of conductor. Since heat transfer between boiling liquid in mini gaps of less than 3 mm is a rather complicated process, the heat transfer laws based on the large space pool boiling are no longer applicable. The heat transfer coefficient in the mini gaps will change greatly with the change of heat flux, mass flow rate and size of the gap, which even might drop sharply due to dryout of the liquid nitrogen. In order to find out the effectiveness of mini gaps to increase the cooling efficiency of the pulsed magnets, an apparatus was developed to test the heat transfer properties of a mini gap with radial dimension of 1 mm. Simulations were carried out to optimize the cooling gaps in a pulsed magnet based on the tested results. In this paper, the experiment of the testing process will be described. The simulation of a 40 T fast cooling pulsed magnet will be presented.

1 Frings P, Witte H, et.al, Rapid Cooling Methods for Pulsed Magnets. Applied Superconductivity, IEEE Transactions on, 2008, 18(2): 612-615

Submitters Country:

China

Tue-Af-Po2.02 / 1038

Fast dipole magnet development

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For the simultaneous operation of several parallel free electron laser beam lines and/or accelerator test experiments it is mandatory to have a device capable of fast switching of electron bunches between the different beam lines with high accuracy. Such devices are the described pulsed dipole magnets. Two magnets allow for an 8 degree kick to a 1.6 GeV electron bunch. Time of increase of a magnetic field is less than 100 μ s. Field delay from current is less than 2 μ s due to that the core of a magnet is assembled from a 80 μ m thick steel. Magnetic field integral $B_0 \times L$ is 0.375 Tm. Magnets should operate at a frequency of 10 Hz. Particular attention is paid to minimizing the power dissipation due to Foucault currents. For this purpose, the magnetic field component perpendicular to the laminas has been minimized.

Submitters Country:

Russia

Tue-Af-Po2.02 / 1241

Fast ramped dipole and DC quadrupoles design for the Beam Test Facility upgrade

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The Beam Test Facility (BTF) is part of the DAΦNE accelerators system of INFN Frascati National Laboratory (LNF). It is a transfer-line optimized for selection, attenuation and manipulation of electrons and positrons extracted from the DAΦNE LINAC. An upgrade of the line is scheduled by the end of 2018 in order to reach a beam energy of 920 MeV (with respect to the actual 750 MeV) and a new branch of the actual transfer line, in order to have two different beam lines. The layout of the new transfer line foresees seven new quadrupoles and a beam deflection of 135 degrees achieved through a 15 degrees fast ramped dipole, two 45 degrees H-shape sector dipoles and finally a 35 degrees C-shape sector dipole.

The design of the magnets has been completely performed at INFN, including electromagnetic, mechanical, thermal and hydraulic aspects. This effort leads to a complete set of detailed CAD drawings that can be directly used from Industrial partners to build the magnets. The manufacturing processes have been studied in detail in order to reduce the fabrication cost. The goal is to boost the manufacturing of prototypes and small series from Small and Medium Enterprises. Magnetic measurements will be later performed at our Institute.

In this paper we report on two types of magnets for this new line. The first magnet is designed to switch the beam alternatively in the two lines. It will be operated in a fast ramped mode, with a rise time of 100 ms. For that reason, a laminated yoke is necessary: the lamination thickness has been analysed in detail. The gap of the magnet is 25 mm with a magnetic field of 1.11 T. The second is a family of seven quadrupoles with a gradient of 20 T/m and a bore of 46 mm.

Submitters Country:

Italy

Mon-Mo-Or3 / 1167

Fatigue failure analysis of a 60T pulsed magnet at the WHMFC

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Fatigue failure had recently occurred on a 60T pulsed magnet at the Wuhan National High Magnetic Field Center (WHMFC). It was designed to produce a peak field of about 63T and had practically endured a total number of 2124 shots with 573 of them above 56T. In this paper, the cause of failure is numerically analyzed using the conductors and reinforcing fibers at the mid-plane of the magnet. The damage-coupled constitutive model of conductor is applied with two failure criteria so that the mechanical behavior and fatigue life of the magnet during multiple pulses can be predicted. The analysis is divided into three steps where special attention is paid to the effects of bending pre-strain and axial pressure on conductors. The first step is about the stress distribution during the first pulse. It is found that the maximum stress of reinforcing fibers can be increased by about 600 MPa at 63T considering the axial pressure and pre-strain. The second step is failure analysis at certain level of magnetic field. It is found that the fatigue life of the magnet between 56 ~ 63T drops rapidly from about 1000 pulses to less than 100 pulses as the field increases. In this region, the main cause of failure is the axial strain of conductor reaching its critical value. The third step is failure analysis according to the practical sequence of pulses. It is found that the 573 pulses above 56T decides the failure of magnet where the axial strain keeps increasing until the critical value is reached.

Submitters Country:

China

Mon-Af-Po1.06 / 663

Feasibility Study of MgB₂ Cable for Pancake Coil of Energy Storage Device

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Since MgB₂ wires have been developed and commercially available, large scale cable assembled with MgB₂ strands is required for fabricating Superconducting Magnetic Energy Storage (SMES) devices. To form the MgB₂ superconducting material, heat treatment procedure is needed forming intermetallic compounds like Nb₃Sn. In general, magnets using those types of materials are constructed in simple processes, where the magnets are wound before heat treatment, namely "Wind and React (W&R)" method, and the heat treatment process is performed before coil fabrication, called "React

and Wind (R&W)” method. The W&R process simplified initial development. The R&W process has several important advantages, such as reasonable heat treatment reactor size, simple insulation, compatibility with existing coil winding and SMES manufacturing, and dimensional control of the coil. Therefore, we have chosen to explore the R&W approach. For instance, the difficulty of applying the R&W process is that we should design the cables and magnets in which the strain must satisfy the acceptable level, only 0.24 % after heat treatment. To verify the applicability of the fabrication process, we performed the feasibility study based on the bending strain analysis of cable and double-pancake coil for several tens of kJ class SMES system. Calculation of curvature distributions based on a three-dimensional space curve theorem for both round cable and rectangular cross section cable like Rutherford type are investigated. They strongly depend on cable dimension parameters such as twist pitches, coil radius, and conductor former. The investigated results can allow us to construct the robust energy storage system using MgB₂ wires.

Acknowledgements: This work was supported by Advanced Low Carbon Technology Research and Development Program (ALCA) of Japan Science and Technology Agency (JST).

Submitters Country:

Japan

Thu-Af-Po4.10 / 584

Feasibility Study on Mitigation of Screening Current-Induced Field in a Conduction-Cooled REBCO Magnet

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¹ *Korea Basic Science Institute*

² *Seoul National University / National High Magnetic Field Lab.*

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⁷ *Kunsan National University*

The screening current-induced field (SCF) is well known to be an intrinsic problem for an REBCO magnet to have an NMR-quality field homogeneity. According to recent studies, the SCF in an REBCO magnet may be effectively reduced by the current sweep cycle method that requires “overshooting” in the magnet current. When an REBCO magnet is operated at a “low” temperature and thus has a large current margin to the magnet’s critical current, the overshooting often needs to be unacceptably “large” to eliminate a significant amount of SCF. In this study, we present an effective solution for this problem for the current sweep cycle method combining the thermal cycle. The SCF at a given operating current is known to be large at a small load factor, while it decreases as the load factor increases. Combined with the thermal cycle, the current sweep cycle technique is expected to be more effective as the temperature rise may reduce the magnet load factor. This paper presents test results of a conduction-cooled REBCO magnet that consists of a stack of 32 double pancake coils. This work was supported by the KBSI grant (D37611) to S.-G.L.

Submitters Country:

South Korea

Tue-Af-Po2.12 / 82

Feasibility Study on a Multi-pole Electro-magnet using Parallel Iron-core Structure

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¹ *Korea Basic Science Institute*

This paper deals with a design concept of a multi-pole electro-magnet using parallel iron-core structure. The electro-magnets can be used in many kinds of magnetic study such as magnetic susceptibility, hall effect research, magneto-optical effect, and hysteresis measurement. In electro-magnets, generally, only a single probe can be applied at a time due to the single pole structure, and it is also very hard to measure many samples at a time. The present paper proposes multi-pole electro-magnet that has parallel iron-core structure unlike the conventional electro-magnet system. To verify the feasibility of the structure, a lab-scale multi-pole electro-magnet was designed using commercialized FEM software. Based on the design results, a parallel iron-core and coils assembly was fabricated, and the performance of magnet was evaluated with respect to the core structure. This work was supported by a KBSI Grant (D37614).

Submitters Country:

South Korea

Thu-Af-Po4.10 / 497

Field Mapping System for a 230 MeV Superconducting Cyclotron

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¹ *China Institute of Atomic Energy*

A superconducting cyclotron is designed and under construction at China Institute of Atomic Energy to provide 230 MeV proton beam for cancer therapy. The fine machining of the main magnet will be finished soon and then the iterative shimming process is normally performed to get the ideal isochronous field, which requires the relative measured field error should be within 10⁻⁴. A searching coil sensor mapping system is established to satisfy the measurement accuracy requirements, including a nuclear magnetic resonance (NMR) probe to measure the field at the cyclotron center precisely and a moving searching coil to obtain the field differences. Moreover, a hall probe is integrated in the system to verify the field data. A measurement apparatus is designed to move the searching coil and hall probe in the median plane, focusing on the positioning accuracy and mechanical stability. A highly automated control software is developed to complete the movement and data collecting with operator interface and data storage. In this paper, the field measurement requirements are listed, the field mapping devices selection are described with reasons and the field mapping system, including mechanical structure and control system, are presented in detail.

Submitters Country:

China

Tue-Af-Po2.02 / 889

Field Measurement of a Pulse Bending Magnet for a Beam-Switching System in the J-PARC

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¹ *JAEA/J-PARC*

At the Japan Proton Accelerator Research Complex, a new experimental facility called the Transmutation Experimental Facility (TEF) is planned for the Accelerator-Driven System. The TEF facility will use the 400 MeV proton beam from the LINAC, which requires introducing a beam switching system at a Beam Transport from the LINAC to the 3GeV Rapid Cycling Synchrotron (RCS). A pulse bending magnet is one of key components of the beam switching system. To supply the beam to the TEF in addition to the beam operation of the RCS and downstream facilities, the LINAC should be operating in 50Hz. And half of the beam pulses of 25 Hz will be injected into the RCS and the other half will be delivered to the TEF. Thus the pulse bending magnet may repeat turning on and off operation in 25Hz. In this case, it is essential to assess not only a magnetic field in excitation but also a residual magnetic field at zero current. A magnetization curve (B-H curve) of the iron core of the pulse bending magnet is a key parameter to calculate the field accurately by the 3D field simulation code (OPERA 3D). Ring samples of the same production lot were made and the B-H curves were measured in detail.

In this presentation, we will report field measurement results of the pulse bending magnet. And the comparison with the calculation results by using the measured B-H curves will be also introduced.

Submitters Country:

Japan

Tue-Af-Po2.01 / 495

Field Measurement to evaluate iron saturation and coil end effects in the 2-m Model Magnet of Beam Separation Dipole for the HL-LHC Upgrade

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We have been developing the beam separation dipole magnet for the High Luminosity LHC (HL-LHC) upgrade. The magnet has a coil aperture of 150 mm using NbTi superconducting cable and dipole magnetic field of 5.6 T will be generated at 12 kA at 1.9 K to provide the field integral of 35 Tm. We have started development of the first 2-m-long model magnet (MBXFS01) to evaluate the design and the performance. In the first cold test in 2016, quench performance was not satisfactory because the coil stress at pole was completely released during excitation. It was decided that the model magnet was reassembled with increasing the coil stress to improve the quench performance. The excitation test of the modified model magnet (MBXFS01b) was performed at 1.9 K from February 2017 at KEK. The magnet showed much better quench performance and succeeded to reach the ultimate current of 13 kA as acceptance criteria. After the train campaign, magnetic field measurement was performed by a rotating coil method. The coil systems with an internal compensation of main dipole field were superior to simple coils in measuring the high-order multipole components and eliminating a variety of measurement errors. Due to the large coil aperture and limited outer diameter of the iron yoke, the control of iron saturation effects on the field quality has been a design issue. Regarding the magnetic performance, field saturation effects on the transfer function and the multipole field variation along the excitation, and coil end effects to the straight section need to be evaluated by the field measurement. In this work, field measurement results will be presented and the comparison with the 3D field calculation will be discussed.

Submitters Country:

JAPAN

Thu-Af-Po4.10 / 343

Field Stabilization Method of the Persistent Current Mode Coil Made of 2G HTS tape at 77 K

Derong Qiu¹ ; Zhuyong Li^{None} ; Wei Wu^{None} ; Zhen Huang^{None} ; Zhiyong Hong^{None} ; Zhijian Jin^{None}¹ *Shanghai Jiao Tong University*

Several joint-less coil structures were developed in the past decade that allow the coil made of HTS coated conductors operate in persistent current mode (PCM) at 77 K. The PCM coils could operate as the main magnet or shielding coil for small MRI/NMR or in maglev at 77 K to simplify the cryogenic system and lower the cost. While after the PCM coil is magnetized, the field trapped in the coil will endure an initial fast decay for several hours due to the current density redistribution and flux creep. In this paper, we tried to find effective methods to shorten the initial fast decay process and stabilize the trapped field as much as possible. An electromagnet is used to magnetize the joint-less coil with field cooling and zero field cooling method. Then the field reversal and field shaking are conducted on the coil to accelerate the current density redistribution process. The result shows that the initial fast decay process can be effectively shortened from several hours to tens of minutes, which can reduce the magnetization time in real application.

Submitters Country:

China

Mon-Af-Po1.09 / 1168

Field-assisted Joining of (RE)Ba₂Cu₃O_{7-x} Coated Conductors

Author(s): Carolyn Grimley¹**Co-author(s):** Justin Schwartz ¹¹ *North Carolina State University*

One of the most promising commercially produced high temperature superconductors is (RE)Ba₂Cu₃O_{7-x} (REBCO) in the form of a coated conductor on a Ni-alloy substrate. Its high critical current and mechanical strength make it promising for many applications. Yet the inability to create low-cost superconducting joints has long been one of the barriers in the use of REBCO tapes for applications which require long lengths of superconductor. Current joining techniques utilize either full or partial melting of the REBCO layer, which is detrimental to the oxygen content of the interface, or a non-superconducting solder. Melt-based techniques often require impractically high processing temperatures to accomplish joining as well as long timescales to restore superconductivity, and solder techniques consistently yield low-resistance joints at best. No technique yet has achieved a balance between practical processing conditions and usable results. In the broader ceramics processing community, several groups have shown that the application of an electric field during annealing can reduce the processing temperature required to produce diffusion in ceramics. This technique is known as electric field assisted sintering. Motivated by this conceptual foundation, we demonstrated the successful bonding of REBCO tapes under the assistance of both uniaxial pressure and an electric field at temperatures below the melting point of REBCO. The results from this preliminary study were presented previously, from which we concluded that interfering surface morphologies were a significant impairment to the bonding process in tapes from many manufacturers. A superconducting joint was demonstrated between conductors from AMSC, although the critical properties were reduced. Here, we discuss the continuing development of this project, addressing and improving the parameter reduction and focusing on improvements promoted by the electric field incorporation.

Submitters Country:

United States

Tue-Af-Po2.04 / 549

Finite Element Model for the Elasto-plastic Stress Analysis of Pulsed High Field Magnets

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Electromagnetic fields, temperature fields and stress fields co-exist and interact in a pulsed magnet. The stress field analysis is one of the critical problems for a pulsed magnet design. When the magnetic field is higher than 40T, the massive Lorentz force may explode the conductor windings [6]. And thus the internal reinforcement technique is invented to support the windings to stand the Lorentz force. When the demanded pulsed magnetic field becomes higher and higher nowadays, the mechanical stress issue becomes even more prominent. The stress distribution in the pulsed magnets can be calculated by commercial FEA software such as ANSYS or COMSOL, but they have some limitations and are not flexible for pulsed magnets design: (1) Spending a lot of time on establishing and meshing the complex geometry model for each single pulsed magnet design. (2) Divergence problem usually occurs when calculating contact problem between freestanding layers. (3) Complex physics processes as multi-field coupling, pre-stress and thermal stress is not easy to deal with by non-open code software. (4) Other problems such as poor portability, no friendly and intuitive interface. An efficient and effective finite element (FE) model is presented in this paper, which is capable to calculate the stress distribution of the pulsed magnet driven by Lorentz force body load, which is verified by the experimental results. Additionally, three important pulsed magnet techniques including internal reinforcement, separation and uneven layer height are also discussed and demonstrated in this paper as well.

Submitters Country:

China

Tue-Af-Po2.08 / 932

Finite element analysis of strain distribution of REBCO coated conductors subjected to bending conditions experienced in high-field magnet applications

Author(s): Federica Pierro¹Co-author(s): Luisa Chiesa¹ ; Soren Prestemon² ; Xiaorong Wang³¹ Tufts University² LBNL³ Lawrence Berkeley National Laboratory

A finite element method was developed to investigate the strain distribution of REBCO coated conductors under bending conditions relevant to high-field accelerator magnets. Due to their high current and high field capabilities, REBCO tapes are promising conductors for high field magnet applications. During magnet fabrication, REBCO tapes bend around a former. Because of the asymmetric architecture of the tape, the REBCO layer does not lie on the neutral plane and will experience strain during bending. The brittle characteristic of the superconducting layer requires the investigation of the generated strain distribution to avoid overstrains and damages of the tapes. In this work, the effect of bending on the strain distribution of a tape was analyzed using 3D numerical simulations. Various bending configurations relevant to high-field magnet applications were analyzed, including canted-cos θ (CCT) dipole and quadrupole. For both configurations, strain results were presented as function of the winding tilt angle and mandrel diameter. In addition, the strain generated by bending in the coil ends of a possible configuration presented by CEA Saclay was investigated. To validate the developed finite element model, we compared the calculated strain to the measurement based

on the strain gauges mounted on the tape surface subjected to various bending modes. The results are used to identify possible design solutions to apply REBCO tapes in accelerator magnets.

Submitters Country:

United States

Wed-Af-Po3.08 / 705

Flow Analysis of Magnetic Fluid around a Permanent Magnet in Magnetic Fluid Damper

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Magnetic fluid is a kind of magnetic functional material. In a gradient magnetic field, a permanent magnet can be suspended in the magnetic fluid by the second-order buoyancy due to the magnetic force. Based on this principle, the passive magnetic fluid damper is proposed. Much work has been researched in the field of magnetic fluid and magnetic fluid damper [1-2]. However, there is no comprehensive theoretical model for this kind of damper. This paper establishes the energy dissipation model considering the magnetic field and liquid flow. The magnetic fluid damper is composed of a non-magnetic cylindrical container, magnetic fluid and a cylindrical permanent magnet. The container is filled with magnetic fluid and sealed. The permanent magnet immersed in the magnetic fluid is forced not only by buoyancy of liquid but also by the magnetic force, which is called second-order buoyancy. Based on the Bernoulli equation, the velocity of magnetic fluid and the energy dissipation can be calculated. The flow loss is related to the viscosity of the magnetic fluid, the remanence of the permanent magnet, and the sizes of the damper. The three dimensional simulation model of the magnetic fluid damper is also built. The magnetic field distribution of the permanent magnet can be calculated. The results show that this damper can work with no external magnetic field and is suitable for low-frequency vibration of some longer objects in spacecraft.

1 Y I Dikanskii, A G Ispiryan, et al, "On the nature of the maximum in the temperature dependence of magnetic liquid susceptibility," *Technical Physics*, vol. 60, no. 8, pp. 1204-1207, 2015.

1 K I Ohno, T Sawada. "An effect of vertical sloshing on a fluid pressure and a surface displacement in a tuned magnetic fluid damper," *Int J Appl Electromagnet Mech*, vol.33, no. 3, pp. 1411-1416, 2010.

Submitters Country:

China

Wed-Af-Po3.05 / 229

Flux Characteristics Analysis of Single-phase Tubular Permanent Magnet Linear Motor

Hao Chen¹; Zhixiong Li¹

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The flux characteristics of a single-phase tubular permanent magnet linear motor (TPMLM) is analyzed with magnetic equivalent circuit (MEC) method in this paper. The flux linkage of the proposed single-phase TPMLM is generated by the permanent magnets and the bread type windings. The magnetic lines of flux travel through the stator yoke, the stator sleeve, air gap, and the mover to form a closed flux loop. First of all, the single-phase TPMLM is mainly divided into five parts, including stator sleeve, stator yoke, air gap, the permanent magnetic part of mover, and the ferromagnetic part

of mover. In consideration of saturation, the flux linkage of the single-phase TPMLM at four special mover positions can be calculated with the help of magnetic tube method and Gauss-Seidel iteration. The nonlinear relationship between flux linkage, mover position, and current can be mapped utilizing a high order Fourier series with the flux linkage data obtained from MEC method. It is consistent with 3-D FEM and experimental data. What's more, the simulated dynamic and static performance of the TPMLM are also consistent with experimental data, which verifies the effectiveness of the proposed MEC method.

Submitters Country:

China

Mon-Af-Po1.04 / 13

Flux Characteristics Analysis of a Single-phase Tubular Switched Reluctance Linear Motor

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¹ *China University of Mining & Technology*

This paper analyzed the flux characteristics of a single-phase tubular switched reluctance linear motor (TSRLM) based on magnetic equivalent circuit (MEC) method. The stator is composed of a stator sleeve and a bread type winding. There are two teeth on the stator. The bread type winding is embedded in the slot of the stator, which can improve the coil factor and decrease the end effect. The mover is mainly composed of the mover teeth rings and the mover yoke sleeve. Three mover teeth rings are uniformly distributed on the mover yoke sleeve. The single-phase TSRLM is divided into five different parts, which are the teeth of the stator, the yoke of the stator, air gap, the teeth of the rotor, and the yoke of the rotor. The reluctance of every part is expressed in analytical formulas at five special mover positions. The flux linkages at five special mover positions are calculated by magnet tube method and Gauss-Seidel iteration method which takes the saturation into consideration. It gives the analytical expressions of reluctances of each part in the single-phase TSRLM. Therefore, the flux linkage at certain mover position and certain current can be calculated with MEC method. A high order Fourier series is used to map the nonlinear relationship between flux linkage, current and mover position with the flux linkage data calculated by MEC method. The calculated flux linkage is consistent with 3D finite element method (FEM) and experimental results. Three specific currents are chosen to compare the generated static thrust, which are 2A, 4A, and 6A. The dynamic and static performance of the simulation utilized with MEC method are consistent with those in experiments, which verifies the accuracy of the MEC method proposed in this paper. The proposed MEC method can obtain the flux linkage data quickly under acceptable accuracy.

Submitters Country:

China

Wed-Af-Po3.07 / 765

Force Calculation and Thermal Analysis of the Maglev Machine for the 1000 MW Hydraulic Generator Set

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Co-author(s): Hongzhong Ma ; Lei Huang ²

¹ *China University of Petroleum (Hua dong)*

² *Southeast University*

The vertical axis hydroelectric generating set (HGS) is more commonly applied in large and medium size system. Because of the great bulk, the rotating parts are very heavy. In addition, water flow impacting the runner will produce a down force named axial hydro-thrust. Both gravity and hydro-thrust are born by a thrust bearing, which leading it susceptible to be damaged, difficult to maintain and bringing heavy economic burden. For the super capacity generators of 1000 MW, maglev technology is considered to deal with the question. Considerable interest has been generated during the past few years in the use of magnetic levitation like tracked vehicles and wind power generation field. The electro-dynamic levitation with AC current is selected for the system because of stable force, simple structure and controlling system. A superconducting induction magnetic levitation device is presented for the hydraulic generator to get large maglev force. The proposed device breaks the traditional thrust-bearing design which has to bear all the vertical forces from the motor and water flow. Analytical method based on Maxwell's equations is used to seek for theoretical problem of the magnetic field and force. Because of the disc structure, the magnetic field and forces are analyzed in cylindrical coordinate system. Both are important for the design and application. The results is verified by FEM and compared with the simplified model in Cartesian coordinate system. Additionally, according to the heat transfer theory, a three-dimension temperature field model was established. The finite element method (FEM) was used for the analysis and calculation of the temperature field. Heating and temperature of each component was studied and optimized, which could provide some reference for the research on the cooling approach.

Submitters Country:

China

Mon-Af-Po1.01 / 257**Frequency domain Diagnosis Methods for Quality Assessment of Nb3Sn coil Insulation systems and impedance measurement**Arnaud Foussat¹ ; David Smekens¹ ; Ludovic Grand-Clement¹ ; Francois-Olivier Pincot¹ ; Frederic Savary¹¹ CERN

Abstract - In recent years, the Superconducting Nb3Sn cable material became the privilege mature candidate for the High Field magnets in new projects like High Luminosity LHC (HL-LHC) accelerator at CERN. The technology needs in the years 2017-2021 to be deployed through unprecedented magnet series production with dedicated on-line quality control. The key fabrication stage of the Vacuum pressure impregnation after heat treatment reaction of Nb3Sn coils like on the new 11 T dispersion HL-LHC dipole enhances both the structural integrity and the dielectric strength of winding packs. The final epoxy CTD-101K resin impregnated insulation system composed of mica-fiber glass is commissioned under 5 kV high voltage test to ground. The global vacuum impregnation pressure method exhibits various merits in insulation performance and high dielectric strength reliability which strongly dependent on the success of the resin filling cycle. There is currently limited information and understanding on what could be a good dielectric frequency domain response of Nb3Sn coils. Due to importance of this issue, the monitoring of the resin content is introduced on using capacitance measurement and the quantitative dielectric response analysis both in the time and frequency domain. This proposed method enables during the VPI cycles to derive comparative master trend curves of various coils. These quantitative measurements enable to improve the quality of the composite insulation by possibly optimizing the heat and pressure cycle. Optimally, a combination of above methods can further help taking decision during manufacture on the wetting extent and bring insights on the impacts of resin type, the degree of curing, effects of void contents and coil geometry on the dielectric response. An independent insulation dielectric permittivity measurement provides a reference for the impregnation manufacture quality. The frequency impedance measurement of first short dipole model provides the distributed network lumped circuit fitting electrical parameters.

Submitters Country:

switzerland

Tue-Af-Po2.11 / 472

Frequency ramping effects on a dynamo-type HTS flux pump

Author(s): Andres Pantoja¹**Co-author(s):** Rod Badcock¹; Zhenan Jiang¹; Sinhoi Phang¹; Chris Bumby¹¹ *Victoria University of Wellington*

Flux pumps can inject high dc currents into superconducting coils, without requiring electrical connections between the cryogenic superconducting circuit and the room-temperature environment, thus significantly lowering the heat load on the cryogenic cooling system. Here we study a dynamo-type flux pump employing 2G ReBCO coated conductor wire at 77 K with multiple spinning Nd-Fe-B magnets and a soft ferromagnetic iron yoke, with all moving parts situated outside of the cryogenic environment. Dynamo-type flux pumps can be modelled as a DC voltage source with an internal resistance, where all output parameters are functions of the speed (frequency) of the spinning magnets. In this work we focus on the frequency dependence of the DC output voltage. From instantaneous traces of the generated voltage waveform, we observe three distinct frequency regimes of behaviour. We class them into regions of 'low', 'mid' and 'high' magnet frequency, depending on the magnitude of the DC open-circuit voltage and the shape of the voltage waveform. The voltage-generation mechanism is qualitatively understood at 'low' magnet frequencies, and in this regime the DC voltage increases proportional to frequency. However at 'mid' and 'high' magnet frequencies, the flux pump output deviates from this accepted model. In the 'mid' frequency regime, the DC output voltage is roughly constant with frequency, but is unstable. At 'high' frequencies, the DC voltage drops with increasing frequency following an approximately $1/f$ dependence. We have also studied the effects of ramping direction and rate, noting a high degree of reproducibility in the low and high frequency regimes, but complex unstable behaviour in the intermediate regime. We discuss our results in the context of self-heating due to emf-driven eddy-currents, leading to partial-quenching of the coated conductor wire. This becomes the dominant limiting factor in flux pump output at high frequencies, eventually suppressing the DC output altogether.

Submitters Country:

New Zealand

Wed-Af-Po3.10 / 38

Friction-coefficient between the Ti6Al4V loading pole and the 316LN steel shims of the HL-LHC 11 T magnets

Thomas Gradt¹; Christian Scheuerlein²; Friedrich Lackner²; Frederic Savary²¹ *Federal Laboratory for Materials Research (BAM)*² *CERN*

As part of the Large Hadron Collider High Luminosity upgrade (HL-LHC) project, 11 tesla Nb₃Sn dipole magnets will replace some of the existing 8.33 T Nb-Ti LHC main dipole magnets. The 11 T dipole coils are mechanically loaded through a removable pole wedge. The force exerted on the Ti6Al4V pole wedge is transmitted onto the coils via tangential sliding of the wedge on the coil shims and loading plates. We have measured friction coefficients of Ti6Al4V sliding on 316 LN under a pressure of 100 MPa and 200 MPa in ambient air and in liquid helium at 4.2 K, and we discuss the effect of the friction behavior on magnet training and performance. Potential benefits of solid lubricant coatings are discussed as well.

Submitters Country:

Switzerland

Thu-Af-Po4.03 / 53

Full Scale Conduction Cooled Superconducting Undulator Coils – Training, Stability and Thermal Behavior

Author(s): Andreas Grau¹**Co-author(s):** Sara Casalbuoni²; Nicole Glamann¹; Tomas Holubek²; David Saez de Jauregui²; Cristian Boffo³; Thomas Gerhard³; Melanie Turenne³; Wolfgang Walter³¹ *Karlsruhe Institute of Technology, Institute for Beam Physics and Technology*² *IBPT-KIT*³ *Babcock Noell GmbH*

Since several years the Institute for Beam Physics and Technology (IBPT) of the Karlsruhe Institute of Technology (KIT) is collaborating with its industrial partner Babcock Noell GmbH (BNG) in a R&D program on superconducting undulators (SCUs). At present the collaboration is primarily working on a SCU with a period length of 20 mm (SCU20). This device is foreseen to be installed at ANKA, the test facility and synchrotron radiation source, run by the IBPT. The 1.5 m long undulator coils have been tested in a horizontal, conduction - cooled measurement setup. This contribution describes the training, the stability and the thermal behavior of the coils.

Submitters Country:

Germany

Thu-Af-Po4.02 / 234

Further development of fusion enabling systems in Russia: suggestions on superconductors and current leads for DEMO-FNS facility.

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The consortium of Russian researchers is discussing further works on new fusion devices. One of the goals is the development of superconducting magnets of the demonstration hybrid facility - Fusion Neutron Source (DEMO FNS) based on the tokamak concept with the conventional aspect ratio ~3 [1, 2]. This device should have 5 T on the plasma axis and ~12 T on the toroidal coils. Because of high neutron flow and thick shielding necessity, a tight space remains for TF magnet inner legs that leads to a high current density in windings and high operating current. Several magnet designs have been addressed up to now. In all proposals the toroidal winding should be made of Nb3Sn based CICC with critical current density of Nb3Sn wires ~1300 A/mm². That is at least twice higher than in the ITER and could be achieved by use of internal tin technology development. Electrical and mechanical parameters of SC strands should survive in high neutron fluency and will be explored using fast particles irradiation. The new design of conductor prototypes and basic strands should be developed for such conditions. The high mechanical stresses of DEMO-FNS magnet system should be taken into account along with desirable minimization of AC losses. In this review, we discuss

possible designs of TF magnet system; requirements for parameters of strands; actual progress and prospective in Nb₃Sn wires fabrication (including activities in collaboration with CERN); different designs of conductors for DEMO-FNS. The developments of HTS current leads with low heat leak and bus burs for fusion machine are discussed as well.

1. D.P. Ivanov, et.al, "Superconducting Magnet for Russian Fusion Neutron Source DEMO FNS", Proceedings of 25 IAEA Fusion Energy Conference FEC 2014, , Poster FIP/P 7-10,

2. D. P. Ivanov, et.al, "Superconducting Magnet for Thermonuclear Neutron Source", available at: http://snf.ieeeecsc.org/sites/ieeeecsc.org/files/documents/snf/abstracts/HP103_Magnet%20TNS_final_012216.pdf

Submitters Country:

Russia

Wed-Af-Or23 / 444

Geometric field errors of Short Models for MQXF, the Nb₃Sn low-beta Quadrupole for the High Luminosity LHC

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In the framework of the High-Luminosity upgrade of the Large Hadron Collider, the US LARP collaboration and CERN are jointly developing a 150 mm aperture Nb₃Sn quadrupole for the LHC interaction regions. Due to the large beam size and orbit displacement in the final focusing triplet, MQXF has challenging targets for field quality at nominal operation conditions. Three short model magnets have been tested and around thirty coils have been built, allowing a first analysis of the reproducibility of the coil size and turns positioning. The impact of the coil shimming on field quality is evaluated, with special emphasis on the warm magnetic measurements and the correlation to magnetic field measurements in operation conditions. The variability of the field harmonics along the magnet axis is studied by means of a Monte-Carlo analysis and the effects of the corrective actions implemented to suppress the low order un-allowed multipoles are discussed.

Submitters Country:

SWITZERLAND

Thu-Af-Po4.05 / 590

HEV Motor Comparison of IPMSM with Sintered Rare-Earth Magnet and Bonded Dy Free Injection Magnet in the Same Size

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This paper studied on the comparison of traction motor for same size with sintered rare-earth magnet and bonded Dy free magnet. We designed PMASynRM with bonded Dy free injection magnet by changing only rotor and experimented to verify performance at the same size IPMSM with sintered rare-earth magnet. We simulated the magnetic orientation of the injection Dy free magnet to make the performance prediction precise. And we studied about overcoming the problem to improve the performance.

Submitters Country:

Korea

Thu-Mo-Or31 / 1055

HTS Accelerator Magnet Dipole Assembly and Cold Test by CERN for EuCARD2

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² CEA Saclay

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⁴ KIT

⁵ TUT

⁶ VUM. NZ

⁷ Bruker

Abstract— EuCARD-2 is a project partly supported by FP7-EuCARD2 n.312453 Commission aiming at exploring accelerator magnet technology for 20 T dipole operating fields. The EuCARD-2 collaboration is liaising with similar programs for high field magnets in the USA and Japan. EuCARD-2 focuses, through the work-package 10 “Future magnets”, on the development of a 10 kA-class superconducting, high current density cable suitable for accelerator magnets, for a 5 T stand-alone dipole of 40 mm bore and about 1 m length, named “FeatherM2”. After stand-alone testing, the magnet will possibly be inserted in a large bore background dipole, to be tested at a peak field up to 18 T.

After the successful testing of the subscale test coil named FeatherM0.4 achieving 13 kA @ 20° K. This confirm the assembly philosophy for the full EuCARD2 five Tesla dipole magnet. This paper presents the detailed magnet assembly of FeatherM2. We describe cable preparation for winding, the winding process, integration of instrumentation, impregnation procedure, magnet assembly, the challenging detailed design and procedure for jointing the multi strand REBCO Roebel 13 KA high current connections. Then we present the variable temperature magnet testing from 80°K in gas, down to 4°K in liquid powering. Culminating in magnetic field measurements using high speed rotating probes to measure magnetic field quality during magnet ramping.

Finally we discuss the important impact of this development for future Ultra High-field accelerator magnets. We discuss the next steps in the future development of such magnets.

Submitters Country:

Switzerland

Wed-Af-Po3.11 / 18

HTS Magnet with Smart Insulation Method

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If a quench occurs in an HTS magnet, it is almost impossible to protect the magnet from being burned. So far, it was usual to wind a magnet with insulated wires. However the insulated magnets are easily burned by a quench. To solve this problem no-insulation winding technique is developed recently. A no-insulation magnet shows very stable performance. However this magnet shows very poor controllability; when we charge the magnet, for example, it is not possible to build the magnetic field on time, because of large delay. Some people are trying to use metal co-winding method. The co-winding technique is a trade-off, and it is not easy to satisfy the stability and controllability. This paper suggests an advanced way to satisfy the stability and controllability together. This new way adopts metal-insulator transition (MIT) material between turns of HTS magnets. MIT material is an insulator when the temperature is lower than a certain value. Above the certain temperature, the MIT material becomes a conductor. This transition can be used as a switch between turns of HTS magnets. We call this smart switch operating by the temperature as "Smart Insulation." Considering the operating temperature, we selected V2O3 as the material for the smart insulation. In this paper, a fundamental experiment with regard to the MIT characteristics was conducted to prove the feasibility of the proposed method, and the resistivity change was verified according to the temperature of the V2O3 material manufactured in a form that can be easily applied to the magnet. In conclusion, we have experimentally verified that the advantages of both the insulation magnet in a normal state and the no-insulation magnet during quenching could be simultaneously obtained.

Submitters Country:

Republic of Korea

Tue-Af-Po2.05 / 256

HTS Shim Coils Energized by a Flux Pump for the MIT 1.3-GHz LTS/HTS NMR magnet: Design, Construction, and Results of a Proof-of-Concept Prototype

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In this paper we present design, construction, and preliminary test results of a proof-of-concept (POC) prototype, high-temperature superconductor (HTS) shim coils energized, for the first time ever, by a flux pump. For high-resolution NMR spectroscopy the spatial magnetic field must be uniform to within <0.1 ppm over a given region of interest (ROI). Field shimming is indispensable for achieving the required uniformity. For conventional NbTi shim coils, placed outside a magnet containing an HTS insert, the shim field is not only attenuated by the diamagnetic wall effect of the insert, but also distorted when it reaches the ROI. Therefore, we propose to develop HTS shim coils, placed inside the cold-bore of the innermost HTS coil of LTS/HTS or all-HTS NMR magnets, as a means to minimize the diamagnetic wall effect. For operation of HTS shim coils at 4.2 K, a flux pump improves cryogenic efficiency because it does not require high-current leads. As a POC, we

built and operated, at 77 K, flux-pump-energized Z1 and Z2 prototype HTS shim coils of 2-mm wide REBCO tape; final versions of these shim coils will be installed inside the bore of the MIT 1.3-GHz LTS/HTS NMR magnet.

Acknowledgement: Research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health

Submitters Country:

United States

Wed-Mo-Pl6 / 1249

HTS high current cable for fusion application

Thu-Af-Po4.10 / 186

Hall probe Calibration System Design for the Mu2e Solenoid Field Mapping System

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Mu2e experiment at Fermilab is set out to search for charged-lepton flavor violation by looking for muon to electron conversion in the field of the nucleus. The concept of the experiment is to generate low momentum muon beam, stopping the muons in a target and measuring the momentum of the conversion electrons. The implementation of this approach utilizes a complex magnetic field: graded solenoidal and toroidal field. Precise knowledge of the magnetic field is crucial in the muon transport process and in the electron momentum measurement. It is planned to map the solenoid field with calibrated 3D Hall probes up to 10^{-4} accuracy. This article describes a new design of a Hall probe Calibration System that will be used to calibrate 3D Hall probes to better than 10^{-4} accuracies for the Mu2e Solenoid Field Mapping System.

Submitters Country:

USA

Tue-Mo-Or14 / 598

Hardware integration and performance analysis of a 10 kW HTS wind power generator

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High Temperature Superconducting (HTS) generator for a large-scale wind power generation system draws much attention as a contemporary research item. Excitation systems in HTS generators, particularly brushless HTS exciters are a new challenge. This paper deals with the performance analysis of a 10 kW HTS wind power generator with brushless exciter and examines application possibility of the generator for wind turbines through hardware integration with the exciter. To supply DC current into the HTS coils, a brushless exciter was adopted in the generator. The field current of the generator supplied by the brushless exciter passed through the HTS coil without any mechanical connections. The HTS generator, which consisted of 6 pole racetrack type HTS coils for rotor and 36 slots copper windings for stator, was designed and fabricated. The HTS coils were mounted in a vacuum vessel integrated into the rotor, and cooled down by thermo-syphon cooling method with a cryogenic refrigerator. Through the physical fabrication of the machine, we confirmed several important results as follows. The rated output power of the generator reached to 10 kW at 300 rpm, and the operating temperature was maintained at 30 K by the cooling method. The operating field current was 95 A at operating temperature. When the performance results of the conventional power supply and the brushless exciter were compared, the magnetic flux densities of the generators were almost identical, and the total harmonic distortion of the output voltage of the generator using the brushless exciter was 3.2% which is under the IEEE standard limit of 5%. The results will be utilized to practical design of a generator with brushless exciter through which the heat loss reduction of the field winding and the simplicity of the structure of a large-scale HTS wind power generator will be achieved.

Submitters Country:

Rep. of Korea

Wed-Af-Po3.09 / 255

Heat treatment of MgB₂ superconductors with different metal sheaths

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The superconductors based on magnesium diboride have a lot of advantages in compare with traditional ones, such as relative simplicity of the superconducting compound synthesis process, small weight of finished product, possibility to manufacture superconductors in form of wires and tapes, absence of superconducting properties anisotropy. In this work the results of manufacture and study of MgB₂ superconductors, which metal sheathes differ by mechanical and physical-chemical properties, were presented. Inside of sheath there was Mg and B powders mix in required proportion. The series of annealings of produced superconductor samples has been carried out at temperatures from 650 to 7000C within from 15 to 60 minutes. After heat treatment, the microstructure of the formed compound has been studied by the scan electron microscopy method and critical temperature of superconductors has been also measured. It was established, that the minimal temperature of superconducting MgB₂ compound synthesis, depends on physical-chemical properties of the metal sheathes. It is necessary to increase the heat treatment temperature up to 7000 C for wires which sheathes material has low value of heat conductivity but the temperature of heat treatment can be 6500 C if the cover material has heat conductivity value close to one of copper. Critical temperature

of produced superconductors after heat treatment by optimal regime was 38.5 K that was close to theoretical value – 39 K.

Submitters Country:

Russia

Mon-Mo-Or1 / 29

Hi-Lumi LHC Twin Aperture Orbit Correctors Magnet Assembly & Cold Test

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Abstract— The Large Hadron Collider (LHC) upgrade, called High Luminosity LHC (HL-LHC) is planned for the next decade. A wide range of magnets and new technologies are currently under development. One of these systems will be a set of twin aperture beam orbit correctors positioned on the approaches to the ATLAS & CMS experiments. This twin aperture magnet system comprising 16 magnets, approximately 2 m long, with large 105 mm clear aperture coils. Each aperture will independently deliver 5 T.m integral field, between apertures the field vectors are rotated by 90° from each other, and individually powered.

This paper presents the sequence of component developments to produce a cost-performant, canted cosine theta (CCT) model magnet. We describe the challenges encountered during the manufacture of the coil formers with their helical canted coil winding process which places a number of insulated wires into the CNC 3.5 axis machined slots. We describe the: pressurized impregnation process, multiple jointing to connect inner and outer sets of wires within the confines of the coil assembly, magnet assembly into support structure and yoke. Finally we present the quench performance and, initial magnetic field measurements of this novel coil configuration.

Submitters Country:

Switzerland

Mon-Af-Po1.04 / 1098

High Efficiency Permanent Magnet Linear Synchronous Motor

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Linear induction motors (LIMs) have been widely applied in urban transit systems, such as in metros and low-speed magnetically levitated train. Due to the inherent eddy-current loss on the secondary reaction plate, the LIM applied in urban rail transit suffers from poor power factor and efficiency. And the efficiency of the current linear synchronous motors in urban rail transit is also unsatisfactory. A high efficiency permanent magnet linear synchronous motor (PM-LSM) is proposed in this paper. This single side PM-LSM adopts coreless long stator with single turn single layer wave winding which is segmented, and the secondary is a PM array fixed under the train. As a result of the tiny

stator inductance, the PM-LSM's power factor is very high. In order to maximize the thrust in the direction of the motion of the train and get the maximum output power at some a speed, one pole of the secondary is consisted of four PMs and furthermore the magnetization direction of two adjacent PMs is 45 degrees to get an appropriate magnetic circuit. Through selecting the appropriate length of the stator segment to diminish the copper loss. Considering the facts and high efficiency, we selected the proper current amplitude of the coils, speed of the train, the length of the stator segment and number of the PM-LSMs installed on a train to build a finite element model and carry out simulation and optimization. The simulation results show that the power factor of the proposed machine can reach 0.98 and its efficiency runs up to 92%. More elaborate results of analysis and comparison will be exhibited in the full paper.

Submitters Country:

China

Thu-Af-Pl8 / 1221

High Field Accelerator Magnets: a Path to New Physics

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¹ CERN

The discovery of the Higgs boson at the Large Hadron Collider at CERN has brought High Energy Physics (HEP) in the spotlight. One of the aims of the next step in HEP is to find physics "Beyond the Standard Model" (BSM). This relies on the systematic analysis of the events generated, searching for the unexpected, as well as precision measurements, checking for anomalies. Though it is generally accepted that BSM physics must exist, it is not clear where and what BSM physics will be. Several paths are being traced for this search. One of them depends on brighter beam collisions, and larger, higher energy colliders. These are priorities identified in the 2013 European Strategy for Particle Physics, confirmed in the 2014 report of the US Particle Physics Project Prioritization Panel. A cornerstone of this search is high field accelerator magnet technology. This presentation focuses on the high-energy physics motivation for high field magnets, a short overview of the state-of-the-art of accelerator magnet technology beyond 10 T, the R&D targets for the next 10 years, and an overview of what are the main issues towards 20 T accelerator magnets.

Submitters Country:

CERN hosted in Switzerland&France

Thu-Mo-Or31 / 930

High Field Coil Technology with Bi-2212 Round Wire

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One major goal at the NHMFL is the development of high field NMR quality magnets beyond 1 GHz using high temperature superconductors (HTS). Since Bi-2212 is very versatile and can be made in the much more desirable isotropic, round wire, twisted multifilament architecture, it appears to be particularly valuable for high field NMR magnets. We are in the process of building a layer-wound, round-wire Bi-2212 insert magnet, which is expected to approach the 1 GHz limit in combination with our 16.5 T low temperature superconducting (LTS) outsert magnet. A pair of layer-wound Bi-2212 compensation coils will be used to achieve a field homogeneity (z2 component) targeting the ppm range (10 mm DSV). The implementation of Bi-2212 conductor in such magnets poses various materials, magnet manufacturing, and other technological challenges that are being addressed. A series of test coils are currently being made to address a variety of technological aspects that go along with making this magnet. Here we present the current status and results of the ongoing project. This work is supported by the National Science Foundation under DMR-1157490, by a grant from the National Institute of Health under 1 R21 GM111302-01, and by the state of Florida.

Submitters Country:

USA

Wed-Af-Or25 / 1158

High Field, Large Aperture HTS Solenoid for Axion Dark Matter Search

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The Center for Axion and Precision Physics (CAPP) at the Institute for Basic Science (IBS) is setting up a major facility in Korea to search for Axion dark matter. Axion dark matter is partially converted to a very weak flickering electric field in the presence of a strong magnetic field applied with a resonating cavity. One key component of this proposed state-of-the-art experiment will be the high magnetic field (25 T), large aperture (100 mm) solenoid. In addition to the large stresses associated with such a large aperture high field solenoid, the specific challenges also include the quench protection needed for the reliable operation of such a HTS solenoid in a user facility environment. The basic design of the IBS solenoid will be based on the 25 T, 100 mm HTS solenoid that Brookhaven National Laboratory (BNL) designed and constructed with ReBCO tape as part of a Superconducting Magnetic Energy Storage System (SMES). During the initial tests at 27 K, the SMES solenoid successfully reached the field expected, 12.5 T. Even though the test could not be completed due to electrical problems, the tests established that the basic HTS solenoid design could be used for the overall design of the IBS solenoid. The major difference between the SMES and IBS solenoid, however, will be switching over from the metallic-insulation (stainless steel tape) to no-insulation to provide an extra level of protection against the quench. The no-insulation scheme is particularly attractive in this case since the field quality and ramp rate requirements are rather relaxed. In addition to the overall design of this large aperture, high field no-insulation HTS solenoid, the paper will also present test results of the no-insulation pancake coils built and tested with ~12 mm wide ReBCO tapes.

Submitters Country:

USA

Wed-Af-Po3.01 / 415

High Gradient Nb₃Sn Quadrupole Demonstrator MKQXF Engineering Design

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The future upgrades of the CERN accelerator chain along with the future high energy colliders, notably the FCC, will require high gradient quadrupoles. As part of the HL-LHC project, the 11T Dipole was the first Nb₃Sn magnet designed from the beginning to be compatible with the accelerator requirements and industrial production. It is based on the “pole-loading” concept, in which the Ti-alloy pole is not part of the coil, but inserted during the assembly process. This allows shimming at the pole and uses the collars more efficiently for creating the coil pre-stress. MKQXF is the further development of the “pole-loading” concept for Nb₃Sn quadrupoles. The pole region of the coils is identical to the 11T dipole and the collared coil is based on dipole-type collars. This concept can easily be extended to any length and applied on both 1-in-1 and 2-in-1 configurations. For benchmarking purposes and to compare with the present base-line design of the HL-LHC IR quadrupole QXF, based on bladder-and-key concept, this conceptual study was made with identical coils and quasi-identical magnetic characteristics. The design features 140 T/m gradient in 150 mm coil aperture. This paper describes the design concept of MKQXF and the fully 2D & 3D parametric multi-physics finite element model (FEM), including the end regions. The design optimization is described and the optimized assembly parameters and the effect of the manufacturing tolerances are presented.

Submitters Country:

GREECE

Wed-Mo-Pl5 / 1222

High Magnetic Field Science and Technology

Greg Boebinger¹¹ National High Magnetic Field Laboratory / Florida State University

Intense magnetic fields provide experimentalists with a particularly versatile thermodynamic parameter that addresses a wide range of modern questions in physics and materials research. However, the generation of intense fields, including the proposed 60T DC magnet and 150T non-destructive pulsed magnet, requires continued development of high-strength materials and high-current-density superconductors. This talk will survey both high magnetic field science and technology.

Submitters Country:

USA

Thu-Mo-Or32 / 1067

High Modulus Reinforcement Materials

ke han^{None} ; yan xin^{None}

Ke Han, Vince Toplosky, Robert Walsh, Na Min, Pingli Mao, Yan Xin

Materials used as reinforcement for conductors in high field magnets require both a high capacity for load bearing and a high resistance to deformation under stress; that is a high value for tensile strength and a high modulus of elasticity. In addition, compatibility between the reinforcement materials and the magnet conductor has to be carefully evaluated in terms of their capability for thermal expansion, stability at high temperature, and resistance to oxidization and crack propagation. Austenite stainless steels have been used as reinforcement materials for decades, in particular for cable in conduit superconducting magnets. The Young's modulus for most stainless steels, however, is below 200 GPa, lower than the value desired for very high field magnets. Increasing the modulus of stainless steels without significantly modifying the chemistry is at present impossible. We studied nickel-based superalloys, whose chemistry is designed for high-temperature applications and therefore has a high Young's modulus. Our samples had been subjected to various procedures that had strengthened the alloys by long range ordering. Our initial work was focused on changes that occur during the deformation in these nickel-based alloys at either cryogenic or room temperature conditions. We observed distinct interfaces between the ordered area and the matrix; we decided that these materials could be described as precipitate-strengthened alloys. At cryogenic temperatures, both the ordered area and the matrix had more resistance to plastic deformation than those same areas at room temperatures. To enhance strength further, we also modified the chemistry of the alloy by doping other elements. This paper outlines the properties of the new alloys and establishes their compatibility to certain conductors commonly used for high field magnets.

Acknowledgement: Financial support of National Science Foundation Cooperative Agreement No. DMR-1157490 and the State of Florida.

Submitters Country:

united state

Thu-Af-Po4.02 / 433

High Temperature Superconductors for Fusion Nuclear Science Spherical Tokamak

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¹ *Princeton Plasma Physics Laboratory*

Princeton Plasma Physics Laboratory is currently leading the design studies of Fusion Nuclear Science Facility and pilot plants based on the most promising magnetic confinement configurations including the low aspect ratio Spherical Tokamaks. An innovative magnet design approach is needed to close the gap between rapid advances in High Temperature Superconductor (HTS) and the maximal fusion energy extraction from ITER-like burning plasma development. Significant performance improvement in HTS cables utilizing a stack of REBCO tapes as well as the high current density Bi-2212 round wires provides targeted magnet R&D opportunities to support the design consideration of low aspect ratio spherical tokamak pilot plants. We present conductor design options based on recent test results of high current HTS cables and discuss the optimal winding pack layout for the TF and CS coils within the design space allocated for the 3-m HTS ST-FNSF magnet system. The rectangular shaped high current density CORC cable made of YBCO tapes will be analyzed to validate feasibility of TF coil winding pack design for the ST FNSF. For the CS coil, a series of pancake YBCO coils with metal insulations, or solenoids consist of Bi-2212 round wires can be shown to meet the physics requirements of magnetic flux swing in facilitating initial plasma operation. Irradiation limit of magnet materials for the next step fusion reactors will also be discussed.

Submitters Country:

United States

Tue-Af-Po2.09 / 752

High definition 3D finite element analysis of low temperature Rutherford cable

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A multi-scale mechanical model of Rutherford type, low temperature superconducting cable is discussed in this paper.

First, the numerical approach for the mechanical analysis of the cable using bi-metallic description of the strands is presented. The process of the three-dimensional geometrical reconstruction of the cable during operation, up to the scale of the strand, is described. The homogenization of the mechanical properties of the superconducting bundle is explained, and several options for the description of the strand annular topology are compared on the basis of local models. The inclusion of a high definition three-dimensional sub-modelling of the strand geometry is illustrated, up to the superconducting filaments scale. The geometrical reconstruction of cable stacks longer than a twist pitch is finally demonstrated. In a second part of this paper, we present the first attempts of confrontation of this finite element model with experimental results performed on stacks of conductors, with a view in estimating the cable current transport capability thanks to existing scaling laws.

Submitters Country:

France

Tue-Af-Or17 / 84

High performance coated conductors wire for magnet applications

Markus Bauer¹

¹ THEVA Dünnschichttechnik GmbH

THEVA Pro-Line coated conductors based on ISD-MgO buffer layers and e-beam evaporation are available today in large length and critical current above 500 A/cm (77 K, s.f.) as it is necessary for magnet applications. An overview will be given on recent progress of the performance and length of these kind of coated conductors. The performance in magnetic fields at medium temperatures in the range of 30 K to 50 K used for generators and motors as well as 4.2 K will be discussed together with the angular behavior of the magnetic field performance. Mechanical and electrical performance of copper laminated as well as copper plated types of variable width will be shown. Finally, a reliable joining technique will be addressed that was successfully used in a series production of generator coils for the EcoSwing project where a 3.6 MW wind power generator will be developed.

This work was supported by the European Union's Horizon 2020 research and innovation program under grant agreement No. 656024.

Submitters Country:

Germany

Thu-Mo-Or28 / 50

High-field dipoles using superconducting cable-in-conduit

Peter McIntyre¹ ; Jeff Breitschopf¹ ; Daniel Chavez² ; James Gerity¹ ; Joshua Kellams³ ; Akhdiyov Sattarov¹

¹ Texas A&M University

² *Universidad Guanajuato*

³ *Accelerator Technology Corp.*

Dipoles with 15-20 T operating field are required for some designs of future hadron colliders. Such dipoles require the use of high-field superconductors Nb₃Sn, Bi-2212, and REBCO. Designs are presented for block-coil dipoles using superconducting cable-in-conduit. This approach conveys several benefits that are important for high-field operation: cable-level stress management; compact, robust flared ends; and in-cable cryogen flow. It naturally accommodates a hybrid coil configuration in which sub-windings of Bi-2212, Nb₃Sn, and NbTi can be separately heat-treated, assembled, and preloaded in a compact assembly.

Submitters Country:

US

Wed-Af-Po3.07 / 118

High-gradient magnetic separation properties of rice hull magnetic activated carbon for water clarification

Author(s): Keisuke Ishida^{None}

Co-author(s): Tatsuki Anzai ; Osuke Miura

We have newly developed a rice hull magnetic activated carbon (RH-MAC) and studied its adsorption properties against harmful substances in water and high gradient magnetic separation properties. RH-MAC was synthesized by impregnating rice hull with an iron nitrate solution and heat-treatment in nitrogen and carbon dioxide atmosphere. In those processes, a large number of meso-pores and nano-size magnetite were generated inside the activated carbon grains. RH-MAC showed the effective adsorption performance against humic acid and mercury, cadmium, lead and arsenic. The magnetization of RH-MAC increased with increasing concentration of iron nitrate solution, and the mass magnetization of RH-MAC made from 1.6 mol/L iron nitrate solution reached 20.8 Am²/kg at 0.5 T. Three-dimensional analysis of magnetic field, flow velocity, and particle tracking was carried out using FEM-based software COMSOL Multi-physics to study the high gradient magnetic separation properties. From the calculation results, the high-speed magnetic separation at 0.1 m/s for high-gradient magnetic separation using a permanent magnet of 0.5 T and 1 m/s for 2 T high-gradient magnetic separation using a superconducting magnet were derived.

Submitters Country:

Japan

Wed-Mo-Pl6 / 1247

High-speed thermal imaging of quench propagation in HTS tapes using temperature-sensitive fluorescent films

Thu-Af-Po4.11 / 1257

High-speed thermal imaging of quench propagation in HTS tapes using temperature-sensitive fluorescent films

Roland Gyuráki¹ ; Frédéric Sirois² ; Francesco Grilli¹

¹ *Karlsruhe Institute of Technology*

² *Polytechnique Montréal*

The Normal Zone Propagation Velocity (NZPV) and quench are areas of intense research for High Temperature Superconductors (HTS). While normal zones travel with speeds in the order of magnitude of m/s in Low Temperature Superconductors (LTS), in HTS coated conductors this speed is in the order of cm/s. This makes ensuring a quick and uniform quench, and thereby the cryostability of tapes, challenging. Such slow NZPV can lead to excessive local heating and hotspots in applications such as cables and magnets, leading to the destruction of the equipment. To develop new HTS tape manufacturing techniques and architectures that help increase the NZPV a reliable measurement method is needed for evaluating the merits of these technologies.

In this work a new optical method is presented for thermal imaging and measurement of quench propagation and NZPV in HTS tapes. The novelty of the method is that it allows mapping the temperature distribution on a 2-D surface, in real time. The technique is based on the temperature dependent light emission of a rare-earth fluorophore in conjunction with a high-speed camera, capable of recording the fluorescence at 2500 frames per second. Together these allow for direct observation of dynamic events, such as the quench, in the time domain of milliseconds. Using the light intensity of each pixel in the recording and adequate post-processing steps allow for the extraction of thermal data. Hence the measurements serve with both qualitative and quantitative temperature information, which can be used to compare quench behaviour of various tapes and architectures. This work shows a proof of concept of the developed method together with preliminary results of quench propagation measurements in silver stabilized HTS tapes.

Submitters Country:

Germany

Tue-Mo-Or12 / 83

High-speed thermal imaging of quench propagation in HTS tapes using temperature-sensitive fluorescent films

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² *Polytechnique Montréal*

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Submitters Country:

Germany

Wed-Mo-Or21 / 1188

High-temperature superconducting CORC® magnet cable and wire development and their application

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¹ *Advanced Conductor Technologies*

² *NHMFL-FSU*

³ *NHMFL*

⁴ *National High Magnetic Field Laboratory*

⁵ *Lawrence Berkeley National Laboratory*

⁶ *LBNL*

⁷ *University of Twente (NL)*

⁸ *CERN*

Advanced Conductor Technologies has been developing Conductor on Round Core (CORC®) cables and wires wound from REBCO coated conductors for use in high-field magnets. An overview of the current status future developments of the CORC® cables and wires is presented. CORC® cables with thickness of 5 to 8 mm have been developed for use in larger magnets that require only very limited bending of the cable. CORC® cables have been bundled into 6-around-1 cable in conduit conductors (CICC) for fusion and detector magnets. The latest results of a 80 kA CORC®- CICC tested at 11 T in SULTAN will be highlighted. Much more flexible CORC® magnet wires are being developed for accelerator magnets that require a current density J_e at 20 T of at least 300 A/mm². We will outline the development and test results of a 3.7 mm thick, robust CORC® wire wound from tapes with 30 μ m substrates, that is bendable to diameters of less than 50 mm. The CORC® wire is capable of reaching a J_e at 4.2 K and 20 T of over 300 A/mm², and likely over 600 A/mm² when wound from tapes with even thinner substrates that are expected later in the year. Finally, two high-field insert magnets are being developed using high- J_e CORC® wires. The first is a high-field insert solenoid that is expected to generate at least 3 T in a background field of 14 T, while the second magnet is an accelerator-grade canted cosine theta insert magnet that would generate 5 T in a background field of 10 T. The development of these first two CORC®-based high-field magnets will be discussed.

Acknowledgement: This work was in part supported by the US Department of Energy under agreement numbers DE-SC0007891, DE-SC0007660, DE-SC0009545, DE-SC0014009 and DE-SC0015775.

Submitters Country:

USA

Wed-Af-Po3.10 / 169

Hot cracking in laser welding with filler wire of ITER grade austenitic stainless steel

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A lot of thick-section welding tasks of ITER grade austenitic stainless steel were existed in the ITER engineering manufacturing, and the laser welding with filler wire was given priority since its reducing the dependence of laser power to the welding depth compared to the autogenous laser welding and its huge advantage of smaller welding distortion compared to other traditional arc welding methods. Austenitic stainless steel was generally known to have very good weldability, while some

welding issues e.g. hot cracking susceptibility were difficult to control if the special grades of fully austenitic structure were used. As we all known, the hot cracking susceptibility of the welding of austenitic stainless steel were depended on material composition, welding constraint and welding process. Therefore, the hot cracking issue on laser welding of ITER grade austenitic stainless steel should be seriously concerned because of the special requirements of fully austenitic structure for base material and welded joint, also the high cooling rate of laser welding and very rigid welding condition in engineering. In this paper, the features of laser welding with filler wire of 20mm thick section ITER grade 316LN austenitic stainless steel were described. The hot cracking susceptibility of laser welded joints was highlighted according to the experimental design which includes the standard welding joint and special welding joint in order to emulate the rigid welding condition, and related observations and examinations of the welding process based on the layered implementation.

Submitters Country:

China

Thu-Mo-Or29 / 860

Hub- and Site-cooling of MRI magnets using a mobile cryogenic system

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³ *Siemens*

We present a compact, mobile pre-cooling cryogenic system (cooler) developed by Sumitomo Cryogenics as a solution that can significantly reduce helium losses associated with shipping medical MRI magnets globally. In contrast to conventional cold-shipping of MRI magnets, the cooler can enable MRI magnets to be shipped with the cryostat at room temperature, and then pre-cooled either during the installation at the hospital (site-cooling), or at a local facility (hub-cooling). This logistics model dramatically reduces the helium boil-off losses normally incurred when the MRI magnet is in transit. Compared to using liquid nitrogen for pre-cooling, the cooler pre-cools to a lower temperature (~25 K), which effectively eliminates the helium loss that is incurred when cooling the MRI cryostat further to 4K. An example of using the cooler at a hub-cooling facility in Brazil is discussed in this paper. This facility pre-cools warm-shipped magnets from a Siemens MRI factory in Shenzhen, China, using a prototype of the cooler technology. The cooler comprises of five separate mobile units with a compact footprint that enables its use in a standard MRI room. It uses helium gas as a heat transfer fluid in a closed-loop circuit between the magnet cryostat and four GM cryocoolers with heat exchangers that provide the cooling of the gas. The helium gas is circulated between the cooler and the MRI cryostat by means of a cryogenic centrifugal fan. The processes for MRI magnet pre-cooling, helium gas circuit cleaning and system performance test are fully controlled and automated by the system software.

Submitters Country:

United Kingdom & United States

Wed-Af-Po3.09 / 520

Hysteresis modeling of MgB₂ using simplified Jiles-Atherton model

Kun dong¹

¹ *the Ohio state university*

The continuous advancement of superconductors has empowered numerous industrious, power system, and military utilizations. The performances of MgB₂ expand the utilization of superconductors through power transmission, power generation, transportation vehicle, propulsion vessel and several other applications. The proposed higher-level model provides a computationally-efficient tool capable of predicting the hysteretic magnetization of MgB₂. It is well-known that Jiles-Atherton model is probably the most important hysteresis model in the literature and has been used extensively as a fundamental tool for modeling and interpreting several complex magnetizing processes in magnetic materials. Phenomenologically, the superconducting hysteresis is analogy to that of ferro-magnetic hysteresis although their physical mechanisms are different. However, Jiles-Atherton modeling of superconducting hysteresis has not proven popular. Mayergoyz showed that the Bean critical-state model is a particular case of the Preisach model and concluded that, perhaps, it is more accurate to use it to describe superconducting hysteresis than ferromagnetic hysteresis. Follow-up work³ showed that in addition to a slight modification to the classical Preisach formulation, a set of first-order reversal curves is required which was predicted to emerge as the standard technique for characterizing hard superconducting hysteresis. Although promising, Preisach modeling of superconducting hysteresis has not proven popular. This might be because it provides little-to-no physical insight into the processes of interest or because it requires extensive experimental data. In this paper, a simplified Jiles-Atherton model is presented via combination of the bean critical current model and Jiles-Atherton mathematical model. The model macroscopically consists of the hysteretic (irreversible) and non-hysteretic (reversible) fluxoid pinning and motion. The calculated results from the proposed model are compared with the experimental data, and comparison results show that the proposed model is capable of simulating various shapes of hysteresis loops of MgB₂.

Submitters Country:

china

Tue-Af-Po2.11 / 473

Impact of stator ring width on output of a dynamo-type HTS flux pump

Author(s): James Storey¹

Co-author(s): Andres Pantoja¹ ; Zhenan Jiang¹ ; Rod Badcock¹ ; Chris Bumby¹

¹ *Victoria University of Wellington*

Dynamo-type flux pumps provide a contact-free method of energizing currents in superconducting coils. Since a detailed predictive theory for these devices does not yet exist, the effect of design parameters must be studied empirically. In this work we investigate the performance of an experimental flux pump employing a high-temperature superconductor stator located upon a ring shaped iron yoke. The radial width of the yoke ring was varied and the DC output parameters of the device characterised at various operating frequencies and flux gaps. We observed that flux pump performance was relatively insensitive to the yoke ring width, for the range of values studied. A four-fold increase in ring width caused the open circuit output voltage and internal resistance to increase by less than 30% at the closest magnet-stator separation. The short circuit current was found to be almost entirely independent of the yoke width. Time-resolved output voltage waveforms were also obtained and related to the normal component of the magnetic field at the coated conductor stator wire, as calculated by finite element modelling. Our results imply that thin stator yokes can be utilized with little adverse impact on the electrical performance of these devices. Thin yokes reduce the total amount of iron required, and this is advantageous in terms of weight, cryogenic efficiency and eddy current losses.

Submitters Country:

New Zealand

Thu-Af-Po4.07 / 1143

Improved Design of Klystron Beam Focusing System with Permanent Magnets

Yasuhiro Fuwa¹ ; Yoshihisa Iwashita¹¹ *Kyoto University*

Klystron beam focusing system with permanent magnets can increase reliability of RF power system and reduce its power consumption. A prototype magnet system with ferrite magnets was fabricated for a L-band 800 kW klystron. The power test of the klystron with the prototype magnet system has proved the feasibility of the prototype. However, multi-pole transverse magnetic field components might reduce peak output power compared with the electro-magnet.

In order to improve the performance of beam focusing systems with permanent magnets, new design concept of the focusing system has been studied. In this design, magnets are symmetrically arranged around the beam axis to reduce the multi-pole field component. In this presentation, the design procedures and designed focusing systems will be reported.

Submitters Country:

Japan

Tue-Af-Po2.06 / 714

Improved Inner Stator-Magnet Moving-Iron Transversal-Flux Linear Oscillatory Machine with Magnets in Inner Stator Yoke

Xiang Li¹ ; Wei Xu¹ ; Caiyong Ye¹¹ *School of Electrical and Electronics Engineering, Huazhong University of Science and Technology*

Abstract- The stator-magnet moving-iron transversal-flux linear oscillatory machine (SMTLOM) offers the merits of high reliability and robustness, high material utilization ratio, low fabrication difficulty and cost and so on. However, due to its iron mover, the weight of moving structure is relatively higher than that of moving-magnet linear oscillatory machine (MLOM). Consequently, a rather rugged resonant spring is required to match the system resonant frequency, which would increase the fabrication and maintenance cost. Also, with the magnets and winding fixed on same stator, the temperature of magnets would rise easily. Therefore, in order to reduce the mover weight and prevent magnets away from winding (regarded as the main heat source), meanwhile still inherit the advantages of high reliability and robustness, low fabrication difficulty etc., from SMTLOM, one improved inner stator-magnet moving-iron transversal-flux linear oscillatory machine (ISMTLOM) is proposed, with magnets inserted in the inner stator core and the redesigned lighter iron mover placed in the dual air-gap between the inner and outer stators. In such structure, the weight of iron mover could be reduced by as lighter as magnets mover. Furthermore, with the magnets and winding placed on different stators, the heat is hard to conduct from outer stator to inner stator, thus the temperature of magnets would be lower. More detail of performance analysis and comprehensive comparison with conventional SMTLOM in key indexes such as size sensitivity, flux field distribution, static thrust, and temperature distribution etc., are going to be revealed in the upcoming full paper.

Submitters Country:

China

Tue-Af-Po2.10 / 1119

Improved Modeling of Canted-Cosine-Theta Magnets

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³ *Lawrence Berkeley national laboratory USA*

The Canted-Cosine-Theta (CCT) is a design option for the next generation of high field superconducting dipoles which is being pursued within US Magnet Development Program. This paper presents new modeling techniques developed for design and analysis of this type of magnet. For mechanical modeling in ANSYS, three approaches with increasing accuracy will be compared: 2D symmetry models, 3D periodic symmetry models, and full 3D models. Methods for static and transient magnetic simulation using ANSYS will be presented with a focus on circuit coupled models for predicting magnet behavior following quench. Where applicable, simulation results will be compared to data from CCT magnet tests at Berkeley.

Submitters Country:

United States

Wed-Af-Po3.04 / 153

Improved Overall Efficacy in Transcranial Magnetic Stimulation of Human Brain with Semi - ellipse Coil Pair

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Transcranial magnetic stimulation (TMS) is a modern technology for non-invasive modulation of the cortical tissue excitability in specific brain regions. Because of better focalization, planar Figure of Eight (FOE) coil is most widely used in magnetic stimulator nowadays, whereas it has two negative peaks besides the positive peak of interest and the ratio of peak value to negative peak value (RPN) is low. In order to obtain stronger induced electric field intensity and higher RPN without weakening focalization, a coil pair of innovative geometric structure is proposed in this paper based on the idea of special-shaped magnet. Projected onto a plane parallel to objective target, the two adjacent coils are in semi-ellipse shape. From the top view, the semi-ellipse coil pair (SEP) is bended along two mutually perpendicular axes with a range of radians which matches more with human head. The Finite-Element Method (FEM) is adopted to analyze the 3D spatial distributions of the induced electromagnetic field produced by SEP coil and the conventional FOE coil (mean diameter of 82mm) under the same excitation condition. A comparison function is constructed to analyze the new design's feasibility from therapeutic effect. The heating problem during a typical psychiatric treatment is discussed considering medical safety. Comparing to FOE coil, the geometry optimization of SEP coil with 60° radian can enhance the peak of induced electric field by 18.7%, raise RPN by 74.2% while improving the overall efficacy by 47.9%. A real human head modeled as homogeneous and isotropic is occupied in this paper to verify our method.

Acknowledgements: The authors would like to acknowledge the supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Thu-Af-Po4.03 / 99

Improvement of Field Simulation Concept of Staggered Undulator with HTS YBCO Bulk

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An undulator with a strong magnetic field in a short period will become an important light source device in an accelerator storage ring or a free-electron laser. The bulk YBCO can be used to construct a high-temperature-superconducting undulator with staggered array structure. The bulk YBCO of diameter 32 mm and thickness 2.5 mm was constructed and assembled as a staggered magnet array. The period length was 5 mm; the magnet gap is 4 mm. To estimate the strength of a sinusoidal field and to optimize the end-pole design to minimize the first field integral (i.e. electron angle) and second field integral (electron position), an energy-minimization method (EM-method) based on Bean's model to simulate the field trapped in the HTS-Bulk is introduced. In this paper we focus on promoting the practical value of the EM-method simulation. Aggregating the experience of measurement of the bulk YBCO undulator at 77 K and 7 K and the experience of simulation work based on the EM-method, we tackle some issues to enhance the integrality of this undulator design work.

Submitters Country:

Taiwan

Thu-Af-Po4.05 / 401

Improvement of Reluctance Torque in Fault-Tolerant Permanent-Magnet Machines with Fractional-slot Concentrated-Windings

Jinghua Ji¹ ; Xinxing Zhang¹ ; Wenxiang Zhao¹¹ *JiangSu University*

Fault-tolerant permanent-magnet (FTPM) machines provided high efficiency, good fault-tolerant capability and high reliability. The electromagnetic torque of FTPM machine contains both permanent magnet (PM) and reluctance torques. At high speed operation condition, high reluctance torque can not only help prevent machines out of control when using flux weakening control method but also contribute to widen the speed range. However, the existing FTPM machines suffer from the relatively low reluctance torque. In this paper, a new rotor structure for FTPM machines with fractional-slot concentrated-windings is designed to improve the reluctance torque. In the proposed FTPM machine, new rotor structure has been designed. One of the keys of the new rotor structure is the division between each pole. The flux barriers are added between divisions to decrease the unbalance armature reaction. Besides, the two-layer interior magnets are set in oriented direction and the special designed flux barrier between two layer magnets is introduced into the machine. Therefore, this proposed rotor structure can effectively decrease the permeance of D-axis without any effect on the permeance of Q-axis, thus improving the reluctance torque greatly. In order to verify the proposed FTPM machine, finite-element analysis is employed to analyze the electromagnetic performance. The D-Q axis flux distributions of the proposed and existing FTPM machines have been analyzed respectively. It shows that the proposed rotor topology can significantly decrease both the unbalance armature reaction and the permeance of D-axis. Compared with existing FTPM machine, the reluctance torque of the proposed one is enhanced by about 22.15% with little torque loss, only approximately 3.2%. Besides, the proposed FTPM machine presents wider speed range and provides higher efficiency in field-weakening range than the existing one.

Submitters Country:

China

Wed-Mo-Or20 / 1239**In Memory of David Hawksworth**Graham Gilgrass^{None}

Dr David Hawksworth, former Managing Director of Oxford Magnet Technology Ltd., passed away on March 15th aged 63. David's significant contribution to development of magnets for MRI is reviewed from joining Oxford Instruments in 1981 through to Director of Oxford Magnet Technology Ltd., where he was instrumental in leading the team which developed the first high field whole body 1.0T, 1.5T and 4.0T active shield MRI magnets.

Submitters Country:

UK

Tue-Af-Or17 / 1017**In-field Characterization of Local I_c and n -indices as a Function of Longitudinal Coordinate in a Long-length GdBCO Coated Conductor**

Takanobu Kiss¹; Takumi Suzuki¹; Kohei Higashikawa¹; Takahiro Fukuzaki¹; Yuhei Nishimiya¹; Daiki Tsujino¹; Shohei Noda¹; Yuta Onodera¹; Masayoshi Inoue¹; Mitsunori Igarashi²; Kazuomi Kakimoto²; Yasuhiro Iijima²

¹ *Kyushu University*

² *Fujikura Ltd.*

We have succeeded in evaluating local critical current (I_c) and n -indices in a long-length GdBCO coated conductor as a function of longitudinal coordinate with a spatial resolution of 1 mm under external magnetic fields up to 5 T at both temperatures of 77 K and 65 K. While the sample was carried in reel-to-reel manner in a liquid nitrogen bath with an external magnetic field, we measured magnetization of the tape continuously. The temperature was varied down to 65 K by using a subcooled liquid nitrogen circulation system. This allows us to evaluate spatially-resolved in-field I_c distribution in the long-length tape. A method to evaluate position dependent n -indices based on the magnetization measurements was also proposed. We've confirmed the validity of the analyses by comparing the results with site-specified transport measurements by the four-probe method using the same sample. These characterizations are very useful to understand the current transport properties in the full-length of the coated conductors including the influence of localized flux flow dissipation originating from the positional variation of I_c in the tape strand under practical operation conditions not only 77 K, self-field. Namely, this method has a strong impact on the characterization of long-length coated conductors for magnet applications.

Acknowledgements: This work was supported by "JSPS KAKENHI (16H02334)".

Submitters Country:

Japan

Tue-Mo-Or14 / 926

In-vacuum magnet technology inspired from semiconductor equipment

Author(s): Ton Peijnenburg¹

Co-author(s): Aernout Kisteman¹ ; Paul Blom¹

¹ *VDL Enabling Technologies Group*

Outside of the application field of (scientific) particle accelerators, in the applications area of semiconductor manufacturing equipment, demanding modules similar to accelerator magnets are developed and used: high field accuracy, high power levels (for high productivity), ultra-high vacuum regimes (EUV lithography), very limited outgassing and particle contamination (contamination of substrates impairs yield) and excellent reliability (equipment up-time is important). We believe that these modules are worth being considered by the magnet community, potentially inspiring novel engineering practices. Typical topologies: An application area is the e-beam technology: critical magnetic design in vacuum environment with strict thermal requirements for stability. Another application area are electrodynamic actuators, for magnetic levitation and active position control with μm or sub-nm level accuracy. They generate highly accurate forces of several kN peak. A typical short stroke electrodynamic actuator consists of a yoke with permanent magnets, and a coil unit in between, enabling contactless actuation in a UHV environment. Force levels and linearity are constantly improved, leading to high-density designs of coils and permanent magnets topologies and the use of high grade materials. Water cooling is applied on both sides of the coil, achieving a high thermal efficiency (temperature gradient in the order of 10 K) at only a small expense in air gap. Both coil and permanent magnet structures are encapsulated for use in UHV. For this, high-reliability designs and manufacturing processes have been developed. Why consider these modules for accelerator magnets? By building magnets closer to particle beam, smaller (aperture) size can be realized, leading to smaller (chromatic) aberrations, higher achievable field strength and a lower volume claim for total magnet system. Challenges for (scientific) particle accelerators: Special materials are required for use in the 1E-10 to 1E-11 mbar regime and complex shape magnetic lenses will require special (e.g. 3D-printed) thermal cooling channels.

Submitters Country:

The Netherlands

Mon-Af-Po1.12 / 374

Indirectly cooled superconducting power supply for the CMD-3 thin solenoid

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A thin superconducting solenoid is used to provide magnetic field in the CMD-3 particle detector. For power supply of the solenoid a superconducting fullwave AC/DC rectifier is designed. The rectifier is a current step-up superconducting transformer with two thermally controlled superconducting switches connected to its secondary windings. The CMD-3 solenoid is indirectly cooled, so the indirect cooling method is used for the rectifier. The transformer and switches are mounted on the outer surface of the stainless cylindrical vessel. They face the protection vacuum of the CMD-3 cryogenic system. The vessel is filled with liquid helium, so the rectifier is cooled via thermal conductivity of the vessel's wall. Placing the rectifier outside of the liquid helium bath allows avoiding the use of vacuum tight high current connectors for current leads from the rectifier to the solenoid. The rectifier is designed to provide charging the solenoid, long-term magnetic field stabilization and discharging the solenoid. At the bench tests with dummy coil the rectifier output current up to 1600 A had been achieved. The solenoid operational magnetic field is 1.3 T with 860 A current. The rectifier charges the solenoid to this field within 7 hours. Achieved long-term stability of the field is 2×10^{-5}

T. The rectifier has been demonstrating good reliability since 2010, when the magnet system of the CMD-3 had been commissioned. Design, test results and performance of the rectifier are reported here.

Submitters Country:

Russia

Tue-Af-Po2.12 / 1122

Induced Voltage Characteristics by Back-Iron Effect for Electro-magnetic Energy Harvester Using Magnetic Fluid

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Energy harvesting refers to a process that derives a small amount of power from external energy sources. The energy sources of harvesters can be easily obtained anywhere from vibration, wind power and wave power. In this study, we will focus on vibration, one of the typical energy sources that can be easily changed into an electromotive force (EMF), as our study subject. Mechanical vibration is highly attractive as an energy source because it is readily available around us. Vibration energy can be converted into electric energy via the following methods: piezoelectric, electrostatic, and electromagnetic transduction. On the other hand, an electro-magnetic energy harvester using a magnetic fluid can be utilized with vibrations of a low frequency. A magnetic fluid is a colloidal fluid produced by a nanoscale permanent magnet dipole. The shape of a magnetic fluid can be freely changed so that an EMF can be produced even with a small vibration. Since the magnetic fluid has fluidic and magnetic properties, as found in soft ferromagnetic substances, it can be often employed in energy harvesters. In contrast with existing harvesters using permanent-magnet vibration, the harvester proposed in this study used a sloshing phenomenon of the magnetic fluid to change the amount of magnetic flux interlinked at the coil. The sloshing phenomenon can also be seen in the small vibration at a low frequency. This movement generates an EMF by changing the amount of magnetic flux interlinked at the coil. In this study, two types of electro-magnetic energy harvesters were built to compare the induced EMF. One used an air yoke, which returned the magnetic flux of the permanent magnet back to the air, and the other used a back-iron yoke consisting of a ferromagnetic material which reduced the magnetic resistance of a magnetic circuit.

Submitters Country:

South Korea

Wed-Af-Po3.05 / 1121

Influence Analysis according to Shape Changes of Magnetic Salient Pole Structure on Performance Characteristics of Megawatt-Class HTS Wound Rotor Synchronous Motor

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This study presents the structural design and finite element analysis (FEA) results on main shaft of a 1.5-MW-Class high-temperature superconducting (HTS) synchronous motor for electric ship propulsion considering sudden short-circuit fault condition which occurs in three-phase armature windings of synchronous motor. In the beginning of fault process, prodigious transient torque is up to 10 times to the rated value acting on a motor's main shaft, and it is proportional to short circuit current amplitude on the armature windings. Therefore, for stable motor operation, it is crucial to design the rotor's main shaft taking into account the severe fault condition. The sudden short-circuit fault condition of megawatt-class HTS motor was simulated by using the electromagnetic FEA. The external three-phase sudden short-circuit was applied to get transient characteristics such as short circuit current and torque profile. Then, structural FEA of rotor's main shaft based on the transient torque profile was performed to analyze mechanical characteristics of main shaft.

Acknowledgement: This work was supported in part by the Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), grant funded by the Ministry of Trade, Industry & Energy, and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP), Republic of Korea. (Nos. 20164030201230 and 2016R1A2B4007324)

Submitters Country:

Republic of Korea

Tue-Af-Po2.01 / 406

Influence of 3D effects on field quality in the straight part of accelerator magnets for the High Luminosity Large Hadron Collider

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The new D1 beam separation dipole is currently developed at KEK for the Large Hadron Collider Luminosity upgrade (HL-LHC). Four 150 mm aperture, 5.6 T magnetic field and 6.7 m long Nb-Ti magnets will replace resistive D1 magnets in the insertion regions of the LHC. The development includes fabrication and testing of 2.2 m model magnets. The magnet has single layer coil and thin spacers between coil and iron, giving a non negligible impact of saturation on field quality at nominal field. The magnetic design of the straight section coil cross section is based on 2D optimization by means of the ROXIE code, and a separate optimization of the coil ends. However, magnetic measurements of the short model showed a large difference (tens of units) between the sextupole harmonic in the straight part and the 2D calculation. This difference is correctly modelled only by a 3D analysis: 3D calculation performed with Opera-3D and ROXIE show that the magnetic field quality in the straight part is influenced by the coil ends, even for the 6.7 m long magnets. The effect is even more remarkable in the short model. In this paper we investigate similar 3D-effects for other magnets, namely the 11 T dipole for the HL-LHC for which the effect is clearly visible for the single aperture model. On the other hand in the double aperture configuration with field in opposite direction the effect is negligible. We also consider the case of the 4.5 T recombination magnets for HL-LHC (D2), where the lower field and the larger space between coil and iron makes this effect less important, but still visible. We conclude the paper by outlining the different classes of accelerator magnets where this coupling between 3D effects and iron saturation can be relevant.

Submitters Country:

Switzerland

Thu-Af-Po4.10 / 646

Influence of E-J characteristics of coated conductors and field ramp-up rates on the shielding-current-induced fields of magnets

Author(s): Yang Li¹Co-author(s): Yusuke Sogabe¹; Kikuchi Takashi; Naoyuki Amemiya¹¹ *Kyoto University*

The shielding-current-induced field (SCIF) of coated-conductor magnets has been studied mainly for dc magnets. In dc magnets, E-J characteristics of coated conductors can influence their field stabilities, because shielding currents should decay by the finite resistivity, i.e. E divided by J. In magnets generating time-variant magnetic fields, the field ramp-up/down rates as well as E-J characteristics can influence SCIF. J at an arbitrary point in a coated conductor is associated with E due to the E-J characteristic. Because E is determined by the electromagnetic induction during the field ramp-up/down phase of a magnet, J, as well as the shielding current, should be influenced by the ramp-up or ramp-down rate and E-J characteristics. We carry out numerical electromagnetic field analyses on the SCIF of coated-conductor magnets while varying the field ramp-up/down rates as well as the E-J characteristics of coated conductors. The analyses are conducted on simple axisymmetric coils and the cross-sectional model of a cosine-theta magnet designed for a rotating gantry for carbon cancer therapy. As for the excitation pattern of the magnets, we use simple temporal profiles with repeating ramping-up, flat top, and ramping-down phases for the axisymmetric coils, and temporal profiles simulating the excitation of a magnet for a rotating gantry for the cosine-theta magnet. We look at the influence of the ramp-up/down rates and the E-J characteristics on the current distributions in coated conductors in various phases, i.e. ramp-up/down phases, the flat top phase, and steps of the repeating ramp-up/down phases. Then we discuss their influences on the shielding-current-induced fields.

This work was supported in part by JSPS KAKENHI Grant number 16H02326 and in part by MEXT under the Innovative Nuclear Research and Development Program.

Submitters Country:

Japan

Wed-Af-Po3.09 / 1174

Influence of Nd, Dy and Er substitution on the structural and superconducting properties of the $\text{RuSr}_2\text{GdCu}_2\text{O}_{8\pm Z}$

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In this study, the effect of substitution of the Nd, Dy and Er for Gd on the structural and electric properties of the rutheno-cuprate $\text{RuSr}_2\text{GdCu}_2\text{O}_{8\pm z}$ (Ru-1212) was investigated. The polycrystalline samples of $\text{RuSr}_2\text{Gd}_{1-\text{Ln}}\text{Cu}_2\text{O}_{8\pm Z}$ system ($0 \leq x \leq 0.1$, Ln = Nd, Dy and Er) were prepared by solid-state reaction at ambient pressure at temperature between 960°C to 1040°C in air and the oxygen treatment was carried out at 1060°C for 72 hour. Powder X-ray diffraction indicates the formation of a pure phase for all samples. The structure of the samples was investigated by. The results of Rietveld refinement indicate that the parameters cell a and c decrease with the ionic radius of Nd, Dy and Er. The electrical resistance measurements show that the samples present superconductor behavior with TC between 24 K and 30 K. In addition, it was observed that the TC values are not sensitive to the type nor the concentration of the cation doped.

Submitters Country:

Mexico

Wed-Af-Po3.08 / 493

Influence of Operating Parameters on Discharge Characteristics of Superconducting High Field MagnetronTianlong Wang¹; Qingquan Qiu²; Fei Qu¹; Liwei Jing¹; Jianlin Zhang¹; Guomin Zhang³¹ *Institute of Electrical Engineering, Chinese Academy of Sciences*² *Institute of Electrical Engineering, Chinese Academy of Science*³ *Applied Superconductivity Key Lab, Institute of Electrical Engineering, CAS, Beijing, 100190, China 2University of Chinese Academy of Sciences, Beijing, 100190, China and University of Chinese Academy of Sciences, Beijing, 100190, China*

The operating parameters of magnetron discharge include many factors, such as magnetic field intensity and balance degree, cathode voltage, gas pressure and target-substrate space. High quality functional thin films can be prepared by high magnetic field magnetron sputtering at low pressure and long target-substrate space. In this paper, based on VSIM software, using PIC-MCC method, a two-dimensional self-consistent particle simulation is carried out for a superconducting high field magnetron. The distribution of electrons, ions and potential will directly affect the quality of the film, in order to explore the optimal coating process, the influence of above operating parameters on discharge characteristics is studied. Finally, the simulation results are verified by plasma diagnosis, and the low resistivity Mo thin films are prepared.

Submitters Country:

China

Mon-Af-Po1.08 / 56

Influence of Reaction Heat Treatment Conditions on Interstrand Contact Resistances of Nb₃Sn Rutherford CablesTed Collings¹; Mike Sumption²; Milan Majoros²; Xiaorong Wang³; Daniel Dietderich³; Arend Nijhuis⁴¹ *MSE, The Ohio State University*² *The Ohio State University*³ *Lawrence Berkeley National Laboratory*⁴ *University of Twente*

For the high luminosity upgrade of the large hadron collider (LHC) the US accelerator research program (LARP) is developing a magnet designated MQXF and its associated 40 strand Nb₃Sn Rutherford cable designated QXF. To suppress interstrand coupling currents generated during field ramp 25 μm thick stainless steel cores may be included in the QXF cables. For the present study cables with cores of various widths were wound and interstrand contact resistances (ICR) were extracted from the results of AC-loss measurements obtained by way of pickup-coil magnetometry. The ICR so obtained is generally the combined result of crossover- and adjacent- strand contact resistances, R_{c→} and R_a, respectively. In preparation for AC-loss measurement each cable stack was reaction heat treated (RHT) in a closed fixture just large enough to contain it when expansions of 1.5% in width and 4.5% in thickness are expected to take place, a protocol that follows magnet fabrication specifications. In previous studies when RHT was performed under considerable uniaxial pressure the ICR was very low in uncored cable and increased with increasing core width. In the present case, in which RHT took place under ambient pressure, the crossover contact was found to be nonexistent.

With Ra left as its sole contributor, ICR turned out to be relatively large, independent of core width, and unpredictable in value.

Submitters Country:

USA

Wed-Af-Po3.06 / 1084

Influence of Rotor Structure on End Effects of High-Speed Permanent Magnet Synchronous Generators Using 3D Finite Element Analysis

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With many advantages such as high efficiency, high power density, small size, low weight, simple mechanical construction, no excitation loss, easy maintenance, and good reliability, high-speed permanent magnet synchronous generators (PMSGs) are gaining considerable amount of attention from many researchers and institutions worldwide. Due to the high centrifugal forces exerted on the permanent magnets, a robust rigid rotor construction is paramount in high-speed operations of the generator. A high-strength material is used for the shaft coupling part due to the stiffness of the shaft. However, since this high-strength material has a magnetic property, the winding reactance consists of large amount of leakage reactance. Therefore, an accurate value of the total leakage reactance is important in the electromagnetic evaluation of high-speed PMSGs. In this paper, an accurate analysis for determining the electromagnetic performance is proposed and the influence of rotor structure on the leakage inductance is explored. In particular, compared with two-dimensional (2-D) finite element (FE) analysis, the electromagnetic parameters, which are influenced by the rotor structure, have been identified and a method to predict accurate electromagnetic performance has been proposed. The performance of the proposed analysis is evaluated using 3-D FE analysis and experimental validation. This paper, in short, illustrated the calculations of the end-winding leakage inductance and analyzed its influence on the end and active regions. The model of the stator end-winding described here is quite general and hence the proposed method is also suitable for calculating the end-winding leakage inductance of other electric machines. In particular, it is suggested that characteristic analysis considering the 3-D effect is necessary in the process of design and analysis since there is a reduction in output power due to leakage inductance. The analysis results, discussions, and measurements of the high-speed PMSG will be presented with more detail in the final paper.

Submitters Country:

Republic of Korea

Thu-Af-Po4.10 / 193

Influence of Soft Ferromagnetic Section on Trapped Field of High Temperature Superconducting Bulk Magnet used for linear motor application

Author(s): Junjie Tang^{None}

Co-author(s): Jing Li ; Guangtong Ma ; Xiang Li ; Kun Liu

High temperature superconductor(HTS) bulk has significant potential in linear motor application due to relatively high trapped field compared with the permanent magnet. However, the trapped

field in a HTS bulk would be attenuated or even erased when bulk is subjected to a time-varying external magnetic field. Therefore, it is important to develop a method to protect bulks from demagnetization. In this work, YBCO HTS bulk which was magnetized by field cooling was attached by ferromagnetic plate on the top surface or ferromagnetic ring round the periphery, then subjected to traveling magnetic field. The relationships between the trapped field attenuation, electromagnetic force of HTS bulk magnet with ferromagnetic section and the amplitude, frequency of traveling magnetic field would be investigated experimentally. The trapped magnetic field are measured by Hall probe mapping and electromagnetic force are obtained by a home-made measuring equipment. Meanwhile, numerical model was built with finite element software Comsol Multiphysics. Based on the verified simulation, further investigations were carried out to systematically examine the dependence of the trapped field attenuation of bulk on the different geometrical parameter of ferromagnetic section. Conclusions would be beneficial to the design and applications analysis of the superconducting linear motor.

Submitters Country:

China

Thu-Af-Po4.05 / 996**Influence of Stator Structure on the Static Characteristics in Axial Field Flux Switching Permanent Magnet Machine****Author(s):** Li Hao^{None}**Co-author(s):** mingyao lin¹; nian li²; Da Xu¹ Southeast University² Southeast university

Axial field flux-switching permanent magnet machine (AFFSPMM) has the advantages of inherent sinusoidal back-EMF waveform, high power density, and large torque capability, which is suitable to use in electric vehicle. The investigated AFFSPM machine is composed of two outer stators and one inner rotor both with a doubly-salient structure. The stator contains 12 modular U-shaped laminated segments, PMs, concentrated armature coils and field windings. A concentrated armature coil is wound around the two adjacent stator teeth with a piece of PM in the middle. The PMs are magnetized circumferentially and the magnetization is reverse in polarity from one magnet to the next. There is neither PMs nor coils in the rotor. In order to reduce the usage of permanent magnet and improve the static characteristics of AFFSPMM, three different stator structures, including parallel stator tooth and parallel slot (PST-PS), parallel stator tooth and parallel permanent magnet (PST-PPM), parallel permanent magnet and parallel slot (PPM-PS), are investigated. Based on 3-D finite element, the static characteristics, such as the flux-linkage, back-EMF, output torque, and cogging torque are analyzed. The influence of stator tooth width, permanent magnet width, stator yoke width, stator axial length, rotor shape angle, and rotor tooth width on the static characteristics of AFFSPMM with three different stator structures is investigated. The results show that increasing the rotor tooth width and the rotor shape angle can improve the characteristics of PPM-PS and PST-PS structure. For PPM-PST structure, stator structure has great influence on the characteristics. The PPM-PS structure can gain more sinusoidal back-EMF, larger output torque, and lower cogging torque than the other structures. The prototype with PPM-PS structure is made and the experiments are done.

This work is supported by the Natural Science Foundation of Jiangsu Province (BK20161425), and the National Natural Science Foundation of China (51277025 and 51577027).

Submitters Country:

China

Wed-Af-Po3.12 / 897

Influence of Three Phases Imbalance on the AC Losses of Tri-axial HTS CORC Cable used in an All-Electric Aircraft

Zixuan Zhu^{None} ; Yawei Wang¹ ; Min Zhang¹ ; Weijia Yuan¹

¹ *University of Bath*

High temperature superconducting (HTS) Tri-axial CORC cable shows great advantages on compactness, reduced usage of HTS tapes, low AC losses and low leakage field. Therefore, it becomes a potential candidate for the transmission line used in an all-electric aircraft. The cable often suffers three-phase imbalance in electrical aircraft, which can have a significant influence on the AC loss distribution of the cable. This paper is to study the AC losses of the tri-axial HTS cable under three-phase imbalance. A powerful three-dimensional finite element method (FEM) model based on the T-A formulation is developed to calculate the AC loss in a tri-axial CORC cable. A circuit network model is coupled to the FEM model to simulate the three-phase imbalance loads. A tri-axial CORC cable designed for an electrical aircraft is investigated using the numerical model. AC loss is analysed under both balanced and imbalanced operation. Results show that the AC loss shows an approximately uniform distribution under balanced loads, while a relatively non-uniform AC loss distribution is observed among different layers under three-phase imbalance operation. This issue has to be considered carefully in the design of the cooling system. The results also show that the distribution of AC loss among layers can be optimized by adjusting the winding angle, winding pitch and tape numbers.

Submitters Country:

UK

Tue-Af-Po2.09 / 947

Influence of bolt positions and electrode structure in Yoroi-coil structure on stress distribution in an HTS coil winding

Masahiro Kato¹ ; Daisuke Miyagi¹ ; Makoto TSUDA¹ ; Satoshi Awaji¹

¹ *Tohoku University*

Large hoop stress causes the deterioration of the transport properties of the winding. Therefore, high electromagnetic force tolerance is required for structure of the winding, and at the same time, it is necessary to limit the current density so as not to deteriorate the superconducting characteristic. As this countermeasure, a high strength pancake coil structure called "Yoroi-coil" (Y-based oxide superconductor and reinforcing outer integrated coil) is suggested. Yoroi-coil structure is expected to reduce the electromagnetic force applied to the winding and the volume of the coil frame at the outside of the winding. In previous studies, it has been reported the effect of hoop stress reduction in ideal "Yoroi-coil" structure without bolts and an electrode. However, in the practical "Yoroi-coil" structure, there are some bolts for fixing a frame and reinforcing outer plates, and the frame shape is not cylindrical but C-shaped because there are electrodes. Therefore, in order to clarify the effect of the hoop stress reduction by the practical "Yoroi-coil" structure, it is necessary to investigate the influence of the actual frame shape and bolts on the stress distribution in an HTS coil winding. In this study, the effect of the stress reduction of an HTS coil winding by the practical "Yoroi-coil" structure considering bolts, an electrode, and a bobbin was examined by three-dimensional finite element method. Numerical results show that stress distribution is generated in the winding according to the bolt position and it is necessary to increase the number of bolts to suppress stress distribution in the winding. Local large stress is also applied to the winding around the electrode. In order not to apply the local stress to the winding, the mechanical strength of the electrode is very important. Based on these results, design guidelines for the practical "Yoroi-coil" structure is clarified.

Submitters Country:

Japan

Wed-Mo-Or21 / 1110

Influence of field cycle and applied current on coated conductor magnetization and decay for accelerator applications

Mike Sumption¹ ; Cory Myers² ; Ted Collings³¹ *The Ohio State University*² *Ohio State University*³ *MSE, The Ohio State University*

Coated conductors are now being considered for use in beam steering and focusing magnets for high energy particle accelerators. However, coated conductors and cables have substantial magnetization, important for field quality. Magnetization decay, although suppressed, is also important for field quality retention. In this work we investigate the influence of applied current and selected field cycle on magnetization and magnetization decay for YBCO coated conductors at low temperatures. Field cycles mimicking what would be experienced for accelerators were applied to the samples, including (1) starting a high field, (2) dropping to a field between 0-1 T, and (3) increasing again to a field of 1 T. The magnetization and magnetization decay were measured as a function of the lower field point, and it was seen that while M could be suppressed with a conductor-specific lower field, time dependence (decay) was only partially reduced. Additionally, current of 0-100 A were applied and the influence of the magnetization for fields applied perpendicular to the tape surface were mapped as a function of lower field hold point and injected current.

Submitters Country:

usa

Wed-Af-Po3.11 / 69

Influence of high thermal conduction plastic having negative thermal expansion property on cooling performance in conduction cooled HTS coils

Author(s): Tomoaki Takao¹**Co-author(s):** Yuki Tanaka¹ ; Shota Suga¹ ; Taro Takano¹ ; Atsuhiko Yamanaka²¹ *Sophia University*² *Nagoya University*

A glass fiber reinforced plastic (GFRP) has been widely used for electric insulation in a high temperature superconducting (HTS) winding. Since thermal conductivity in the GFRP is low, the GFRP makes thermal flow from the superconducting winding to a cold head of a refrigerator worse. When a high thermal conduction plastic is used instead of the GFRP, the cooling performance in the winding becomes better. We have experimentally and numerically studied increase of cooling performance in the winding having the high thermal conduction plastic sheet. In the plastic sheet, high thermal conduction fibers are embedded perpendicular to the sheet, and hence the thermal conductivity to the direction is good. At first, we measured the thermal conductivity along the fibers in the plastic. According to the experimental results, the thermal conductivity of the plastic was 20 times larger than that of the GFRP. And next, thermal expansion/contraction property of the plastic was estimated experimentally. The experimental results said that the plastic expanded approximately 0.2% to the fiber direction during cool down from room temperature to liquid nitrogen temperature. Finally, a YBCO tape was holed from upper and lower faces with the plastic sheets, and the tape quenched with the local heater put on the tape. From the quench tests, thermal stability of the tape with the high thermal conduction sheets was higher than that with the GFRPs. We used a 3D-FEM software and numerically simulated the quench test. From the calculated results, contact thermal resistance between the YBCO tape and the plastic sheet was about a half value of that between the YBCO tape and the GFRP. From those experimental and numerical results, we think the plastic sheet is useful

to increase the thermal stability of the HTS winding.

This work was partially supported by JSPS KAKENNHI Grant Number JP 16K06238.

Submitters Country:

Japan

Mon-Af-Po1.10 / 819

Influence of local critical current degradation on quench characteristics of a ReBCO coil

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The simulation analysis of thermal and electromagnetic behaviors in ReBCO coils after a local normal conduction transition has been performed by many research groups. The numerical analysis, however, were about the behaviors after generating an initial normal spot and the occurrence factor of the initial normal conduction transition has not been sufficiently clarified yet. To clarify the occurrence factor of the initial normal conduction transition is very important to take coil protecting measures against the local normal conduction transitions. We focused on local critical current degradation and investigated the influence of the local critical current degradation on the thermal and electromagnetic behaviors around the local degradation region and the time change characteristics of the voltages across the degradation region. The local critical current degradation was produced by cutting a part of the width of a GdBCO tape. The current at the disconnection of the tape and the increasing speed of the voltages across the degradation region were measured in short samples and coils using the GdBCO tape. In the sample without stabilized copper layers covered by Styrofoam, the voltage rapidly increased in a short time and the sample was disconnected soon after the operating current exceeded the local critical current. On the other hand, the tape with the stabilized copper layers cooled by LN₂ could stably maintain the voltage even when the operating current largely exceeded the local critical current. Moreover, the current at the disconnection of the tape with the stabilized copper layers cooled by LN₂ was improved much more than that of the tape without the stabilized copper layers covered by Styrofoam. The differences of the current and thermal distributions between these samples and the relationship between the voltage increase and the current and thermal distributions were investigated by the finite element analysis.

Submitters Country:

JAPAN

Thu-Af-Po4.08 / 452

Influence of picosecond and femtosecond laser impact on magnetic and transport characteristics of the HTS tape

Author(s): Sergei Pokrovskii¹

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It is well known that the second generation high-temperature superconductor (HTS) tapes have local inhomogeneities of magnetic and current-carrying characteristics. These features of the material often limit the length of tape suitable for applications. The main purpose of present work is to

improve the magnetic and transport characteristics of 2G HTS tapes by creating an ordered lattice of artificial pinning centers. By using pico- and femto-second laser exposure we have performed modification of HTS GdBa₂Cu₃O_{7-δ} industrial tape produced by SuperOx (Russia). To modify superconducting film we have used automated FEMTO-T laser complex 1. Laser complex includes an adjustable laser-energy attenuator, a focusing system, a CCD video camera, a three-coordinate system for positioning objects and a control PC with all necessary interfaces. The pulse width can be varied from 150 fs to 3 ps, the wavelength is 870 nm and 1064 nm. The pulse energy varied from 50 to 4000 nJ. We have created the local lattice of defects with the period 50 μm and the size of every hole up to 1 μm which is close to the diffraction limit of the laser system. It was investigated the influence of the laser exposure on the structure of the film in the area where artificial defects were created. We have performed the measurements of the magnetization, local trap field and current distribution in samples before and after modifications. Also the critical current dependence on magnetic field was measured and dependencies of the pinning force and n-values on the energy of laser pulse were obtained. So we have shown that the created pinning centers lead to the appearance of point pinning centers that can improve the local critical current of tape.

1 A.V. Gordienko, O.B. Mavritskii, A.N. Egorov, A.A. Pechenkin, D.V. Savchenkov // *Quantum Electronics* 44 (12), 2014, pp. 1173 – 1178

Submitters Country:

Russia

Wed-Af-Po3.12 / 175

Influence of the modeling depth and voltage level on circulating currents in parallel conductors of a PMSM

Author(s): Florian Birnkammer¹

Co-author(s): Junquan Chen²; Dieter Gerling¹

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² *Naval University of Engineering*

In automatically wound machines, the actual position of each single conductor in the slot is usually unknown. However, depending on the individual placement in the slot, parallel-connected strands can lead to differing circulating currents. Since the flux-linkage due to leakage flux in the slot varies in radial direction, increasing towards the slot opening, the induced voltage also differs in parallel strands that are aligned in radial direction, resulting in circulating currents and thus additional copper loss in the stator winding. The circulating currents itself cannot be seen in standard phase current measurements, but manifest in a change of the phase resistance. Analysis of AC effects, such as skin and proximity effect as well as the circulating currents and corresponding losses are usually done by finite element analysis (FEA), while mostly only a single slot is considered, neglecting the influence of neighboring slots on the flux density of the stator iron and thus the resulting slot leakage flux. This work compares different levels of detail of 2D FE models, e.g. single slot, single pole and pole pair model, and investigates the impact of the modelling depth on the resulting copper loss. Moreover, the potential increase of AC-losses is assessed for two machines that are identical except for the stator winding, i.e. one and the same machine is investigated at two different voltage levels, namely 400 V and 800 V. The reference machine is a 160 kW nominal power and 9000 rpm maximum speed permanent magnet synchronous machine already running in various applications. Since the magnetic circuit has to remain constant, both designs share the same overall winding scheme and total number of strands per slot but differ in the number of parallel and serial connected strands. As described above, this will lead to different circulating currents and therefore also different losses.

Submitters Country:

Germany

Tue-Af-Po2.02 / 235

Injection Kicker for HESR at FAIR using Semi-Conductor Switches

Author(s): olivier cosson^{None} ; olivier maulat^{None}

Co-author(s): Raimund Tölle

The High Energy Storage Ring (HESR) for Antiprotons is going to be built at FAIR in Darmstadt on the extended GSI campus. Charged particles (including protons and antiprotons) of 13 Tm magnetic rigidity will be injected into this synchrotron and storage ring. The injection system of the HESR ring is based on 4 UHV 360 mm long ferrite kickers, each kicker having to generate a 25 T.mm integral field, during 500 ns, with rise time and fall time lower than 220 ns. Each kicker is supplied by a 4000A / 40 kV pulser, based on Blumlein topology, with semi-conductor switches. A prototype of the pulser, using water lines instead of conventional coaxial cables, has been developed to feed the UHV kicker. Electric and magnetic measurements are presented, as well as magnetic transient modelling.

Submitters Country:

france

Tue-Af-Po2.12 / 1106

Injection control by neural network approach for Pulse-magnet of Taiwan Light Source

HUNG-CHIAO CHEN^{None} ; Cheng-Ying Kuo¹ ; Hsin-Hui Chen^{None} ; Chang-Hor Kuo^{None}

¹ NSRRC

Top-up operation has been started since many years ago at Taiwan Light Source Storage Ring (TLS-SR). To realize the operation of the ring by top-up injection mode, a coherent oscillation of the stored beam is one of serious problem. This phenomena is exited in every injection period due to error in the injection pulse-magnets. For this operation it is important to reduce the beam injections should not excite the oscillation of stored beams. Artificial neural network (ANN) technology was used to analyze and optimize the injection pulse-magnets parameters of the storage ring. The results of this research are discussed in this study.

Submitters Country:

Taiwan

Wed-Af-Po3.05 / 1090

Integrated Motor Propulsor Magnet Design with Hybrid Halbach Array for Torque Ripple Reduction

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Co-author(s): Cheol Han ; Chang-Woo Kim ¹ ; Cheol-Hoon Park

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Recently, integrated motor propulsors (IMPs) have been under extensive research and development because of the numerous advantages of underwater propulsion for vehicles. IMPs require minimized torque ripple for smooth and quiet operation when used in undersea vehicles or unmanned submarines. Thus, torque ripple reduction should be considered in the design stage. In the IMP case, a permanent magnet (PM) design with a Halbach array should be developed. PMs with radial array

are not available because of the minimized flux leakage. With regard to torque ripple reduction researchers have proposed various designs for IMPs. However, these research activities didn't consider the influence of the width ratio and material of PM in IMPs with a Halbach array. Therefore, this paper presents a magnet design with a Halbach array for torque ripple reduction according to the width ratio, and deals with influence of material of radial array permanent magnet. We believe that the proposed method is useful and effective in designing other models. This paper is divided into two main parts. The first part focuses on the PM width ratio, which use a downscaled PM to compensate for the torque pulsation. Because the magnetization of a magnet in the x-axis direction is the same as that in the air gap, the torque ripple varies. The second part is based on the PM material. Generally, the same arrangement is used in the Halbach array, but the back-emf is affected by the magnet width in the y-axis direction. The material of radial array PM does not matter if the material changes because x-axis does not significantly affect the magnetic flux. The results are calculated by a two-dimensional finite element method (FEM). A more specific comparison with an accurate initial design method in consideration of the mechanical structure will be investigated for its contribution to related researches.

Submitters Country:

Republic of Korea

Wed-Af-Po3.02 / 320

Inter-layer Joint for the TF Coils of DEMO - Design and R&D

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In summer 2015 a new reference baseline is issued for the DEMO EUROfusion tokamak. Thereafter, the toroidal field (TF) coils have been updated with the new layout of the react-and-wind conductor proposed by the Swiss Plasma Center (SPC). Each TF coil consists of 12 single layers of graded Nb3Sn conductors connected in series by "invisible" inter-layer joints fully embedded in the winding pack. The high-grade Nb3Sn conductor operates at 63 kA, 12.4 T with Tcs above 6.5 K. The new prototype of the high-grade cable has been manufactured and delivered to SPC: 20 meters of Nb3Sn and about 10 meters of copper dummy conductor. The copper dummy conductor, which is structurally identical to the Nb3Sn conductor, was used for assembly trials of dummy inter-layer TF coil joint in order to develop the technological process. To prepare the joint, the sub-cables of the heat treated conductors are cut at staggered positions and matched to restore the geometry of the cable, without protrusion. The joint assembly is soft soldered to reduce the contact resistance and encased in the conduit shells. A SULTAN sample including a TF coil Nb3Sn inter-layer joint is being completed at SPC, the test of this joint is expected in October 2017.

Submitters Country:

Switzerland

Wed-Mo-Pl6 / 1252

Into the future with high temperature superconductors

Thu-Af-Pl9 / 1255

Introduction to MT26 in Vancouver

Mon-Af-Po1.04 / 801

Investigation and Optimization of the Field Regulation Capacity in a Hybrid Axial Field Flux-Switching Permanent Magnet Machine

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Hybrid Axial Field Flux-Switching Permanent Magnet (HAFFSPM) machine is a novel hybrid excited machine which incorporates the merits of flux-switching PM (FSPM) machine and axial field PM machine. This machine is composed of two co-axial outer stators and one inner rotor with doubly-salient structure and is suitable for electrical vehicle drive because of its shorter axial length, higher torque/power density and more flexible flux regulation. Unlike the traditional hybrid excited machines, there are not only parallel flux paths of the direct current (DC) excitation and the permanent magnets which is effective, but also series flux paths which is additional and adverse in the HAFFSPM machine. For the HAFFSPM machine, the series flux should be weakened while the parallel flux should be strengthened to obtain good field regulation capacity. The field regulation capacity of the HAFFSPM machine, which is an important electromagnetic characteristic, is thoroughly investigated in this paper. The influences of the design parameters, such as the PM material, the rotor pole number, the rotor pole shape angle, the rotor pole width, the stator yoke depth and the stator middle pole width, on the field regulation capacity of a 3-phase 6/10 stator/rotor-pole HAFFSPM machine are analyzed based on the 3-D finite element method (FEM). The above parameters are optimized comprehensively with the design of experiments (DOE) method for flexible flux regulation and high average output torque which means a wide speed range and a high torque density. The theoretical prediction is compared with the 3-D FE analysis. The research results indicate the design and optimization rules of field regulation capacity for the HAFFSPM machine, with the combination of the parameter selection.

Submitters Country:

China

Tue-Mo-Or11 / 731

Investigation of Design Considerations for an Electromagnetic Induction Coilgun System

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An electromagnetic induction coilgun system accelerates a projectile in the axial direction which is a non-periodic moving. In addition, since the electromagnetic coilgun system converts the electrical

energy to mechanical energy, the interactions between variables are very complex. Therefore, during a design process of the coilgun system, the design considerations are much more complicated and difficult to analyze compared to others electro-mechanic systems. Some of the design considerations have been published in previous researches, but some others are still deficient in study. A thorough study of the design considerations is necessary to design the coilgun system. This paper investigates the design considerations of an electromagnetic induction coilgun system and suggests reasonable parameters of the system to achieve high energy efficiency.

Some common design considerations such as capacitance, voltage level, length of the barrel, switching time, initial position and output velocity of the armature will be evaluated and then their influences on operation and energy efficiency will be assessed from the evaluated data. Some others which still are lacking in researches such as wire size, resistance, air gap, and distance between stator coils will be investigated and explained. A mathematical model of the coilgun is used to study the impact of the design considerations. Finally, the recent achievements, challenges, and trend of the coilgun system will be addressed briefly. We believe that the summary and study on the design considerations are useful and essential to design the coilgun system and largely contribute to its development.

Submitters Country:

Republic of Korea

Wed-Af-Po3.10 / 933

Investigation of Materials and Welds for the Precompression Structure of the ITER Central Solenoid

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The Central Solenoid (CS) is the backbone of the ITER magnet system. It consists of six independent coils held together by a vertical pre-compression structure that must react tensile loads and provide sufficient preload to maintain coil-to-coil contact during all stages of plasma operation. The CS pre-compression system includes three different types of tie plates, lower and upper key blocks, load distribution plates and tubing that will carry supercritical helium at temperatures as low as 4.5 K. Material selection and specifications applicable to the structural components of the pre-compression structure are particularly demanding. These include large forgings manufactured from a high strength austenitic stainless steel (FXM-19) with a stringent specification in terms of fineness of the grain size, inclusion cleanliness, maximum allowed magnetic permeability and ferrite content. In order to meet these requirements, an adapted steelmaking route including Electroslag Remelting must be followed. The melt chemistry is specially tailored. The re-melted ingots are subject to redundant, multi-directional forging. Ultrasonic examination of 100% of the volume of the forgings is performed in accordance with applicable standards, such as ASTM A745/A745M, with acceptance criteria adapted to the functional requirements of the individual components. Stringent requirements are also imposed on all welded joints. Structural welds, as well as the attachment welds of the cooling pipes to the structure, are subject to challenging restrictions in terms of weld imperfections and geometry. They must induce limited distortion and are subjected to inspections carried out in accordance with the most severe acceptance levels of applicable international and national standards. The results of extensive examinations of different components and welds are reported in this paper, particularly focusing on the quality achieved at microstructural and macrostructural level. The influence of the microstructure on the properties and the inspectability of the material by non-destructive examinations is also discussed.

Submitters Country:

Switzerland

Thu-Af-Po4.05 / 1063

Investigation of SMPM Motor with Segmented Eccentric Magnet Pole

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It is well known that the shape of a magnet pole has a significant influence on the air-gap flux density distribution, back-electromotive force harmonic and torque ripple in surface-mounted permanent magnet (SMPM) motors. In general, reducing the torque ripple by changing the shape of the permanent magnet (PM) has a negative effect on the electromagnetic torque and increased cost. This paper proposes a novel segmented PM pole with optimized Halbach array having different eccentricities, i.e., the inner and outer arcs of the segmented PM have different centers. Eccentric segmented magnet pole with Halbach array is carried out, which aims to unite the advantages of section Halbach array and eccentric magnets to achieve low torque ripple and high usage efficiency, while avoiding the decrease of the fundamental amplitude of air-gap magnetic flux density and the torque ripple cause by inter-pole leakage flux. In this paper, each magnet poles have segmented and eccentric magnet with Halbach array is proposed. The expression of air-gap flux density with eccentric magnet pole with Halbach array is detailed, calculating the optimal eccentricity, while its validity is examined by finite-element analysis (FEA). It shows that comparing to traditional three-segment Halbach array and radial magnetization eccentric magnet, through suitable selection of the eccentric distance, harmonic contents of radial flux density can be reduced a lot and can achieve low torque ripple, high electromagnetic torque and low magnet usage.

Submitters Country:

China

Thu-Af-Po4.04 / 555

Investigation of Temporal Stability of a Persistent Current Mode Prototype MgB₂ Coil

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A superconducting magnet commonly used in current MRI systems should be operated in the persistent current mode (PCM) to yield a high-resolution level that requires a magnetic field drift of less than 0.01 ppm/h. To acquire the required field homogeneity as a function of time, the availability and even reproducibility of a superconducting joint technique enabling the PCM of the magnet should be guaranteed quantitatively. Currently, a helium-free MgB₂ MRI magnet is being developed by the collaboration between Kiswire Advanced Technology Co. Ltd. (KAT) and Korea University, which is supported by the Materials and Components Technology Development Program of the Korean Evaluation Institute of Industrial Technology (KEIT), Korea. In this study, we report our progress on the development of a PCM prototype coil fabricated using MgB₂ wires manufactured by KAT. The temporal stability of the prototype MgB₂ coil was evaluated through the field decay tests at 4.2 K.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current

and long length for superconducting medical•electric power equipment] and in part by the Korea Basic Science Institute under Grant D37614.

Submitters Country:

Republic of Korea

Mon-Af-Po1.07 / 875

Investigation of bulging behavior of metallic tube in electromagnetic forming process with a bias magnetic field

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Electromagnetic tube bulging is a high speed forming process shaping metallic tube with pulsed Lorentz force. In conventional electromagnetic bulging process, only a forming coil is inserted inside of the metallic tube, which is energized with a capacitor bank. Then the interaction between the generated magnetic field and the induced eddy current in tube can trigger strong Lorentz force leading to the deformation of the tube. For this process, in practical applications, its forming capability is usually limited due to the insulation strength, mechanical strength, and thermal capacity of the forming coil. To overcome these limitations, a new forming process with the aid of a bias magnetic field is proposed in this work. The bias field is generated by an additional coil co-axially located outside the tube and has a relatively long pulse width compared with the magnetic field generated by the coil insider of the tube, which is used to establish a background magnetic field for increasing the Lorentz force acting on the tube. To validate the effectiveness of the proposed process, both numerical and experimental studies are carried out to investigate the effect of the bias field on the bulging behavior of metallic tube in detail. It has been found that there is an optimal value of bias field for significantly improving the forming capability without changing the field generated by the inner coil.

Submitters Country:

China

Tue-Af-Po2.05 / 281

Investigation of epoxy impregnated Nb3Sn superconducting coil for high field applications

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In order to developing the nuclear magnetic resonance (NMR) superconducting magnet and other applications, a series of high field magnet manufacture technologies are researching in our institute, IEE CAS. The Nb3Sn superconductor is indispensable for the 500 MHz and above NMR magnet. In this paper, a dynamic vacuum pressure impregnation (VPI) process of Nb3Sn coil on the basis of Darcy's law of fluid mechanics in porous media are modeled and analyzed. The influence of several VPI parameters on the impregnation results is studied. Also, the research process of high field Nb3Sn superconducting coil technology is presented. The cryogenic test results show that the critical current of the Nb3Sn coil reaches 400 A, and central magnetic self-field is 6.67 T. Under the

13 T back magnetic field, the Nb₃Sn coil has the critical current of 130 A. The central magnetic field increases to 15.25 T. The critical property of the Nb₃Sn coil reaches 92 percent of that of short sample. The epoxy impregnated Nb₃Sn coil fabrication technology was also introduced in the NbTi/Nb₃Sn split magnet system.

Submitters Country:

China

Wed-Mo-Or21 / 1061

Investigation of the Roebel cable geometry and current homogeneity over lengths relevant to accelerator-type demonstrator magnet.

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A high temperature superconductor accelerator demonstrator dipole magnets are currently under development in frame of the EuCARD2 project. Accelerator magnets require conductor with high overall current density, high field quality and large transverse stress tolerance. REBCO materials which possess uniquely high transport currents at low temperatures and high fields are challenging due to the thin tape geometry. Because of the very high aspect ratio of the tape, new concepts of HTS cables need to be explored, with the goal of having full transposition of the strands, necessary for field quality and current redistribution, acceptable bending ability and a high compaction factor to avoid excessive dilution of the current density. The HTS Roebel cable concept, which was chosen for the coil demonstrators, provides most of the required properties. Up to now short (up to 6 m) and intermediate piece lengths of the cable (24 m) have been prepared. To go beyond first magnet demonstrators, cable lengths of 100 m are needed. Such lengths require characterization of the geometry, tape material as well as of the punched Roebel strand. Besides the material geometry issues, also the influence of critical current properties on the cable is investigated. We are in the process to prepare and assemble dummy cables of 100 m lengths. The geometry of the cable strands will be quantified and qualified with reel-to-reel geometry control system. Cable geometrical uniformities will be compared with tape and strands uniformities. To increase the precision in transposition length, we plan to set up a system that monitors the transposition length in real time and makes corrections using the reel-to-reel system. The tape and strand critical current homogeneity will be investigated using TAPESTAR™ and reel-to-reel transport I_c measurement system (77 K). The characterized current uniformity and its influence on long length cable properties will be studied.

Submitters Country:

Germany

Tue-Af-Po2.09 / 552

Investigation on Minimum Tolerable Bending Diameters of Reacted MgB₂ Monofilament Wires

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MgB₂ superconductors are recognized as one of the promising superconducting wires for utilizations in a current MRI magnet. However, a practical consideration remains that the critical current density and critical magnetic field of the MgB₂ wire strongly depend on the stress applied by bending the reacted MgB₂ wire. Therefore, the investigation of the electrical properties of the reacted MgB₂ wire under various bending stresses should be thoroughly carried out to determine the minimum winding diameter for the module coil, as well as the persistent current switch for the MRI magnet. In this study, the critical current value of reacted MgB₂ monofilament wires, manufactured by Kiswire Advanced Technology Co. Ltd. (KAT), was examined in terms of the bending diameter of the wire at various cryogenic temperatures. Based on the experimental test results, the maximum tolerable bending stress of the MgB₂ wire was quantitatively determined. Consequently, the feasibility of the react-and-wind method for the fabrication of MgB₂ magnets was also examined in detail.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical•electric power equipment].

Submitters Country:

Republic of Korea

Thu-Af-Po4.10 / 587

Investigation on Optimal Third-order Harmonic Shaping Method for Parallel Magnetized Surface-Mounted PM Machine

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Abstract- On the basis of the high power (MW-level) and high torque density requirements for large ship Integrated Full Electric Propulsion (IFEP) system, the optimal third-order harmonic shaping method for parallel magnetized direct-drive surface-mounted permanent magnet (SPM) machine is developed in this paper. In contrast to conventional surface-mounted magnet pole, the sinusoidal third-order harmonic shaping (Sine+3rd) method exhibits smaller cogging and output ripple torques. Meanwhile, the Sine+3rd method provides significant larger average torque or power density than that of traditional sinusoidal shaping method. However, the analytical determination of optimal third-order harmonic injection value for parallel magnetized SPM machine having "bread-loaf" magnet pole is still unknown. In addition, the finite element analysis (FEA) scanning method is very time consuming. Thus, the determination equation to obtain optimal sine+3rd value is derived and its accuracy is validated by FEA. The further investigation reveals that the average torque and power density can be increased obviously for SPM machine using optimal Sine+3rd method.

Submitters Country:

china

Mon-Af-Po1.10 / 545

Investigation on Thermal and Electrical Characteristics of MgB₂ Magnet Using Partial-Insulation Winding Technique

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It is generally agreed that the development of a self-protective MgB₂ magnet may not be achieved because of the slow normal-zone propagation velocity of the MgB₂ wires, compared to their low-temperature superconductor counterparts. However, the use of the no-insulation (NI) winding technique can allow the MgB₂ magnet to be self-protecting, because the excessive heat and current generated by local quenching can be automatically bypassed through the uninsulated turns. Nevertheless, to utilize the NI winding technique for large-scale superconducting magnets such as whole-body MRI magnets, it is essential to ameliorate the charging/discharging delays observed in the NI windings. As an alternative solution, this study examines a partially insulated (PI) MgB₂ magnet that employs layer-to-layer insulations only, in the absence of turn-to-turn insulations. A monofilament MgB₂ wire manufactured by Kiswire Advanced Technology Co. Ltd., was used for the fabrication of the PI MgB₂ magnet. The charge-discharge and over-current characteristics of the PI MgB₂ magnet were investigated to demonstrate the feasibility of employing the PI winding technique to develop a self-protective MgB₂ MRI magnet with fast charging/discharging rates.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical•electric power equipment].

Submitters Country:

Republic of Korea

Tue-Af-Po2.06 / 724

Irreversible Demagnetization Analysis with Respect to Winding Connection and Current Ripple in Brushless DC Motor

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The Brushless DC (BLDC) motor is widely applied in various fields, such as tractions, communication devices, and home appliances, by virtue of its high-power density, wide operating range, high efficiency and simple drive system. Two kinds of BLDC motors, “Y-connection, 2-phase excitation system” and “ Δ -connection, 3-phase excitation system”, have many differences. A major difference is the requisite flat-top width of the phase input current, 120° for Y-connection and 60° for Δ -connection. This flat-top width of phase input current of each winding connection results in the difference of the excitation sequence. Meanwhile, the irreversible demagnetization is a major drawback in the Permanent Magnet (PM) motor. Once this has happened, the motor performance will be degraded to an extreme degree, since the Back-EMF (BEMF) and the output power are reduced. The main causes of irreversible demagnetization are temperature increase, armature reaction, and inverse magnetic fields. This paper conducts the characteristic analysis of irreversible demagnetization in a BLDC motor according to the winding connection, wye and delta. The comparison of irreversible demagnetization about each winding connection is conducted by observation of demagnetization ratio according to winding connection. In addition, their irreversible demagnetization analysis has been performed considering ideal current source analysis and voltage source analysis with 6-step control for consideration of current ripple caused by coil inductance. Consequently, the Δ -connection BLDC motor is more vulnerable than the Y-connection, since the peak value of the input phase current in the Δ -connection BLDC motor is higher than that of the

Y-connection, while the RMS values of the input currents are equal. This is because the BEMF and input current waveform differ, according to the winding connection. Also, the demagnetization characteristics of both Y-connection and Δ -connection BLDC motors depend on a coil inductance which affects electrical time constant.

Submitters Country:

Republic of Korea

Mon-Af-Po1.08 / 623

Irreversible strain characteristics of technical RHQT Nb₃Al superconductors

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In the ITER magnets consisting of Nb₃Sn conductors, the magnets are fabricated through the so-called wind & react (W & R) technique. In the W & R process, the conductors are wound prior to the heat treatment to form the Nb₃Sn superconducting strands from the non-superconducting ductile precursor ones. Then the heat-treated windings are encased into the radial plate keeping their winding shape as it is. The Nb₃Sn strands have lower strain sensitivity, so that the applied bending strain to the Nb₃Sn strands should be suppressed as small as possible. However in DEMO reactor magnets whose size becomes much larger than the ITER ones, the problems concerning dimension accuracy and fabrication cost should become much bigger. In this context, the react & wind (R & W) process would have to be considered as a solution to construct the magnets. The Nb₃Al strands have small strain sensitivity for J_c characteristics. Hence, they could be one of the alternative conductors for realizing the R & W coil. In the R & W application, the irreversible strain characteristics of the strand should be also an important factor as well as the strain sensitivity. The irreversible strain limit should be an index indicating how much the strand is bendable. Hence in this study, we compared the irreversible strain characteristics of various technical rapid-heating, quenching and transformation-processed (RHQT) Nb₃Al strands with a different matrix material and filament diameter.

Submitters Country:

Japan

Mon-Af-Po1.09 / 787

Iseult-Neurospin 1500 A Currents Leads: Conceptual and Experimental Results

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In the framework of the French-German project Iseult, we chose to design the 4.5 K vapor cooled current leads of the 11.75 T MRI magnet using a burn-proof approach, i.e. they are able to withstand a 3-hour current slow dump without any active cooling. This constraint led us to select brass instead of pure copper, resulting in higher mass and thus in higher thermal stability. The drawback is a slightly higher cryogenic consumption. We present here the design studies of those currents leads and compare their theoretical characteristics with the experimental results obtained during the test campaigns at CEA-Saclay.

Submitters Country:

France

Thu-Af-Po4.02 / 123

LAMINAR SUPERCONDUCTING WINDINGS

Evgeny Klimenko¹

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It was declared 1 that large superconducting winding will be saved from current degradation resulting from mechanical perturbations, if the winding has strong and rigid supporting structure, and each turn is rigidly fixed transmitting its force directly to the structure. The superconductor itself shouldn't be used as a structural material. So far the only option was proposed that implements this principle. That is so-called laminar winding. The supporting structure consists of a set of flat sheets. A flexible conductor is adhesively fixed at the sheets. Shear strength of the adhesive is as high as 90 N/mm². This type of windings were successfully used for a long time [2-5]. Additional functions of the sheets were cooling and protecting of the windings. Application of a film adhesive provides dry manufacturing process. The report describes some perspective applications of the laminar windings (energy storage devices, the dipoles of an accelerator and tokamaks).

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Submitters Country:

Russia

Thu-Mo-Or33 / 955

LEDET-ANSYS coupled modeling of transients in superconducting magnets

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The transient behavior of a superconducting magnet is influenced by numerous simultaneous non-linear effects occurring at different spatial and time scales in the electro-magnetic, thermal, and mechanical domains. Recent efforts towards precise and time-efficient modeling follow two distinct approaches. On the one hand, complex and interdependent phenomena are simulated by means of multi-physics finite-element programs. High accuracy is achieved by subdividing the analyzed system into a large number of elements, which is computationally expensive. Modeling effects occurring at a spatial scale corresponding to superconducting wires is possible, but very time consuming for large objects, such as fusion, accelerator, and research magnets. On the other hand, complex phenomena can be simulated using equivalent lumped-element networks, whose response approximates effects occurring in multiple domains. Models based on this approach are generally faster to solve, but are less suitable for simulating effects depending on complex geometries. A new simulation environment for modeling electro-magnetic and thermal transients in superconducting magnets is presented, which couples a 2D lumped-element model developed in LEDET (Lumped-Element Dynamic Electro-Thermal) and a 3D finite-element model developed in ANSYS®. Both models have been independently validated against experimental results and found in good agreement.

The coupled model allows simulating electrical, magnetic, thermal, and mechanical transients in superconducting magnets with good accuracy and time-effectiveness. Multiple nonlinear effects are included in the model, such as inter-filament and inter-strand coupling currents in the superconductor, iron-yoke saturation, eddy currents in various magnet metallic elements, and their combined effect on the magnet behavior during transients.

Submitters Country:

USA

Mon-Af-Po1.11 / 796

LOW VIBRATION VAPOUR SHIELDED CRYOSTATS FOR WIDE BORE HIGH FIELD MAGNETS

Neil Clarke^{None}; Roman Viznichenko^{None}; Joe Brown^{None}; Andrew Twin¹; Ziad melhem¹; David Warren¹; Richard Wotherspoon^{None}

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With the introduction of new wide bore, high field magnets up to 19 Tesla at 150mm and 15 Tesla at 270mm cold bore, new large insert designs have led to an interest in low vibration measurements with large sample sizes at low temperature. Oxford is developing a new generation of high persistence, high field, wide bore magnets moving on from the current generation of driven magnets requiring improvements with respect to helium consumption.

Large cryostats tend to have large helium consumption and traditional nitrogen shielding cannot be used due to the very high vibration from boiling nitrogen. Even with vapour shielding, there are challenges to reduce helium use and associated vibration. This paper describes the latest developments using high enthalpy shielding with liquid nitrogen pre-cooling. This can dramatically reduce helium consumption without the need for other cryogens and the associated vibration.

Submitters Country:

UK

Wed-Af-Or24 / 1172

LTS-HTS Hybrid Dipole Magnet Quench Protection System

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The paper describes intricate cross coupling of quench detection and energy extraction systems to protect a hybrid dipole magnet built with Low Temperature Superconductor (LTS) outer coils and High Temperature (HTS) inner coils during the quench. Quench characteristics of HTS and LTS are quite different and various different parameters had to be considered in designing reliable quench protection system.

LTS-HTS hybrid dipole consist of 10T (Nb₃Sn) outer coil and 12mm ReBCO tape HTS insert to form hybrid dipole with very tight magnetic coupling. LTS and HTS coils are powered by independent current source power supplies along with independent ultra fast energy extraction system but common quench detector hardware platform using Real Time National Instrument PXIe Data Acquisition System, programed in LabView. The novel quench detection algorithm and timing sequence were developed. Fast energy extraction system was realized by using high power IGBT switches.

The behavior of inductive cross coupling of collapsing magnetic fields during energy extraction at quench are clearly presented. Tests were performed at Vertical Cryogenic Test Facility of Superconducting Magnet Division of Brookhaven National Laboratory in 4.2K liquid helium bath.

Submitters Country:

USA

Tue-Af-Po2.02 / 130

Lambertson Septum Magnet Design for the LCLS-II Beam Spreader at SLAC

John Amann¹

¹ *SLAC National Accelerator Laboratory*

The LCLS-II at SLAC utilizes an arrangement of kickers and septa magnets to direct the electron beams from the normal and superconducting linacs to the soft and hard x-ray undulator beamlines. A consequence of the performance requirement for kicker pulse rates as high as 1 MHz. is the beam separation at the face of the septum is limited to 15mm. This imposes physical constraints on the design of the magnet pole and vacuum chamber, requiring a magnet pole with integrated vacuum chamber. The design for the LCLS-II beam spreader Lambertson septum magnet is presented and the engineering and manufacturing challenges are discussed.

Submitters Country:

USA

Mon-Af-Po1.09 / 1054

Lead-free persistent mode joints between NbTi wires

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Co-author(s): Tayebeh Mousavi ¹ ; Adrian Thomas ² ; M'hamed Lakrimi ² ; Chris Grovenor ¹ ; Susannah Speller ¹

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² *Siemens Magnet Technology*

The MRI industry is reliant on persistent-mode superconducting electromagnets for high magnetic fields and increased stability. Achieving persistent coils is entirely dependent on the formation of high quality superconducting joints, currently made using Pb-Bi solder. Whilst this is an effective solution, there is legislative pressure to remove the lead even from medical instruments. There is

also a technical driver to explore new joints in that the critical field of Pb-Bi is much lower than that of the NbTi wires, so joints must be located in regions that experience fields of 1 T or lower, meaning they must be removed from the highest field regions of the magnets. Recent studies of alternative lead-free solders have found no drop-in replacement for Pb-Bi, with even the best of these new alloys having much lower Bc2 values 1. Other lead-free approaches such as spot welding and cold pressing lack the reproducibility required for MRI production 1. We are developing new approaches for joint fabrication, using NbTi as the current-carrying intermediary material between commercial NbTi wires. Several designs of joints have been analysed by SEM, SQUID magnetometry and high current measurements and compared against the performance of Pb-Bi soldered joints. This presentation will compare the properties of these different joint strategies, and suggest which are the most promising directions for the development of lead-free persistent mode joints.

TD is supported by an EPSRC CASE studentship with Siemens Magnet Technology.

1. Mousavi et al., Supercond. Sci. Technol., 29, 2016

2. Brittles et al., Supercond. Sci. Technol., 28, 2015

Submitters Country:

United Kingdom

Tue-Af-Po2.08 / 226

Lessons learnt by manufacturing 100 km of varied type of Cable-in-Conduit-Conductors

Author(s): Simonetta Turtu¹ ; Sandro Chiarelli¹ ; Antonio della Corte¹ ; Aldo Di Zenobio¹ ; Rosa Freda¹ ; Lucio Merli² ; Luigi Muzzi¹ ; Riccardo Righetti³ ; Federico Quagliata³ ; Luigi Affinito¹ ; Alessandro Anemona³

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ENEA, in collaboration with CRIOTEC Impianti S.r.l. and TRATOS Cavi S.p.A. (the three associated members of the Italian Consortium for Applied Superconductivity, ICAS) has manufactured approximately 100 km of Cable-in-Conduit-Conductors (CICCs) in the last decade, mainly for fusion tokamak, but also for different applications such as magnets for testing facilities. This production includes a wide range of CICCs, in terms of type of superconducting material (not only LTS strands but also some samples of HTS-CICC), size (from the large TF DEMO samples to the small EDIPO conductor), shape (rectangular with different aspect ratios, round, round in square, etc.), jacket thickness, cabling pattern (long-short twist pitch), cooling channel, unit length scale (from a few to hundreds of meters), level of current density and other features. In dealing with these different aspects of production on a case-by-case basis, the researchers and engineers had to address technical issues in the manufacturing of CICCs. In the aftermath of finding solutions to given problems, the team have learnt how to manage unpredictable obstacles arising in the conversion of a conductor design to a production sample, thus widening its expertise and improving its manufacturing flexibility. Furthermore, the successful accomplishment of quality assurance/quality control programs demanded by ITER Organization (IO) to ensure conductor production uniformity and full traceability of intermediate assemblies across numerous suppliers, represented a useful acquired workout. The aim of this paper is to share the lessons learnt from this practice. For example, the relation between the starting tube size/shape and the final CICC desired geometry, reached through a compaction process, CICC deformation with spooling, modification of the cabling final stage with insertion, how to handle the design requirement for cabling pattern with the cabling machine limits, safety of strand performances with cabling stresses, best NDT inspection of jacket and welds.

Submitters Country:

Italy

Mon-Af-Po1.05 / 397

Levitation Performance of Bulk YBCO and GdBCO Under a Low-Pressure Condition

Author(s): Yong Zhang¹**Co-author(s):** Jun Zheng¹; Botian Zheng¹; Hongdi Wang¹; Zigang Deng¹¹ *Southwest Jiaotong University*

The high temperature superconducting (HTS) bulk in cryostats is an important part of HTS maglev systems. For the potential application to evacuated tube transportation, it is necessary to recognize the levitation and guidance performance of the bulk under a low-pressure condition. Based on a home-made pressure-reducing platform, we have studied the levitation performance of two kinds of bulks (YBCO and GdBCO) above a Halbach permanent magnet guideway (PMG) under different pressure conditions. Measurements of the levitation force versus vertical motion and the force relaxation were performed in the cases of field-cooling (FC) and zero-field-cooling (ZFC), and measurements of the guidance force versus horizontal motion at a levitation height of 12 mm were performed in the FC case. The experimental results show that the reduced air pressure can significantly improve the levitation force, the force relaxation and the guidance force due to the increasing critical current of HTS bulks in the low-pressure environment, and this phenomenon is universal in the two kinds of bulks. The levitation force of YBCO, GdBCO can increase up to 10.1% and 10.7% in FC, 20.9% and 19.1% in ZFC at 0.2 atm compared with the atmospheric pressure, respectively. The guidance force in FC can increase up to 13.8% and 9.7%, respectively. Moreover, we have found a phenomenon that the same sized YBCO can get the similar levitation performance as GdBCO at low pressure with the same applied guideway. The results further prove the superiority of our work with the combination of HTS Maglev and evacuated tube.

Submitters Country:

China

Mon-Af-Po1.05 / 375

Levitation and guidance forces of CC-tape stacks

Author(s): Maxim Osipov¹**Co-author(s):** Sergei Pokrovskii²; Dmitry Abin¹; Irina Anishenko¹; Igor Rudnev³¹ *NRNU MEPhI*² *National Research Nuclear University MEPhI*³ *National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)*

For the development of CC-tapes based bearings and transportation systems it is important to have not only information on the levitation force, but also the data on stability of the system in response to the lateral displacements. This work continues series of studies on the levitation properties of CC-tapes stacks and primarily focuses on the guidance force. In our report, we present new results on investigation of both levitation and guidance forces of CC-tapes stacks subjected to different lateral displacements above a permanent magnet. In the measurements we used 12 mm wide commercially available CC-tape manufactured by SuperOx. The tape were cut into pieces 12 mm x 12 mm. The number of layers in the stack ranged from 5 to 200. For stacks magnetization we used 8 T superconducting magnet. The experimental investigations on the influence of lateral displacement on the levitation performance of stack of various thicknesses with different various fluxes were processed in this work. In addition, effect of measurement height and maximum lateral displacement distance on the guidance force was studied. Results show that both trapped flux and stack height have much influence on the guidance force. The increase of trapped magnetic flux leads to a larger lateral restoring force. Hysteresis of the restoring force of the stack was observed. The hysteresis increases with decreasing of measurement height. Smaller lateral displacement may lead to the elastic lateral motion of the stack. The influence of lateral displacement distance on the relaxation of both levitation

and guidance forces were studied. The rate of change of levitation force and guidance force was different for different maximum lateral displacements. The experimental results were compared with the results of calculations performed using COMSOL Multiphysics. The analyses and conclusions of this work are useful for the practical application in magnetic-force-based systems.

Submitters Country:

Russia

Wed-Af-Po3.07 / 546

Levitation separation of precious metals utilizing magneto-Archimedes effect in high gradient magnetic fieldsOsuke Miura¹¹ *Tokyo Met. University*

We studied the levitation separation for precious metals utilizing magneto-Archimedes effect in high gradient magnetic fields. In order to enhance the magnetic force cylindrical ferromagnetic materials were set into a 10 T superconducting solenoidal magnet. The power factor of $B_{grad}B$ for magneto-Archimedes force reached the high value over $-1000 \text{ T}^2/\text{m}$ by the optimum arrangement of ferromagnetic materials. We studied the magnetic levitation properties for several kinds of precious metals such as silver, gold and platinum in manganese chloride aqueous solution as a paramagnetic liquid medium. The experimental results showed that silver, gold and platinum levitated at each different height. The levitation height for each metal was almost the same as its own theoretical one, and could be controlled by the positioning of ferromagnetic materials. This indicates the possibility of the magnetic separation for the mixture which is difficult to be separated by the usual method utilizing magneto-Archimedes effect in high gradient magnetic fields.

Submitters Country:

☒☒

Mon-Af-Po1.11 / 1144

Liquid nitrogen level detection method for the safe operation of onboard cryostats of high-temperature superconducting maglev vehicles under vibration conditionYu Ren¹ ; Yihuan Xu^{None} ; Zhang Yulei^{None} ; Yong Zhang¹ ; Jun Zheng^{None} ; Zigang Deng^{None}¹ *Southwest Jiaotong University*

For the safe operation of high-temperature superconducting (HTS) maglev vehicles, the liquid nitrogen level of the onboard cryostat should be monitored in real-time during the whole running process. The previous liquid nitrogen level detection method was proposed by using platinum resistance sensors as testing equipment and estimating the liquid level by threshold value judgment. However, the fluctuation of liquid nitrogen level causes great disturbance for the liquid level detection during the running vehicle, which leads to the false level by the previous detection method. To eliminate the interference caused by liquid nitrogen level fluctuation, the state estimation theory of using particle filter algorithm was employed in this paper to process the data. The real-time measurement results illustrate that this method is able to meet the requirements of the liquid nitrogen level detection with high precision, and a simple hardware is valuable for the practical applications of the HTS maglev vehicle.

Submitters Country:

China

Thu-Af-Po4.11 / 366

Locating Electrical Faults in Superconducting Accelerator Magnets

Andrzej Stafiniak^{None} ; Grzegorz Bezuik¹¹ *Wroclaw University of Technology*

Identifying the location of an electrical fault (mainly short-circuit or circuit break) in close systems like superconducting magnet is very difficult especially when a problem appears only at cold conditions (no resistance). The Time Domain Reflectometry (TDR) method could be useful notwithstanding that there is commonly known limitation on the use of TDR to test the inductive circuit results of the high attenuation of incident and reflected pulses. The paper describes a method for locating electrical faults in superconducting magnets by means of measurements of the pulse response of magnet coil circuits (TDR principle). Due to adapting TDR to test a circuit characterized by high values of equivalent capacitance and inductance, which is a winding of superconducting magnet, a study of the relationship between the frequency response of magnets and the injected pulse transient parameters is presented. The cut-off frequency of the investigated circuit is the crucial information for the pulse shaping. A TDR reflectometer with a pulse shaping circuit which has been developed is described. The instrument consists of commonly available laboratory measuring equipment: pulse generator and 50MHz oscilloscope, which significantly facilitates performance of the measurements. Test measurements were carried out for both the undamaged magnets and the magnets with various locations of coil shorts. Advantages and limitations of the proposed method are discussed.

Submitters Country:

Germany

Tue-Af-Po2.06 / 892

Low Speed Rotating Characteristics of 20 kW Class High Temperature Superconducting Induction/Synchronous Motor

Author(s): Siyu Guo¹**Co-author(s):** Taketsune Nakamura¹ ; Ryohei Nishino¹ ; Kenichi Ikeda² ; Tomoharu Karashima¹ ; Masaaki Yoshikawa³ ; Yoshitaka Itoh⁴ ; Toshihisa Terazawa³¹ *Kyoto University*² *Kyoto University Graduate School*³ *IMRA MATERIAL R&D Co., Ltd.*⁴ *IMRA Material R&D Co., Ltd.*

Our project research group has proposed a High Temperature Superconducting Induction Synchronous Motor (HTS-ISM) for the next generation transportation equipment, such as ships, trains, buses, and automobiles. The basic structure of the proposed HTS-ISM is as same as that of the traditional squirrel-cage induction motor. The difference is replacing the rotor (secondary) windings to the HTS windings. The application of HTS materials in this motor has a lot of advantages compared with the traditional ones. The target of our research is the overload characteristics of the HTS-ISM in low speed rotating mode. The 20 kW class prototype HTS-ISM was cooling in liquid nitrogen at temperature of 77 K. Through changing the excitation conditions of the HTS-ISM, we succeed in driving the motor in low speed rotating mode (< 600 rpm). Moreover, we can increase the voltage gradually from rated synchronous power to make HTS-ISM rotate in an overload mode within a pretty short

time. The overload characteristics of this HTS-ISM can be analyzed by this experiment. We are succeed in achieving the overload slip power at 19.4 kW, the torque at 341 Nm, with the HTS-ISM at 53 V and 20 Hz (Synchronous speed Ns: 600 rpm), which exhibits the overload characteristics of the HTS-ISM in low speed rotating mode. These results show a promising candidate for the practical realization which promote the development of the next generation transportation HTS-ISM system. A presentation will be made based on the experimental results in the following MT-25 conference. Acknowledgements: This work has been supported by Japan Science and Technology Agency under the program of Advanced Low Carbon Technology Research and Development Program (JST-ALCA) in Japan.

Submitters Country:

Japan

Mon-Af-Po1.08 / 651

Low loss NbTi Superconducting Wires for the SIS100 Main Magnets made by Luvata

Author(s): Mikael Holm¹

Co-author(s): Jarmo Seppälä¹

¹ *Luvata Pori Oy*

The “Facility for Antiproton and Ion Research - FAIR” will be built near the premises of the renowned physical research institute GSI Helmholtzzentrum für Schwerionenforschung GmbH in Darmstadt Germany. The company Luvata has been the sole supplier for low loss Superconducting wires for the SIS100 main magnets. SIS100 is a ring accelerator (heavy ion synchrotron) with a circumference of 1100 meters to be associated with a complex system of cooler and storage rings and experimental setups. The synchrotron will deliver ion beams of unprecedented intensities and energies. A total of 1030 km of 25 000 ultrafine filament wire having filament diameters around 3 μm, has been delivered for the project. The OK25000 wire has a CuMn interfilamentary matrix embedded in a high purity copper matrix, all manufactured in house at the premises of Luvata. To guarantee low loss performance Luvata incorporated several technologies to reduce the AC losses. In this paper we will present the results of the wires electromagnetic performances, including critical current density, twist pitch, hysteresis losses, RRR and resistivity compared to the customer specified values.

Submitters Country:

Finland

Thu-Af-Po4.03 / 342

Low temperature Hall probe calibration system for the TPS cryogenic permanent magnet undulator

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Co-author(s): Wen-Hsuan Hsieh¹ ; Yung-Teng Yu¹ ; Jui-Che Huang¹ ; Yun-Liang Chu¹ ; Cheng-Ying Kuo² ; Ching-Shiang Hwang²

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A cryogenic permanent-magnet undulator (CPMU) with 15mm period length is being constructing for the TPS. Field measurement of this undulator will be performed at cryogenic temperature, so a

field strength and temperature dependent calibration system of a Hall probe is necessary. This system consists of a cryocooler and a heater to control the Hall probe temperature, a home-made dipole electromagnet, a nuclear magnetic resonant teslameter (NMR), and two angle adjusting stages. These stages will rotate the Hall probe to measure the angular accuracies of the Hall sensor axes with respect to the reference ceramic surfaces and the planar Hall effect coefficient. A two-axis compact SENIS Hall probe with thickness only 0.9vmm is adopted due to the very small gap (minimum gap 3vmm and nominal gap 4mm) of this CPMU. The detail designs of this system, alignment and calibrating process, and calibration results at various temperatures will be presented in this paper.

Submitters Country:

Taiwan

Wed-Af-Po3.02 / 129

MIFI (Magnet Infrastructure Facilities for Iter) : activities overview

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Co-author(s): Roland Piccin

¹ CEA

July 2014 has seen the establishment of MIFI (Magnet Infrastructure Facilities for ITER), a collaboration agreement to provide technical and logistic support from CEA to ITER Magnet Division. The implementation of the agreement led to the creation of 4 laboratories in the areas of: High Voltage; Low Voltage and Instrumentation; Machining and Assembly; Insulation Manufacturing & Cryogenics. In addition, a large area is dedicated to the storage of magnet and auxiliaries components. As ITER Magnet system is approaching the assembly phase, CEA offers through MIFI the support and facilities for coping with the growing activities such as: qualification and quality control of magnet instrumentation; components; managing the logistics of magnet instrumentation; qualification of assembly procedures, building and sharing knowledge in cutting edge technologies; training the operators involved in the assembly operations. Among the various technical matters treated, the paper focuses on two specific activities. The first one is related to high voltage testing and diagnostic of glass-kapton-glass (G-K-G) resin impregnated insulation, which is the main electrical insulation in the magnet system. In MIFI high voltage laboratory, the voltage withstand capabilities of several insulated component mock-ups are AC, DC and impulse tested. In addition, traditional insulation diagnostic techniques are investigated next to more innovative ones (e.g. partial discharge) in order to define quality control and maintenance strategies. The second described activity is directly linked to the assembly of the Toroidal Field magnets. It is the preparation of a scale 1 mock-up and the test of the full assembly procedure for the Intermediate Outer Intercoils Structure (IOIS). One of the specificity of this assembly is to be able to support shear loads generated by electromagnetic fields up to 2500 tons with a precision of 10µm.

Submitters Country:

FRANCE

Wed-Mo-Or20 / 680

MRI scanner development in Russia

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1.5 T magnetic resonance scanner has been successfully completed and high resolution images have been acquired. It is based on 1.5 T superconducting magnet developed and manufactured within the Russian Everest project with warm bore 90 cm. Peak field on the coil windings is about 3.5 T. The field homogeneity is about 1 ppm in 45 cm sphere, the magnet field stability is better than 0.02 ppm/hour. The magnet is actively shielded; the 0.5 mT line of a fringe field is located at 2.6 /4.4 m from center in radial / axial directions correspondingly. The gradient coils are actively shielded, the gradient value is 35 mT/m. The magnet operation is stable and has zero helium losses within 15 months measurements. The software is developed and enables the high precision tomograms of all human organs with spatial resolution 0.4 mm. Coils for all main anatomies like full body, knee, head, shoulder, ankle, wrist and spine have been developed and successfully tested on a specially developed imaging software.

Submitters Country:

Russia

Thu-Af-PI9 / 1254

MT25 Conference Data

Mon-Af-Po1.02 / 1078

Magnet System for the BabyMIND Neutrino Detector at J-PARC

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¹ *CERN*

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The BabyMIND Experiment, supported by the CERN Neutrino Platform program, is a downstream muon spectrometer on the T2K beamline for the WAGASCI experiment at J-PARC in Japan. The BabyMIND detector aims to improve the measurements of the ratio of neutrino interaction cross-section on water and carbon, and to establish charge identification for muons with momenta below 1 GeV/c, where multiple scattering degrades muon momentum measurements. The detector's magnet system comprises a horizontal stack of 30 mm thick individually magnetized iron plates of size 2.0 m by 3.5 m. The overall mass of the block shaped magnet system is about 65 t including 2.3 t of insulated aluminum strip-shaped conductor. An innovative method of plate magnetization was developed. The magnetization scheme developed is optimized flux return for minimum stray field and operating current, while maximizing the useful tracking area with one-directional homogeneous magnetic field of 1.5 T. The magnet is operated at 140 A for generating the nominal field in the iron plates requiring only 12 kW power consumption with no need of any active cooling system. The magnet system for BabyMIND was constructed in 2016 and tested at CERN early 2017. In this paper the development and optimization of a new type of magnetization layout and its advantages are discussed. The coil module and overall system design, coil winding method, construction of the magnet modules, system assembly on site, as well as the results of the module and system testing are presented.

Submitters Country:

Switzerland

Tue-Mo-Or15 / 447

Magnet quench protection of the FCC-hh 16 T block-type dipole magnet by means of quench absorption coils

Author(s): Matthias Mentink¹**Co-author(s):** Tiina-Mari Salmi²; Marco Prioli¹; Junjie Zhao²; Clement Lorin³¹ CERN² Tampere University of Technology, Finland³ CEA/IRFU, Centre d'étude de Saclay Gif-sur-Yvette (FR)

For future particle colliders at the energy frontier such as the future circular collider for hadron-hadron collisions (FCC-hh), 16 T dipole magnets are needed to maintain the high-energy particle beams on their trajectories. This type of magnet features a very high stored energy density resulting in a challenge from a magnet quench protection perspective. A possible method for improving magnet quench protection involves using secondary normal conducting coils, so-called quench absorption coils, placed in close proximity to the primary superconducting coils. As the primary coil quenches, current is inductively transferred into the secondary coils and a substantial fraction of the stored energy is dissipated there. The secondary coils comprise insulated copper windings which are placed in series with a blocking diode, so that during regular ramping undesirable heating and field errors are avoided. In a previous numerical analysis of the R&D Nb₃Sn dipole 'HD2', it was found that by adding the quench absorption coils to the heater-based magnet protection system (without an external dump resistor), the hotspot temperature was reduced by 100 K and the peak resistive voltage by 50%. We explore the feasibility of this concept for the FCC-hh block coil design, with an emphasis on magnet cost reduction. Firstly, a study is done to determine how much the size of the superconducting coil can be reduced while maintaining the specified hotspot and peak turn-to-turn voltage and voltage-to-ground. Secondly, the inductive interaction between the secondary coils and the coupling-loss-induced quench system (CLIQ) is studied. Thirdly, a mechanical analysis is performed to see if and how the presence of the secondary coils affects the overall mechanical behaviour. Based on the results of these investigations, the costs and benefits of this concept are weighed to see whether this magnet quench protection concept may prove useful for this type of magnet.

Submitters Country:

Switzerland

Tue-Af-Po2.01 / 480

Magnetic Design Update of Large Aperture Beam Separation Dipole for the HL-LHC Upgrade

Author(s): Michinaka Sugano¹**Co-author(s):** Tatsushi Nakamoto¹; Yukiko Ikemoto¹; Shun Enomoto¹; Kento Suzuki²¹ KEK² High Energy Accelerator Research Organization

High-luminosity Large Hadron Collider (HL-LHC) upgrade aims increase of peak luminosity by a factor of five and integrated luminosity by a factor of ten over the life of the upgraded machine in comparison with the current LHC. Large aperture final focusing quadrupole magnets play a major role to obtain a smaller β^* at an interaction point and they are being developed by CERN and US-LARP. Large beam separation dipole magnets (D1) are also needed for the new beam optics and KEK has been in charge of development of D1 in the framework of CERN-KEK collaboration. This magnet is based on Nb-Ti technology and generates field integral of 35 T·m at 12.0 kA and 1.9 K in a coil aperture of 150 mm. One of the difficulties in magnetic design of D1 is management of severe iron saturation due to a large coil aperture and limitation of an outer diameter of iron yoke.

Main design parameters were once fixed after a series of design studies and the first 2 m model was fabricated and tested at cold in 2015 – 2016. However, it was recently decided by CERN that heat exchanger holes have to be in line with those of the inner triplets and modification of cross section of D1 magnet was requested. This was a very large impact on field quality and re-optimization of coil and iron yoke should be performed. In this paper, we will report magnetic design with new cross section of the coil and the iron yoke with four heat exchanger holes. Optimal conditions of the field tuning holes to reduce variation of multipole coefficients from the injection to the nominal current will be discussed. Optimization of coil end shape will be also mentioned considering minimization of cable strain and integrated multipoles over 7 m long magnet.

Submitters Country:

Japan

Tue-Af-Po2.06 / 1196

Magnetic Field Analysis of a Novel Configuration of Reluctance Machine with Axial Magnetic Flux and Radial Assisted Excitation

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Co-author(s): Aimin Liu² ; Peng Sun¹

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² *Shenyang University of Technology*

In order to improve the power density and speed range of reluctance machine, to consider the higher demand of the future industrial field, this paper studies the new method for reconstruction of the reluctance machine configuration, that a novel two sets salient-pole rotor reluctance machine with axial magnetic flux is proposed. The stator and rotor are constructed with two dependent magnetically sets, in which the two sets are exactly symmetrical with respect to a plane perpendicular to the middle of the motor shaft. There is a coil is placed the plane perpendicular to the middle, used for producing axial auxiliary magnetic flux with DC, to form coil assisted reluctance machine. The proposed machine rotor has no windings and permanent magnet, so that it is simple, rugged, low cost and high reliability. It also can generate both the magnetic torque and the reluctance torque which is the important characteristic. The higher output torque characteristic of the machine can be achieved by improving the air-gap flux, and speed range is expanded. Because of the machine axial flux being not alternating, the core loss is reduced greatly, the power output and the power density are further improved. The machine is numerically computed by 3-D FEM, the accuracy and effectiveness of 3-D FE analysis is verified. The novel configuration reluctance machine experimental platform of control system has also been built and tested its reliability, and to lay the foundation for the further research of the motor speed control system.

The project is supported by National Natural Science Foundation of China (51377107).

Submitters Country:

China

Thu-Af-Po4.10 / 192

Magnetic Field Measurement and Analysis of the CSNS/RCS Quadrupole Magnets

Li Li^{None}

The China Spallation Neutron Source (CSNS)/rapid-cycling synchrotron (RCS) quadrupole magnets excited by both DC current and 25Hz AC biased DC current were tested and measured in the past

two years. All the magnets had been installed in the tunnel by the end of December, 2015. The challenges of the field measurements included the measurement repeatability of the DC field and the time harmonic measurement of the DC+AC field. The paper will summarize the results of the DC field measurement and the DC+AC field measurement, the key techniques of the rotating coil fabrication, and the measurement stability for the CSNS/RCS quadrupole magnets.

Submitters Country:

China

Thu-Af-Po4.04 / 560

Magnetic Field Stability Improvement of HTS-MRI Magnet under Power Supply Driven Operation with a Micro Current Trimming Control

Author(s): Takeshi Kawashima¹ ; Takayuki Yachida^{None} ; Shirai Yasuyuki^{None}

Co-author(s): Ohya Masayoshi ; Matsuda Tetsuya ; Yokoyama Shoichi

¹ *Kyoto University*

There are two major problems for introducing HTS-MRI magnets. One is a long-lasting attenuation of screening current induced on the superconducting tapes at the initial excitation. The screening current affects the MRI field stability both temporally and spatially. Another is that it is by now difficult to realize a superconducting junction of REBCO tapes and a superconducting switch for the persistent current operation of MRI magnet. One of our solution is to use a power supply driven MRI-magnet system instead of the persistent current operation. Our goal is to reduce the current fluctuation of the power supply and to compensate the magnetic field deviation due to the screening current by a proper current control of the power supply. It was reported that the magnetic field deviation was reduced to a certain extent by an over-shoot excitation method (the magnet is once over-excited through the target current and then discharged to the target to eliminate the screening current). In this paper, to improve the field stability more, a micro current control function is designed. The power supply current is controlled through a major control loop based on the magnet current sensor, and at the same time, it is trimmed with range of μA through a minor control loop based on the magnetic field sensor (NMR probe) of MRI magnet. We carried out the magnetic field stability experiment with 32-H HTS-MRI magnet excited by the highly stabilized power supply equipped with the designed micro current control. The MRI magnet was excited to the target current 66 A (1.5T) without the overshooting method, and then kept 66 A constant through the major current control loop and the magnetic field stability was trimmed through the minor micro current control loop down to 0.7ppm/hr, while it was 6 ppm/hr without the micro current control.

Submitters Country:

Japan

Mon-Af-Po1.01 / 895

Magnetic Measurements on Short Models and Long Coil Assemblies of the 11-T dipoles for HL-LHC

Author(s): Lucio Fiscarelli¹

Co-author(s): Olaf Dunkel¹ ; Massimo Giovannozzi¹ ; Susana Izquierdo Bermudez¹ ; Stephan Russenschuck¹ ; Frederic Savary¹ ; Gerard Willering¹

¹ *CERN*

For the High-Luminosity upgrade of the Large Hadron Collider (HL-LHC), the development of the 11-T Nb3Sn dipole is progressing. At present, one double-aperture and five single-aperture short-model magnets have been built and tested. Magnetic measurements have been performed both at ambient and cryogenic temperature. Besides, the first 5.5-m-long prototype is being produced and the first collared-coil assembly has been measured at ambient temperature. In this paper, the results collected up to the present moment are reported and discussed. The geometrical field multipoles, the iron saturation effects as well as the effects of persistent currents are presented. Experimental data are compared with the magnetic calculations using the CERN field computation program ROXIE, and discussed in view of the construction of the final magnets.

Submitters Country:

Switzerland

Mon-Af-Po1.01 / 900

Magnetic Measurements on the First Models of the Insertion Quadrupole MQXF for HL-LHC

Author(s): Lucio Fiscarelli¹

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The High-Luminosity upgrade of the Large Hadron Collider Luminosity (HL-LHC) requires new high-field and large-aperture quadrupole magnets for the low-beta inner triplets (MQXF). CERN and LARP collaboration are currently developing a 150-mm-aperture quadrupole based on Nb3Sn superconducting cables for the coils, and an aluminum shell with the bladder-key technology for the support structure. This paper presents the test setups for magnetic measurements, both at ambient and cryogenic temperatures, and the instrumentation being used for the first two short-models of MQXF built and tested at CERN. Finally, the measurements results, in terms of field quality, effects of persistent currents, and iron saturation, are reported and discussed.

Submitters Country:

Switzerland

Tue-Af-Po2.02 / 689

Magnetic Septa for the SIS100 Accelerator at FAIR

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The future heavy ion synchrotron SIS100 will have series of two dc magnetic septa for the injection and three dc septa on the extraction line. The extraction line will allow for two different extraction schemes for vertical fast extraction and initially horizontal slow extraction. The latter requires among other components two additional Lambertson-type septa. The design of the magnets had to account not only for creating a high field with a narrow septum width. A way of providing bakeout

jackets while limiting the technicians' exposure to radiation had to be found. Another issue was to minimise the chance of failure e. g. by limiting the number of soldered joints with contact to the cooling channels and by reducing the current density with help of wedge-shaped conductors. While the injection septa are under construction, still some design work is in process for the extraction septa. We will present some of our solutions and concepts.

Submitters Country:

Germany

Mon-Af-Or6 / 453

Magnetic and mechanical design of a 16 T common coil dipole for FCC

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² *CIEMAT*

EuroCirCol is a conceptual design study for a post-LHC research infrastructure based on an energy-frontier 100 TeV circular hadron collider. In the frame of the high-field accelerator magnet design work package of this study, the feasibility of a 16-T dipole in common coil configuration is being studied. This paper shows the electromagnetic calculations performed to achieve the required field quality while minimizing the superconductor volume and taking into account the input parameters and assumptions of EuroCirCol study. FEM models have been used to analyze the stress distribution and deformations under the large Lorentz forces due to the very high magnetic field. Several iterations have been necessary to obtain a feasible magnet design. 3-D electromagnetic calculations are also included in this paper.

Acknowledgments: This work has been partially supported by the European Union's Horizon 2020 Research and Innovation Programme under grant No. 654305, EuroCirCol project.

Submitters Country:

Spain

Tue-Af-Po2.07 / 115

Magnetic field and characteristic analysis of the superconducting fault current limiter for DC applications

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With the development of DC power supply systems, breaking capacity of circuit breakers has been increasingly unable to meet the growing requirements for DC system short-circuit current level. To ensure the safety of the systems, a fault current limiter must be used in series with circuit breakers. The properties of superconducting fault current limiters such as fast reaction rate, simple structure, small size have caused widespread concern, the research on superconducting fault current limiters is becoming a hotspot in the field of DC system protection. In the paper, the FEM computational models of superconducting fault current limiters for the steady-state operation and the transient impulse are established. Using the steady-state model, we have calculated the magnetic field distribution and the inductance of superconducting coils, and using the transient impulse model, we have analyzed the transient magnetic field distribution of superconducting coils and electromagnetic force on the coils. On the basis of the calculation of the magnetic field, the influences of magnetic field distribution on

the critical current at the steady-state and the current limit characteristics at the transient impulse of the superconducting coils with different structures and geometries are studied. The results can be used for performance analysis and design optimization of superconducting current limiters. In addition, an experimental model of superconducting current limiters, which is used to verify field calculation results, is developed, and the relevant data is measured.

Submitters Country:

china

Thu-Af-Po4.06 / 1146

Magnetic field distribution prediction of a field-modulated tubular linear generator with quasi-Halbach magnetization for ocean wave energy conversion

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Ocean wave energy has a higher energy density than other renewable resources such as solar, wind, and tide energy. In recent years, a various ocean wave energy extraction systems have been proposed and established. But the average speed of ocean wave is generally slow. This will lead the traditional linear generator with disadvantages of large weight and low power density. In order to solve this problem, there are a lot types of magnetic gear have been applied to increase the speed of the motor. But some of them are complex to manufacture and may cost a lot. Furthermore, the complex structure will reduce the stability of the generator device and make it unsuited for long-term operation in the sea. The FM-TLPMG with quasi-Halbach magnetization proposed in this paper is similar to the traditional cylindrical linear motor in the structure. Its simple structure and higher power density make it suitable for direct ocean wave conversion. But they operate in a completely different principle. The FM-TLPMG combined with the magnetic field modulated technique can accelerate the speed of the traveling magnetic field by the teeth in the primary. So the magnetic field distribution is a crucial step in the analysis and design process of this motor. The analytical solutions of magnet and armature magnetic field distribution of the proposed motor have been validated by finite-element calculations. Comparing analytically predicted and FEA calculated field components distributions for a given position that can be seen that the analytical prediction agrees well with FEA results.

Submitters Country:

China

Wed-Mo-Or20 / 735

Magnetic field homogeneity and stability of a conduction-cooled REBCO MRI magnet with a room-temperature bore of 396 mm

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⁴ *Okayama University*

⁵ *Hokkaido University*

We started developing REBa₂Cu₃O_{7-δ} (REBCO) magnets for ultra-high-field MRI systems in 2013. Our final targets are 9.4 T MRI systems for whole-body and brain imaging. In the project, a conduction-cooled REBCO MRI magnet having a room-temperature bore of 396 mm was fabricated and tested in order to evaluate the magnetic field homogeneity and stability. The magnet composed of 60 single pancakes whose inner diameter was 500 mm. The total conductor length was 10.3 km, and the total inductance was 12.4H. The size of the homogeneous magnetic field region was 200 mm diameter square volume (DSV). The central magnetic field was as high as 1.5 T at 192.7 A. The measured field homogeneity was 249.7 ppm because of the tolerances in the z-axis positions of the coils, and this was improved to 4.1pm by shimming. The field stability was improved from 2 ppm/h to 0.09 ppm/h by not only operating the magnet with current sweep reversal but controlling the coil temperature. Furthermore, the magnet was energized over 1.5 T, and the field homogeneity and stability were measured. This paper describes the experimental results of the field homogeneity and stability, not only when the magnetic field was changed but also when the coil temperature was changed.

Submitters Country:

Japan

Tue-Mo-O10 / 41

Magnetic field measurements of full scale conduction cooled superconducting undulator coils

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¹ *IBPT-KIT*

² *Babcock Noell GmbH*

The Institute for Beam Physics and Technology (IBPT) of the Karlsruhe Institute of Technology (KIT) and Babcock Noell GmbH (BNG) are collaborating to develop superconducting undulators for ANKA and low emittance light sources. The collaboration is now focusing on a superconducting undulator with a period length of 20 mm (SCU20) planned to be installed at the accelerator test facility and synchrotron light source ANKA. The local magnetic field and the field integrals of the SCU20 1.5 m long coils have been characterized in a conduction cooled horizontal test facility developed at KIT IBPT. Here we present the main results, as well as their analysis including the expected photon spectrum.

Submitters Country:

Germany

Tue-Af-Po2.01 / 1047

Magnetic measurements of the NICA booster superconducting magnets

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Co-author(s): Pavel Akichine² ; Alexander Bychkov¹ ; Alexei Donyagin¹ ; Oleg Golubitsky¹ ; Hamlet Khodzhbagiyani¹ ; Sergei Kostromin¹ ; Mikhail Omelyanenko¹ ; Mikhail Shandov¹ ; Andrey Shemchuk¹

¹ *Joint Institute for Nuclear Research*

² *Joint Institute for Nuclear Research (JINR)*

Magnetic measurements of the NICA booster superconducting magnets NICA is a new accelerator collider complex under construction at the Joint Institute for Nuclear Research in Dubna, Russia. The facility includes a new superconducting booster synchrotron consists of 40 dipole and 48 quadrupole superconducting magnets. Booster magnets are under series production, assembling and testing at new test facility in Joint Institute for Nuclear Research, Dubna. Dipole magnets for the NICA booster are 2.14 m-long, 128 /65 mm (h/v) aperture magnets with design similar to the Nuclotron dipole magnet but with curved (14.1 m radius) yoke. Measurement of magnetic field parameters is assumed for each booster magnets. We present “warm” and “cold” test results obtained by magnetic measurements almost all of dipole magnets and compare them with the predicted values and the requirements of specification.

Submitters Country:

Russia

Wed-Af-Po3.12 / 511

Magnetization loss in REBCO Roebel cables with varying strand numbers

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Co-author(s): Michael Staines² ; Wenjuan Song¹ ; Chris Bumby² ; Rodney Badcock² ; Nicholas Long² ; Jin Fang¹

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Assembled coated conductors are essential in many high current HTS applications. There are two ways to achieve assembled coated conductors. One way is to vertically stack the coated conductors, and the other is to use continuously transposed Roebel cables. In addition to high current carrying capacity, Roebel cables offer both low AC loss and mechanical flexibility. In this work, we measured magnetization loss in REBCO Roebel cables with varying strand numbers from six to fourteen at 77 K to investigate the number dependence of AC loss characteristics of the Roebel cables. The source material for the Roebel strands are non-stabilized 10 mm-wide Fujikura REBCO wires (FYSC-SC10). The wires were punched into 4 mm-wide Roebel strands, and the transposition length for the Roebel cables is 300 mm. The applied field amplitude, frequency and the angle of the applied field to the wide face of the Roebel cables are varied. Three 10 mm-wide vertical stacks with the conductor number of seven, five, and three were prepared using the same source Fujikura materials to demonstrate the AC reduction effect of the Roebel cables over the vertical stacks. The measured magnetization loss values of the Roebel cables are compared with those of the reference stacks as well as numerical results for the Roebel cables and stacks obtained from COMSOL software.

Submitters Country:

China

Tue-Af-Or18 / 1020

Magnetization of CORC, TWST, and Roebel Cables for HEP applications and Associated Error fields

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Magnetization and AC loss measurements were performed on cables made from HTS coated conductors. Coated conductor-based CORC, Twist stack, and Roebel Style cables were measured and were compared. In a first set of runs, magnetization was measured out to 1.4 T at 4 K, and was compared for the various cable options with reference to the field at injection for particle accelerators. Additionally, progress and initial measurements made with a new 3 T/4 K small dipole measurement system are presented. The M-H measurements were compared to values for the coated conductor tapes themselves, and to simple analytical models. CORC cables made with tapes with different levels of striation are presented. The penetration field and the saturation magnetization, as well as the magnetization at injection are compared for the various cable types. CORC cables are seen to shield and trap flux from the whole of the cable (including the central core) at lower fields, while flux penetration is enhanced in CORC cables with striated strands. The measured magnetization values were then used to compute error field harmonics for a 4-layer, canted-cosine dipole magnet using two different approaches: (1) a Biot Savart and doublet approach, and (2) FEM modelling using COMSOL.

Submitters Country:

USA

Mon-Af-Po1.06 / 615

Manufacture and tests of a 1 MJ HTS Magnet for a SMES-FCL

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An magnet was manufactured and tested for a 1 MJ/0.5 MVA Superconducting Magnetic Energy Storage and Fault Current Limiter system (SMES-FCL) with HTS tapes recently. It consists of 46 double pancakes with an inductance of 13.3 H, and the rated operating current is 388 A, the maximum magnetic field is up to 3.5 T. In this paper, the fabrication and tests of the 46 double pancakes, the assemblage of the magnet are described in detail. And then, the fundamental performances testing of the magnet were carried out at liquid nitrogen and sub-cooled liquid nitrogen, respectively. And then, the magnet was soaked in liquid neon and cooled with four AL325 cryo-coolers to keep zero neon vaporization. After the whole 1 MJ/0.5 MVA SMES-FCL were field installed and tested, it had been put into operation since January 6 of 2017 at a 10.5 kV wind farm locating in Yumen, Gansu Province of China.

Submitters Country:

China

Tue-Mo-Or13 / 177

Manufacture of the ITER Central Solenoid components

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¹ *ITER Organization*

² *CERN*

³ *US ITER Project*

⁴ *General Atomics*

⁵ *NHMFL*

The ITER Central Solenoid (CS) components are now being manufactured. This superconducting magnet will provide the magnetic flux swing required to induce up to 15 MA as plasma current. It includes six identical coils, called modules, stacked on top of each other to form a solenoid, enclosed inside a structure that has nine subsets, to provide vertical pre-compression and mechanical support. Using a 45 kA Nb₃Sn superconducting conductor requires a long heat treatment at 650 °C to form the Nb₃Sn alloy. The conductor lengths wound into multiple pancakes are connected with each other before heat treatment and electrically insulated afterwards. High mechanical stresses in materials and high voltages call for the use of high mechanical resistance structural materials and high dielectric strength insulating materials. The pulsed operation imposes materials with high fatigue resistance at cryogenic temperatures. The unique requirements derived from the operating conditions impose specific materials, manufacturing routes and dedicated working stations for the different steps in the manufacture of the components to achieve the required quality. Whereas for the structure, large existing manufacturing tools are required, the modules required construction of a dedicated manufacturing line. Qualification of the different manufacturing procedures is of prime importance to ensure that the magnet will meet the requirements during operation. A comprehensive qualification programme is being performed at the manufacturers before applying procedures for the production of the CS components. The paper describes the main characteristics of the CS components, their manufacturing routes and the different elements of the qualification programme. The overall plan for the manufacture is reported, including the identified risks and the mitigation items. The status of the first components manufactured is shown as well as the planned delivery schedule to the ITER site.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Submitters Country:

France

Wed-Mo-Or20 / 650

Manufacturing Completion of the Iseult/INUMAC Whole Body 11.7 T MRI System

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Neurospin is a neuroscience research center located in France at CEA Saclay. Since its opening in November 2006, several MRI equipment are operated. The facility will be equipped with an innovative Whole Body 11.7 T MRI magnet, as part of the Iseult/Inumac project, a French-German

initiative focused on very high magnetic-field molecular imaging. The Iseult/Inumac magnet is an actively shielded magnet manufactured from NbTi superconductor. It will generate a homogeneous field of 11.75 T within a 90 cm warm bore. It is operated at a current of 1483 A, in driven mode, in a bath of superfluid helium at 1.8K. The stored energy is 338 MJ and the inductance 308 H. The cryostat has external dimensions of 5 m in diameter and 5.2 m in length, for a total magnet weight of 132 tons. After 3 years of R&D and 7 years of manufacturing, the magnet fabrication at GE Belfort and the ancillary equipment installation at Neurospin have been successfully completed. This paper intends first to recall the main design features and decision makers. The main magnet manufacturing steps and their related advantages or issues are then presented. In a last section, the commissioning status of the magnet and of the ancillary equipment is also described.

Submitters Country:

France

Mon-Af-Po1.09 / 845

Manufacturing and Qualification Test of ITER Busbar Joint

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¹ ITER Organization

² CEA

The paper describes the result of the ITER feeder main busbar joint sample qualification test as confirmation of the requirement of busbar joint resistance; 2 nΩ at 70 kA at zero background field, as well as those of joint performance in various magnetic fields to investigate stability and current distribution characteristics in feeder-type joint box. The results support the quality of the joint manufacturing process for ITER main busbar joint. The qualification sample design was prepared to be tested in SULTAN facility. The production of the full-scale sample was manufactured in ITER magnet workshop located at CEA with contribution from CEA collaborators. The SULTAN joint ample consists of joints to be qualified at the level of the peak field and upper terminations. In bottom joints, twin-box feeder-type paying hands configuration is applied. In upper terminations, one of them is made with solder-filled cable for optimum current distribution. The other takes the same length of the copper sole and contact with the busbar cable as those positioned in bottom of the sample. The performance of this leg is compared with the other leg consisting of both ends manufactured with two twin-box feeder-type joints, which could have a lowered Tcs if the current redistribution is an issue. The sample undergoes a test program including joint resistance measurement, AC losses and stability margin test. The outcome of the following test program are to be reported; DC joint resistance measurement by voltage taps and calorimetry at 0 - 70 kA and 0 - 3.8 T, AC loss measurement with AC field transverse to copper face, stability limit under single trapezoidal field pulse transverse to copper face, and joint degradation study under repulsive and attractive load applied to the joints.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Submitters Country:

France

Tue-Af-Po2.12 / 419

Measurement and Analysis of Amplitude Magnetic Permeability and Magnetic Losses of Silicon Steel Sheet

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The amplitude of magnetic permeability and the electromagnetic losses of silicon steel sheet are important to design all kinds of motors. It is necessary to analyze magnetic permeability and electromagnetic losses before designing efficient motors. Different magnetic hysteresis loops are measured using AMH-1M-S dynamic testing system from Laboratorio Elettrofisico Walker LDJ Scientific, Italy under different conditions, which are the same saturated magnetic field under different frequencies, the same magnetic field frequency under different maximum saturation flux density and the same maximum saturation flux density under different frequencies. The amplitude of magnetic permeability, medium energy storage and magnetic losses are analyzed using the testing data. The results show that amplitude of magnetic permeability decreases continuously and electromagnetic loss increases rapidly with the increasing of frequency under the same saturation magnetic field. Amplitude of magnetic permeability increases continuously. Energy storage medium and electromagnetic loss increase respectively with the increasing of maximum saturation flux density under the same frequency. Amplitude of magnetic permeability reduces continuously and electromagnetic loss increases rapidly with the increasing of magnetic field frequency under the same maximum saturation flux density. The detailed results from magnetic hysteresis curves under the maximum saturation flux density of 1.2T and different frequencies 20, 30, 40, 50, 100, 150, 200Hz show that the electromagnetic losses is about 0.629 W/kg when frequency is 20 Hz, while it is 18.437 W/kg when frequency is 200 Hz. It is obvious that electromagnetic losses increase rapidly with the increasing of magnetic field frequency. The frequency has a great influence on electromagnetic losses. The amplitudes of magnetic permeability under frequencies 20, 30, 40, 50, 100, 150, 200 Hz are 6140,6123,6084,6049,5837,5194,4328. The results show that hysteresis increases with increasing of magnetic field.

Submitters Country:

China

Wed-Af-Po3.08 / 743

Measurement and Torque Calculation of Magnetic Spur Gear Based on Quasi 3-D Analytical Method

Author(s): Tae-Kyoung Bang¹; Jang_young Choi²

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¹ Republic of Korea /Chungnam National University

² Chungnam National University

A mechanical spur gears inherently suffer from the drawbacks of high transmission loss, bulky size, high noise, wear-and-tear. In order to alleviate these problems, magnetic spur gears are designed which use the magnetic force. They offer the advantages of reduced silent operation, overload protection and maintenance fee. As the magnetic spur gear diverges in all directions according to the divergence theorem of magnetic flux, a leakage flux in the z-axis direction develops. Therefore, it is necessary to consider the magnetic flux in the z-axis direction for the accurate analysis of the characteristics and for the calculation of torque. Thus, in order to design a magnetic gear through the three dimensional (3D) finite element method (FEM), however it is time consuming and the results are not intuitive. It is difficult to design a magnetic gear that has variable design point. However, by using analytical methods, the analysis time is shorter than 3D FEM and is intuitively understood according to the change of parameters. This paper deals with design and analysis of the magnetic spur gears using analytical method. Based on the governing equation and boundary condition, analytical solutions are obtained for magnetic fields produced by source magnets. Based on these solutions, the magnetic field are determined analytically. Next, the drive magnet is reduced to equivalent current densities, and the torque is computed on these current densities in the external magnetic field, which is obtained from simpson's method. Finally, in order to consider the z-axis direction magnetic flux, by employing the curve-fitting. We proposed a quasi- 3D analytical method using curve-fitting and verified it with 3D FEM and experimental results. The detailed analysis results, discussions, and measurements of the magnetic spur gear will be presented in the final paper.

Submitters Country:

Republic of Korea

Wed-Af-Po3.09 / 902

Measurement campaign on critical current for MgB₂ wires and tapes under a magnetic field up to 8T**Author(s):** Julien Avronsart¹**Co-author(s):** Christophe Paul Berriaud² ; Xavier Chaud³ ; Clement Hilaire⁴ ; Mario Kazazi⁵ ; Davide Nardelli⁶ ; Matteo Tropeano⁷¹ CEA² CEA/IRFU, Centre d'étude de Saclay Gif-sur-Yvette (FR)³ CNRS / LNCMI⁴ CEA Saclay / Irfu⁵ Cea Saclay⁶ Columbus Superconductors⁷ Columbus Superconductors, SpA

The critical currents of several configurations of MgB₂ conductor from “Columbus Superconductors” were characterized under high magnetic field. The measurements were performed at LNCMI Grenoble at a temperature of 4.2 K and a magnetic field ranging from 3 up to 8 T. The characterization of the different configurations takes into account different parameters as filling factor, number of filaments, shape, and type of matrix. Moreover, in order to define the minimum bending radius, the different samples were pre-bent on different diameters before the test, from a minimum of 25 mm to a maximum of 400 mm. This work investigates the critical current density (J_c) and the engineering current density (J_e). Measurement precisions are presented in detail according to the small length of voltage measurement that are only 1 cm long. The different types are compared according to their critical current density and engineering density. The influence of the parameters on the measurement result is discussed and the performance evolution of the Columbus engineering critical current density is also presented.

Submitters Country:

FRANCE

Tue-Af-Po2.01 / 119

Measurement facility and test results for FRIB superconducting magnets at IMPWenjie Yang¹ ; Beimin Wu² ; Wei Wu³ ; Dongsheng Ni⁴ ; Enming Mei³ ; Lizhen Ma⁵¹ University of Chinese Academy of Sciences² The Key Laboratory of Mechanics on Western Disaster and Environment, College of Civil Engineering and Mechanics, Lanzhou University³ Institute of Modern Physics, Chinese Academy of Sciences⁴ Institute of Modern Physics Chinese Academy of Sciences⁵ Institute of modern physics, CAS

The Facility of Rare Isotope Beams (FRIB) superconducting magnets are used to focus and steer the heavy ion beams of the FRIB driver linac. All the magnets are designed as a solenoid with bucking coils to suppress the stray field and have superconducting dipole correctors to steer both horizontal and vertical field. Two types of magnets are manufactured in China and some of them have been tested at Institute of Modern Physics (IMP). This paper describes the measurement facilities and magnetic axis measurement method. We also present a summary of the measurement process and test results of the magnetic performance.

Submitters Country:

China

Wed-Af-Po3.12 / 1185

Measurement of AC Losses of HTS Conductors on Round Core with Filamentary Strands

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Co-author(s): Woo-Seok Kim¹

¹ *Korea Polytechnic University*

The high temperature superconducting (HTS) conductors with low AC losses are essential for the HTS power devices. There are many studies for the development of 2G HTS conductor with the low AC loss and large current capacity, such as Roebel assembled coated conductors (RACC), conductors on round core (CORC), twisted stacked tape cable (TSTC), coated conductor Rutherford cable (CCRC), and so on. Striation on the 2G coated conductor (CC) tape is considered to decrease the AC loss because the AC losses depend on the width of the tape. However the striated tape should be twisted to decrease the loss. We prepared two CC tapes with different width. One has the width of 12 mm and the other has 4 mm. Several CORC samples were fabricated with these tapes. To simulate the striation, three tapes with 4 mm width were wound on the copper core in parallel, side by side. We also made four samples with different pitches to investigate the effect of the pitch length. The test results were compared with the calculated ones for straight samples and CORC samples. The result showed the possibility of low loss HTS conductors.

Submitters Country:

Korea, Republic of

Tue-Mo-Or14 / 127

Measurement of Magnetic Materials at Room And Cryogenic Temperature for Their Application to Superconducting Wind Generators

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Compact, lightweight and large-scale generators are desired for offshore wind energy application due to transportation and installation requirements. In order to reduce the levelized cost of wind energy, larger and larger wind turbines are under researches and superconducting wind generators are proposed as they have high power density and light weight. Due to the expensive price of the superconductor, iron core is usually employed to reduce consumption of the superconductor as well as to divert the flux direction to the superconductor. However, in many designs and studies, losses and permeability of the silicon lamination sheets used in cryogenic temperature are from room temperature, which is not appropriate. Hence, the performance of the silicon lamination sheets at low temperature is essential and in urgent need to develop and commercialize the superconducting wind generators. We made magnetic properties tests of toroidal cores at both room temperature and 77 K with four different materials and the result shows that the permeability of silicon sheets and losses are higher at 77 K than room temperature.

Submitters Country:

Germany

Wed-Af-Po3.11 / 502**Measurement of overall thermal resistance and contact thermal resistance in conduction cooled HTS magnets****Author(s):** Seokho Kim¹**Co-author(s):** Jihoon Seok¹¹ *Changwon National University*

AC loss and eddy current loss are inevitable in AC HTS (High Temperature Superconductor) magnets and even in DC HTS magnets under varying magnetic field or current. To secure thermal stability, especially in the conduction cooling, reduction of contact thermal resistances (CTR) is one of the crucial factors. To avoid the delamination problem, epoxy is not usually used between turns of ReBCO wires while thin epoxy layers between coil surfaces and metallic bobbins are used to enhance thermal conduction and remove the heat loss in conduction cooling applications. Therefore, appropriate thermal modeling of the HTS coil is necessary to ensure the stable operation with an appropriate overall thermal resistance value, which includes the contact thermal resistances between turns of the coil, in transverse direction of the coil. This paper describes the measurement of the overall thermal resistances and thermal contact resistance in transverse direction in the coils. Three test coils are fabricated with ReBCO wires: 1) a coil without conduction plates except a metallic center form connected to a cryocooler; 2) two coils with conduction plates filled by epoxy (Stycast 2850 FT, CTD 521) layers. The overall thermal resistance is measured for the coil without conduction plates from 10 to 50 K. The CTR, which can be used as a typical value of other coils, is also obtained by investigating the measured overall thermal resistance, the known transverse thermal conductivity of the wire and the epoxies. The overall thermal resistances of the coils with the conduction plates and epoxy layers are also measured and they are compared with an analysis model results that includes the conduction plate, epoxy layer, and the measured CTR. The results validate the measured CTR, which can be applied for the estimation on the overall thermal resistance of other coils with given ReBCO wires.

Submitters Country:

Republic of Korea

Thu-Mo-Or32 / 332**Measurement of persistent current Gd123 coil for superconducting joint fabricated by CJMB method****Author(s):** Xinzhe Jin¹

Co-author(s): Yoshinori Yanagisawa² ; Hideaki Maeda³

¹ *Muroran Institute of Technology*

² *RIKEN*

³ *j*

Recently, we suggested a new bridge-type joint between two REBa₂Cu₃O_{7-δ} (RE123, RE: Rare Earth such as Gd, Y) conductors using RE'123 (RE': Rare Earth for low melting point of RE123, such as Yb, Y) bulk by heat treatment with crystal growth at boundary of wire-bulk. We call this method as crystalline joint by melted bulk (CJMB). In the CJMB method, only the bulk is incongruent melting that the Gd123 layers in the coated conductors keep the solid phase during heat treatment. we have been reported a model experiment results for the joint boundary between the coated conductor and the Y123 bulk as first step, and it is obtained that the interface has a critical current of 10 A with a high mechanical strength, indicating the feasibility of the practical superconducting joint. For superconducting joint between wires, we developed an infrared heater to heat treat in a small area about 10 mm diameter.

In this study, we successfully developed superconducting joint between Gd123 coated conductors during short preparation time below one day with critical current above 10 A at liquid nitrogen (77 K), also persistent current coil is prepared and measured in liquid nitrogen. In result, the persistent current gently decays after about 50 hours, then, the resistance is $8 \times 10^{-13} \Omega$.

In MT25, we would like to talk about the fabrication method and experimental results for the persistent current coil and superconducting joint fabricated by CJMB method.

Submitters Country:

Japan

Mon-Af-Or7 / 539

Measurements of Persistent Current Effects in FNAL 11 T Nb₃Sn Dipole Models

Author(s): Thomas Strauss¹ ; Gueorgui Velev²

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Fermilab, in collaboration with CERN, has developed a twin-aperture 11 T Nb₃Sn dipole suitable for the high-luminosity LHC upgrade. During the 2012-2014, a 2-m long single-aperture dipole demonstrator and three 1-m long single-aperture dipole models were fabricated and tested at FNAL Vertical Magnet Test Facility. Collared coils from the two 1-m long models were then used to assemble the first twin-aperture dipole demonstrator. This magnet was extensively tested in 2015-2016 including quench performance, quench protection and field quality. The paper reports the results of measurements of persistent current effects in the single-aperture and twin-aperture 11 T Nb₃Sn dipoles and compares them with similar measurements in previous FNAL magnets.

Submitters Country:

USA

Tue-Af-Po2.03 / 236

Measurements of the Effective Thermal Conductivity of the ITER TF Coil Case Cooling System

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The ITER magnet system contains 18 Toroidal Field (TF) coils and each TF winding pack is enclosed in a stainless steel coil case. During plasma operation, the coil case will be subjected to eddy current heating and nuclear heating, in addition to the static heat loads (thermal conduction and radiation). In order to minimize the heat transfer to the superconducting winding pack, the coil case is cooled by a flow of helium at 4.5 K circulating through an array of cooling pipes. In the baseline design, the thermal contact between the cooling pipes and the coil case is made by an epoxy bond. A series of mock-up samples has been prepared reproducing the geometry of the grooves where the coil case cooling pipes are embedded. The mock-up samples explore the ITER baseline design as well as an alternative design based on the contact between metallic surfaces. The effective thermal conductivity has been measured in the SULTAN facility by circulating a constant flow of helium at 10 bar and 4.5 K and applying a steady state heat load. The measurements show no indication of cracks or delamination decreasing significantly the overall heat conductivity of the mock-ups after cool-down, even after a 4 point-bending process representative of the assembly process.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

Switzerland

Mon-Af-Po1.01 / 378

Mechanical Analysis of the Dipole Magnet FRESCA2 During Assembly, Cool-Down and Training

Author(s): Etienne Rochepault¹

Co-author(s): Philippe Grosclaude ; Michael Guinchard¹ ; Francoise Rondeaux² ; Gijs De Rijk¹ ; Juan Carlos Perez¹ ; Jerome Feuvrier¹ ; Gerard Willering¹ ; Pierre Manil² ; Paolo Ferracin¹ ; Nicolas Bourcey¹ ; Jean-Michel Rifflet

¹ CERN

² CEA/IRFU, Centre d'etude de Saclay Gif-sur-Yvette (FR)

The FRESCA2 dipole magnet has been developed within a collaboration between CEA Saclay and CERN. The main goal of the magnet is to provide a 13 T nominal bore field into a clear aperture of 100 mm diameter, for the second generation cable test facility FRESCA2 (Facility for the REception of Superconducting Cables) at CERN. The coils have been produced in a joint effort between CEA Saclay and CERN. The magnet has been assembled at CERN, pre-loaded at room temperature, cooled-down in liquid helium, and powered with several current cycles. The magnet is mechanically instrumented with strain gauges on the external shell, tie rods, and central post of the coils. This paper reports the results of the mechanical measurements collected during pre-load, cool-down, powering, and warm-up of the magnet. This data is also compared with a 3D mechanical model, in order to validate different assumptions such as friction coefficients, material properties, and pre-stress levels.

Submitters Country:

Switzerland

Mon-Mo-Or3 / 392

Mechanical Analysis of the Short Model Magnets for the Nb₃Sn Low-Beta Quadrupole MQXF

Author(s): Giorgio Vallone¹ ; Paolo Ferracin¹

Co-author(s): Daniel Cheng² ; Giorgio Ambrosio³ ; Helene Felice⁴ ; Heng Pan² ; Juan Carlos Perez¹ ; Mariusz Juchno¹ ; Michael Guinchard¹ ; Nicolas Bourcey¹ ; Philippe Grosclaude ; Soren Prestemon²

¹ CERN

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During the development of MQXF, the new Nb₃Sn quadrupole to be used in the LHC inner triplets for the Hi-Luminosity upgrade, three short models were tested: MQXFS1, MQXFS3 and MQXFS5. These models differ in the use of thin or thick laminations for the iron components, and in the coil strands, RRP or PIT. In the MQXF design, the azimuthal prestress is provided at room temperature by means of the bladder-key technology, and it is further increased during the cooldown by the differential thermal contraction of the various components. Four aluminum rods provide the longitudinal prestress. Both systems allow for a flexible control of the amount of prestress applied. As a consequence, it was possible to test the models exploring different azimuthal and longitudinal prestress conditions, in an attempt to understand their impact on the magnet performances. This paper studies the mechanical behavior of these short models, also providing the strain and stresses measured by means of strain gauges installed on the aluminum shell, on the winding poles and on the rods. Finally, the paper compares the measures with the results from FE models.

Submitters Country:

Switzerland

Tue-Af-Po2.09 / 356

Mechanical Design Analysis of MQXFB, the 7.2 m Long Low- β Quadrupole for the Hi-Luminosity LHC Upgrade

Author(s): Giorgio Vallone¹

Co-author(s): Daniel Cheng ; Friedrich Lackner¹ ; Giorgio Ambrosio² ; Helene Felice³ ; Heng Pan⁴ ; Juan Carlos Perez¹ ; Mariusz Juchno¹ ; Michael Guinchard¹ ; Nicolas Bourcey¹ ; Paolo Ferracin¹ ; Philippe Grosclaude ; Soren Prestemon⁴

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⁴ LBNL

As part of the Hi-Luminosity LHC project, a set of Nb₃Sn quadrupoles are being developed aiming to enhance the performance of the inner triplets. The new magnets, identified as MQXFA and MQXFB, will share the same cross section with two different lengths, respectively 4.2 m and 7.2 m. During the magnet development, three short models were tested, along with a number of mechanical models, demonstrating the capability of the magnet cross-section to achieve the desired performances. Same performances are now required for the full-length magnets. To insure this, the authors studied the impact of the magnet length on the capability of the structure to provide an adequate support to the coils. FE and simplified analytical models were used to evaluate the impact of the magnet length on the stresses in the magnet ends and coil elongation during powering. The models were calibrated using the results from the short models tests, and used to provide an indication on the required prestress and its foreseen impact on the magnet performance.

Submitters Country:

Switzerland

Mon-Af-Po1.01 / 896

Mechanical Design of a Nb₃Sn Superconducting Magnet System for a 45 GHz ECR Ion Source

Author(s): Mariusz Juchno¹

Co-author(s): Aurelio Hafalia¹; Daniel Xie¹; Emmanuele Ravaioli¹; GianLuca Sabbi¹; Hongwei W Zhao²; Li Zhu³; Liangting Sun³; Wang Lu¹; Wei Wu³

¹ LBNL

² Institute of Modern Physics, Chinese Academy of Sciences

³ Institute of Modern Physics, Chinese Academy of Sciences

Lawrence Berkeley National Laboratory (LBNL) in collaboration with the Institute of Modern Physics (IMP) is developing a Nb₃Sn superconducting magnet system for a fourth-generation ECR source operating at the microwave frequency of 45 GHz. This paper presents a mechanical design capable of supporting the magnet up to the required operational level, resulting in peak coil fields of the order of 12 T, without exceeding the stress limits of each component, in particular the brittle Nb₃Sn conductor. The coil system, based on the sextupole-in-solenoid configuration, is supported by a shell-based structure that uses an aluminum cylinder pre-tensioned with water-pressurized bladders during the magnet assembly. High thermal contraction of the shell allows reaching the target preload level at a cryogenic temperature without over-stressing the coils during assembly. We present the optimization steps of the support structure, describe its main components and assembly procedure, and we analyze expected coil stress at each step of the magnet assembly and operation using three-dimensional finite-element mechanical model.

Submitters Country:

United States

Tue-Af-Po2.09 / 570

Mechanical Performance of a Superconducting 28 GHz Ion Source Magnet for FRIB

Author(s): Heng Pan¹

Co-author(s): Diego Arbelaez²; Helene Felice³; Soren Prestemon²; Aurelio Hafalia⁴; Eduard Pozdeyev⁵; Etienne Rochepault⁶; Guillaume Machicoane⁵; Xing Rao⁵; Mykola Omelayenko⁵

¹ Lawrence Berkeley National Lab

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⁴ Unknown

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⁶ CERN

The superconducting ECR source magnet for the Facility for Rare Isotope Beams (FRIB) at Michigan State University was designed and built by the Superconducting Magnet Group at Lawrence Berkeley National Laboratory (LBNL) in 2016. The 28 GHz NbTi ion source magnet features a sextupole-in-solenoids configuration which is comparable to the VENUS ECR magnet operated at LBNL. However, the mechanical design of this magnet utilizes a shell-based support structure which allows fine adjustments to the sextupole preload and reversibility of the magnet assembly process. The magnet

has been assembled and tested to operational currents at LBNL. This paper describes the mechanical analyses performed to estimate the sextupole's and solenoids' preloads. We will report on the comparison between strain gauges measurements and the 3D finite element analysis during room temperature assembly, cool-down and magnet training tests. Finally, we will describe the performance of the support structure during the quench training.

Submitters Country:

USA

Wed-Af-Po3.11 / 440**Mechanical Structure for the PSI Canted-Cosine-Theta (CCT) Magnet Program**

Ciro Calzolaio¹ ; Bernhard Auchmann² ; Lucas Brouwer³ ; Shlomo Caspi⁴ ; Gabriella Rolando² ; stephane sanfilippo¹ ; Giuseppe Montenero^{None}

¹ *Paul Scherrer Institut*

² *PSI*

³ *LBNL*

⁴ *Lawrence Berkeley national laboratory USA*

CCT technology promises, by its intrinsic stress-management, to lower coil stresses in high-field accelerator magnets. This is especially relevant for Nb3Sn magnets, which may be subject to irreversible degradation if the coil stresses exceed critical values. The internal structure of CCT coils, however, dilutes the engineering current density. For an efficient design, the internal structure, therefore, needs to be reduced to the limit given by the CNC machining capabilities. In that case, however, the mechanical stiffness must be provided by an external structure. For the PSI CCT program, we intend to build one such mechanical structure to be used in different iterations of technology model magnets. The structure is based on the bladder and key concept. CCT-specific deviations from the prevalent bladder and key implementations will be discussed in detail in the full paper, where we will also lay out 2-D and 3-D analysis in all stages of loading, cooling, and powering of the magnet, as well as sensitivity and tolerance analyses.

Submitters Country:

Switzerland

Wed-Af-Po3.10 / 54**Mechanical properties of ITER CICC jacket in China**

Jinggang Qin^{None}

The ITER Cable-In-Conduit Conductor (CICC) used in the superconducting magnet system consists of a cable made of 300 to 1440 strands housed in a stainless steel jacket. China needs to provide six different kinds of conductor. The jackets are circular, square, as well as circle-in-square jackets made of either a very low carbon AISI 316LN and AISI 316L grade stainless steels. The mechanical properties of jacket were tested at room temperature and/or cryogenic temperatures (<7 K) at predefined mechanical deformation and heat treatment condition. The mechanical tests such as tensile strength, fracture toughness, and fatigue crack growth rate were performed. This paper will introduce the results, and compare them among different kinds of jacket.

Submitters Country:

China

Wed-Af-Po3.10 / 78

Mechanical properties of aged 316LN butt-welding joint at cryogenic temperature for CFETR CS model coil

Huan Jin^{None}; Yu WU¹; Jingang Qin^{None}; Guojun Liao^{None}; Houxiang Han^{None}; Jing Jin^{None}; Min Yu^{None}; Qiyang Han^{None}

¹ ASIPP

Institute of Plasma Physics Chinese Academy of Science (ASIPP) is designing and manufacturing a Central Solenoid Mode Coil (CSMC) to develop the manufacturing process for China Fusion Engineering Test Reactor (CFETR) CS coil. The hybrid magnet structure is employed for the CSMC, and modified 316LN stainless steel is selected as the jacket material for the Nb3Sn cable in conduit conductor, which will be connected by butt-welding to reach the required maximum length of about 780 m. Automatic welding and manual welding methods are used for the circular and corner parts of the round in square tubes respectively. The purpose of this paper is to qualify the 316LN welding joint performance. Tensile properties, fracture toughness and fatigue crack growth rates of the aged 316LN butt-welded joint at liquid helium temperature were evaluated and reported.

Submitters Country:

China

Tue-Af-Po2.09 / 76

Mechanical properties of bulk MgB₂ superconductors processed by spark plasma sintering at various temperatures

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Superconducting bulk materials have high trapped magnetic field ability at a temperature lower than the critical temperature. Since superconducting bulk materials are subjected to electromagnetic force during magnetization process, improvements of the mechanical properties are indispensable for the development of high performance bulk materials. However, the mechanical properties of conventional MgB₂ superconducting bulk materials are inferior to those of rare-earth based superconducting bulk materials, which is mainly due to the lower packing ratio. In this study, high packing ratio MgB₂ bulk materials are obtained through spark plasma sintering SPS at various temperatures: 1223, 1273 and 1373 K. Effects of the SPS temperature on the mechanical properties of the MgB₂ bulk materials are investigated through bending tests of specimens cut from the bulk materials. Both the Young's modulus and bending strength are improved by the increase of SPS temperature. It is deduced that the improvements of the mechanical properties are mainly due to the improvement of the packing ratio. Relationship between the bending strength and packing ratio of the spark plasma sintered MgB₂ bulk materials can be approximated by using an exponential equation. The approximation curve is similar to that obtained from the data of MgB₂ bulk materials fabricated by other sintering methods such as capsule method and hot isostatic pressing in the previous study.

Submitters Country:

Japan

Mon-Mo-Or3 / 1062

Mechanical–electric Model for Multifilament Composite Superconducting Strands

Yuanwen Gao¹ ; Xu Wang^{None} ; Yang Liu^{None} ; Youhe Zhou^{None}

¹ Lanzhou University

In this study, a 3D multi-filament FEM model is developed for some kinds of superconducting strands, such as LMI strand, SMI-PIT strand and Bi2212 round wire. Some important factors, such as the initial thermal residual stress, the breakages of superconducting filament and twist pitch (for LMI, SMI-PIT) are taken into account. In this FEM model We calculate this thermal residual stress system, and apply the results into the multi-filament model. For considering the influence damage of SC filament on the electromechanical behavior of SC strand, we choose the representative volume element (RVE) as a concentric cylinder with a single filament in the matrix. Since the damage of the filament and its evolution are almost random, hence, we consider the distribution of the break points to be of a Weibull form. According to the GLS model of Curtin and Zhou, the effective constitutive relation of this RVE can be obtained. So a 3D FEM model of SC strand is built. The tension, bending and cyclic behaviors of these strands have been investigated, respectively. From the comparisons with these two experiments in axial tension and bending respectively, it can see that our model has good accuracy in the prediction of the mechanical behavior of the SC strands. The critical current of the strand under axial and bending loads are calculated with the invariant temperature and field strain functions, the results indicate that the damage and current transfer length in the strand have significant effects on the critical current. The calculated critical currents under tensile and bending load with every factor taken into consideration agree well with the experiments.

Submitters Country:

China

Mon-Af-Or9 / 935

Mechanisms to enhance stability, post-quench recovery and availability in non-insulated REBCO magnets

Wan Kan Chan¹ ; Justin Schwartz¹

¹ North Carolina State University, Raleigh, USA

Due to low turn-to-turn contact resistances, non-insulated (NI) REBCO coils possess much higher thermal stability than their insulated counterparts. Experiments even showed that NI coils are in general self-protecting, recovering from a quench without external quench protection mechanisms. Recent studies showed that an uncontained local quench can amplify itself quickly, leading to an abrupt loss of the azimuthal current and thus a sudden drop in the magnetic field. Moreover, within a NI multi-coil magnet, a quench-resulted sudden drop in magnetic field in one coil can inductively induced another quench in another coil. These phenomena result in lower thermal stability and lengthened recovery time in self-protecting NI magnets. The ultimate consequences are lower operational reliability and availability, and even catastrophic disruption in operational functionality. Here a novel graded-resistance method is proposed to tackle the mentioned problems while maintaining the superior thermal stability and self-protecting capability of NI magnets. The method is studied and designed via a network-thermo-electromagnetic NI REBCO multi-coil model. The multi-coil model is composed of multiple serially connected, spirally-wound equivalent circuit network pancake coil models coupled with an equal number of three-dimensional thermal and electromagnetic pancake models. Patterned thermally and electrically resistive-conductive layers are inserted at strategically selected turn-to-turn contacts to contain hot-spot heat propagation while maintaining the turn-wise current sharing required for self-protection. The heat containment enables the retention of useful azimuthal current responsible for magnetic field generation, resulting in faster post-quench recovery and reduced magnetic field transient. Through the proposed method, REBCO magnets with higher thermal stability, lower likelihood of quenching, and rapid, passive recovery can be built to enhance operational reliability and availability. The effectiveness of the method is assessed by comparing the recovery times, magnetic field transient rates and thermal stabilities between the modified and original NI multi-coil magnets at 4.2 K and 77 K.

Submitters Country:

USA

Tue-Af-Pl3 / 1227

Meeting Divergent Expectations: Superconductors between Industrial Applications & Cutting-Edge ScienceBurkhard Prause¹¹ *President & CEO Bruker EST, Inc.*

For over 40 years metallic superconductors have been an industrialized product, serving primarily the medical and science communities' needs for high performance magnets. The last decade has seen a rapid divergence between the requirements of these two user communities. Superconductor use in medical diagnostics, analytics and treatment is well established. Cost and reliable high-volume supply are the most important considerations for this industry. On the other hand, the science community continues to explore the limits of superconductor performance, conceiving ever larger and cyclical projects to push the boundaries of human knowledge. This divergence creates increasing difficulties for the superconductor industry to meet both challenges equally.

Bruker is an integrated manufacturer of superconductors and superconducting magnets, as well as fully integrated analytical and research systems. As part of the manufacturer and user communities, we are in a unique position to share insights into requirements, as well as our approach to address the needs of both science and industry.

How much can the user communities benefit from each other? How do we leverage insights for one community into advances for the other? The talk will explain that these opportunities have indeed diminished. Superconductor manufacturers have to increasingly tailor their value proposition to fit the needs of a specific user or user community. Performance requirements have diverged. Product life cycles are shorter. All the while, both communities insist on ever decreasing cost, faster innovation and higher flexibility. The superconductor industry has seen two consolidation waves in the last decade alone, because of the underlying mismatch between expectations and capabilities of user communities and manufacturers. It is Bruker's mission to ensure that both affordable and high performance superconductors remain available to the largest possible user base. That requires an understanding of the underlying economics, which this talk aims to achieve.

Submitters Country:

Germany

Thu-Af-Po4.05 / 657

Methodology of Incorporating Mechanical and Electromagnetic Characteristics Analysis for Separated Pole-Piece Type Ferrite Magnet MotorWon-Ho Kim¹ ; Sung-Gu Lee² ; Sung-Hyuk Park³¹ *Gachon University*² *Busan University of Foreign Studies*³ *Samsung Electronics*

A novel separated pole-piece type ferrite magnet motor (FMM) is comprises pole-pieces and webs separated from each other in order to maximize its magnetic performance and to minimize leakage flux. However, since such disconnected pole-pieces and webs are constrained only by end plates and rivets, the motors are vulnerable in terms of mechanical integrity at high rotating speeds (and thus under large centrifugal forces). Therefore, both electromagnetic and mechanical requirements must

be satisfied when a motor is being designed. This paper proposes a methodology of incorporating mechanical and electromagnetic characteristics analysis for separated pole-piece type FMMs and the suggested motor design was validated by comparing the actual experimental results with the predicted results from the model. The volume ratio of magnets and nonmagnetic material is determined through irreversible demagnetization analysis, and stress analysis is conducted based on the suggested configuration. Electromagnetic excitation forces applied on tooth surfaces are calculated, and the resulting vibration and noise are then predicted. Eddy current loss inside the rivets and end plates, as well as loss from the coil and core, is calculated and then applied to thermal analysis. The proposal enhanced the accuracy of the electromagnetic simulation results such as loss and heating source, and led to an improvement in prediction of temperature, vibration, and acoustic noise. The process was validated by comparing the predicted data with the actual measurements. It was suggested that the accuracy of the prediction would be remarkably improved by incorporating motor control in a coupled analysis, to include the effect of current harmonics on electromagnetic forces and loss.

Submitters Country:

Korea, Republic of

Tue-Af-Po2.11 / 655**Methods to Increase the Pumping Rate of Rotary HTS Flux-pump with Rotating HTS Tape to Charge the Field Coil of the Synchronous Motor.****Author(s):** Haeryong Jeon¹**Co-author(s):** jeyull Lee¹; Seunghak Han¹; Ji Hyung Kim²; Chang Ju Hyeon²; Ho Min Kim²; Yong Soo Yoon³; Tae Kuk Ko⁴¹ *Yonsei University*² *Jeju National University*³ *SHIN ANSAN UNIVERSITY*⁴ *Electrical and Electronic Engineering, Yonsei University*

Recently, the Rotary flux-pump using HTS tape has been researched to apply for superconducting applications. In this paper, we studied the charging characteristics of the field coil of the HTS synchronous motor that field coil is charged by Rotary HTS flux-pump. The two advantages can be obtained by using Rotary HTS flux-pump to the synchronous motor. 1) The high thermal efficiency 2) simple cryogenic design because the direct physical connection is not necessary. The prototype of the rotary HTS flux-pump with rotating HTS tape is fabricated to investigate the basic charging characteristics. In the test model, the HTS tapes and the coil are rotated together and the permanent magnet is fixed outside of the rotor because it is similar to the actual model of the synchronous motor. The N50 permanent magnet is used to apply the magnetic flux into the HTS tape. The charging speed of the rotary HTS flux-pump is closely related to magnetic flux linkage on the HTS tape. To increase the pumping rate of the flux-pump, the test of case 1 was conducted with respect to the different background material like iron or Permalloy of the HTS tape. In the test of case 2, the two HTS tape was overlapped to extend the flux linkage area on the HTS tape and each HTS tape was connected to HTS coil together. In order to measure the charging speed and pumping rate with respect to the magnetic flux changes, a hall sensor was installed at the center of the HTS coil.

Submitters Country:

Republic of Korea

Thu-Mo-Or30 / 233**MgB2 cables from wires made PIT and IMD process.**

Pavol Kováč¹ ; Lubomír Kopera¹ ; Tibor Melišek¹ ; Ján Kováč¹ ; Miloslav Kulich¹ ; Imrich Hušek¹

¹ *Institute of Electrical Engineering of SAS*

Many superconducting devices require higher currents which leads to the request for cables assembling single wires or tapes. MgB₂ cables were developed with different geometries: twisted and braided cables, Roebel and Rutherford style geometries. MgB₂ cables allow to make winding with small diameters without current degradation and reduce the AC losses through the lowered coupling loss. The most attractive version is the Rutherford cable which gives opportunity for very complex structures, the use of mono- or multicore wires and the mixture of strands with stabilizing Cu and reinforcing stainless steel wires to address all possible application requests. To reduce AC losses in transposed cables is more effective than use of twisted filamentary MgB₂ wires with reduced current carrying capacity. For cabling purposes, PIT in situ and IMD MgB₂ wires are the best candidates to realize a transposition of strands, allowing hard bending before reaction treatment without damage. Engineering current densities, strain tolerances and AC losses of MgB₂ cables with different compositions and manufactured by PIT and IMD process are presented, compared and discussed. Balancing the final properties of a cable to an optimum is still a challenge and requires more work in particular the application for specific requirements (e.g. for wind generators), which determine the detailed cable design and preparation approach.

Submitters Country:

Slovakia

Mon-Af-Po1.09 / 867

MgB₂ superconductive short winding joints: mathematical prevision of current behaviours and experimental validations

Author(s): Giovanni Valesi¹

Co-author(s): Alessio Capelluto² ; Giovanni Masullo² ; Roberto Marabotto²

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The advent of new kind of superconductors can introduce a new application age. Modern magnet designs and applications push towards persistent mode system realized with multiple superconductive connected coils. The quality of field persistence is fundamental in order to characterize the goodness of the superconductive joint technical implementation. A theoretical methodology able to predict the field and the current evolution in the superconductive closed loops is necessary to introduce innovative material as MgB₂ in fabrication technology and to develop robust joint techniques. ASG laboratory developed a new energetic model able to predict the ending currents of closing circuits and evaluate the persistent circuit total efficiency with short field acquisitions. This innovative model represents a powerful and flexible tool, as it is easily implementable in the study of arbitrary superconductive closed loops and applicable to complicated winding geometry. The mathematical method will be presented, and theoretical results will be compared with experimental measurements performed on specific MgB₂ winding samples.

Submitters Country:

Italy

1246

Mijn verhaal

Tue-Af-Po2.06 / 653

Minimization design of torque ripple for bearingless synchronous reluctance motor

Xiaoyan Diao¹ ; Huangqiu Zhu² ; Chenyin Zhao^{None}¹ *Jiangsu University*² *Jiangsu university*

Bearingless synchronous reluctance motors (BSRMs) have received more and more attention in recent years. Besides some general advantages of non-friction, high critical speed and non-lubrication of bearingless motors (BMs), the BSRM have some additional characteristics of simple structure, low loss and low temperature rising. Therefore, BSRMs have wide application prospect in some special fields including aerospace, high speed drive, precision manufacturing and flywheel energy storage. At present, the conventional BSRM with salient pole rotor is easy to process and manufacture at the cost of low torque output and high torque ripple. In order to decrease the torque ripple and increase the torque output of BSRMs, a novel BSRM with improved rotor structure is proposed in this paper. Firstly, the fundamental structure and operation principle of the proposed BSRM are analyzed, based on which the mathematical models of radial suspension force and electromagnetic torque are established respectively. Secondly, on this basis, the improved rotor structure, the parameters of magnetic bridge and air gap magnetic barrier are designed with the objective of torque ripple minimization. Finally, the relationships between winding current, radial suspension force and torque are simulated and analyzed using finite element method (FEM), and the computed radial suspension force, maximum torque and average torque ripple are further compared with those of the conventional BSRM. The comparison results show that the torque ripple by utilizing this improved rotor structure decreases about 27% and the torque output increases about 23% compared with those of the conventional salient pole rotor structure, and that it further leads to more stable suspension force output.

Submitters Country:

China

Mon-Af-Po1.06 / 531

Modeling and Analysis of Parasitic Capacitance of High-Frequency High-Voltage Transformer Using Finite-Element Method

Author(s): Le Deng¹**Co-author(s):** Tao Peng¹ ; Shuang Wang² ; Fan Jiang ; Quqin Sun ; Houxiu Xiao²¹ *Wuhan National High Magnetic Field Center*² *Huazhong University of Science and Technology*

The high-frequency high-voltage (HFHV) transformer acts as a key part for galvanic isolation, energy transmission and voltage conversion in high-frequency resonant converter. And the performance is highly affected by the parasitic parameters, especially the parasitic capacitance. However, the existing techniques have a lot of shortcomings when determining the parasitic capacitance of multi-section multi-layer multi-turn HFHV transformers. A methodology has been proposed to predict the parasitic capacitance of multi-section, multi-layer and multi-turn secondary winding of HFHV transformer based on a 2D-axisymmetric model using finite-element analysis (FEA) software of COMSOL. The magnetic field produced by the coils and the corresponding voltage of each turn were evaluated. The electric field distribution along the windings was analyzed. A 20 kHz, 40 kW transformer with the input voltage of 380 V and the output voltage of 25 kV was designed. The capacitance of the windings with different number of sections, layers and turns was investigated. And an optimum structure of winding was derived, consisting of 9 sections, 9 layers and 4 turns. The winding was manufactured and the parasitic capacitance was measured by the LCR meter using frequency sweeping method. Compared to the classical analytical method with the maximum error

of 21%, the method proposed in this paper drastically reduces the error to be less than 10%. The error resources of the classical analytical method are analyzed by the electric energy distribution.

Submitters Country:

China

Wed-Af-Po3.12 / 907

Modeling of AC losses in the CS and TF conductors for the ITER Project

Marco Breschi¹ ; Marco Bianchi¹ ; Pier Luigi Ribani¹ ; Anna Chiara Ricchiuto¹ ; Arnaud Devred²

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² *ITER International Organization*

The cable-in-conduit conductor (CICC) that will be adopted for the 3L module of the ITER Central Solenoid (CS) coil and for the Toroidal Field (TF) magnets of the ITER Machine have been extensively characterized in the SULTAN facility in Villigen, Switzerland by means of DC and AC tests. The AC tests were performed superimposing a sinusoidally varying magnetic field, with amplitude of 0.2–0.3 T and frequency in the range 0.1 – 5 Hz, to a background constant magnetic flux density of 2 T and 9 T. These tests were performed before and after the electromagnetic cyclic loading of the conductors, either without transport current or setting its value to the nominal level. This paper describes the analysis of the AC loss results obtained on two CIC Conductors, namely identical to those used for the manufacturing of the CS Insert and TF Insert recently tested in the CSMC facility in Naka, Japan. The numerical modeling of these experiments was performed by means of the THELMA model, previously developed and validated at the University of Bologna, by pushing the analysis to different levels of discretization (sub-cables, triplets, strands). The comparison between measured and computed losses per cycle is presented in a wide range of experimental conditions. This study allows assessing the variations of interstrand contact resistances during the test campaign. Moreover, the numerical model provides useful hints for the interpretation of the experimental results. Finally, the results of the numerical model are compared with analytical formulae available in the literature.

Submitters Country:

Italy, France

Wed-Af-Po3.12 / 164

Modeling of magnetization loss in HTS tape exposed to all magnetic field direction

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The magnetization loss model in HTS tape when the magnetic field is exposed to the HTS tape face is suggested to be a Brandt model. In the case of a thin HTS tape, when the magnetic field exposed perpendicular to the HTS tape axis and the tape face is rotated, the magnetization losses correspond with Brandt model when the linkage magnetic field exposed. We previously reported the AC loss characteristic in a Bi2223/Ag tape applied a magnetic field in all direction. With decrease in the angle of the tape axis to the magnetic field, the magnetization losses are reduced. To complete the model of the magnetization loss in HTS tape, we suggest a new model for all magnetic field directions. It was reported that the critical current and cross-section are affected by the magnetization

loss characteristics. We used three types of HTS tape, Bi2223/Ag tape measured previous report, new Bi2223/Ag tape in which the critical current is higher than in the previous experiment, and YBCO tape, to compare the magnetization loss model. Our new model is based on the measured magnetization losses because the loss is affected to the intrinsic critical current distribution and cross-section. The conditions of the base magnetization losses consist of the magnetic field exposed perpendicular to the tape axis and parallel to the tape face, perpendicular to the tape axis and perpendicular to the tape face, and parallel to the tape axis. The model enables us to induce the magnetization losses in response to change in the amplitude of the magnetic field, the angle of the tape axis, and the angle of the tape face. This model corresponds with the magnetization losses in each tape in all magnetic field directions.

Submitters Country:

Japan

Mon-Af-Po1.12 / 329

Modified Design of Power Supply System for 100 Tesla Pulsed Magnetic Field

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High pulsed magnetic field is becoming more and more widely used in physics, biology and materials. For serving scientific experiments better, a power supply system for 100 Tesla magnetic field is designed at Wuhan National High Magnetic Field Center (WHMFC). In the preliminary design, the 100 Tesla magnet consists of three coils in a coaxial structure. The outer coil is powered by pulse-rectifier generator in series to battery banks. The middle coil and the inner coil are energized by capacitor banks separately. Each coil is fired in designed sequence. Because of the magnet is a multi-coil system with a strong-coupling structure, the current of the outer coil will drop when the middle coil fired. And the current drop will cause adverse effects that the burden of the power supply and the stress of magnet increase. Based on analysis of the mathematical model for power supply circuit, a modified design for power supply system is proposed which is connecting a coupling transformer to the outer coil and the middle coil for the compensation of the current drop. Parameters of the coupling transformer and the requirements of power supply are also discussed. In order to verify the feasibility of the scheme, the simulation model based on the MATLAB/ Simulink platform is established and the tests are carried out on the prototype of three-coil magnet. Both simulation and experimental results verify the feasibility of the proposed design and the effectiveness of the compensation method.

Acknowledgements: The authors would like to acknowledge the supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Wed-Af-Po3.04 / 1187

Modified Halbach Magnets in Medical Science Applications

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Dipole and Quadrupole magnets or a combination of both with rather strong magnetic fields are required in many medical applications. Although such magnets can be built with warm temperature electromagnets, under certain physical conditions such electromagnets can be replaced by Halbach type permanent magnets in combination with rather small inexpensive electromagnets to provide variability of the magnetic field. In this paper we provide results from 2D and 3D calculations¹ which compare electromagnets with Halbach type of permanent magnets.

Submitters Country:

USA

Wed-Af-Po3.06 / 228

Moduling Axial-flux Compensated Pulsed Alternator

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Compensated pulsed alternator (CPA) is a kind of device supplying power for pulsed equipment such as pulsed laser, accelerator and electromagnetic railgun. The most widely researched scheme of CPA is the air-core self-excitation one which is capable of supplying high current and power. But it needs a bulky capacitor to provide seeding current and a prime motor which complicates the power system and reduces its reliability. Besides, multi-phase discharge sometimes is hard for traditional air-core CPA because of the coupling of phases. The moduling axial-flux compensated pulsed alternator (MACPA) is designed to simplify the system and decouple the affect among phases. The MACPA consists of decoupled modules including discharging portions and motor portion. And it is excited by permanent magnet (PM) which saves the capacitor and complicated self-excitation process. Firstly, the structure of MACPA is proposed including discharging module and motor module. Then, fundamental of MACPA and principle of decoupling are investigated for proving the feasibility of the moduling scheme. Afterward, the dynamic characteristics of MACPA is analyzed insuring the safety of the machine, because the rated speed is high. Finally, a 3-D Finite Element Method (FEM) model is built, and functions of motor and multi-phase discharge are tested. The simulation results show that the MACPA can decouple the affect among phases efficiently and integrate the function of discharge and motor into one machine, which is a new way of thinking in designing CPA.

Submitters Country:

China

Mon-Mo-Pl1.2 / 1245

Mon-Mo-Pl1.2: IEEE Awards Presentation

Submitters Country:

Thu-Af-Po4.10 / 184

Mu2e Solenoid Field Mapping System Design

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Mu2e experiment at Fermilab is set out to search for charged-lepton flavor violation by looking for muon to electron conversion in the field of the nucleus. The concept of the experiment is to generate low momentum muon beam, stopping the muons in a target and measuring the momentum of the conversion electrons. The implementation of this approach utilizes a complex magnetic field: graded solenoidal and toroidal field. Precise knowledge of the magnetic field is crucial in the muon transport process and in the electron momentum measurement. It is planned to map the solenoid field with calibrated 3D Hall probes up to 10^{-4} accuracy. This article describes the design of the Field Mapping System Mu2e will use to measure the magnetic field in the Mu2e solenoid system.

Submitters Country:

USA

Tue-Af-Po2.12 / 1087

Multi Objective Design Optimization of Permanent Magnet Driver Based on PSO Algorithm and Nonlinear Equivalent Magnetic Model

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Permanent magnet driver transfers the torque by the coupling effect of magnetic field and its induced magnetic field, there are multiple parameters in its structure design, which change would affect the overall performance, such as conductor thickness, PM duty ratio, pole number and yoke thickness. In fact, inappropriate yoke and conductor thickness would cause magnetic saturation and heating problem. PM duty ratio would affect the utilization rate of permanent magnet. Pole number would have an effect on magnetic flux leakage, eddy current, and manufacturing cost. Therefore, structure optimization is becoming increasingly important in design process. The traditional method could be incompetent to coordinate structural parameters and objectives, it is necessary to study multi-objective optimization design of permanent magnet driver. In this paper, take torque and volume as objective functions, add demagnetization temperature and magnetic saturation as restrictions. Specific modeling is divided into the following steps: 1) A nonlinear equivalent magnetic circuit model of cylinder permanent magnet driver is built, nonlinear material characteristics would be considered; 2) Magnetic flux density is given; 3) According to Faraday's law of electromagnetic induction, evaluating expressions of power loss and torque are presented; 4) Volume expressions are obtained; 5) Expressions for calculating temperature rise are developed. The multi-objective optimization model is established as follows: 1) Construct multi objective function and restriction conditions; 2) Set initial PSO parameters; Calculate candidate solution information, compare used Pareto dominance

relation; 3) Update particle positions ,flight speeds and optimal solution set, perform iterative computation ; 4) If the terminating condition is achieved, the iteration would be suspended, Pareto front would be obtained, otherwise, continue iteration. Use contour line method to select the optimal solution in Pareto front. The nonlinear model is verified by FEM. The advantage of optimization model is demonstrated by the comparison between pre-optimized and optimized model.**

Submitters Country:

China

Mon-Af-Po1.06 / 537

Multi-objective filter designing for HTS SMES considering the voltage distribution characteristic

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In SMES system, the power conditioning system (PCS) interfaces the superconducting magnet and the AC system. At present, PCS generally adopts PWM converter based on the high-frequency switching devices. The converter outputs PWM pulses voltage with steep rising and falling edges. It is transmitted to the superconducting magnet via the cable, which leads to a spike overvoltage at the superconducting magnet terminals. The high frequency component of the PWM pulse voltage causes a severe uneven distribution within the magnet windings. And it can also accelerate the insulation of the magnet. An effective way to solve this spike overvoltage is to add a filter placing between PCS and superconducting magnets. This paper firstly gives the frequency domain solving method of HTS SMES transient model. And then a frequency spectrum of the system is determined in frequency domain. According to the obtained spectrum, resonant frequencies can be found out which would provide useful information on the subsequent filter designing between PCS and superconducting magnets. However, the addition of the filter also brings the disadvantage of affecting the response speed and even control instructions of the PCS. Thus, it is need to suppress the overvoltage and ensure the response speed of PCS at the same time. Multi-objective optimized algorithm is adopted in the filter design and its parameter selection with the aim to find a balance point, which would suppress the spike overvoltage and keep the system normal operating at the same time.

Submitters Country:

China

Mon-Mo-Or3 / 425

Multi-scale approach to the mechanical behaviour of epoxy impregnated Nb3Sn Dipole Coils for the 11T Dipole.

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Co-author(s): Christian Hannes Loffler ¹ ; David Smekens ¹ ; Ana Teresa Perez Fontenla ¹ ; Oscar Sacristan De Frutos ¹ ; Michael Guinchard ¹ ; Frederic Savary ¹

¹ *CERN*

The superconducting dipole magnets being developed at CERN for the HL-LHC project are equipped with coils manufactured from Nb3Sn Rutherford cables, following the *Wind & React* fabrication technique. The brittleness of the multifilamentary structure of the Nb3Sn within the cable strands exposes the coils to permanent performance degradation when subjected to excessive strain during assembly and operation. The coils have to be heavily pre-stressed to ensure the required mechanical

stability of the cables under the Lorentz forces when the magnet is powered to maximum current under high field. Reaching the maximum acceptable stresses during assembly and operation without causing permanent damage requires refined knowledge of the mechanical behaviour of these epoxy impregnated Nb₃Sn coils. This paper will show a detailed analysis of the characterisation of cable stacks (10-stack) under compression using representative coil material in order to predict the behaviour of the Nb₃Sn coils. By means of standard mechanical measuring techniques and finite element analysis, the results from the 10-stack measurements are extrapolated to an actual and fully detailed coil cross section using 2D imaging techniques. The stress and strain distribution from the actual coil geometry are used to predict the stresses and strains at the strand level and the filaments within the strand. The model of the strand and filaments is based on a scanning electron microscope image of a strand of interest within the original coil in order to provide a realistic geometry and a better representation of the stresses and strains within the multi-filament structure. The results from this multi-scale approach has allowed for a better understanding of the stresses and strains that are observed at the strand and filament level by accounting for the global stresses and strains of the realistic coil geometry.

Submitters Country:

Switzerland

Thu-Mo-Or33 / 1014

Multiphysics FEA Led Design of Bi-2212 Round Wire Prototype Coils

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Addressing an NHMFL goal of developing high temperature superconductor (HTS) technology applied toward nuclear magnetic resonance (NMR) at high fields (~1 GHz), the work presented here focuses on the finite element analysis (FEA) led designs of Bi₂Sr₂CaCu₂O_{8-x} (Bi-2212) round wire prototype coils. With the goal of an HTS insert coil that produces a significant portion (>20 %) of a combined low temperature superconductor (LTS) & HTS magnet system's total field, the required operating conditions approach the performance limits of the insert coil. Composed of filaments in a pure Ag matrix within an Ag-alloy sheath, Bi-2212 RW conductors experience mechanical strain generated from large Lorentz forces that stress the coil, and at the target high fields the integrity of the Bi-2212 superconducting filaments are pushed near their critical strain limits. Thus, a series of prototype coils has been designed to systematically address coil-level reinforcement, via stress/strain management schemes. Prototype designs are constrained to the size of the over-pressure furnace, in which the Bi-2212 coils are reacted, as well as the available size and field strength of the LTS outsert, in which experimental tests are performed. Multiphysics FEA was used to set prototype coil dimensions within these constraints, large enough to strain the conductors during in-field experimental tests to values similar to seen in the NMR demonstration coil, yet small enough to not become prohibitively expensive. Details of the complexity of the models, a predicted critical surface describing the prototype performance limits, and some experimental results are reported. Overall, high detail modeling has proven invaluable, and successful coil-level stress/strain management provides a roadmap towards making Bi-2212 a viable conductor for high field, high homogeneity magnet technologies.

Submitters Country:

United States of America

Wed-Af-Po3.02 / 1109**NDT STATUS OF PF-1 COIL WELDS****Author(s):** Artem Belyaev¹**Co-author(s):** Egor Marushin ¹ ; Igor Rodin ¹ ; Igor Sokolov ; Michail Panteleev ² ; Tamara Guryeva ¹¹ JSC "NIEFA"² JSC NIEFA

Stock Company "NIEFA", Russia, within the framework of the international project ITER produces and supplies the superconducting poloidal field coil PF-1. The choice of design solutions, materials and technologies is due to high electromagnetic and thermal loads. The superconducting poloidal coil uses liquid helium as a cooling system, which is fed into contact junctions through helium inlets. Contact joints are bimetallic structural components obtained by explosion welding technologies and argon arc welding with a complex structural profile. Materials used: austenitic stainless steel, bimetallic copper - steel; bonded technology: argon arc welding, explosion welding. The quality of materials, explosion border and welds are subject to the highest requirements of European standards. Technologies of industrial manufacture of the PF-1 coil require the use of non-traditional, non-destructive testing (NDT) procedures, caused by complex weld profile, small testing zone, and heterogeneity of welds. The complex using of radiation, endoscopic, penetrate and ultrasonic NDT methods allows to ensure the required quality. The ultrasonic method is effective to testing and assessing the quality of weld without direct access to the root. The application of innovative developments in ultrasonic tomograph and antenna array technologies, helps to solve problems with a small testing zone, to provide visualization of the testing results over the weld section. The features of using an ultrasonic tomograph for austenitic welds are considered, examples of acoustic images and evaluation of defects are given. The comparability of the testing results of welds using various NDT technologies was demonstrated. Also in this report, features of radiation testing using the technology of reusable phosphor plates on the full-scale object of PF-1 are considered. Analysis of the results presented in the report allows us to conclude that the development and implementation of an effective non-destructive testing complex in the manufacture of PF-1 ITER is actual and important.

Submitters Country:

Russia

Tue-Af-Po2.05 / 1071**NMR Solenoid for Multi-Sample Spectroscopy****Peter McIntyre¹ ; Akhdiyov Sattarov¹ ; Joshua Kellams²**¹ Texas A&M University² Accelerator Technology Corp.

NMR spectroscopy is a powerful tool for structural biology and molecular medicine. It can be used to locate binding sites on a protein, so that the mechanisms that control healthy and disease processes can be traced. Cost and time presently limit the scope for applications of NMR: each instrument costs \$millions, and a single high-resolution spectrum can take a week to acquire. ATC is developing new technology that would make it possible to independently acquire spectra from multiple samples simultaneously in a single instrument.

Submitters Country:

US

Mon-Af-Po1.08 / 551**Nb-rod-method Cu-Nb/Nb₃Sn wires for practical React-and-Wind applications****Author(s):** Masahiro Sugimoto¹**Co-author(s):** Kota Katayama¹ ; Akira Takagi¹ ; Hitoshi Shimizu¹ ; Hirokazu Tsubouchi¹ ; Satoshi Awaji² ; Hidetoshi Oguro³¹ *Furukawa Electric Co., Ltd.*² *Tohoku University*³ *Tokai University*

Nb-rod-method Cu-Nb reinforced bronze process Nb₃Sn (Cu-Nb/Nb₃Sn) wires are applicable to React-and-Wind processed Nb₃Sn coils. The Cu-Nb composite material functions as a reinforcing stabilizer during the superconducting magnet operation. Moreover, it suppresses the damage of reacted Nb₃Sn filaments due to the applied stress during manufacturing process such as the pre-bending treatment, the insulating and the winding. Plural new Cu-Nb/Nb₃Sn wires with the high tin bronze (Cu-15.7wt%Sn-0.3wt%Ti) were investigated in the superconducting properties. The round wire of 0.8 mm diameter with pre-bending strain of ±0.5% demonstrated the non-Cu-J_c values (at 4.14 K, defined by 10 micro-V/m) of 1150 A/mm² at 12 T and 410 A/mm² at 17 T, which were 1.5 times and 1.4 times larger than those of the previous wires (with Cu-14wt%Sn-0.2wt%Ti). As for rectangular wires of 1.7 mm x 1.13 mm, the pre-bending strain was applied from the flatwise direction and/or the edgewise direction. In case of pre-bending strain of ±0.5% applying alternately from both directions, the non-Cu-J_c was 355 A/mm² at 17 T of which was 1.6 times larger than that of the as-reacted wire without pre-bending treatments. These results suggest that the performance of large capacity conductors consist of the advanced Cu-Nb/Nb₃Sn wires can be further improved by controlling both magnitude and direction of the pre-bending strain in React-and-Wind process.

Submitters Country:

Japan

Thu-Mo-Or30 / 427**Nb₃Sn strand designs and heat treatments for high field magnet applications**Michael Field¹ ; Hanping Miao² ; Jeff Parrell¹¹ *Bruker OST*² *Bruker-OST*

In recent years Nb₃Sn strand made by the internal tin process has been proven as an industrial scale high field conductor, previously by the high volume production for ITER and presently for the CERN High Luminosity upgrade. Strand manufactured by a flexible internal tin Nb₃Sn method may be readily customized for particular applications. The challenge for particle accelerator applications is to maintain high J_c and RRR in strands with effective filament size < 40 microns, and new heat treatments have shown this to be possible with existing strand architectures. We are also continuing to modify the RRP® strand architecture in order to improve properties at lower subelement size. For magnet application where larger effective filament diameters are acceptable, RRP® strands can reach over 1400 A/mm² at 16T, and we will show our work in increasing this value to the target of 1500

A/mm² at 16T for FCC. We are continuing to develop RRP® distributed barrier and single barrier strands having small effective filament diameters for fast ramping laboratory magnets, and strands with low hysteretic losses for use in low or cryogen free magnets.

Submitters Country:

USA

Thu-Af-Po4.11 / 125

New Bridge Temperature Sensor for Superconducting Magnets and other Cryogenic Applications

Alexey Dudarev¹ ; Johan Bremer¹ ; Tim Mulder² ; Matthias Mentink¹ ; Jeroen Ter Harmsel³ ; Herman Ten Kate¹

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³ *Twente Technical University (NL)*

A few hundred temperature sensors are used to control the temperature behaviour of the gigantic ATLAS toroid superconducting magnet system during cool down and normal operation. In order to guarantee good sensitivity of temperature measurements in the range from liquid helium to room temperature, two types of sensors are positioned at the same location: platinum resistance thermometers for the range 30-300 K and carbon composition resistors (Allen-Bradley) for the 4 to 30 K range. Both types are very well known for use in cryogenics and they perform nicely during 10 year of ATLAS operation. The sensors are easy available and cheap and the main cost is for the many kilometre of cold and warm instrumentation cables, connectors, conditioners and installation work. A reduction of the amount of measurement channels is an important issue and this motivated us to develop a new compact and robust sensor module covering the entire temperature range that would combine advantages of both platinum and carbon resistors. The solution is trivial, elegant and simple. Two resistors with positive temperature derivative and two resistors with negative temperature derivative are connected in a full bridge connection. We used two platinum and two carbon resistors. The output signal is a result of the subtraction of voltages across positive and negative temperature derivative resistors that makes this temperature bridge sensor very sensitive for the entire temperature range. Variable temperature characterization tests were performed in helium gas environment in the CERN Cryogenic Laboratory. The bridge sensors have shown a full range sensitivity better than 0.1 mV/K at a supply current of 100 μ A. In the meantime a few other superconducting detector magnets in experiments operating at CERN are equipped with these new simple and robust temperature sensors.

Submitters Country:

Switzerland

Mon-Af-Po1.04 / 1058

New Modular Magnetic Equivalent Circuit of Dual-Permanent-Magnet-Excited Machine with Modulation Effect Consideration

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Co-author(s): Yang Shen¹ ; Jinghua Ji¹

¹ *School of Electrical and Information Engineering of Jiangsu University*

Recently, based on the effect of magnetic-gearing or field-modulation, a new dual-permanent-magnetic-excited (DPME) machine attracts extremely attention. Due to its high-torque density, DPME machine can be used in direct-drive applications such as wind power generation and electric vehicles propulsion. However, it should be noted that its complex bi-directional PMs structure and the so-called bi-directional filed modulation effect (BFME) will definitely increase the modeling and analysis difficulty of the magnetic field. In order to solve the problem, this paper will propose a new modular dynamic equivalent reluctance network method, which possesses high accuracy, applicability and short computing time. The proposed model is based on magnetic equivalent circuit (MEC) theory, in which the flux distribution is different at the no-load and on-load conditions on account of the modulation effect. Two methods is investigated in order to model two cases. Namely, the no-load one is built based on the exact air-gap modeling method, while the on-load one is constructed based on the simplified air-gap modeling approach. Further, leakage flux in stator teeth and iron saturation are considered in the models. Moreover, a novel modified circuit computing method is developed to accelerate convergence speed in iteration process for the two situations. Then, the improved MEC method is used to preliminarily analyze and validate the air-gap flux density, back-electromotive force, torque and inductance. Lastly, the proposed method is verified by using finite-element method and experimental results.

Submitters Country:

China

Tue-Mo-O10 / 325**New design of a pulse magnet for the J-PARC RCS injection shift bump magnet**Tomohiro Takayanagi¹ ; Yoshiro Irie² ; Kazami Yamamoto¹ ; Junichiro Kamiya¹ ; Pranab Saha¹ ; Tomoaki Ueno¹ ; Koki Horino¹ ; michikazu kinsho¹¹ JAEA/J-PARC² KEK

The 3-GeV Rapid-Cycling Synchrotron (RCS) at the Japan Proton Accelerator Research Complex (J-PARC) has achieved the designed high power beam operation at 1 MW output. The study of an upgrade plan is then started to realize the 1.5-MW beam power. Regarding the radiation protection at the upgrade plan, a new injection system has been proposed to secure enough space for radiation shielding and maintenance work. For this purpose, it is necessary to integrate the splitted iron cores of the injection shift bump magnet into one core, the length of which is shorter than the total length of the splitted cores. The number of coil turns for the new one core magnet is then increased from 2 to 4. The structural design of the new shift bump magnet excited at 25Hz repetition rate is in progress from view point of eddy current losses at the magnet edge and the coil temperature by using the OPERA-3D. This paper details these aspects and outlines the new power supply briefly.

Submitters Country:

JAPAN

Wed-Af-Po3.02 / 318**New inspection method of joint resistance at room temperature for ITER TF Coil****Author(s):** Hideki Kajitani¹**Co-author(s):** Tsutomu Hemmi¹ ; Yasuhiro Uno¹ ; Tatsuya Shimizu¹ ; Minoru Yamane¹ ; Mio Nakamoto² ; Kunihiro Matsui¹ ; Norikiyo Koizumi¹

¹ *National Institutes for Quantum and Radiological Science and Technology*

² *National Institutes for Quantum and Radiological Science and Technology*

It is important to achieve sufficiently low joint resistance (RJ), such as order of nano ohm, in ITER TF coils. However, a huge equipment is necessary to measure RJ at 4 K because of huge mass and size of TF coil. On the other hand, according to experiences by the authors, good RJ could be successfully achieved in ITER EDA model coils. In addition, severe process control is being done in ITER TF coil joint manufacture. However, it is useful to confirm RJ with simpler inspection. Authors therefore developed the inspection method, which enables to detect some abnormality in joint, while it is not direct estimation of RJ at room temperature. RJ of TF coil joint is mainly determined by contact resistance between cable and copper sole of the joint box (R_c), and contact resistance between copper sole soldering. Quality of soldering can relatively easily be controlled by process control and inspected by visual inspection. In contrast, R_c cannot be inspected at all so far. Therefore, the authors focused on development of inspection of R_c . R_c affects current penetration length (CPL) between cable and copper sole. The author thus supposed that when joint could be fabricated with proper process (i.e. R_c is sufficiently low), the behavior of CPL is repeatable. On the other hand, when there is some abnormality in manufactured joint, we can find irregular behavior on CPL from the normal repeatable behavior. Thus, authors established measurement system to acquire voltage profile of copper sole at room temperature. As results of the measurement, good repeatability of CPL could be shown in actual all ITER TF coil joints tested, while significant difference of CPL was observed in a joint sample which includes some disturbances. Thus, we can conclude that simple inspection method of R_c could be developed.

Submitters Country:

Japan

Thu-Af-Po4.09 / 323

New method for magnet protection systems based on a direct current derivative sensor

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Co-author(s): Daniel Calcoen¹; Reiner Denz¹; Jens Steckert¹; Mikael Balto Storkersen²

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² *Bergen University College (NO)*

A new method of the Quench Detection Systems (QDS) designed for the LHC 600 A corrector magnet circuits and 6 kA Individual Powered Quadrupole (IPQ) magnet circuits is presented. In order to improve the dependability of QDS a direct measurement of the power converter current derivative is proposed. Actually, the quench detection scheme for the 600 A corrector magnet circuits uses the current derivative numerically evaluated from a direct current measurement. In order to make the calculation of the derivative stable, the input signal is heavily filtered, thus introducing a significant phase shift, which restricts the operational range of circuit parameters like ramp rate and acceleration. For the 6 kA IPQ magnet circuits the main quench detection is based on a classical bridge configuration. The introduction of an additional detection channel for the direct measurement of the current derivative helps to overcome the lack of sensitivity to fully aperture symmetric quenches of the bridge configuration. Transformer-based current derivative sensors are currently under development, using cut-cores for easy prototyping, performance control and installation. Prototypes for the ± 600 A current range and ramp rates between 0.1 and 5 A/s were build using different core materials (electrical steel and nanocrystalline cores), and pickup coils with 10000 and 20000 windings. In order to characterize the prototypes, the performance was defined in terms of mean sensitivity of the sensor response in V/A/s and the Performance Quality Factor (PQF), defined as a percentage of nonlinearity of the response. An optimization procedure was implemented for finding the best configuration of the sensors, i.e. the airgap in the cut core in order to maximize the mean sensitivity and to minimize the PQF. The tests were carried out at different working points (current ranges and rates) showing promising results (PQF < 0.5 % with a sensitivity of 5.5 mV/A/s).

Submitters Country:

Switzerland

Wed-Af-Po3.12 / 715

Non-uniform ramping loss distribution of multiple no-insulation REBCO magnet

Yawei Wang¹ ; honghai song² ; Min Zhang¹ ; Zhiyong Hong^{None} ; Zhijian Jin^{None} ; Weijia Yuan¹¹ *University of Bath*² *Brookhaven National Laboratory*

This paper presents a study on the ramping loss of a high-temperature superconductor (HTS) no-insulation (NI) magnet consisting of multiple coils. An HTS magnet consisting of 14 identical NI coils are investigated. To calculate the ramping loss, a numerical model is built by coupling an equivalent circuit network model and an H-formulation HTS model. During ramping operations of the NI HTS magnet, Joule loss is generated on both turn-to-turn resistances and superconducting layers. The former one generated by the radial current is called 'turn-to-turn loss'; the latter one induced by flux creep and jump is called 'magnetization loss'. Both the turn-to-turn loss and magnetization loss shows a considerable non-uniform distribution among coils of the NI magnet, which is induced by the unbalanced electromagnetic coupling between different coils. Highest turn-to-turn loss happens in the middle part of the magnet, while highest magnetization loss happens at the end of the magnet. Since the turn-to-turn loss is often one order of magnitude higher than the magnetization loss, highest total ramping loss happens in the middle part of the NI HTS magnet. While in the conventional insulated HTS magnet, highest ramping loss happens on the ends of the magnet. This unique characteristic has to be considered carefully in the engineering design of NI HTS magnet.

Submitters Country:

UK

Thu-Af-Po4.05 / 523

Nonlinear Sensorless Control including Zero Speed of Permanent Magnet Synchronous Motor Drives

Author(s): Kyoung-Jin Joo^{None}**Co-author(s):** Seung-Joo Kim¹ ; Ju Lee²¹ *Korea Testing Certification*² *Hanyang University*

An internal permanent magnet synchronous motor (IPMSM) has a high output density per volume but has non-linear characteristics due to a beta angle control. Moreover, it is also difficult to precisely control by changing the motor parameters in a nonlinear manner with magnetic flux and torque according to load and temperature characteristics during operation. Therefore, we propose a new sensorless method based on a stability of Lyapunov that drives robustly IPMSM from zero speed by detecting the stability of the motor operation in real-time according to these changes. Lyapunov stability theory is crucial to stability analysis in control theory. In particular, if the parameters of the system are uncertain in robust stability analysis, it is necessary to find an appropriate evaluation value using the Lyapunov equations. This paper shows how this approach can be used to apply algorithms to tune parameters in motor systems. To do this, we first derive a differential equation for the error, and use the Lyapunov function candidate (LFC) to prove that the error dynamics equation is asymptotically instable. To ensure convergence of the error to zero, the Lyapunov function is chosen as follows. “^” is estimation value.

$$V(\text{Flux}_d^{\wedge}, \text{Flux}_q^{\wedge}, \text{Estimated_speed}) = 1/2\{(\text{Flux}_d^{\wedge} - \text{Flux}_q^{\wedge})^2 + (\text{Flux}_q^{\wedge})^2 + 1/r(\text{Estimated_speed})^2\}$$

When this LFC is developed by definition of the function, for known values of the initial rotor position, R_s , L_s , λ_f , the observer can converge to the correct rotor position. The results of simulation and experiment should be included in the full paper. The proposed algorithm has been verified via simulation and experiment, and the results show that this method has been successfully implemented over all speed range. And the method is able to produce estimates of position and speed with a precision good enough to replace position sensor.

Submitters Country:

Republic of Korea

Thu-Af-Po4.02 / 485**Nonlinear multiscale structural analysis of a superconducting coil and support structure for the helical fusion reactor****Author(s):** Hitoshi Tamura¹**Co-author(s):** Takuya Goto¹; Nagato Yanagi¹; Junichi Miyazawa¹; Teruya Tanaka¹; Akio Sagara¹; Satoshi Ito²; Hidetoshi Hashizume²¹ *National Institute for Fusion Science*² *Tohoku University*

The system architecture of a fusion reactor demands an enhanced magnetic field and downsizing to improve plasma-confinement and reduce the difficulties in construction. Since an electromagnetic force induced by a magnet system is proportional to the square of the magnetic field intensity ratio, the stress on the magnet system can be extremely severe. For FFHR, a helical fusion reactor, several design options are being studied. For instance, FFHR-d1A is a steady-state self-ignition demonstration reactor that operates at a magnetic field intensity of 4.7 T; moreover, the helical coil's major and minor radii in this type of reactor are 15.6 and 3.744 m, respectively. Furthermore, FFHR-c1 is a small-size reactor that aims to realize steady electrical self-sufficiency. It has a magnetic field intensity of 7.3 T and 0.7-times reduced major and minor radii as compared with those of FFHR-d1A. According to the latest structural analysis of the magnet system of FFHR-d1A, the maximum von Mises stress in the coil support structure was 764 MPa at a typical thickness of 250 mm. The coil support structure of the reduced-size FFHR-c1, including its thickness, needs modification, otherwise the stress level will exceed 1.8 GPa. Coil components such as the superconductor, sheath, and insulation also need a detailed structural-soundness evaluation. A nonlinear multiscale finite element method analysis was performed to facilitate a detailed investigation of the superconducting coils and their support structure. Consequently, robust designs of the helical coil and its support structure were demonstrated. Moreover, considering a contact and a slide among the component materials in the coil, mechanical behaviors of the components were evaluated.

Submitters Country:

Japan

Tue-Af-Po2.06 / 706**Novel 4/4 Stator/Rotor Single-Phase Asymmetric Stator-Pole Doubly Salient Machine with Permanent Magnets on Stator Teeth**Wei Xu¹; Mingjie He¹; Caiyong Ye¹¹ *Huazhong University of Science and Technology*

Recently electric tools have been widely used in industrial applications and human livings, and will be increased very greatly in near future. Till now, most electric tools have been driven by concatenated induction machine, which suffers big volume, low torque density, low efficiency, poor reliability, etc. Fortunately, single-phase doubly salient permanent magnet machine (SP-DSPMM) has been decided as one good candidate for electric tools due to its advantages over high torque density, high efficiency, high reliability, low maintenance, etc. However, the traditional SP-DSPMM up to now has poor starting capability and relatively large torque ripple, which limits its wide application in electric tools. Thus, one novel 4/4 stator/rotor single-phase asymmetric stator-pole doubly salient machine with permanent magnets on stator teeth is proposed in this paper. The stator poles for the proposed machine are distributed non-uniformly along the circumference. More specifically, the angle between adjacent stator poles is 45 degrees. The radially magnetized permanent magnets are placed on the stator teeth. Full-pitch winding is adopted in the proposed machine, which is similar to that of traditional SP-DSPMM. The rotor is rather simple and very suitable for high speed application. This paper is organized as follows. Firstly, the research background of driving motor for electric tools is introduced briefly. Then, it investigates the new topology and operation principle based on diagram description and mathematical derivation. And then, the two-dimensional finite element analysis (2D FEA) models for the proposed and traditional machine are made and optimized based on the given specifications. Finally, comprehensive comparison on main electromagnetic performance indexes for the optimal machines are performed, including starting torque, average torque, efficiency and so on. It indicates that the proposed machine enjoys higher torque density, lower torque ripple, higher efficiency, higher starting torque, etc. More details will be given in the final paper.

Submitters Country:

China

Thu-Af-Po4.10 / 921**Novel Cavity Feature On Dipole Magnet Pole Face Improves Field Homogeneity While Reducing Coil Complexity****Author(s):** Christopher Yeckel¹**Co-author(s):** Paul Holen¹¹ *Stangenes Industries*

FEA simulation software OPERA 3D is used to develop a geometric cavity feature on the pole face at the beam entry and exit points of a dipole magnet. This cavity is incorporated into a prototype magnet designed at Stangenes Industries to improve field homogeneity along the beam arc to 0.1%. The magnet design handles beams entering at different angles, positions and beam energies. The optimized cavity lowers the cost and footprint of the magnet by allowing the coil to remain rectangular in shape. The magnet has been tested and installed at the beam line at LLNL as part of a compact accelerator creating radiographic images using quasi-mono-energetic fast neutrons. The dipole bends both 4 and 7.07 MeV D+ ion beam 66 degrees on a 457.2 mm radius. The magnet is also capable of bending the same beams in multiple trajectories depending on applied field strength. The field strength is adjustable up to 1.4 T center field with minimal pole saturation, but operates at 1.2T nominal.

Submitters Country:

USA

Thu-Af-Po4.06 / 408**Novel Control Strategy of Wave Energy Converter using Linear Permanent Magnet Synchronous Generator**

Author(s): Ye Jun Oh¹

Co-author(s): Ju Lee¹ ; Kyoung-Jin Joo ; Gang Seok Lee²

¹ *Hanyang University*

² *Hanyang Univ.*

There are two ways to maximize the electric power extracted from a Wave Energy Converter(WEC): The first is a passive method through the design of the buoy shape and the next is an active method by controlling the phenomenon that occurs when a Power Take Off(PTO) device extracts maximum electric power. The former method does not have a considerable degree of freedom and has several practical constraints because it depends on the structure and property of the buoy. Therefore, the latter can improve the quantity of the extracted power more conveniently through a control strategy. The permanent magnet linear generator is directly connected to a buoy and the applied WEC system extracts power through damping control. This study proposes a high-speed operation damping control strategy for a WEC. Further, a damping control method that could improve the extracted power for a wide speed range is examined. The mechanical dynamic characteristics of a WEC system against the heave motion is analyzed. The added mass, radiation damping coefficient, and the excitation force are determined using ANSYS AWQA numerical analyses. The viscous damping coefficient is derived from the free-decay test of a 1/25 down-scaled model. The results of this study show that it is possible to expand the operating region and maximize the power extraction by software implementation only, without additional hardware. The validity and benefits of the proposed control algorithm are verified by experimental results using a down-scaled WEC model. The dynamo motor speed by wave dynamics analysis is calculated and then speed command is transferred to the dynamo motor drive. The wave dynamics are second-order differential equation. In this paper, for solving the equation, the Runge-Kutta 4th method is applied. The numerical results of the model well agreed with the experimental data.

Submitters Country:

Republic of KOREA

Tue-Af-Po2.06 / 879

Novel Heteropolar Hybrid Radial Magnetic Bearing with Double-Layer Stator for Flywheel Energy Storage System

Wei Xu¹ ; Runze Zhu¹ ; Caiyong Ye¹

¹ *Huazhong University of Science and Technology*

Traditional heteropolar radial hybrid magnetic bearing (HRHMB) with eight poles has been widely applied in high-speed applications, such as flywheel energy storage system (FESS), because of its simple structure, low power loss, and high critical speed. However, this topology suffers large displacement stiffness, magnetic coupling, and non-negligible rotor iron loss. To overcome these drawbacks, one novel HRHMB with double-layer stator is proposed in this paper. In this structure, permanent magnets (PMs) are located between X and Y stator teeth, and X and Y stators are separated by PMs and nonmagnetic ring. The bias-flux is closed through PMs, X and Y stator teeth, air gap and rotor and the control-flux is closed through X/Y stator, air gap and rotor respectively. Compared with the conventional HRHMB, there are only four poles with active control coils, which means smaller displacement stiffness, less fluctuation of magnetic field and lower rotor core loss in the proposed novel HRHMB. Besides, the control of X and Y dimension in the new structure are independent of each other due to the effect of nonmagnetic ring, which decreases the control magnetic field coupling of the two dimensions significantly. This paper is organized as follows. Firstly, the topology and working principle for the new HRHMB are introduced in details. Then, the mathematical expressions are derived based on equivalent magnetic circuit model, including displacement stiffness, current stiffness and load capacity. Finally, one three-dimension finite element analysis (3-D FEA) model is built based on the given specifications to further analyze its suspension performance indexes, magnetic coupling, power losses, etc. Comprehensive investigations indicate the novel HRHMB has small displacement stiffness, good decoupling control and low rotor iron loss, which makes it more suitable to high-speed FESS. More details will be given in the final paper.

Submitters Country:

China

Wed-Af-Po3.05 / 231

Novel U-shaped Structure Switched Reluctance Machine With a Module Outer RotorHao Chen¹ ; Wenju Yan¹¹ *China University of Mining & Technology*

This paper presents a novel 16/12 outer module rotor-type switched reluctance machine. Unlike conventional structures, the rotor of the proposed structure includes a series of discrete module, and every outer module rotor is U-shaped structure and has two rotor pole. Each phase winding is composed of two series coils wrapped on two stator teeth. The short flux paths can be generated by excited adjacent phase and use the U-shaped module rotor. The module rotor can also decrease the mass of the rotor. The proposed structure may increase the electrical utilization, reduce magnetomotive force requirement and decrease the iron loss compared with the conventional machine. To verify the proposed structure, the operation principle and the design rules of the proposed machine are illustrated and expounded. The finite-element method is employed to obtain both the static and dynamic characteristics of the conventional 16/12 and proposed machine. The simulation results are presented and analyzed to confirm the effectiveness of the proposed machine. Static performance shows that the average electromagnetic torque of module machine is larger than the conventional machine and the peak torque is also large than conventional machine. The copper loss in the proposed machine is smaller than the conventional machine. The iron loss in the stator is almost equal but the iron loss on the rotor of proposed machine is smaller than conventional machine. The efficiency of proposed modular machine is larger than conventional machine. Because of the copper loss and iron losses of the proposed machine are all smaller than the conventional machine.

Submitters Country:

China

Thu-Af-Po4.10 / 411

Numeric Analysis of the Rib geometry effect on multipole magnetic fields**Author(s):** Seong Yeub Shim¹**Co-author(s):** Kalliopi Dermati¹ ; Stefan Wilfert¹¹ *GSI*

The present paper presents the effect of the secondary magnetic field by the ribs on the vacuum beam tube in the SIS100 superconducting dipole magnet. The beam tube and its components are the objects closest to the accelerated beam and exposed to the same magnetic field with the accelerated beam. Therefore, the influence on the magnetic field of the beam tube and its components on the magnetic field should be clarified for the beam operation. The ribs have geometrically long length with the direction of the applied magnetic field. This geometric structure increases the effect of the permeability of the material on the magnetic field quality. Since the ribs are located periodically in the beam direction, we compare the pattern of the magnetic fields in the plane with and without rib in the direction of the magnetic field. The effect of the ribs appears noticeably in the area more than half of the radius of the beam dynamics area. The beam direction magnetic field, which is perpendicular to the applied dipole field, is also generated. Due to the geometric shape of the rib, the phenomenon of a small permeability appears remarkably. The field effect should be also considered in rib design procedure.

Submitters Country:

Germany

Mon-Af-Po1.04 / 491**Numerical Analysis and Design of SPM Type Variable Flux Memory Motor Considering Magnetization and Demagnetization Characteristic of Permanent Magnet****Author(s):** Jin-Seok Kim¹ ; Sang-Yong Jung²**Co-author(s):** Dae-Woo Kim¹¹ *SUNGKYUNKWAN UNIVERSITY*² *Sungkyunkwan Univ*

Variable Flux Memory Motor(VFMM) is able to vary its magnetic field intensity of the permanent magnet(PM). Thus, VFMM has advantage for high speed operation with higher efficiency, when field intensity of PM is reduced. However, shape of the motor and arrangement of PM are important factors within restricted geometry of VFMM, because large d-axis current pulse is requisite to achieve high demagnetization and remagnetization ratio of PM. Moreover, the variable magnetized PM(VMPM) with low coercive force(Hc) is selected in general, for smooth remagnetization and demagnetization. For this reason, undesired demagnetization occurs on PM in load condition, since the magnetic field generated by stator reduces the magnetic field at rear edge of PM, which leads to output performance reduction of VFMM. Thus, it is necessary to design motor considering easily demagnetized part of the PM. This paper proposes a novel design method of surface mounted PM(SPM) type hybrid VFMM(HVFM). The rotor pole of proposed structure is composed of two different PM materials in each pole. The rotor PM placed in front of the rotational direction is ferrite VMPM, which is selected to vary main flux field by varying its magnetic field intensity. The PM placed at rear of the rotational direction is constant magnetized PM(CMPM), which uses NdFeB, to produce the main flux of the rotor. The arrangement of these PMs is determined to prevent demagnetization of the PM in load condition, and to take advantage of the combined PM pole, which are increase in thrust of the magnetic system and torque density of the motor. To verify the validity of the proposed structure, nonlinear 2-dimentional finite element method and magnetic equivalent circuit are adopted to analyze operation characteristics of VFMM. Finally, we propose novel design configuration and parameters of SPM type HVFM for 30kW traction motor.

Submitters Country:

Republic of Korea

Wed-Af-Po3.05 / 1140**Numerical Analysis of Variable Flux Memory Motor Considering Characteristics of Permanent Magnet Load-Line****Author(s):** Wonseok Han¹ ; Sang-Yong Jung²**Co-author(s):** Yong-Jae Kim³ ; Jun-Young Song⁴¹ *Sungkyunkwan University*² *Sungkyunkwan Univ*³ *Chosun University*⁴ *School of Electronic and Electrical Engineering, Sungkyunkwan University*

In order to achieve high efficiency over wide-speed operation, variable flux memory motor (VFMM) has been proposed. This new class of motor can control the magnetization state by applying direct-axis (d-axis) current pulses. When designing VFMM, it is important to study nonlinear magnetization state considering the electrical constraints, since the PM magnetization strength must be controlled only with limited current fed by inverter. Meanwhile, the PM magnetization characteristics of VFMM are highly correlated with how PMs are arranged in the rotor. In other words, it is significant for designers to select structural topologies for VFMM properly in initial design stage, which has great effect on the magnetization capability. In this paper, we investigated PM load-lines to identify and compare the magnetization characteristics for two general types of PM type VFMMs. The PM load-line is an essential factor to examine magnetization characteristics of VFMMs, which can be obtained with the mandatory condition to yield the PM operating points in accordance with different values of remanence flux density via finite element analysis (FEA). If the main flux path of VFMM becomes saturated, the PM load-line is distorted. Hence, the PM load-line is derived via nonlinear FEA considering magnetic saturation phenomenon in this study. Generally, it is known that if d-axis current is applied to PM motor, the PM load-line is shifted the magnetic flux density-axis horizontally on the B-H characteristic curve of the PM. However, the results showed that it does not move horizontally but in askew direction on account of magnetic saturation. The magnetization characteristics of analysis models are compared, by identifying these change of the PM load-line with respect to various d-axis current conditions. Finally, we confirm the performance of the models when those are both demagnetized and magnetized states.

Submitters Country:

south korea

Thu-Af-Po4.02 / 771**Numerical Simulation of Thermal Behavior In a No-insulation Toroidal Magnet**Yi Zhang¹ ; Yuejin Tang^{None} ; Li Ren¹ ; Ying Xu¹¹ *Huazhong University of Science and Technology*

The toroidal field (TF) magnet in Tokamak system is required generate a high-steady field to confine and shape the high-temperature plasma. To secure high current density and high thermal stability, the no-insulation(NI) winding technique is used in the fabrication of TF magnet. During plasma operation, heat generated in the TF magnet due to the interaction with central solenoid(CS) coils, poloidal field(PF) coils and the plasma current. The heat generated in NI coils is complex due to the existence of current flow between adjacent turns, thus, it is necessary to calculate the thermal problems. This paper presents the thermal behavior of a NI toroidal magnet under different operating conditions, considering the effect of turn-to-turn contact resistance. The analysis procedure combine FEM and equivalent circuit model. This analysis has applicability and practical directive to the design of cryogenic cooling system for NI toroidal magnet.

Submitters Country:

China

Tue-Af-Po2.08 / 340**Numerical Study on Electro-thermal Characteristics of Core Cable Consisted Of YBCO Coated Conductor**shanshan fu¹ ; ming Qiu¹ ; jianbo Guo¹ ; jiahui Zhu¹ ; panpan Chen¹¹ *China electric power research institute*

High temperature superconducting (HTS) device is a new application of superconducting technology in power system. In real utility, HTS device expose to environment where there exists many problems, such as crushing stress, bending stress, background magnetic field and so on. To ensure the safety of the HTS device, it is necessary to study the stability behaviors of HTS tapes. In addition, since various HTS devices require high current density cables for superconducting winding, several approaches have been developed to combine YBCO coated conductors into a cable for a large high-field magnets.

In this paper, firstly a core cable is introduced which has copper former, conductor layer and insulation layer, and its structure is similar to superconducting transmission cables, but with a much smaller former. Then a 3-D coupled electric and thermal model of the core cable is developed in a COMSOL Multiphysics environment. The model couples the electromagnetic and thermal equations through temperature dependended material properties. The thermal equation of the Joule power is computed by the electromagnetic model. The simulation results give the distribution of temperature, electromagnetic field and thermal field in the core cable with different carrying currents. And the investigation of quench caused by a distributed disturbance is useful to the stability of the core cable.

Submitters Country:

China

Thu-Af-Po4.09 / 548

Numerical and Experimental Evaluations of the Quench Detection Performance of NbTi/YBCO Hybrid Tape

Author(s): Shin Hasegawa¹

Co-author(s): Satoshi Ito¹ ; Hidetoshi Hashizume¹

¹ *Tohoku University*

Quench detection is important for the application of the high-temperature superconducting (HTS) tape, especially REBCO tape. However, there is a serious issue that voltage drop is too small to detect quench due to the small normal zone propagation velocity (NZPV) in HTS. To address this issue, we have proposed a quench detectable LTS/HTS hybrid tape consisting of the low-temperature superconducting (LTS) wire used for quench detection and the REBCO tape used for current transportation. In our previous report 1, we conducted the numerical simulation and experiment with the prototype of the hybrid tape. Then, the validity of the analysis code for the hybrid tape and the possibility that voltage occurred over the LTS wire before HTS tape burned out were demonstrated. However, NZPV and detectable voltage in the NbTi were small for the quench detection due to its copper stabilizer with low resistivity and its large critical current. According to the numerical simulations, this issue would be overcome by decreasing copper ratio or critical current of the NbTi wire. Hence, the purpose of this study is to clarify the influences of copper ratio or critical current of the NbTi wire on the quench detection performance of the hybrid tape. We made the numerical model of the hybrid tape where thin pure NbTi wire was fixed on the YBCO tape with epoxy. The simulation showed that 1 V scale voltage occurred over the NbTi wire before YBCO tape burned out when 0.1 A was applied to the NbTi wire, respectively. Details of the numerical simulation and experiment will be presented at the conference.

Acknowledgements: We would like to give gratitude to Furukawa Denko Co. and Axis Co. who provide us NbTi wires.

1 S. Hasegawa, et al. Abstracts of 1st Asian ICMC-CSSJ 50th Anniversary Conference (2016), pp. 6

Submitters Country:

Japan

Thu-Af-Po4.10 / 48

Numerical modelling of iron-pnictide bulk superconductor magnetization

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The discovery of superconductivity in iron-pnictide compounds in 2008 raised the prospect of finding high-temperature superconductivity in materials other than cuprates and a great deal of research has been carried out towards practical implementation in thin film, wire and bulk forms. Bulk superconducting materials, in particular, can be used as super-strength, trapped field magnets (TFMs) and magnetic fields greater than 17 T have been achieved in large, single-grain (RE)BCO (where RE = rare earth or Y) bulk superconductors. This makes them attractive for a number of engineering applications that rely on high magnetic fields, including compact and energy-efficient electrical machines, magnetic separation and magnetic drug delivery systems. The iron-based superconductors exhibit a number of properties attractive for applications, including low anisotropy, high upper critical magnetic fields (H_{c2}) in excess of 90 T and intrinsic critical current densities above 1 MA/cm² (0 T, 4.2 K). It was shown recently that bulk iron-pnictide superconducting magnets capable of trapping over 1 T (5 K) and 0.5 T (20 K) can be fabricated with fine-grain polycrystalline Ba_{0.6}K_{0.4}Fe₂As₂ (Ba122). These Ba122 magnets were processed by a scalable, versatile and low-cost method using common industrial ceramic processing techniques. In this paper, a standard numerical modelling technique, based on a 2D axisymmetric finite-element model implementing the H-formulation, is used to investigate the magnetization properties of such iron-pnictide bulk superconductors. Using the measured $J_c(B, T)$ characteristics of small specimens taken from bulk Ba122 samples, the experimentally measured trapped fields previously published are reproduced to good effect. Additionally, the influence of the geometric dimensions (thickness and diameter) on the trapped field is analysed, with a view of fabricating larger samples to increase the magnetic field available from such TFMs.

Submitters Country:

UK

Thu-Af-Po4.02 / 176

Numerical modelling of the quench propagation phase in the JT-60SA TF coils tested in CTF

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Co-author(s): Laurent Genini² ; Louis ZANI³ ; Patrick Decool³ ; Quentin Le Coz⁴ ; Roser Vallcorba⁵ ; Sylvie NICOLLET³ ; Alexandre Torre³ ; Benoit LACROIX³ ; Walid Abdel-Maksoud³ ; Daniel Ciazynski⁴ ; François Nunio⁶

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In the framework of the European-Japanese project JT-60SA, quench tests are performed for each one of the 18 NbTi superconducting Tokamak Toroidal Field (TF) coils in a Cold Test Facility at CEA Saclay. While launching these experimental quench tests, the conductors' Tcs are reached by progressively increasing the inlet helium temperature so as to trigger a fast discharge of nominal current

(25.7 kA) on a dump resistor (6.2 mΩ). Quite complex quench dynamics were observed due to several coupled physical phenomena's influencing the quench propagation. In order to better understand the experimental analyses on coils' quench behavior, a dedicated model has been developed by coupling two computation codes, THEA (Thermal Hydraulic and Electric Analysis of superconducting cables) for 1D thermo-hydraulic modelling along the CIC (Cable-In-Conduit) conductor and Cast3M for 2D transverse thermal diffusion in a limited number of coil cross-sections. This multi-physic platform can give a better assessment for the two quench propagations' velocity and their possible variation thanks to a more realistic assessment for heat exchange through insulation in the coil between turns, pancakes, or even between Winding Pack and Casing. In this paper, the main results of these computations will be presented and compared to the quench experimental data. The analysis will focus on the quench propagation phase after its initiation sequence by studying: the longitudinal quench propagation velocity through one conductor, the transverse quench propagation velocity from turn to turn, the impact of the casing temperature (electromagnetic quench-back) on quench propagation and the impact of the full-quenched state on quench propagation.

Submitters Country:

France

Tue-Af-Po2.09 / 547

Numerical simulation of electromagnetic and thermal hoop stresses in REBaCuO superconducting ring and disk bulks reinforced by stainless steel ring with various thicknesses during field-cooled magnetization**Author(s):** Keita Takahashi¹**Co-author(s):** Hiroyuki Fujishiro¹ ; Tomoyuki Naito¹ ; Yousuke Yanagi² ; Yoshitaka Itoh² ; Takashi Nakamura³¹ *Iwate University*² *IMRA Material R&D Co., Ltd*³ *RIKEN*

RE-Ba-Cu-O (RE: rare earth element or Y) bulk superconductors have promising potential to be used as a strong trapped field magnet (TFM), which ever can trap a field of over 17 T on a Gd-Ba-Cu-O disc bulk reinforced with the shrink-fit steel. Ring-shaped bulk cylinders with a concentric hole are also considered in practical applications, such as nuclear magnetic resonance (NMR) spectrometer and a magnetic resonance imaging (MRI) apparatus. Since bulk superconductors suffer Lorentz force due to the current-field interaction between induced persistent current and magnetic field during magnetization process, the reinforcement by a metal ring against the electromagnetic hoop stress must be considered to avoid the fracture behaviours of the bulks for the practical applications. In this paper, we analysed the electromagnetic stress (hoop stress and radial stress) in finite-height RE-Ba-Cu-O bulk superconductors with various geometries, including both disc- and ring-shaped bulks when fully activated by field cooled magnetization (FCM) from 20 T at operating temperature of 50 K, using the finite element method (FEM) based on both electromagnetic and elastic equations. The trapped field and electromagnetic hoop stress was compared between those bulks. To discuss the effectiveness of the reinforcement, a stainless steel ring with various thicknesses was fitted for each bulk. Analytical results show that the hoop stress, which concentrates at inner periphery of the ring bulk, was remarkably alleviated by the mechanical reinforcement by the stainless steel ring. The thermal compressive stress by a stainless steel ring, which was due to the difference of the thermal contraction coefficient between the ring and bulk, was also considered when cooling from 300 to 50 K. A scheme to reduce the electromagnetic and thermal hoop stress by the optimal reinforcement is proposed.

Submitters Country:

Japan

Thu-Af-Po4.02 / 345

ON A FULL 3D THERMAL STRUCTURAL AND HYDRAULIC FINITE ELEMENT MODEL OF THE JT-60SA TOROIDAL FIELD COILS

Author(s): Valerio Tomarchio¹**Co-author(s):** Manfred Wanner¹¹ *Fusion For Energy*

The JT-60SA Toroidal Field Coils (TFC) are currently being manufactured in Europe, and their assembly is progressing at full speed in QST, Naka. As part of their final acceptance, the coils are tested in working conditions and at full current in a dedicated facility in Europe. To help defining the cool down strategy for the testing of the TFCs, and also to anticipate their behavior during the cooling down of the JT-60SA tokamak, a fully 3D finite element model of a TFC has been created, which includes finite elements with both thermal-mechanical and hydraulic formulations, to simulate in real time the interaction between the Helium coolant flow and the structures. The model has been extensively used for predicting the behavior of the TFC during cool down and warm up, and the results have been benchmarked against the experimental evidence collected during the cold tests carried out in Europe. Several kind of analyses were carried out, from simple cool down simulations, to more sophisticated simulation of fast transient events, like the signature dynamic quench test which all TFCs have undergone. The model is built using the ANSYS commercial Finite Element code and is readily up-scalable to any size of similar magnets. This paper describes the rationale behind the definition of the model, and the results obtained in preparation of the first cold tests, and in view of the operation of the Tokamak. The associated modeling challenges are reviewed and critically discussed.

Submitters Country:

Germany

Mon-Af-Po1.02 / 861

OPTIMIZATION, DESIGN AND OPERATION ASSESSMENT OF A MULTIPURPOSE DETECTOR FOR NICA COLLIDER

Author(s): Martina Neri¹**Co-author(s):** Simone Grillo¹; Alessio Capelluto¹; Roberto Marabotto¹; Giorgio Salvitti²; Nicolò Valle¹; Stefano Cuneo¹¹ *ASG Superconductors s.p.a.*² *ASG Superconductors s.p.a.*

Nuclotron-based Ion Collider state-of-art design involves innovative solutions in superconductive applied technology. Thanks to its consolidated experience, ASG has been directly involved into the program by providing to Joint Institute for Nuclear Research (JINR) a large 0.5 T Nb-Ti superconductive magnet equipped with an active (resistive) modulation system. Typical solutions have been specifically optimized in order to guarantee the maximum flexibility in all operative conditions. ASG has been involved in the whole design of magnetic, structural, thermal and protection systems. Magnetic configurations meeting optimized field requirements have been identified also accounting in detail the expected significant technological deviations. The two resistive coils, forming the active modulation system, principally perform the identification of the optimized magnetic configurations. Lorentz forces and coil interactions produced by the system have been calculated in order to verify mechanical structure and stresses on the coils. The protection system of the magnet in case of quench has been designed in order to minimize thermal stresses on the cold mass components. The electro-magnetic interactions between components, during dynamic events, have been evaluated in order to verify the cryogenic and structural stability of the system. Manufacturing phase is ready to start. Main results will be presented to illustrate the adopted process and technological solutions.

Submitters Country:

Italy

Wed-Af-Po3.06 / 372

Obtaining of Inductance with Dependence on Rotor Position via Measurements, and Modeling of Inductance using Analytical and Fast Fourier transforms approaches for Lumped Parameter Model ApplicationsDmytro Bilyi¹¹ FEAM GmbH

The following publication describes a method for obtaining and modeling of the stator inductances. This method was verified with measurement results on a claw-pole synchronous machine. Based on the described analytical and FFT methods, a script for the modeling of the stator inductances has been designed. Three methods for modeling the stator self- and mutual-inductances, such as, based on measurements, FFT and analytical calculations, have been considered, reviewed and compared. The proposed analysis for self- and mutual inductances allows modeling the inductances matrix with dependence on rotor position (which was previously proved as essential) and based on that the two decoupled dq frames can be derived and implemented for control of multiphase machines.

Submitters Country:

Germany

Mon-Af-Po1.08 / 839

Ongoing efforts at internal-tin Nb₃Sn strand with higher J_c and lower Q_h for fusion applicationJianwei Liu¹ ; Ke Zhang¹ ; Yigong Shi¹ ; Jianfeng Li¹ ; Xianghong Liu¹ ; Yong Feng¹ ; Pingxiang Zhang¹¹ Western Superconducting Technologies, Co. Ltd.

After mass production for ITER, Western Superconducting Technologies, Co. Ltd. (WST) still takes great efforts at internal-tin (IT) Nb₃Sn strand with higher J_c and lower Q_h, for next generation of fusion reactors, such as DEMO in Europe and CFETR in China. Three routes, i.e. Cu split, Sn spacers and 37 subelements were carried out to obtain such strand, based on the structure and process of IT Nb₃Sn strand for ITER. The route of Cu split was discovered to be most efficient to decrease Q_h, which could be as low as 300 mJ/cm³, 30% lower than the average of ITER IT Nb₃Sn strand. Nevertheless J_c was also reduced to about 900 A/mm², 10% lower than the ITER average due to the loss of Nb area by inputting Cu split. Sn spacers between outermost subelements enhanced J_c to about 1100 A/mm² without obvious increase of Q_h, though Sn spacers could be quite harmful to the deformation of Ta barrier. J_c of strand with 37 subelements could reach 1100A/mm², about 20% higher than the average J_c of ITER IT Nb₃Sn strand, and Q_h could be as low as 400 mJ/cm³. This strand was delivered to EPLF, Switzerland to fabricate experimental conductor sample for DEMO.

Submitters Country:

China

Wed-Af-Po3.05 / 211

Online Parameter Identification for IPMSM by Electric Torque Estimator

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² *Hanyang University*

This paper proposed a new magnetic flux estimation algorithm. The magnetic flux of IPMSM is different from the actual operation points because it changes according to the external environment and the condition of the motor. Since the d-axis inductance is constant in the conventional techniques, it is difficult to accurately estimate the magnetic flux due to the inductance error because the nonlinearity of the inductance due to saturation of the core cannot be considered. Therefore, this paper deals with the design of a model reference adaptive control (MRAC) for the magnetic flux of the PMSM estimation. Unlike the convenience algorithms, the proposed magnetic flux estimation algorithm does not need information on inductances. Therefore, it can estimate parameter regardless of the change according to operation point and cross-saturation effect. The validity and usefulness of the proposed estimation technique is verified by MATLAB/Simulink and experimental results. The proposed algorithm is based on the reactive power. In this paper, reactive power expressed by d and q axis current and voltage is used as an adaptive model, and the reactive power expressed by the parameters of the equivalent circuit is used as an adjustable model. The magnetic flux can be estimated by the adaptive mechanism of the error between the reference model and the adaptive model. This technique can also be used when the d and q axis inductances are unknown. Further, since saturation of the core can be considered, it is possible to estimate the flux through the permanent magnet which is robust to the condition of the motor and the external environment.

Submitters Country:

Republic of Korea

Thu-Mo-Or32 / 454

Open Material Property Library With Native Simulation Tool Integrations (OpMaST)

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² *CERN*

Reliable material property data is crucial for trustworthy simulations in magnet design phase. The variety of tools scientist and engineers utilise for electromagnetic and mechanical design and quench, at least, is large. Centralised effort to distribute material data within communities, like superconductor accelerator magnet R&D community, will result in large time savings. We have started developing a database for storing all kind of material property data online. This includes, but is not limited to, anisotropic critical current surfaces for high temperature superconducting materials, electrical resistivities as a function of temperature, RRR and magnetic field, general fits for describing material behaviour etc. This database is easily accessible even with a mobile device and it has easy-to-use native integration tools for various programming languages, modelling frameworks and software. The reliability of the data can be assessed by stars given by users. With a large user base this defines the best data for various needs. This work introduces the database and is the reference document for citing the database when it is used.

Submitters Country:

Finland

Tue-Af-Po2.12 / 321

Operating Characteristics of Underwater Wireless Power Transfer for Maritime Applications Using Strong Copper Resonance Coupling Coils

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¹ *suwon Science College*

² *Yonsei University*

The wireless power transfer (WPT) technology based on strongly resonance coupled method realizes large power charging without any wires through the air. Recently, the WPT systems have started to be applied to the wireless charging for unmanned underwater vehicles (UUVs), power is the critical factor that often determines mission lifetime. Unlike many terrestrial vehicles, where batteries can be easily replaced or recharged, UUVs must either surface for battery replacement, or make watertight connections to safely recharge. In both cases, the solution typically requires human interaction, which increases the risk to both the vehicles and operators, as well as raising the total operating cost. One solution for increasing the operational lifetime of UUVs is the use of resonance coupled power transfer system to wirelessly recharge the vehicle batteries while the UUV itself remains submerged. While the commercial protocols for wireless power transfer are useful for many consumer applications, there are a number of challenges that limit their use for UUV charging in the maritime environment. To expediently charge a UUV, it is desirable to charge at higher power levels. The development of a functional underwater wireless power transfer system for charging UUVs is a complex process and requires an examination of many factors, including bio-fouling, thermal dissipation, power transfer, and communications between the transmitter and receiver. This paper focuses specifically on the wireless power transfer portion, and presents the fabrication and characterization of a power transfer system capable of delivering up to 120W to the load. The experimental setup used to demonstrate power transfer to a resistive load is then presented, followed by a discussion of the measured power transfer efficiency in both air and water using RF Power of 370kHz and 100kHz of 1KW rate. Finally, conclusions and future work are presented.

Submitters Country:

South korea

Tue-Af-Po2.12 / 541

Operating characteristics of Arc-induction type DC circuit breaker

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AC CB(circuit breaker) at the fault occurred in the existing AC distribution system is limiting the fault-current through zero crosspoint. But, DC CB does not have zero crosspoint. Therefore, arc occurred by on-off operation of DC CB is very huge. Nowadays, many research team are studying the way to decrease breaking time which is one of the essential conditions in DC CB. We suggested novel arc-induction-type DC CB in this paper. The proposed arc-induction type DC CB is composed of the mechanical Arc-ring and DC CB. We confirmed the operation of arc-induction DC CB through the Maxwell 3D simulation program and performed the experiment for operation characteristics. Results showed that arcing time of the arc-induction-type DC CB by using induction ring was faster about two times than existing mechanical DC CB. On the transient system, we confirmed stable operation characteristics of the arc-induction-type DC CB through the simulation and experimental results. We expect that the proposed arc-induction-type DC CB technology is will go to stay ahead

of the existing DC CB technology.

This research was supported by Korea Electric Power corporation [grant number: R15XA03]. This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (NRF-2015R1D1A1A01059489)

Submitters Country:

South Korea

Mon-Af-Po1.11 / 63

Operation of the helium cryogenic system for the hybrid superconducting outsert at CHMFL

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¹ CHMFL

A hybrid magnet which is capable of producing more than 40 T steady field has been put into operation early this year at CHMFL. The superconducting outsert of the hybrid magnet is wound with Nb₃Sn CICC and cooled with forced flow supercritical helium at 4.5 K. The helium cryogenic system mainly includes a helium refrigerator and a cryo-distribution box for cooling superconducting coils, structures, transfer line and current leads. This paper highlights the main features and operating situations of the helium cryogenic system.

Submitters Country:

CHINA

Wed-Af-Or25 / 183

Operational Experience with the MICE Spectrometer Solenoid System

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The Muon Ionization Cooling Experiment (MICE) located at Rutherford Appleton Laboratory at England utilizes a superconducting solenoid system for the muon beamline that also holds particle tracking detectors and muon absorbers inside their bores. The solenoid system installation has been completed in summer of 2015 and after commissioning of the system it has been running successfully. This paper summarizes the commissioning results and operational experience with the magnets focusing on the performance of the two Spectrometer Solenoids built by the US.

Submitters Country:

USA

Mon-Af-Po1.02 / 1030

Operational experience with the combined solenoid/dipole magnet system of the COMPASS Experiment at CERN

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In 2015, the first ever polarized Drell-Yan experiment was performed at the COMPASS spectrometer at CERN. A 190 GeV/c pion beam with an intensity of 108 pions/s interacted with a transversely polarized NH₃ target. The hydrogen nuclei in the solid-state NH₃ are polarized by dynamic nuclear polarization (DNP) in a 2.5 T longitudinal magnetic field, while the target material is cooled down to below 100 mK. Transverse polarization is obtained by rotating the magnetic field and thus making use of the superposition of the magnetic fields generated by a solenoid as well as a dipole magnet, which are both superconducting and integrated in a common cryostat. The main solenoid coil comprises three sections and is complemented with 16 superconducting shim coils. It provides a 2.5 T magnetic field along the particle beam axis. The magnet has a large aperture, which is essential for the COMPASS spectrometer acceptance. The Solenoid has inner and outer radii of 340 mm and 361 mm, respectively. Over the volume of the target cells, the homogeneity is better than 10⁻⁴. Besides this homogeneous solenoidal magnetic field necessary for the DNP, in addition a saddle type dipole coil enclosing the solenoid is required, providing 0.63 T transverse magnetic field used in the frozen-spin mode to keep the polarization during data taking. It has inner and outer radii of 420 mm and 452 mm, respectively. The system is slightly over 2 m in length. One of the operational difficulties is the interaction between the main coil sections and the large forces that are involved. The stored energy of the system at nominal current, i.e. 650 A for the main solenoid – and 590 A for the dipole circuit, are 2.58 MJ and 0.468 MJ, respectively. The operational experience with this unique system and its controls will be presented.

Submitters Country:

Switzerland

Mon-Af-Po1.03 / 658

Optimal Design Methodology of Multi-Width HTS Magnet

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It is well known that critical current (I_c) of an high temperature superconductor (HTS) magnet comprising a stack of pancake coils is limited by that of “one” pancake, while the rest of the pancakes still have substantial margin to their own I_c . This unfavorable design issue is often mitigated by the so-called multi-width (MW) technique, where pancake coils wound with the narrowest tapes were placed at and near the magnet center and those with progressively wider tapes toward the top and bottom of the magnet. To date, several MW HTS magnets were fabricated and successfully generated their target fields significantly larger than those of their single-width counterparts. Currently, the SuNAM provides MW tapes grading width of 4 – 12 mm in every 1 mm. So far, critical currents of the previous MW magnets were mostly limited by the I_c of the top or bottom most pancake wound with the narrowest tape, chiefly due to the angular dependency of the tape’s I_c . Further grading of the tapes, say in every 0.5 mm, may be beneficial in terms of mitigating the tape’s angular dependency in the magnet. This paper investigates an optimal design methodology for MW HTS magnets. For a given design target of field strength and winding bore, input parameters include tape width, number of grading tapes, and number of pancakes coils for each tape, while the main objective is to minimize the magnet volume, i.e., essentially the stored energy and thus the cost. A magnet with a

single-width tape is also designed as a control sample for comparison. The results are expected to be beneficial to determine the practical level of HTS tape grading and estimate a volume of an MW magnet.

This work was supported by KBSI grant (D37611) to S.-G.L funded by the Korea Basic Science Institute (KBSI).

Submitters Country:

Korea

Tue-Af-Po2.10 / 282

Optimal Design of the LTS Magnet employing Genetic Algorithm for EMPS

Jang Jae Young¹ ; Young Jin Hwang¹ ; Sangjin Lee² ; Myung Su KIM¹ ; Yeon Suk Choi¹

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² *Uiduk University*

A 5 T low temperature superconducting magnet is designed and will be fabricated for EMPS (Electro-Magnetic Property measurement System) whose sample space is 50 mm in diameter. Since the sample space is twice larger than that of the conventional property measurement systems, it will be possible to measure the electro-magnetic properties of several samples at a time, therefore measurement time could be reduced. With the genetic algorithm incorporated with the linear-programming, optimal design of the 5 T LTS magnet was carried out; 50 mm space field uniformity, magnetic stress, critical current under the magnetic field and cryostat dimensions are considered in the optimizing process. The linear-programming restricts the magnet space and structure to minimize total volume of the wires. Meanwhile, the genetic algorithm calculates the layers, turns and detail dimensions of the magnet in the magnet space confined by the linear-programming. In addition, quench analysis employing finite difference equations in liquid helium was carried out to verify the thermal stability of the LTS magnet. The quench simulation code calculates heat transfer among the unit cells and joule heat of the magnet in three dimension space. The temperature as well as current profiles of the magnet during a quench is investigated using the simulation result.

Submitters Country:

South Korea

Thu-Af-Po4.05 / 912

Optimal desing of PMA-synRM for electric propulsion system considering wide operation range and demagnetization

Author(s): Sang-Yong Jung¹ ; Gyeong Jae Park^{None}

Co-author(s): Jin-Seok Kim¹

¹ *Sungkyunkwan University*

In this paper, permanent magnet assisted synchronous reluctance motor (PMA-synRM) is designed for electric vehicle propulsion system. Synchronous reluctance motor (synRM) does not contains magnet, so that the cost of the motor remains low even the price of the rare-earth magnet increases dramatically. Moreover, it has advantage on high power density due to its structure and thermal robustness owing to low losses at the rotor unlike induction motor or wound rotor type motor. However, synRM could not operate wide operating region since motor does not produce field flux by magnet or wound coil. PMA-synRM is one of the solutions for synRM to operate in wide range.

Most of the PMA-synRM is considered to use ferrite magnet, since it is alternative for the rare-earth magnet motor. Currently price of the rare-magnet is not much higher than ferrite with much higher performance. Therefore, ferrite and the rare-earth magnet are both considered to design PMA-synRM and the of the both magnet model are compared in this research. Optimization on position and the magnetized direction of the magnet is conducted for each model to have best performance. Secondly, demagnetization possibility is considered at design stage. Since PMA-synRM uses limited amount of magnet, it is very vulnerable to demagnetization. Therefore, design considering magnet not to be demagnetized is conducted. Demagnetization simulation is conducted with numerical analysis based on finite element method. Lastly, torque versus speed curve is calculated to prove the operating region is widen. PMA-synRM is compared with synRM to prove its development of the performance and with the other type of motor, such as induction and wound type motor to validate its compatibility..

Submitters Country:

Republic of Korea

Tue-Af-Po2.11 / 1178**Optimising rotor speed and design for an externally-mounted HTS dynamo****Author(s):** Rodney Badcock¹ ; Chris Bumby² ; Andres Pantoja² ; James Storey² ; Zhenan Jiang¹**Co-author(s):** Aaron Barnes²¹ *Robinson Research Institute*² *Victoria University of Wellington*

The HTS dynamo is a type of superconducting flux pump which employs a series of permanent magnets mounted upon a mechanical rotor. Interaction between flux from the rotor magnets and a coated conductor stator wire gives rise to a time-averaged DC emf, which is imposed across a series-connected superconducting coil. By employing a pair of soft ferromagnetic yokes, the device can be arranged such that all active moving parts are placed outside of the cryogenic environment. This minimises thermal losses and provides ease-of-access for maintenance. This arrangement offers great promise as an external 'brushless exciter' for next generation HTS generators and motors. A detailed numerical model of HTS dynamo operation is not presently available, so optimisation of these devices proceeds largely via empirical experiment. Here we report a detailed characterisation of the effect of rotor speed and magnet arrangement on the output performance of an experimental dynamo. Our results show that device performance is determined solely by the frequency at which magnets cross the stator, whilst being independent of the absolute speed. This is consistent with existing qualitative understanding of device operation. We further show that device output becomes unstable at very high rotor speeds. The threshold speed at which these instabilities emerge is systematically affected by the thermal coupling of the stator wire to the surrounding cryogenic environment.

Submitters Country:

New Zealand

Thu-Af-Po4.06 / 154**Optimization Design and Forecast Direct Control System Research on Bearingless Permanent Magnet Synchronous Generator****Yamin Hu¹ ; Huangqiu Zhu² ; Chenyin Zhao^{None}**¹ *Jiangsu University*

² *Jiangsu university*

To avoid the mechanical wear, machine noise and improve the service life of the conventional permanent magnet synchronous generator (PMSG), a bearingless PMSG (BPMSG) is proposed in this paper. The novel BPMSG which integrated the advantages of the conventional PMSG and magnetic bearings has a wider range of application in aeronautics and astronautics, national defense, new energy, and etc.. To begin with, the principles of suspension and the electric power generation are described in detail. Then, the flux linkage and induced voltage equations are derived. Based on the Maxwell tensor method, the mathematical models of the suspension force and electromagnetic torque are established and verified by the finite element analysis (FEA). Parameter analysis is utilized to acquire higher performance, however, the suspension and power generation performance is obviously affected under variable load and speed conditions which shown in the dynamic analysis results. Thus, a forecast direct control strategy based on flux-linkage observation is proposed to remedy the defects of the unstable suspension force and generating voltage caused by the operation changing suddenly. The simulation results show that that the suspension force quickly return to stability within 0.02 second, the overshoot of voltage is reduced to 8.18% and the steady adjustment rate of voltage is 0.45%. Finally, a prototype of a 2.2kW BPMSG is manufactured and tested. The experiment results show that the proposed BPMSG can not only operate steadily under variable load and speed condition, but also have good suspension performance and power generation quality.

Submitters Country:

China

Tue-Af-Po2.06 / 328

Optimization Design of Bearingless Synchronous Reluctance Motor

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In the past two decades, a bearingless synchronous reluctance motor (BSynRM) was proposed and developed. Besides the advantages of the traditional bearingless motors, the BSynRMs have the advantages of simple structure, low cost, low losses and can realize high speed operation using flux weakening control. Therefore, the BSynRMs have broad application prospects in vacuum, high speed, high precision and many other industrial fields. However, the structure of salient pole rotor and the absence of permanent magnets in the BSynRMs lead to low torque density and low power factor, which limit its scope of application in some degree. To balance the contradictions mentioned above, a permanent magnet assisted BSynRM (PMA-BSynRM) is proposed in this paper. Firstly, the basic structure and operation principle of the proposed motor is described detailedly. Secondly, the mathematic model of the radial suspension forces is derived with Maxwell stress tensor method. Then, the parameters of flux barrier layers, rotor air gap ratio, rotor rib width and permanent magnets are optimized. In order to compare the performance of the BSynRMs, based on the finite element analysis (FEA), the BSynRMs with salient pole rotor and the permanent magnet assisted rotor are designed respectively. The simulation results show that the torque density and power factor of the proposed motor increase about 14% and 26% compared with the one with normal rotor, while the average suspension force decreases about 4.6%. Finally, the permanent magnet assisted rotor is adopted to the prototype and new integrated 2x3 phase power inverters with digital controller are applied to build the experimental platform, and the results of the experiment validate correctness of the proposed theory.

Submitters Country:

China

Mon-Af-Po1.07 / 492

Optimization Design of a Permanent Magnetic Actuator for 126kV Vacuum Circuit Breaker

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¹ *Southeast University*

² *Southeast University*

Permanent magnetic actuators (PMAs) have been widely used in driving mechanism of medium-voltage vacuum circuit breakers (VCBs) due to their high reliability and controllability. Different from the applications in medium-voltage situations, the PMA used in high-voltage power system has much longer stroke and requires a much higher velocity, which limit the application of traditional PMA in high-voltage field. In the available literature a bistable PMA with separated magnetic circuits has been proposed. The PMA consists of holding and driving components whose magnetic circuits are separated, which helps to improve the efficiency of coil currents to drive the movable contact. This PMA exerts a good closing performance, however, its breaking performance is not satisfactory due to the fact that coil inductor prevents the rapid growth of current during the initial phase of breaking operation. This paper focuses on the optimization of a monostable PMA with separated magnetic circuits, in which the breaking operation is completed by the spring. This paper divides the whole optimization into three sub-optimization modules, including the optimization of permanent magnetic holding mechanism, breaking spring mechanism and closing driving mechanism. These three sub modules are optimized sequentially and recurrently until the overall performance reaches the best. The average velocities of closing and breaking operations are set as the constraints to make them within the specified range, which is critical to successful operation of VCBs. Final velocities, time durations of both operations and the volume of the mechanism are selected as the optimization goals. As design variables, parameters of excitation circuits and spring, and dimension parameters will be optimized through transient analysis, which is realized by finite element method. The optimization model and algorithm will be studied and the performances in the initial model and the optimized model will be compared in the full paper.

Submitters Country:

China

Mon-Af-Po1.09 / 145

Optimization of 2G HTS Current Leads Working at External Magnetic Field

Vasily Zubko¹ ; Vitaly Vysotsky¹ ; Sergey Fetisov^{None} ; Sergey Zanegin^{None} ; Alexander Nosov^{None}

¹ *Russian Scientific R&D Cable Institute*

Current leads with use of high temperature superconductors (HTS) permit to reduce sufficiently heat transfer to liquid helium in many superconducting magnets applications. They are one of the widest HTS applications. For example, in Large Hadron Collider more than 3000 units of such current leads are used providing sufficient saving of heat transfer to liquid helium. HTS current leads made of 1G HTS tapes are considered for ITER magnet system as well. In most cases the HTS current leads are working in a self-field being removed from the area of a scattered magnetic field generated by a magnet. However, in certain cases with a tight cryostat space it could be necessary to place current leads close to the magnet into an external magnetic field of a magnet. Some specific optimization of current leads in such a case is necessary. We are participation in the project in which due to space restrictions the limited size of a cryostat demands placing horizontal HTS current leads in magnetic field ~2 T. In this paper, we performed the optimization study of HTS current leads used 2G HTS tapes and able to work in the magnetic field up to 2 T. The optimal parameters of the current leads have been determined using numerical simulation. In order to approach the maximum efficiency, it is necessary to have a very good heat exchange between the current leads and evaporating helium gas. The impact of the external magnetic field on the heat leak from current leads into liquid helium has been studied.

Submitters Country:

Russia

Thu-Af-Po4.06 / 251**Optimization of HTS coils for the design of a linear generator for maritime applications**Adrian Gonzalez-Parada¹ ; Marco Bianchetti¹¹ *University of Guanajuato*

A priority topic worldwide is Energy and its sustainability, thus it is imperative to study, explore, and develop new opportunities of electrical energy sources that are efficient and sustainable. The recent developments in HTS technology make the design of innovative electrical machines based on HTS tapes promising. In particular, a large area of opportunity is the design of maritime generators to convert the alternate movement of waves and tides into electric energy. However, the electrical performance of the tape is affected by the dependence of the critical current (I_c), critical temperature (T_c), and critical magnetic field (B_c) on the electromagnetic field. Of those parameters, B_c introduces an important limitation due to the dependence of the superconducting properties on the direction and intensity of the magnetic field. In this work we will present a Finite Element Modelling (FEM) design and optimization of HTS superconducting coils in order to limit the effect of magnetic field direction on the tape for application in a linear generator. The FEM analysis will make use of experimentally measured values such as $I_c(\alpha, B)$, and the final design will be experimentally verified, measuring the electromagnetic performance of the HTS coil, with different magnetic field orientation. Two coils made of BSCCO and YBCO tapes will be designed and evaluated.

Submitters Country:

Mexico

Thu-Af-Po4.02 / 352**Optimization of structural performance of the toroidal field coil system of a tokamak****Author(s):** Ilia Ivashov¹**Co-author(s):** Anatoly Panin²¹ *Forschungszentrum Jülich GmbH*² *Forschungszentrum Jülich GmbH*

One of the key systems of a fusion device is its magnet system producing high magnetic fields to confine plasma. The main component of the magnet system of a tokamak device consists of toroidal field (TF) coils, poloidal field (PF) coils and central solenoid (CS) coils. The shape of the TF coil has a big impact on its structural performance. When the shape is not mechanically optimized the unnecessary bending moments occur in the coil due to the electromagnetic forces acting in the coil plane. Many works on TF coils were conducted where so-called constant tension “bending free” shapes were derived using analytical expressions. The TF coils for many tokamaks like JET and ITER are designed as constant tension D-shaped ones. However, the previous studies regarded only the TF coil winding pack that was treated as a thin filament or a thin beam, thus neglecting the additional stiffness due to the winding finite dimensions, the external TF coil case and the outer intercoil structures. The impact of TFC case stiffness distribution as well as a coil shape on the in-plane bending of a coil winding is studied in this work. Based on the 2015 EU DEMO baseline design a finite element model of a constant tension “Princeton D” TF coil was developed. Electromagnetic

and structural modeling of both the initial and the developed designs were conducted and the in-plane bending in the windings was analyzed. It was shown that a coil case can significantly change bending moment distribution in the coil. A parametric optimization procedure is presented which minimizes in-plane bending in a winding pack by changing the bending stiffness of the case. The way of utilizing this approach at the early design stage for real coils is discussed.

Submitters Country:

Germany

Wed-Af-Po3.02 / 178

Optimization of the ITER Pre-Compression Ring Test Rig Flange

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¹ *Fusion for Energy*

² *F4E*

³ *ITER*

The Pre Compression Ring (PCR) is an important element of the ITER magnetic system since it improves the force distribution among the Toroidal Field magnets during plasma operation. An experimental campaign has been planned at Iter Organization (IO) to characterize the mechanical behaviour of the ring in a test rig able to simulate the ITER assembly conditions. In particular the testing machine aims at simulating the effect of the preload by means of a system of hydraulic cylinders capable to deliver 36K ton of radial pushing force. A steel "cushion" flange acts as interface between the cylinders and the ring distributing the pressure on the surface and preventing the PCR from local breakage. In this paper the shape optimization of such flange is addressed, identifying the optimal geometry basing on the contact stress on the inner surface of the PCR. The study shows how the stress peaks can be avoided obtaining a reasonably homogeneous distribution limiting the risks of peak stresses that might compromise the integrity of the component. The results of this study can also be used as a basis of future studies aiming at optimizing the Iter flange design and the behaviour of the PCR in operative conditions.

Submitters Country:

Spain

Mon-Af-Po1.04 / 293

Optimization of the Pole Piece in Coaxial Magnetic Gears for Transfer Torque Ripple Improvement

Sung-Jin Kim¹ ; Eui-Jong Park¹ ; Lee Sung-Ho² ; Yong-Jae Kim¹

¹ *Chosun University*

² *Korea Institute of Industrial Technology*

A coaxial magnetic gear (CMG) is a non-contact machine that is used to transfer torque and to accelerate or decelerate. This type of gear has several advantages, including no mechanical loss, no required maintenance, and outstanding protection against overload. As a result, they are used in various applications, such as wind power generation and electric vehicles. However, CMGs have high transfer torque ripples due to the difference in the magnetic resistance between the two rotors and the pole piece, and the torque ripple of the inner rotor is higher than that of the outer rotor. These torque ripples must be minimized during the design process because they cause vibration and

noise. Therefore, in this paper, a new pole piece form is proposed that reduces the transfer torque ripples in the CMG. The response surface method (RSM) was used to investigate the relationship between the design variables used for the proposed pole piece and the response variables, such as the transfer torque and the transfer torque ripples. The Box-Behnken design (BBD) was used to establish the experimental plans, and a 2-D numerical analysis based finite element method (FEM) was used to determine the response variables. In addition, an analysis of variance (ANOVA) and regression analysis of the design variables and response variables were used to estimate the response surface equation of the response variables to the design variables, and to determine the optimum design variables for the proposed pole piece. Detailed contents in the topology optimization procedure will be presented in full paper.

Submitters Country:

Rep. of KOREA

Tue-Af-Po2.02 / 1052

Optimization of the Radiation Resistant Quadrupole Magnets for the SIS-100 Accelerator of the FAIR Project

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The SIS-100 is a charge particle accelerator developed as a part of the challenging international project Facility for Anti-proton and Ion Research (FAIR) taking place in Darmstadt, Germany. The ion optics of the SIS-100 accelerator includes superconducting and normal conducting quadrupole magnets. To fulfill the requirements of the field quality in the magnet aperture it is necessary to find an optimal pole tip shape as well as an optimal configuration of the coil system. Requirements for radiation resistant magnets installed near the entrance of the SIS-100 accelerator combine high quality of the field distribution, maximum field intensity at the pole tip of more than 1.3 T, and a wide range of the flux density variation. We used a specially developed optimization procedure for designing the magnet cross section. The pole border line is described by a superposition of hyperbolic functions corresponding to different Fourier components of the magnetic field expansion. Strong correlation between amplitudes of the pole shape and field harmonics enables high performance of the optimization algorithms. The developed procedures have been used for designing a quadrupole magnet with especially wide range of the flux density variation. Integral 3D properties of the developed quadrupoles were ensured by optimization of the magnet end chamfers.

Submitters Country:

Germany

Mon-Mo-Pl2 / 1218

Overall Status of the ITER Project

Bernard Bigot¹

¹ *ITER International Organization*

ITER, a first-of-a-kind nuclear tokamak, is being constructed by a partnership between China, European Union, India, Japan, Korea, Russian Federation and USA, in southern France. The buildings are well under construction and the tokamak components, largely supplied in kind by the partners, will

start arriving at the end of this year. Component assembly activities start in 2018 and continue until 2025. Fabrication of the vacuum vessel is moving forward, manufacturing of the thermal shield is in progress, and cryostat elements delivered by India are being assembled into large-scale sections of the cryostat (~29m diameter ~29m height). The magnet system, with 50GJ of stored energy, will be the largest ever built. Over 600t of Nb₃Sn and 300t of NbTi superconducting strand were produced for these magnets and 95% of the superconductors for the magnets are now complete. Winding packs, weighing 100t each, for the first 2 toroidal field coils were completed in Europe and the double pancakes for a further 2 were stacked in the EU and Japan. About 60% of the winding of the TF coils is completed. Winding of the first central solenoid coil is underway at a supplier in USA. The first double pancakes for the poloidal field coils are being wound in the European Union, Russia and China. The feeders, complex and vital parts of the system, are fabricated by Chinese suppliers and the first units will be delivered in August. At this point the project is successfully overcoming multiple challenges simultaneously. For example, as the first magnets are built and tested adjustments and corrections are made to maintain performance, without loss of schedule. The restructuring of the ITER organization in 2015 and 2016, and a positive spirit of mutual collaboration among the partners, is helping us to stay on track for first plasma in December 2025.

Submitters Country:

ITER IO in France

Mon-Af-Po1.09 / 36**Overview of JT-60SA HTS current lead manufacture and testing**

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The Karlsruhe Institute of Technology (KIT) agreed to construct and test the High Temperature Superconductor Current Leads (HTS-CL) for the tokamak JT-60SA presently under construction in the frame of the Broader Approach agreement between Europe and Japan. In total 6 HTS-CLs for 25.7 kA for the TF coils and 20 HTS-CLs for 20 kA for the PF and CS coils are required and all of them have to be tested at operating temperatures in the test facility CuLTKa at KIT. The manufacturing started in 2014 and the last current leads will be tested in July 2017. The main parts of the acceptance test are the determination of the heat load at 4.5 K, the 50 K He mass flow rate through the heat exchanger, and the simulation of a loss of flow accident. One test of the PF current leads includes a pulse test at 20 kA to demonstrate their PF operation capability.

In the present paper an overview of the manufacture and the acceptance tests of the HTS current lead is given. The results for the different current leads are summarized and compared to the specifications showing a good and reproducible performance.

Submitters Country:

Germany

Mon-Af-Or9 / 1022**Overview of Recent Progress in No-Insulation REBCO Magnet Research**

Author(s): Seungyong Hahn¹

Co-author(s): Iain Dixon² ; Mark Bird³ ; Kyle Radcliff⁴ ; Thomas Painter⁵ ; Kwanglok Kim⁴ ; Kwangmin Kim⁴ ; Dmytro Abrahimov⁶ ; Jan Jaroszynski⁴ ; Kabindra Bhattarai⁷ ; David Larbalestier⁴ ; Xinbo Hu⁷

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⁶ *NHMFL*

⁷ *Applied Superconductivity Center-NHMFL*

For the past few years, notable progress has been made in the no-insulation (NI) high temperature superconductor (HTS) magnet technology. *Electromagnetic* (thus fast) quench propagation, the key mechanism for the “self-protecting”, has been demonstrated in experiments of >100 NI modules and test coils, as well as various numerical simulations. Major drawbacks of the NI technique, including the intrinsic charging delay and non-linear electromagnetic behaviors, have been actively studied; variations of the NI technique together with complementary techniques have been proposed for performance improvement of NI magnets. This paper presents a brief overview of the recent progress in the NI REBCO magnet technology, which include: (1) a 11 T NI-REBCO insert that generated 42.5 T at a coil current density of 1150 A/mm^2 in a bore of the 31 T resistive background magnet at the National High Magnetic Field Laboratory (NHMFL); (2) a 20 T all-superconducting magnet consisting of a 13 T NI-REBCO insert and a 7 T NbTi background magnet, which will be on service as the first user magnet in early 2017 at the Applied Superconductivity Center of the NHMFL; (3) partial and metal insulation approaches for faster charging and their “safe” operating conditions without losing the self-protecting feature; (4) active feedback control to mitigate the charging delay and non-linear behavior of an NI coil; (5) “defect-irrelevant” behavior of NI coils at 4.2 K and 77 K.

Acknowledgement: This work was supported by the National High Magnetic Field Laboratory (which is supported by the National Science Foundation under NSF/DMR-1157490), and by the State of Florida.

Submitters Country:

United States

Wed-Af-Or22 / 39

Overview of the Present Progress on the Superconducting Magnet System of CFETR-Phase II

Jinxing Zheng¹ ; Song Yuntao¹ ; Liu Xufeng¹ ; Li Jiangang¹ ; Wan Yuanxi¹ ; Lu Kun¹ ; Liu Huajun¹ ; Qin Jingang¹

¹ *Institute of Plasma Physics, Chinese Academy of Sciences*

CFETR (China Fusion Engineering Test Reactor) concept design work was started in 2012. It is developed in two stage. CFETR-Phase I is designed with major radius $R=5.7\text{m}$, minor radius $a=1.6\text{m}$ and magnetic field at plasma region $BT=4-5\text{T}$. 16 toroidal field coils and 6 central solenoid coils were designed by Nb3Sn CICC with maximum operation current of 64 kA and 50 kA, respectively. Three types of plasma equilibrium shape was designed as ITER-like single null, super-X and snowflake. The maximum flux provided by central solenoid is designed as 180 volt second. However, in order to get much high operation parameters such as steady-state operation, particle and heat exhaust, disruption mitigation and avoidance, ELM control, and material damage by high heat flux and neutron, the superconducting magnet system of CFETR-phase II has been updated based on the larger machine with $R = 6.7\text{m}$, $a=2.0\text{m}$, $BT= 6-7\text{T}$. With this new design, over 1GW fusion power can be achieved and advanced plasma performance can be obtained. In consideration of the maximum magnetic field of TF coils of CFETR-phase II, high performance of Nb3Sn CICC magnet was designed which can withstand 14-15 T. Besides, in order to save the space for blanket system and get much high flux, high temperature superconducting Bi-2212 magnet with better current carrying performance under high field is supposed to be employed for CS coils of CFETR-phase II. The HTS CS coils can provide a high voltage second of about $480\text{V}\cdot\text{s}$ and the maximum magnetic field is about 17.5T. In addition, Bi-2212 CICC conductor sample was tested at 4.2 K with critical current of 26.6 kA under its self-field.

Submitters Country:

China

Thu-Af-Po4.02 / 66**PARAMETRIC ANALYSES OF JT-60SA TF COIL IN COLD TEST FACILITY WITH SUPERMAGNET CODE****Author(s):** Sylvie NICOLLET¹**Co-author(s):** Alexandre Torre¹; Benoit LACROIX¹; Daniel Ciazynski²; J. Cazabonne; Louis ZANI¹; Patrick Decool¹; Walid Abdel-Maksoud¹¹ CEA² CEA-IRFM

The Toroidal Field system of the JT-60SA tokamak comprises 18 NbTi superconducting coils. In each TF coil (TFC), 6 Cable-In-Conduit Conductor (CICC) lengths are wound in 6 double-pancakes (DP) and carry a nominal current of 25.7 kA at a temperature of 4.7 K. After fabrication and before delivering to Japan, each coil is tested in the Cold Test Facility (CTF, CEA Saclay), the test program including a quench for each coil. In order to ensure the tested magnet safety, a regular quench detection system is based on compensated voltages. A coupled model has been developed including: - One model of the external cryogenic circuit with SimCryogenics code (new tool developed by CEA-SBT with process-control possibilities) comprising the pump, an heat exchanger, control valves, quench relief valves and a quench tank; - 12 THEA (Thermal, Hydraulic and Electric Analysis) models for the 12 conductors pancakes of the coil. The quench performed on coil C11 (experimental quench starting on a lateral pancake) and C13 (experimental quench starting on a central pancake) has been simulated, representing the increase of inlet helium temperature up to 7.46 K leading to the quench, followed by the safety current discharge. The simulation results (THEA/SimCryogenics coupled model) are compared with the test measurement signals, in particular the helium temperatures, pressures and mass flows at the extremities of the conductors and coil. Results regarding the external cryogenic loop are detailed and the calculated conductor temperature is also presented. In addition, results of THEA/SimCryogenics simulations applied to coil C11 quench test are compared to previous results from SuperMagnet (THEA/Flower) simulations. This work can also help validating SimCryogenics and Flower codes on a real cryogenics magnet configuration in view to recommend their use in similar models for ITER magnets quench studies and safe operation.

Submitters Country:

France

Wed-Af-Or25 / 249**PENeLOPE: testing a one-of-a-kind neutron storage magnet**Rüdiger Picker¹; Dominic Gaisbauer²; Joachim Hartmann³; Stephan Paul⁴; Wolfgang Schreyer³; Rainer Stoepler^{None}¹ TRIUMF² TU München³ Technische Universitaet Muenchen⁴ Physik Department - Technische Universitaet Muen

Neutrons have a magnetic moment of around 60 neV/T. The force on this magnetic dipole moment in a gradient field can be used to manipulate or store so called ultracold neutrons (UCN), free neutrons with very small kinetic energy and velocity. To create a magnetic storage vessel, one has to create

a low field region surrounded by a high field region; only one spin state of the neutrons can be confined. These traps can be used to resolve the ongoing puzzle of the neutron lifetime more than 70 years after its discovery.

To this end, a large superconducting storage magnet has been developed at Technische Universität München and is built by Babcock Noell. It consists of 24 stacked thick and short solenoids creating a toroidal storage volume.

Several technical challenges arise from the coil topology: each adjacent solenoid has alternating current direction, leading to huge repelling forces. In addition, the space for support structure is very limited. This makes an extensive development and testing campaign necessary. The main features and status of the magnet along with results from coil tests will be presented.

Submitters Country:

Canada

Wed-Af-Po3.01 / 377

Parametric Study of Block-coil Dipoles Using Graded Conductors

Author(s): Etienne Rochepault¹

Co-author(s): Paolo Ferracin¹; Susana Izquierdo Bermudez¹

¹ CERN

In the framework of the Future CERN Collider (FCC) studies, and in order to reach 100 TeV collision energies, 16 T dipoles are under development. To allow for a more compact and cost-effective design, the coils need to be graded. This paper presents a 2D parametric study which explores possible options for an optimal grading. This study uses both analytical formulas and FE analysis. Block coils are considered, using two cable sizes, and therefore two different current densities. Various parameters are also explored, such as cable combinations, current density ratios, or position and size of the blocks. This study shows in particular what are the optimal grading ratio and amount of conductor to reach the 16 T bore field with reasonable margins, while minimizing the conductor area.

Submitters Country:

Switzerland

Thu-Af-Po4.09 / 441

Partial isolation quench protection method for YBCO SMES magnet

Qixing Sun^{None}

Quench protection is one critical problem for superconductor magnet applications. The most common way to deal with quench in magnets is to disconnect and quickly discharge the magnet to prevent damage. In this research a novel proposal concerning quench protection for an SMES wound using YBCO conductor is presented. The new method can provide high reliability of SMES magnet. Based on this research, the SMES magnet can still work during the magnet partial quench situation without damage by using additional electrical circuitry. The additional electrical circuit can partially isolate the quenching pancake coil in the SMES magnet from the remaining coils. After the quenched coil recovers from overheat the coil can be connected back to the SMES magnet using the proposed control method. The novel control method is designed in this research which can both make the SMES magnet constantly work during the quench and protect the SMES magnet from damage. In this paper, the new proposed SMES control circuit and the novel control method will be presented and the simulation performance will be shown at the end of the paper.

Submitters Country:

UK

Wed-Af-Po3.10 / 248

Particle Reinforced Cu Matrix Conductors for High Field Pulsed MagnetsKe Han¹ ; Robert Goddard^{None} ; Vince Toplosky^{None} ; Rongmei Niu^{None} ; Jun Lu^{None} ; Doan Nguyen^{None}¹ *Nationa High Magnetic Field Laboratory*

The high strength conductors used in pulsed magnets in the US National High Magnetic Field Laboratory (MagLab) are manufactured from Cu matrix composites. One of the composites is made from particle reinforced Cu. The fabrication of these composite conductors requires high deformation strain, which creates high densities of dislocations and reduced particle spacing. Both mechanical strength and electrical conductivity can be predicted from particle spacing and dislocation density. When dislocation density reaches a certain value, the particle size, distribution and shape becomes important to mechanical properties. We studied the particle size, distribution and shape in high-strength conductors with respect to the properties of the conductors. The two most important factors related to above parameters were dislocations near the interface between the particle and the matrix, and the stress concentration near the particles. By engineering these variations, the properties of the conductors can be optimized. This paper reports our understanding of the relationship between critical properties and particle distribution in composite conductors for high field pulsed magnets.

Acknowledgment: The work was undertaken in the National High Magnetic Field Laboratory, which is supported by NSF DMR-1157490, the State of Florida, and DOE.

Submitters Country:

USA

Tue-Af-Po2.07 / 852

Performance Analysis and Electromagnetic Design of a Flux-coupling type SFCL**Author(s):** Sinian Yan¹**Co-author(s):** Li Ren² ; Zuoshuai Wang ; Ying Xu² ; Zhang Lihui ; Yuejin Tang ; Yang Zhangwei ; jingdong Li²¹ *Huazhong University of Science and Technology, China*² *Huazhong University of Science and Technology*

Superconducting fault current limiter (SFCL) is an efficient way to solve the short-circuit problems in modern power system. A novel Flux-coupling type SFCL (FC-SFCL) based on disconnecting coupling windings for current-limiting has been proposed. For its low steady impedance at normal state and high limiting one after fault, FC-SFCL is considered as a potential scheme to limit short-current. It contains a pair of high temperature superconducting (HTS) coupling windings wound on an iron-core with air gap. Improving coupling coefficient of the HTS coils and reducing losses are essential issues, which are affected by iron-core structure and winding processes of HTS coils. In this paper, performance analysis of FC-SFCL is discussed. Magnetic field distributions of different structures are analyzed and the way to decrease leakage magnetic field is researched. Then the electro-magnetic design of a 10 kV / 500 A FC-SFCL prototype is carried out based on genetic algorithm. Coupling degree and losses of the prototype are evaluated to demonstrate that the electromagnetic parameters meet the design requirements.

Submitters Country:

China

Thu-Af-Po4.08 / 578**Performance Degradation of YBCO Tapes after Suffering Lightning Impulse Current****Author(s):** Daoyu Hu¹ ; Zhiyong Hong^{None} ; Zhijian Jin^{None}**Co-author(s):** Zhuyong Li¹¹ *Shanghai Jiao Tong University*

High temperature superconductors (HTSs) are developed for applications in HTS power devices such as power transmission cables, transformers, superconducting fault current limiters (SECLs) superconducting magnetic energy storage (SMES). Over-current performance of YBCO tapes at power frequency has been well studied by previous researches. However, in a power grid, superconducting apparatus might also experience a lightning impulse current. This paper will mainly focus on the performance degradation of YBCO tapes after suffering lightning current. The standard 8/20 μ s lightning current is applied to the YBCO tapes. The critical currents and n-values of each YBCO tape before and after the lightning current experiment are tested and compared. The microstructure of the damaged tapes is showed by SEM. Moreover, a numerical model is also used to study the distributions of current and temperature in YBCO different layers. The results of this paper will provide fundamental understanding for the intrinsic mechanism of the performance degradation of YBCO tapes after suffering a lightning impulse current.

Submitters Country:

China

Tue-Af-Po2.06 / 10**Performance Evaluation of a Novel Axial Flux Claw Pole Machine with Soft Magnetic Composite Cores**chengcheng liu¹ ; wang youhua² ; jianguo zhu³ ; Bo Ma³ ; Gang Lei³ ; Long Chen⁴¹ *Hebei university of technology*² *hebei university of technology*³ *UTS*⁴ *HEBUT*

By using the powder metallurgy technology and magnetic isotropy characteristic of the soft magnetic composite (SMC) material, various kinds of permanent magnet (PM) machine can be designed and fabricated easily. However, if the torque density of the PM machine with SMC cores is much lower than that with the silicon steels, if it is designed with the traditional structures and methods. In the designing of PM machine with SMC cores, some design guidelines should be followed, e.g. 3-D magnetic flux path and high operation frequency. In this work, a novel axial flux claw pole machine (AFCPM) with SMC core is proposed and its performance is comparative studied with the benchmark of a standard transverse flux machine (TFM) with SMC cores.

The structure of the AFCPM is very novelty, it has both merits of the axial flux machine and the claw pole machine, its operation principle is quite similar to that of the traditional claw pole machine however its main flux path is on the axial direction. Considering that the manufacturing cost of the AFCPM with SMC cores is very low, this work proposes two kinds of AFCPM, one is designed for high performance application which is with NdFeB magnets and another one is designed for the low cost application which is designed with ferrite magnets. For the performance calculation, the 3-D

finite element method (FEM) is used. To evaluate the performance of these two AFCPMs, a TFM with SMC cores and NdFeB is used. It can be found that the AFCPM with the NdFeB can provide higher torque density, ration of torque to cost and efficiency than those of TFM with NdFeB. As for the low cost application, the AFCPM with ferrite magnet is a good choice.

Submitters Country:

China

Mon-Af-Po1.09 / 749**Performance of a HTS Persistent Current System for REBCO pancake coil****Author(s):** Kohki Takahashi¹**Co-author(s):** Tomoya Hase¹ ; Satoshi Awaji¹ ; Akinobu Nakai² ; Satoshi Yamano² ; Shinichi Mukoyama² ; Hisaki Sakamoto²¹ *IMR, Tohoku University*² *Furukawa Electric Co., Ltd.*

HTS superconducting magnets for MRI or NMR should be operated in persistent current mode to achieve high homogeneity and stability. A persistent current switch and a superconducting joint are the key technologies for persistent current operation. Recently, a superconducting joint has been fabricated successfully in Furukawa Electric Co., Ltd. We made a persistent current system including the superconducting joints, a persistent current switch and a REBCO double pancake coil. In this paper, we report detail results of persistent operation test of the system in self-field and applied magnetic field of 1 T. The double-pancake coil of 160 turns with the inner radius of 44 mm and the persistent current system were fabricated with SuperPower REBCO tapes (6 mm width). The persistent current system was cooled by the second stage of the GM cryocooler in a cryostat installed in a room temperature bore of a cryocooler-cooled superconducting magnet. The current decay behaviors in the persistent current mode up to 170 A at 20 K were measured using a Hall probe located at the center of the coil. The magnetic field generated by persistent current was 0.59 T at 170 A and the decay rate of the field after five days operation was estimated to be 1.5 ppm/h in self-field. The detailed results will be discussed with considering operating current and applied field dependences.

Submitters Country:

Japan

Wed-Af-Or26 / 87**Performance of the ITER CS joints****Author(s):** Nicolai Martovetsky¹ ; Boris Stepanov^{None}**Co-author(s):** Wayne Reiersen² ; David Everitt¹ ; John Smith³ ; Alan Stephens³ ; Robert Potts³ ; Pierluigi Bruzzone⁴¹ *ORNL*² *PPPL/ORNL*³ *GA*⁴ *EPFL-CRPP*

The US Domestic Agency (USDA) is the supplier of the Central Solenoid (CS) for ITER. The ITER CS uses three different types of joints. In order to verify the joint performance in close to the operational conditions, the USDA built a test sample that contains all three types of CS joints in order to test it in the SULTAN facility. The SULTAN facility allows testing under a variable DC magnetic field, a variable AC field, a variable temperature, and can charge the joints with currents up to 100 kA. The CS SULTAN Sample containing all three CS joints was built by the industrial vendor using their qualified manufacturing procedures. The SULTAN test program is focused on characterization of these CS joints, as well as measurements of resistance, AC loss, and temperature margins in different relevant conditions. We report the test results of all three CS joints in the SULTAN facility and compare them with the theoretical predictions and earlier results on the joints, which was obtained in the Joint Test Facility at Oak Ridge, TN during the R&D phase of the CS project.

This manuscript has been authored by UT-Battelle, LLC under Contract No. DE-AC05-00OR22725 and by Lawrence Livermore National Security, LLC, under Contract No. DE-AC52-07NA27344 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan(<http://energy.gov/downloads/doe-public-access-plan>).

Submitters Country:

USA

Wed-Af-Or24 / 886

Performance of the quench protection system of the first LARP-CERN quadrupole magnet models

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¹ *LBNL*

² *Centro de Investigaciones Energéticas Medioambientales y Tecnológica*

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⁴ *Fermilab*

⁵ *Brookhaven National Laboratory*

⁶ *FNAL (US)*

CERN and LARP (LHC Accelerator Research Program) are jointly developing Nb₃Sn quadrupole magnets to be installed in the LHC for its upgrade to higher luminosity. The quench protection system of these magnets will include a combination of quench heaters attached to the coil surface and CLIQ units electrically connected to the coils. This solution provides an effective reduction of the coil's hot-spot temperature after a quench and increased redundancy against component failures. The different quench protection elements, quench heaters and CLIQ, have been characterized separately and simultaneously on two 1.2 meter long model quadrupole magnets, tested at FNAL and CERN, and one 4 meter long mirror magnet tested at BNL. The time required to initiate a quench using quench heaters was measured and found in good agreement with simulations. The variation of this parameter for quench heater strips attached to different coils was analyzed. Furthermore, it was verified that the target energy density deposited by the quench heaters is well above the measured minimum energy density to initiate a quench even at low current. Three different CLIQ connection schemes were tested, confirming that the configuration selected as the baseline achieves the best performance in terms of lower hot-spot temperature and voltage to ground. Various magnet discharges were initiated by triggering quench heaters, CLIQ, or combinations of those. These experimental results constitute a wealth of information crucial to validate and refine the magnet's electrical, magnetic and thermal model. Simulations performed with the LEDET program are in very good agreement with the experimental results. The same software is used to predict the performance of the quench protection system as installed in the LHC.

Submitters Country:

USA

Thu-Mo-Or31 / 726**Performance of two-ply four-filaments Gd123 tape coil****Author(s):** Satoshi Awaji¹**Co-author(s):** Tatsunori Okada¹ ; Kohki Takahashi¹ ; Hiroshi Miyazaki² ; Sadanori Iwai² ; Shigeru Ioka² ; Yasuhiro Iijima³ ; Masanori Daibo³¹ *HFLSM, IMR, Tohoku University*² *Toshiba Corporation*³ *Fujikura Ltd.*

We have succeeded in the development of the 25T cryogen-free superconducting magnet recently. As a next step, a development of 30 T class superconducting magnet is planned. In order to realize high field superconducting magnets beyond 30 T, the reliability of REBa₂Cu₃O_y (RE123, RE: Y and rare earth) conductors should be improved. For this purpose, we made single pancake coils by co-winding two-ply (two-stacked) RE123 tapes as an R&D study. The tape used in this study is a four-filaments Gd123 tape, whose Gd123 layer was divided by a scratch on the IBAD-MgO layer. Two of the four-filaments Gd123 tapes were wound together with a polyimide tape insulation, so that the Gd123 sides of two tapes are face-to-face without the insulation. Finally, the Gd123 single pancake coil was impregnated by epoxy. The inner and the outer diameters of the Gd123 single pancake coil are 50 mm and 92.5 mm, respectively. The critical currents and n-values of the two-ply Gd123 tape coil at 77.3 K are 206.9 A and 15.2 for the inside-winding and 207.6 A and 15.0 for the outside-winding. The detailed coil performance will be presented and be compared to the two-ply mono-filament Gd123 coil.

1 S. Awaji et al., Supercond. Sci. Technol. submitted. 1 S. Fujita et al., IEEE TAS 27 (2017) 6600504.

Submitters Country:

Japan

Tue-Af-Po2.07 / 863**Performance simulation of a bias-flux superconducting fault current limiter (SFCL) based on MATLAB/SIMULINK****Jiang Shengqian**^{None} ; **Zhu Jiahui**^{None} ; **Wang Shanming**^{None} ; **Gong Jun**^{None} ; **Chen Panpan**^{None} ; **Zhao Yongqing**^{None} ; **Zhao Xin**^{None}

Superconducting fault current limiter (SFCL) can not only reduce the capacity of the circuit breaker but also lower the cost of line construction, it become more and more popular for the application in a high-voltage transmission line. A novel superconducting fault current limiter with bias magnetic flux is proposed by using a reactor with two symmetrical split copper windings and a non-inductive YBCO magnet which is in series to one copper winding. A magneto-thermal coupled FEM model of the bias-flux SFCL with the YBCO magnet and the reactor is established based on MATLAB/SIMULINK. The performance parameters are calculated through the simulation of a prototype SFCL. The response speed, overvoltage and overcurrent characteristics considering the influence of different fault current are compared and the robustness of the SFCL in a power system are discussed under different operating conditions simulation. These results validate the effectiveness of this bias-flux SFCL.

Submitters Country:

China

Thu-Af-Po4.04 / 241

Performance test of 1.5 T cryogen free orthopedic MRI magnet

Author(s): Valeriy Lysenko¹**Co-author(s):** Anton Bagdinov²; Evgeny Demikhov²; Evgeny Kostrov²; Nikolay Piskunov²; Alexander Rybakov²; Yuriy Tsyachnykh²¹ *Lebedev Physical Institute of the Russian Academy of Sciences*² *P.N. Lebedev Physical Institute of the Russian Academy of Sciences*

A 1.5 T cryogen free superconducting magnet for a dedicated orthopedic MRI of human extremities was developed and tested. The magnet has a compact cryostat cooled by a pulse tube coldhead with cooling power of 1 W at 4.2 K. The warm bore of a cryostat is 325 mm in diameter, 600 mm in length. Cost effective NbTi wire was used for making superconducting coils. The magnet is actively shielded. 0.5 mT stray field located at 1.7 / 2.5 m from the magnet center in radial / axial directions correspondingly. A novel approach has been implemented to decrease the cool down time of the magnet. According to it, the coldhead was placed in the separate sleeve filled with the gaseous helium. It was shown experimentally that the convection of helium gas in the coldhead sleeve speeds up the cool down significantly, more than by 40% in this case. Cooling down the magnet from ambient to operating temperature takes about 100 hours. The magnet operates in persistent mode with magnetic field stability of better than 0.01 ppm/hour. Special tests have been performed to investigate the magnet behavior in case the coldhead is switched off. Quenches in the range from near 5 to more than 6 minutes after the coldhead was stopped were observed. The magnet has shown steady operation at 1.5 T in case the coldhead was switched off for four minutes or even longer. At the same time the slight decay of the persistent field of less than 100 ppm was observed.

Submitters Country:

Russia

Wed-Mo-Or19 / 298

Permanent Magnet Dipoles For the ESRF Upgrade

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The new magnet lattice of the European Synchrotron Radiation Facility (ESRF) will include 128 Permanent Magnet (PM) dipoles presently under in-house construction. It requires about 6 tons of high coercivity Sm₂C₀₁₇ permanent magnet material subdivided into 12,300 blocks. The choice of the permanent magnet technology is motivated by an energy-saving context, the compactness of the magnet lattice and also a long experience acquired in this area with Insertion Devices at the ESRF. Each dipole has a length of 1.784 m and is segmented into five modules with different field strengths in order to achieve a longitudinal field gradient as it contributes to the reduction of the horizontal emittance of the stored electron beam. From the concept to the serial production, the project involves several interesting topics such as detailed numerical simulations, a passive method for the temperature stabilization of the magnet, a full methodology for the modules and dipoles assembly

and dedicated magnetic measurement methods as well. Critical subjects, such as long term stability of the PM dipoles, are discussed. A review of the project will be presented.

Submitters Country:

France

Thu-Af-Po4.08 / 190

Pinning Force and critical properties in YBa₂Cu₃O_{7-δ}

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In this work we have studied the critical properties of YBa₂Cu₃O_{7-δ} thin films. The studied sample YBa₂Cu₃O_{7-δ} is a monocrystalline thin film deposited by the ablation laser method on the surface (001) of a SrTiO₃ substrate. We have examined the variation of critical density J_c as a function of temperature for different values of a fixed magnetic field. This investigation shows that, in the absence of thermal activation and for the weaker values of magnetic field, J_c exhibits a behaviour according to $[1-(T/T_c)^2]^{m'}$ with a critical exponent m' varying with a variation of magnetic field. On the other hand, we studied the variation of m' parameter with the pinning force variation F_p for different value of magnetic field. More scaling formulas were used to adjust our results in a large range of temperature and field, different parameters depending on the pinning mechanism such as m , γ , n and δ were determined. m and γ represent respectively the temperature and magnetic field dependence. Moreover, the values of m are related to the pinning force variation. The calculated value of n is compared with other investigations results, n is a good parameter reflecting the anisotropy of superconductor's. Flux pinning mechanism of YBa₂Cu₃O_{7-δ} has been also investigated by magnetic measurements. The field dependence of critical current density J_c (H) was studied within the collective pinning model. The main results in our research are the dependence of the parameters m and m' to the volume density of pinning force in the Kramer model.

Submitters Country:

MOROCCO

Thu-Af-Po4.07 / 626

Polar transformed subdomain modeling for primary-segmented permanent magnet linear synchronous machine applied in tracked inspection robots

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Tracked inspection robots is a special robot to replace or assist of manual inspection, has great application prospects. Linear permanent magnet machine with primary-segmented is a good choice which can motion on the long distance without the use of gears. In this paper, adopting polar transformed subdomain modeling for predicting the magnetic field and forces in primary-segmented permanent magnet linear synchronous machine (PS-PMLSM). Compared with the traditional finite element method, this analytical methods can reduce the solution time, improved the efficiency. In the

paper, Firstly, the PS-PMLSM is deformed into an arc-segment linear PM machine, calculating the magnetic field in Polar coordinates instead of Cartesian coordinates. In equivalent analytical model, the secondary is assumed infinite length, the back-iron is extended into a ring, the secondary are converted to rotary PMSM, the different is that PMs in analytical model is not full filled in direction of the circumference. Meanwhile, the primary iron is converted to an arc-shape stator. Comparing with the analytical model in Cartesian coordinates, the number of subdomains in equivalent analytical model is reduced. The whole magnetic field domain is divided into four types of simple subdomains, viz. magnets, air-gap, slots, and end regions. The analytical field expression of each subdomain is obtained by the variable separation method and Fourier series method, the coefficients in the field expressions are determined by applying the boundary and interface conditions. Then, the analytical solution of each subdomain is derived, magnetic field, thrust force and the normal force are determined based on the field solutions. Finally, numerical results are validated by finite element method. The results show that the analytical model can accurately predict the magnetic field and forces.

Submitters Country:

China

Tue-Mo-Or12 / 915

Prediction and analysis of quench propagation test results in the ITER TF Insert Coil using the 4C code

Author(s): Roberto Zanino¹**Co-author(s):** Roberto Bonifetto¹; Alberto Brighenti²; Hidemasa Ozeki³; Tomone Suwa⁴; Katsumi Kawano⁵; Takaaki Isono⁵; Nicolai Martovetsky⁶; Laura Savoldi¹¹ *Politecnico di Torino*² *NEMO Group, Dipartimento Energia, Politecnico di Torino, Torino, Italy*³ *National Institutes for Quantum and Radiological Science and Technology*⁴ *QST*⁵ *National Institutes for Quantum and Radiological Science and Technology, Naka, Japan*⁶ *ORNL*

The ITER TF Insert (TFI) coil is a 43 m long single-layer solenoid wound in the grooves of a stainless steel mandrel, using one of the Nb3Sn circular cable-in-conduit conductors adopted in the winding of the ITER TF coils and cooled with supercritical He in forced circulation at ~4.5 K. The TFI is the last in a series of ITER Insert Coils, all tested in the bore of the ITER Central Solenoid Model Coil at Naka, Japan, under conditions relevant for the actual ITER operation. Several tests were devoted to the study of quench propagation, aimed at the assessment of the hot spot in the conductor. The quench was initiated pulsing an inductive heater, located at mid length of the TFI, at increasing energies. Different delay times (3 s, 5 s, 7.5 s) after quench detection were imposed, before the 68 kA TFI current was dumped on an external resistor. In the first part of the paper, the main results of the TFI quench tests are presented and discussed. In the second part, we focus on the numerical analysis of the quench using the state-of-the-art 4C code: for the first time since the ITER Insert Coils program started, more than fifteen years ago, an attempt was made to predict the quench propagation in the strict sense, i.e., performing the simulations before the tests. Here we present the results of the comparison between predictions and measurements, showing that global as well as local voltages, i.e. the hot spot temperature and the propagation of the quench, were very well predicted by the 4C code. The success of this predictive exercise confirms that the 4C code can be reliably used to address quench-related issues in the design of future Nb3Sn magnets and/or in the planning of their operation.

Submitters Country:

ITALY

Tue-Af-Po2.01 / 384

Preliminary design of the FAIR Super FRS superferric branched dipoles

Author(s): Arnaud Madur¹**Co-author(s):** Chhon Pes¹; Eun Jung Cho²; Hans Mueller²; Hervé Allain¹; Hugo Reymond¹; Jorge Muñoz-García³; Lionel Quettier¹; Martin Winkler²; Patrick Graffin¹ CEA Saclay² GSI Darmstadt³ CEA

CEA has the responsibility of the design studies for the superferric 1.6 T dipole magnets of the Superconducting FRagment Separator (SuperFRS) which is part of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. After completing the study for the 21 superferric SuperFRS standard dipole magnets, CEA is currently analysing conceptual solutions for the 3 superferric branched dipole magnets. Branched dipole magnets are necessary to allow the separated particles to be directed along each of the three branches of the separator. The branched dipoles will keep most of the features incorporated in the standard dipole magnet design but they will have increased complexity to make them compatible with the vacuum chamber layout at the branches locations (Y-shape). The magnetic design of the yoke will be slightly modified whereas a new cryogenic design is required. We present in this paper the design concepts envisioned for the FAIR SFRS branched dipole magnets along with preliminary design simulation results (magnetic, cryogenic and mechanical analyses).

Submitters Country:

France

Thu-Mo-Or30 / 1080

Present status of Bi-2212 conductor technology

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A critical stage for any conductor technology, especially a wind and react (W&R) technology like Bi-2212 or Nb3Sn occurs when manufacturing becomes sufficiently mature for magnet use. This is now the case for Bi-2212, the only round wire, twisted, multifilamentary HTS conductor. Bi-2212 had fallen out of favor a decade ago because of its inferior Jc and complex heat treatment for W&R use. In the last 5-7 years, with support from the US DOE-HEP Office, all facets of the conductor technology have now been demonstrated. After losing the legacy powder provider 3 years ago, good powder is now being manufactured by two sources (MetaMateria and nGimat) and one wire company (OST) is making very high critical current density wire in single, multi-km piece lengths on the 10 kg scale. Although the highest Jc values are only presently obtained with overpressure heat treatments at ~ 50 bar, such heat treatments also considerably broaden the heat treatment window, making the heat treatment compatible with full-scale coil manufacture. Insulation schemes fully appropriate for magnets have also been demonstrated. The current density properties are very attractive for use in high fields: for example, Jc(16T, 4.2K) now reaches 4000 A/mm², some 3 times the value possible with Nb3Sn, while Jc(30T) can reach 2900 A/mm². Hysteretic losses of twisted wires are very comparable to ITER Nb3Sn wires, much less than for REBCO and Bi-2223 tape conductors. While the Ag matrix has low E and generally low yield stress, reinforced, slightly rectangular conductors with high strength properties are being developed by Solid Materials Solutions. At the MagLab we

are applying Bi-2212, Bi-2223 and REBCO to high field magnets with fields >20 T. Our view is that there are clear advantages to using Bi-2212 for high homogeneity magnet applications and those requiring flexible conductor architectures.

Submitters Country:

USA

Thu-Af-Po4.07 / 379

Principle and realization of an electromagnetic pulse welding system with a dual-stage coil

Fangxiong Deng^{None} ; Quanliang Cao^{None} ; Xiaotao Han^{None} ; Qi Chen^{None} ; Liang Li^{None}

Electromagnetic pulse welding (EPW) is an effective way to realize the connection of two different kinds of metal materials via pulsed electromagnetic forces. To improve the welding performance, a new EPW process with a dual-stage coil system was proposed for joining aluminum and steel sheets in this paper, in which one coil is used to generate a pulsed magnetic field with a short pulse width for inducing an eddy current in the aluminum sheet, while the other one is applied to generate a background magnetic field with a relatively long pulse width for increasing electromagnetic force acting on the aluminum sheet. The EPW system has been designed and implemented based on the simulation results using the finite element method, with considering the effects of the coil shape, the number of coil turns and the discharge parameters. Finally, experiments are carried out to validate the feasibility of the EPW system, and the microstructure observations of the interfaces show that the welding quality can be effectively improved.

Submitters Country:

China

Mon-Af-Po1.08 / 931

Production of Aluminum Stabilized Superconducting Cable for the Mu2e Transport Solenoid

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The Fermilab Mu2e experiment seeks to measure the rare process of direct muon to electron conversion in the field of a nucleus. The experiment makes use of three large superconducting solenoids: the Production Solenoid (PS), the Transport Solenoid (TS), and the Detector Solenoid (DS). The TS is an "S-shaped" solenoid with a warm-bore aperture of half a meter and field between 2.5 and 2.0 T. The three solenoids feature four different Al stabilized NbTi superconducting cables. All the conductors are manufactured conforming a NbTi Rutherford cable into an aluminum matrix. Cables are subsequently cold-worked to meet the mechanical and electrical cable requirements in terms of yield strength and RRR of the Al stabilizer. This paper describes the various steps that led to the successful procurement of over 700 km of superconducting wire and 44 km of Al-stabilized cable needed to build all the 52 coils for the Mu2e Transport Solenoid (TS). The main cable properties and results of electrical and mechanical test campaigns are presented and discussed for each stage of the cable development process. Critical current measurements of the full stabilized cables are presented and compared to expected critical current values as measured on strands extracted from the final cables after etching of the Aluminum stabilizer. Effect of cable bending on the transport current are also investigated and presented.

Submitters Country:

United States

Thu-Mo-Or32 / 558**Progress Report on Superconducting Joint Technique for the Development of MgB₂ MRI magnet****Author(s):** Young-Gyun Kim¹ ; Haigun Lee¹**Co-author(s):** Jung-Bin Song¹ ; Jiman Kim¹ ; Byeong-ha Yoo¹ ; Juhong Kim² ; Duck Young Hwang²¹ *Department of Materials Science and Engineering, Korea University, Seoul, Korea*² *Kiswire Advanced Technology Co., Ltd., Daejeon, Korea*

Currently, we are conducting a collaborative R&D project to manufacture long MgB₂ wires with a high critical current density, for developing helium-free MRI superconducting magnets, which is supported by the Materials and Components Technology Development Program of the Korean Evaluation Institute of Industrial Technology (KEIT), Korea. Herein, we report our progress on the superconducting joint technique for the development of an MgB₂ MRI magnet as part of a collaborative R&D program. The superconducting joint was achieved by employing an in-situ process using Mg and B powders with unreacted/monofilament MgB₂ wires manufactured by Kiswire Advanced Technology Co. Ltd. The joint process was optimized by the appropriate selection of the optimal joining parameters such as the packing pressure of MgB₂ powder, heat-treatment temperatures, and duration times. In addition, the morphologies and structures of the joint samples were analyzed using scanning electron microscopy (SEM) and x-ray diffraction (XRD), respectively.

Acknowledgement: This work was supported by the Materials and Components Technology Development Program of KEIT [10053590, Development of MgB₂ wire and coil with a high critical current and long length for superconducting medical•electric power equipment].

Submitters Country:

Republic of Korea

Tue-Af-Or17 / 963**Progress in REBCO coated conductors for high magnetic field applications****Author(s):** Venkat Selvamanickam¹**Co-author(s):** Rudra Pratap ; Meysam Gharahcheshmeh ; Aixia Xu ; Yuan Zhang ; Eduard Galstyan ; Goran Majkic¹ *University of Houston*

Rapid progress has been underway in improvement in critical currents of REBCO coated conductors in high magnetic fields at temperatures of 4 to 50 K. Heavy doping of Zr (15 to 25 mol%) in REBCO films have yielded record high pinning force levels above 1800 GN/m³ at 4.2 K and critical current densities (J_c) above 20 MA/cm² at 30 K, 3 T in the orientation of field perpendicular to the conductor. Recently, an Advanced Metal Organic Chemical Vapor Deposition (Advanced MOCVD) method has been utilized to attain similar superior J_c values in REBCO films of thickness above 4 μm. Consequently, critical currents have reached staggering levels of 2120 A/4mm width at 4.2 K, 14 T. The corresponding engineering current density of 5300 A/mm² is 4.5 times higher than that of Nb₃Sn and 7 times higher than Bi-2212 wires. Also, at 30 K, 3 T (field perpendicular to conductor), the thick film conductors made by Advanced MOCVD with 15% Zr addition have exhibited critical currents above 8700 A/12 mm which is twice as high as the previous record. Details of the rapid progress

recently made in high performance REBCO conductors at high magnetic fields will be discussed in this presentation.

Submitters Country:

USA

Wed-Af-Po3.10 / 577

Progress of ITER Feeder System Electrical Insulation Qualification

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Co-author(s): Arnaud Devred ; Chao Wang ; Chen Liu ; Chen-yu Gung ; Chunyu Wang ; Erwu Niu ; Guoliang Li ; Kun Lu ; Linlin Fang ; Xiaowu Yu ; Yuntao Song ; Zhiheng Dai

The ITER Feeder is an important sub-system which transmits the electrical power, conveys the cryogenic coolant and carries the instrumentation wires to the ITER Tokamak magnet system. In the Feeder, all the high voltage (HV) potential components, including the high temperature superconducting current leads, the superconducting busbars, and the busbar joints, need to be insulated with solid composite materials to electrically isolate the HV potential from ground. Due to the complex external configuration, especially at the transition position on current lead and joint, it is difficult to apply the insulation layer on the surface of the components. At the start of the feeder insulation project, ASIPP trialed several alternative technologies, such as the vacuum pressure impregnation (VPI) technology, the "wet-winding" technology, and the pre-impregnated tape (pre-preg) winding technology. Based on over two years of preliminary qualification and experimental comparison, the pre-preg tape and relevant curing techniques were finally chosen as the formal Feeder insulation material and method. The formal insulation qualification was launched, including the material qualification and the component (process) qualification. This paper describes the whole research improvement of ITER Feeder electrical insulation qualification activities, introduces the selection of procured materials and the manufacturing trials, and summarises the formal qualification items and their test results. ASIPP has now completed the static tensile/shear strength, the fatigue tensile strength, the compression-shear strength, and the void content test for the material qualification. Insulated mock-ups of the busbar joints have current lead have been manufactured and electrically tested.

Submitters Country:

China

Wed-Af-Po3.02 / 1101

Progress of ITER TF Coil Case fabrication in Japan

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Co-author(s): Eikou Fujiwara¹ ; Kaoru Nakamura¹ ; Masanobu Ino¹ ; Masao Nishino¹ ; Tsutomu Hemmi¹ ; Nobuhiko Tanaka¹ ; Rei Kikuchi¹ ; Shino Kanamori¹ ; Tomohisa Kurita¹ ; Toshiaki Hanaoka¹ ; Yunseok Hong¹ ; Masataka Nakahira¹ ; Norikiyo Koizumi¹

¹ QST

National Institutes for Quantum and Radiological Science and Technology (QST) which has been Japan Atomic Energy Agency up to March 2016, as Japan Domestic Agency, has responsibility to procure 19 coil cases for ITER Toroidal Field Coils (TFCs) as in-kind components. The TFC Case is a large welded structure having a D-shape with a height of 16.5 m, a width of 9 m, and a weight of about 200 tons. Meanwhile TFC Case is large welded structure, sever dimensional tolerance for

TFC Case is required such as +/-2mm profile. In order to minimize the technical risk during manufacture the TF Coil structures, QST has performed some trials to establish manufacturing procedure before actual manufacturing. After the establishment of manufacturing procedures, JAEA started manufacturing of 1st TF Coil structure from August 2012. In addition to trials of welding and manufacturing processes, some trials have been conducted to rationalize manufacturing processes and establish other manufacturing processes. Finally, it is planned to ship the first unit of TFC Case to Coil assembly site in the summer of 2017. This presentation shows history of manufacturing trials and progress of TFC Case fabrication in Japan.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Submitters Country:

Japan

Mon-Af-Or4 / 237

Progress of the JT-60 SA Toroidal Field coils tests in the Cold Test Facility

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¹ CEA

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JT-60SA is a fusion experiment which is jointly constructed by Japan and Europe and which shall contribute to the early realization of fusion energy, by providing support to the operation of ITER, and by addressing key physics issues for ITER and DEMO. In order to achieve these goals, the existing JT-60U experiment will be upgraded to JT-60SA by using superconducting coils. The 18 TF coils of the JT-60SA device are provided by European industry and tested in a Cold Test Facility (CTF) at CEA Saclay. At the summer 2017, 15 TF coils will have been successfully tested at the nominal current of 25.7 kA and at a temperature between 5 K and 7.5 K. The main objective of these tests is to check the TF coils performances and hence mitigate the fabrication risks. These tests allowed checking a certain number of performances of the TF coils: DC/AC insulation, cooling down characterization, RRR of the conductor, pressure drop in the winding pack and temperature margin against a quench. This paper will show the testing program progress and give an overview of the main experimental results obtained during these tests. The main performances of each coil will be summarized, analyzed and discussed in the light of the expected TF coils performances.

Submitters Country:

FRANCE

Wed-Af-Po3.02 / 161

Progress on European ITER Toroidal Field Coil procurement: Cold Test and Insertion Work Package

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¹ fusion for energy

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The plasma confinement of the International Tokamak Experimental Reactor (ITER) is provided by the magnetic field generated by 18 toroidal field coils (TFC). Fusion for Energy, the European Domestic Agency for ITER, is responsible for the supply of 10 TFC to ITER project. Their procurement has been divided in three main work packages: I) the production of the structural stainless steel components housing the Nb3Sn conductors (radial plates), II) the manufacture of 10 Winding Packs (WP) and III) the Cold Test of 10 WP plus their insertion into the Coil Cases (CC). This article gives an update on the status of the third work package, in particular on the design and procurement of the main special tooling (cryo-plant, gap filling facility, assembly rig) and the activities carried out to qualify the special processes such as welding processes, ultrasonic welding inspection techniques, finite element model to foresee the welding deformation and gap filling process.

Submitters Country:

Spain

Wed-Af-Po3.09 / 1064**Progresses in Mg11B2 intermediate superconductors initiatives in India**Subrata Pradhan¹¹ Institute for Plasma Research

Magnesium Diboride (MgB₂) superconductors with ¹¹B serving as the boron source, is a potential candidate as an intermediate superconductor in thermo-nuclear fusion reactors having higher neutron flux environment. ¹¹B in elemental form is known to be stable against fast neutron irradiation with significantly lower and reduced radioactive properties. Scientific Research Council of Department of Atomic Energy (DAE-SRC), Government of India has recognized the development of Mg¹¹B₂ based intermediate superconductor as one of the research areas appropriate for Tokamak based thermo-nuclear fusion reactors and has begun preliminary feasibility studies since 2016. Under these initiatives; the synthesis of isotope ¹¹B, characterization of the synthesized ¹¹B, fabrication of Mg¹¹B₂ strands and characterization of the Mg¹¹B₂ strands thus fabricated have been planned to be studied extensively. Doping with amorphous carbon towards the possible enhancement of current carrying capabilities of the synthesized Mg¹¹B₂ would also be tried out. The initial progresses made and results achieved in developing the Mg¹¹B₂ intermediate superconductor in India will be discussed in this paper.

Submitters Country:

India

Wed-Af-Or22 / 435**Progresses in cable in conduit for fusion magnets: from ITER to DEMO****Author(s):** Davide Uglietti^{None}**Co-author(s):** Kamil Sedlak¹; Rainer Wesche²; Antonio della Corte³; Pierluigi Bruzzone⁴; Luigi Muzzi³¹ University of Oxford

² EPFL³ ENEA⁴ EPFL-CRPP

According to the European Roadmap to Fusion Electricity, DEMO in Europe is considered to be the nearest-term reactor design to follow ITER and capable of producing electricity and to be a facilitating machine between ITER and a commercial reactor; to achieve this goal the capital costs has to be minimized, including the construction cost of magnets and conductors. Despite the successful large industrial production the performances of Nb3Sn ITER type conductors still have a significant margin for improvements. Two advanced Nb3Sn cable in conduit conductors (SPC-RW1 and ENEA-WR2) have been designed, manufactured and tested in the frame of the Eurofusion R&D for the European DEMO reactor. A comparison of the effective strain has shown a clear improvement with respect the ITER production conductors: from effective strain in the range of -0.6% to -0.9 % (getting slightly more negative after electromagnetic cycling) for ITER TF conductors to about -0.5% for ENEA-WR2 and about -0.3% for SPC-RW1. Such improvements lead to an increase of the average I_c in the strands which can be quantified to be about two to three times (at the same operating conditions). In terms of the amount of Nb3Sn strand required for the construction of the TF magnet system, such improvements may lead to a reduction of factor 2 to 3, corresponding to several hundreds of tons of Nb3sn strand.

Submitters Country:

Switzerland

Mon-Af-Po1.04 / 306**Proposed Commutation Method for Performance Improvement of Brushless DC Motor****Author(s):** Chang-Sung Jin¹**Co-author(s):** Sooyoung Cho ² ; Jae-Kwang Lee ³¹ *Hanwha Techwin*² *Hanyang University*³ *hanyang university*

This study focused on efficiency improvement of BLDC motors via reduction of torque ripple, core loss, and permanent magnet loss. To achieve this objective, we proposed an improved 150° commutation method for three-phase permanent magnet brushless DC (BLDC) motors to improve the current waveform. Although the 120° commutation method is generally employed for a BLDC motor, the 150° commutation method is introduced in order to operate the BLDC with the same efficiency as a brushless AC (BLAC) motor. Moreover, an improved 150° commutation is proposed to reduce the phase current harmonics. The study investigates the attributes of different commutation methods analytically and experimentally in order to determine the optimal commutation method. The result of this study indicates that the improved 150° commutation method is optimum in terms of harmonic attributes, and reduced torque ripple, thereby improving the motor's efficiency.

Submitters Country:

Republic of KOREA

Thu-Af-Po4.01 / 51**Prototype Design of the Dipole for EMuS at CSNS****Author(s):** Yuan Chen^{None}

Co-author(s): Hantao Jing ; Zhilong Hou ¹ ; Zian Zhu ² ; Jingyu Tang ³

¹ *the Institute of High Energy Physics*

² *IHEP Beijing*

³ *Institute of High Energy Physics, CAS*

The EMuS is an excellent platform for the R&D of the key technologies of the next-generation neutrino beam facility at CSNS (China Spallation Neutron Source), also for the multi-disciplinary applications based on μ SR technique. The dipole on the EMuS beamline used for minus/positive particle selection and deflection is designed as a superferric magnet in detail because of its large aperture and high field. The 2D and 3D magnetic field simulations are described. Some optimal methods are employed to reach the required field homogeneity which is better than $\pm 5.0E-4$ at 1.5 T in a wide aperture of 320 mm \times 320 mm. The yield stress and stain analysis of coils show that the magnetic and mechanical designs of this magnet is better than the expected requirements.

Submitters Country:

China

Wed-Af-Or26 / 1051

Pulsed field stability and AC loss of ITER NbTi PF joints by detailed quantitative modeling

Jianfeng Huang¹ ; Tommaso Bagni¹ ; Yury ILIN² ; Arend Nijhuis¹

¹ *University of Twente*

² *ITER IO*

Abstract: The Poloidal Field (PF) magnet system of the International Thermonuclear Experimental Reactor (ITER) consists of six pulsed coils. Each coil comprises independent modules connected with “shaking hands” lap-type joints. The feasibility and stability of the plasma scenario requires the magnets to retain sufficient current and temperature margin. The joints essentially represent the weak and critical region as undertaking a combination of the steady state Joule heating in the resistance and the coupling losses due to the pulsed operations. A dedicated numerical model JackPot-ACDC is developed not only for a qualitative observation of the current and power distribution in 3D visualization, but also for quantitative calculation and analysis.

The current non-uniformity in the joint plays an important role in the power dissipation and consequent electrical and thermal stability. Previously, an updated design of the PF joint was proposed to reduce the largest induced current loops and coupling loss. Therefor a high resistive barrier called “mask” was introduced between strands and sole for the petals having double contact with the sole, subsequently a full-size joint was tested in the SULTAN facility to validate the idea. The mask and even more general non-homogeneous distribution of contact resistance between strands and sole are implemented in the quantitative model. This way the mechanism of the mask, the effect on the total resistance, current distribution, power distribution and stability is fully investigated. Furthermore, the results of the model suggest that the effect of increasing joint resistance with electromagnetic force (B \times I) as observed in the Sultan experiment can be explained by a change in contact resistance between strands and copper sole.

Submitters Country:

the Netherlands, Belgium, France.

Tue-Af-Po2.02 / 322

Quadrupole design for the 2 GeV upgrade of the CERN PS-Booster

Author(s): Jonathan David Speed¹

Co-author(s): Antony Newborough¹

¹ CERN

The CERN LHC Injectors Upgrade (LIU) seeks to reliably deliver the beams required for the High-Luminosity LHC (HL-LHC). As part of this, the Proton Synchrotron Booster (PSB) will be upgraded from 1.4 GeV to 2 GeV and will accelerate higher intensity beams. Along the transfer lines between the PSB and the Proton Synchrotron (PS) there are several D.C. operated quadrupoles which are unable to produce the gradients and field quality required for the 2 GeV HL-LHC beams. To minimise future power consumption, these will be replaced by laminated quadrupoles, operated in pulse to pulse modulation mode. Despite being installed along a transfer line, the field homogeneity requirements imposed on these magnets is very tight, requiring a homogeneity of 5×10^{-4} on the integrated gradient. Such strict requirements presented several issues for the design, especially when considering the space constraints which naturally apply when upgrading a pre-existing accelerator. The design and development process of these quadrupoles is summarised in this report.

Submitters Country:

Switzerland

Wed-Af-Or26 / 160

Qualification Program of Joints for ITER Coils

Y. Ilyin¹; F. Simon²; B.S. Lim²; C.Y. Gung²; P. Libeyre²; B. Turck²; A. Devred²; N. Mitchell²

¹ ITER IO

² ITER

The superconducting coils of the ITER tokamak have hundreds of joints interconnecting conductor unit lengths. The joints operate in magnetic field of up to 4T, field derivatives up to 0.5T/s, and currents up to 70kA. The majority of the joints has a twin-box design, with the exception of the coaxial and splice joints of the Central Solenoid. They are designed differently, to fit into the tight space around the coil periphery and to minimize energy losses under varying field.

The agreed on ground acceptance tests for the coils at 80K (the CS coil to be tested at 4K) creates no possibility to measure the resistance of the joints in the superconducting state. As no reliable NDT method was found to detect a joint failure, the series production of the joints relies on strict adherence to established manufacturing procedures. Furthermore, a periodic test of the joint samples manufactured in parallel with a coil fabrication helps to control the production quality.

To qualify the manufacturing procedures, to establish a series production tools and worker teams, a qualification programme was set up for manufactures of the coils. This programme includes a set of mock-ups and samples to mimic the manufacturing process, submitted to qualification tests. The tests include mechanical testing of materials at room and cryogenic temperature, electrical tests of full size joint samples in the conditions similar to those of the coils, destructive examination of the joint mock-ups, and mechanical test of the full size mock-ups. All tests are carried out in specialised laboratories qualified for this type of work.

The paper describes the main items of the qualification programme, the tests performed and the acceptance criteria. The test results are reported and compared to the criteria.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

France

Thu-Af-Po4.09 / 838

Qualification of movement leading to quench in Nb₃Sn coils by means of induced voltage, quench antenna and vibration measurements.

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A general understanding of training quenches in Nb₃Sn superconducting coils is that they are predominantly caused by settling of the coil while increasing the force in the magnet during current ramp up. In most cases, voltage measurements show precursors that can indicate the magnitude of movement. Three types of movement detection methods were combined in recent tests of Nb₃Sn model magnets: direct voltage measurements, quench antenna and accelerometers. The accelerometer measurements can exclude the electrical origin of the precursors in voltage and quench antenna data, and allow to further investigate the frequency and amplitude spectrum of the vibrations. In this paper we describe the test results of the three movement detection methods on state of the art Nb₃Sn model magnets and compare the results with each other and with existing and new theory. A proposal is made for clear classification of vibrations leading to quenches in the Nb₃Sn model magnets, which can be applied even when only the voltage measurement method is used.

Submitters Country:

Switzerland

Wed-Af-Po3.07 / 132

Quality and Stability Improvement of DC Power Systems in All Electric Ship Using SMES/Battery

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As All Electric Ship (AES) capacity increasing dramatically, load fluctuation of such systems may cause serious problems, such as voltage fluctuation of the ship power grid, increasing fuel consumption, and environmental emissions. In order to reduce the effects of system load fluctuations on system efficiency, and to maintain the bus voltage, a Hybrid Energy Storage System (HESS) is implemented in the AES. The HESS consists of two elements, a battery as a high energy density storage and a Superconducting Magnetic Energy Storage (SMES) as a high power density storage. A droop control is used to control charge/discharge prioritization. In our model, a SMES works as energy buffers to accommodate the quick changes in the load, reducing the power fluctuations, and as a result improving the stability and quality of the system, reducing environmental emissions, and allowing the system to work to its maximum economic efficiency. Manoeuvring and pulsed loads are the main sources of the power fluctuations. There are several types of pulsed loads including electric weapons, such as Electromagnetic Railgun (EMRG). These types of loads need large energies and high electrical powers which makes HESS the perfect power source. Many studies have been done to show the effectiveness of the supercapacitor/battery on the AES power grid, whereas to our knowledge, no study has been done to show the influence of SMES/battery on the AES power grid. In this paper, we propose to use SMES/battery in the AES power grid as a major novelty. Also, a DC droop control is used to coordinate charge/discharge of SMES/battery system. A model of the AES power grid integrated with SMES/battery has been built in Simulink / Matlab to show the effectiveness of SMES/battery on power grid quality. The effectiveness of the SMES/battery and supercapacitor/battery on the AES power grid will be compared under various scenarios.

Submitters Country:

United Kingdom

Tue-Mo-Or15 / 103

Quench (Thermal Runaway) Protection of Bi2223 (DI-BSCCO) Magnets

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Sumitomo Electric has been developing conduction-cooled magnets using Bi2223 wire (DI-BSCCO). Due to high in-field critical current of the wire, the magnets can operate around 20 K. Consequently, iterative excitations and, central field of 10 T or R. T. bore of 300 mm in diameter have been achieved. With respect to reliability of the magnets, quench (thermal runaway) protection might be a problem generally for high temperature superconducting magnets such as BSCCO and REBCO magnets due to the small NZP velocity. Sumitomo Electric confirmed that a bridge circuit with a dump resistor, which detects a quench and dumps the stored energy into the dump resistor, can protect Bi2223 magnets. The experimental coil consists of epoxy-impregnated double-pancake coils between copper cooling plates. The coil was conduction-cooled and then heated around 30 K until it generated a certain voltage. Relationship among the decay time constants, the quench detecting voltages, and the heat loads was investigated. The comparison of different sized coils between inductance 0.4 H and 15 H indicates that the difficulty of the magnet protection depends on the heat production rate of the hotspot, but not on the size of the coil. The operating currents are 200 A, 250 A, and 300 A. The higher operating current, the lower the protectable detecting voltage is. If the decay time constant is long, the protectable heat production rates are almost the same. The results of the experiments have been reflected in the practical design of the magnets.

Submitters Country:

Japan

Mon-Af-Po1.03 / 779

Quench Behaviour of Bi2Sr2CaCu2O8+x insert coils for high field magnets

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Advances in HTS technology have the potential to enable high field magnets with fields in excess of the maximum obtainable with purely LTS magnets. HTS insert coils may be operated in the bore of a high field LTS magnet, or 'outsert', in order to enhance the overall central field. The HTS inserts are usually operated at the same low temperatures as the LTS coils as this allows a common cooling system to be used and because the critical current density of the HTS is significantly higher at lower temperatures. A remaining barrier to widespread commercial application of HTS insert coils in this space is adequate protection of the HTS coil during quench, where the behaviour of such coils is substantially different from that of LTS coils. Oxford instruments is in collaboration with Bruker-OST and Dresden High Magnetic Field Laboratory to design, build and test a set of HTS insert coils to be tested in the bore of the 19T 150mm LTS magnet currently in operation at Dresden. The coils are wound from B-OST Bi-2212 round wire and are of lengths up to 300mm and diameters up to 125mm.

Selected coils have been instrumented for quench initiation and propagation velocity measurements and the relationships between minimum quench energy, quench propagation velocity, operating current and background field have been explored experimentally. Here we discuss the challenges in design, manufacture and test of this set of coils and present experimental results at low and high background field.

Submitters Country:

United Kingdom

Mon-Af-Po1.10 / 974

Quench Behaviour of a Metallic Cladding REBCO Coil Containing Copper Strips for Outer Diameter Adjustment

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When a high temperature superconductor (HTS) magnet consisting of a stack of pancake coils is wound, precisely controlling both the outer diameter and number of turns in the coil is difficult, mainly due to manufacturing uncertainty of the HTS tapes. To “arbitrarily” adjust the number of turns in each pancake is often adopted to precisely control the outer diameters, which obviously jeopardizes the ideally designed field homogeneity of the magnet, an important issue particularly for nuclear magnetic resonance or magnetic resonance imaging applications. A common approach is to place intermediate metal strips in-between selected turns of the pancake coils in a way to control both the outer diameter and number of turns to the design values. Yet, if this approach is used for a no-insulation (NI) HTS pancake coil, there is concern whether or not the coil will maintain the self-protecting feature. This paper investigates this issue in experiments in a bath of liquid helium at 4.2 K. An NI pancake coil was wound with metallic cladding REBCO tapes having a 1 – 2 um stainless steel cladding layer. Multiple quench tests were performed with the coil placed in a bore of a 10 T low temperature superconductor background magnet. The post-quench behaviors of the coil were monitored in various operating currents. The tests were repeated as the coil was reconstructed with different configurations such as the number of copper strips, size of strips, and strip locations. The results are expected to provide some insight for the baseline design of our future NI-REBCO NMR or MRI magnets.

ACKNOWLEDGMENTS: This work was supported by the National High Magnetic Field Laboratory (which is supported by the National Science Foundation under NSF/DMR-1157490), the State of Florida, and the KBSI grant (D37611) to S.-G.L.

Submitters Country:

USA

Tue-Mo-Or12 / 445

Quench Behaviour of the HL-LHC Twin Aperture Orbit Correctors

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¹ CERN

As part of the High Luminosity LHC (HL-LHC) upgrade, a novel type of canted cosine theta (CCT) twin aperture beam orbit corrector, the so-called MCBRB, is being developed that will provide 5 Tm of bending power per aperture in the approach to the ATLAS & CMS experiments. This CCT coil is a novel type of dipole coil, featuring aluminum formers with specially prepared slots that maintain the superconducting Nb-Ti strands in the correct configuration. The quench behaviour of this type of coil is intrinsically three-dimensional in which both the axial quench propagation and the transverse thermal exchange between neighbouring strands, the strands and formers, neighbouring turns, adjacent formers, and towards the helium bath play a role. A three-dimensional quench propagation simulation tool is being developed to investigate how the peak hotspot temperature and internal voltages are affected by the design choices of the CCT coil. The implications of conductor composition, strand insulation, external energy extraction, former insulation, helium cooling, bypass diodes, and quench back are presented. The calculation results are compared to experimental observations of the quench behaviour of a CCT model and the results of this comparison are used to formulate quench-protection-related design choices for the final design.

Submitters Country:

Switzerland

Thu-Af-Po4.09 / 55

Quench Detection Performance of the Magnet Safety System for the inductively coupled KATRIN Source Magnets

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The neutrino mass experiment KATRIN recently operated its complete chain of the superconducting magnets for the first beam test. A Magnet safety system (MSS) for the 16 m long source magnet system has been installed for quench detection and protection of the superconducting magnets. They are cooled by a liquid helium bath at 4.5 K. The magnet system consists of seven main superconducting solenoids with three different current circuits. External dumping of the stored magnet energy and quench heater activation are foreseen by the MSS for quenches. Quench validation is not trivial because of the inductive couplings of the magnets to their neighbors. The MSS was tested with the whole KATRIN magnet chain during the first beam test. The MSS is able to distinguish a quench of its own magnet circuit from a quench of other neighboring magnets and to discharge the magnets by the external dumping. The high-performance MSS allows one significantly to reduce both the helium consumption and the cryogenic recovery time. This paper reports on the first results of the quench detection performance of the MSS for the KATRIN source magnets.

Submitters Country:

Germany

Mon-Af-Po1.01 / 462

Quench Location in the LARP MQXFS1 prototype

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The high luminosity upgrade project US LARP/HiLumi has successfully tested the first 1.5 m prototype quadrupole MQXFS1 at Fermilab' Magnet test facility. Several thermal cycles and test programs were performed, with different pre-load configurations. To localize the quenches a quench antenna and the information of the voltage taps is used. The Quench Antenna was placed in the warm bore of an anti-cryostat centered in the magnet. We varied the length between quench antenna segments from 1" to 6", and shifted the location of the antenna to localize the quench origin along the various wedge and spacers transitions in the lead end of the magnet. We will present results on the identified quench locations for the second and third thermal cycle in this paper.

Submitters Country:

USA

Mon-Af-Po1.10 / 778

Quench Propagation Velocity and Hot Spot Temperature assessments in Nb3Sn Racetrack Model Coils using analytical and Finite Element Modelling approaches

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Since 2010 to present, several sub-size magnet assemblies, designed as test beds for impregnated Nb3Sn-based coil technology validation, are tested at the CERN Superconducting Magnet Test Facility (SM18). These Short Model Coils (SMC) and Racetrack Model Coil (RMC) have been used to characterize two types of Rutherford cables foreseen for the coils of the Nb3Sn magnets for the HL-LHC and High Field Magnets program of CERN. During several SMC and RMC test campaigns, the Rod Restack Process (RRP) and the Powder In-tube (PIT) conductors have been characterized in terms of performance, transversal and longitudinal Quench Propagation Velocity (QPV). Hot Spot Temperature (HST) increase during quenches were registered and signals analysed as function of current and energy. In this paper, the multi-physics problem of quench propagation is addressed by means of a set of analytical formulae and three Finite Element Models (FEM) using MATLAB, ANSYS Mechanical APDL and COMSOL packages aimed at describing the conductor behaviour in lumped 1D, 2D and 3D non-linear transient thermal framework coupled with electric constitutive laws for Nb3Sn and copper. The paper discusses in detail the relevance of the model assumptions taken at the composite cable boundaries (adiabatic condition, normal to superconducting state transition) needed for model reduction as computing time rapidly becomes an issue. The sensitivity of the models on the material properties distribution across the composite and on their temperature, as well the magnetic field dependence along the winding are presented. The comparisons of QPV and HST derived from the voltage and fibre optics sensors signals with the simulation results show a good stability of the models. The paper concludes with an attempt to normalise the QPV data sets from different tested coils.

Submitters Country:

Switzerland

Tue-Af-Po2.01 / 195

Quench Protection Heater Study with the 2-m Model Magnet of Beam Separation Dipole for the HL-LHC Upgrade

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Construction of the High Luminosity Large Hadron Collider (HL-LHC) is being planned for an increase of luminosity in order for the further exploration of the physics beyond the Standard Model. Under this program, a series of final focusing magnets, including a beam separation dipole (D1), has to be upgraded, and we, KEK, are responsible for development of the new D1 magnet. This magnet is designed to have an aperture size of 150 mm and to generate a field integral of 35 Tm. Fabrication of the first 2 m model magnet of D1, called MBXFS01, was completed in 2016, and the subsequent cold test was conducted to ensure its performance. After the test, we re-assembled MBXFS01 to enhance the coil pre-stress, and the second cold test was conducted with the re-assembled one (MBXFS01b) in 2017.

During the first and second cold tests, study on the quench protection was made using spot heaters (SHs) and quench protection heaters (QPHs). SHs are bonded to the inner surface of a single turn of the coil with the highest and the lowest fields, and the detection time of the balanced voltage are experimentally evaluated at given operating currents. The model magnet (MBXFS01 and MBXFS01b) also equips QPHs which cover the outer surface of the coils. These heaters are used to estimate the total heat input required to trigger a quench. In addition, we study how the maximum temperature of the coils varies with given operating currents when we rely only on these QPHs for an extraction of the coil energy. In this paper, we report a series of the quench protection studies and results from the measurements.

Submitters Country:

Japan

Wed-Af-Or24 / 981

Quench Protection Solutions for Magnets fabricated with HTS Conductors

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Quench protection is the elephant in the room that no one seems to see when it comes to HTS magnets. For the most part quench protection has not been much of a problem, because the stored energies of HTS magnets have been low compared to magnets made with LTS conductors. The principles of quench protection are the same regardless of the type of superconductor used. In general, a quench is not a problem if the adiabatic hot spot temperature at the end of the quench is less than a temperature that damages the conductor or its insulation and the magnet voltages are low enough to not breach the magnet insulation. It has long been understood that quench propagation along an HTS conductor is much slower than for a conductor like Nb-Ti. The reason for this is the large enthalpy change that occurs during a quench of an HTS conductor. The quench characteristics of an LTS magnet are a function of the conductor current density, the magnetic field at the conductor, the local temperature margin, and the ratio of copper to non-copper in the conductor. With an HTS

conductor one must add the effect of field orientation in the conductor, which can affect both the critical current and the critical temperature. This paper explores a number of ways for protecting magnets made from ReBCO conductor.

Submitters Country:

USA

Thu-Af-Po4.09 / 70

Quench Protection System for a 12-T dipole magnet

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The proposed CEPC-SPPC project needs thousands of dipole magnets with the field strength of 12-24 T: 12 T magnets for SPPC and 24T magnets for SPPC upgrade. A 12-T twin-aperture dipole magnet is being developed with Nb₃Sn superconductor. Two quench protection methods were mainly taken into consideration for this magnet: dump resistor protection and heater protection. The quench simulation with these two methods has been completed. The hotspot temperature can be limited to 70K when the terminal voltage is no more than 500 V. The experimental behavior and comparison with simulation results will be presented.

Submitters Country:

China

Thu-Af-Po4.09 / 882

Quench Protection of a Nb₃Sn Superconducting Magnet System for a 45 GHz ECR Ion Source

Author(s): Emmanuele Ravaioli¹**Co-author(s):** Aurelio Hafalia²; Daniel Xie¹; GianLuca Sabbi¹; Hongwei W Zhao³; Liangting Sun⁴; Mariusz Juchno⁵; Shijun Zheng⁴; Wang Lu¹; wei wu⁶¹ *LBNL*² *Unknown*³ *Institute of Modern Physics, Chinese Academy of Sciences*⁴ *Institute of Modern Physics, Chinese Academy of Sciences*⁵ *CERN*⁶ *student*

Lawrence Berkeley National Laboratory (LBNL) in collaboration with the Institute of Modern Physics (IMP) is developing a Nb₃Sn based superconducting magnet system for a fourth-generation ECR source, with a goal of achieving the field required for operating at the microwave frequency of 45 GHz. The magnet system is composed of one sextupole magnet and three solenoids of different sizes manufactured using Nb₃Sn round wire. Given the high stored energy density and relatively

low wire copper section, the coils are not self protected in case of a quench. In order to avoid permanent damage due to overheating, an active quench protection system is required. The protection of each individual magnet is analyzed separately maintaining common requirements in terms of maximum allowed hot-spot temperature and voltage to ground. The study of the transient following a quench is carried out by means of the LEDET (Lumped-Element Dynamic Electro-Thermal) program, which includes a detailed simulation of the inter-filament coupling losses developing in the wire. The baseline quench protection strategy includes energy extraction systems protecting each of the four magnet coils under consideration. The resistances of the four extraction resistors are selected as a compromise between a quick current discharge, calling for high resistance, and a low voltage to ground, calling for a low resistance. Non-linear effects occurring in the magnet, such as quench-back and differential inductance reduction, have a significant impact on these magnets' protection. It is shown that energy extraction meets the quench protection targets for the four magnet coils. Furthermore, in order to enhance the redundancy of the quench protection system and reduce the peak voltages to ground, the implementation of a CLIQ (Coupling-Loss Induced Quench) system is under consideration.

Submitters Country:

USA

Mon-Af-Po1.01 / 442

Quench Protection of the 11 T Nb₃Sn Dipole for the High Luminosity LHC

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¹ CERN

The planned upgrade of the LHC collimation system requires the installation of 11 T Nb₃Sn dipole magnets. Due to the large stored energy density and the low copper stabilizer section, the quench protection of these magnets is particularly challenging. A total of ten coils assembled in five single aperture and two double aperture short model magnets have been tested at CERN with different heater to coil insulation lay outs. This paper reports on the test results of the model program, which are used to validate numerical models and to optimize the quench protection performance. A parametric analysis on the impact of different conductor and operation parameters on the peak temperature is presented. Coil voltage to ground and turn to turn voltages are also evaluated under nominal conditions and failure case scenarios.

Submitters Country:

SWITZERLAND

Mon-Af-Po1.10 / 347

Quench analysis and protection design of SECRAL II superconducting magnet

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Superconducting electron cyclotron resonance ion source with advanced design in Lanzhou (SECRAL) has been built and is working in Institute of Modern Physics. SECRAL II is now under development as a preparative ion source. The superconducting magnet for SECRAL II consists of three axis solenoid coils and six sextupole coils with cold iron yoke. A three-dimensional quench simulation of the magnet has been carried out in OPERA-quench, the quench process of the magnet without protection circuit and iron yoke is first performed. Then the protection circuit is designed based on the analysis result. And then the analysis considering quench protection circuit is presented. Finally, the difference between simulation results with and without cold iron core and yoke is discussed.

Submitters Country:

China

Thu-Af-Po4.09 / 564

Quench and Recovery Characteristics of MgB₂ Coil with Various Protection Schemes

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In recent years, magnesium diboride (MgB₂) has been regarded as one of the promising candidates for the development of MRI magnets owing to its critical temperature of 39 K, which allows magnets to be operated without the use of liquid helium (LHe), unlike their low-temperature superconductor counterparts. Prior to the development of the LHe-free MgB₂ MRI magnet, it is essential to investigate the appropriate protection scheme for the magnets. Therefore, this study examined passive and active protections for a proto-type MgB₂ coil using the MgB₂ wires manufactured by Kiswire Advanced Technology Co. Ltd. The quench and recovery characteristics of the MgB₂ coil with various protection schemes were evaluated in terms of the maximum hotspot temperature, maximum induced voltage, and recovery time.

Acknowledgement: This work was supported by the Korea Basic Science Institute under Grant D37614.

Submitters Country:

Republic of Korea

Mon-Af-Po1.10 / 602

Quench and Recovery Characteristics of Racetrack Coil for Large-capacity Wind Generator

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¹ *Shanghai Jiao Tong University*

Second generation (2G) high temperature superconducting (HTS) tapes are now capable of carrying very high transport current and promising for a wide range of applications. A large-capacity wind generator prototype has been developed using HTS tapes. The racetrack coils wound with 2G HTS

tapes are used in the rotor, whereas the conventional technology is employed in the stator. The reliability of superconducting field winding is one of the most important factors for the developed wind generator. Racetrack coil can experience severe quench because of various disturbance, so it is necessary to investigate its stability and normal zone propagation characteristics. In this study, the minimum quench energy (MQE) and normal zone propagation velocity (NZPV) of racetrack coil are investigated using the voltage and temperature profiles in a conduction cooling system. Meanwhile, a numerical model is built to verify the measured results. The major innovation of this paper is the developed numerical model which combines COMSOL and MATLAB and couples electric field, magnetic field and thermal field. Moreover, this model can be used to predict the quench process of large racetrack coils. The detailed results about the experiments and the numerical analysis are presented and discussed in this paper.

Submitters Country:

China

Tue-Mo-Or15 / 1180**Quench detection via Rayleigh backscattering interrogated optical fibers****Author(s):** Federico Scurti¹**Co-author(s):** Weston Straka² ; Justin Schwartz²¹ *NCSU*² *NC State University*

The application of high temperature superconductors for the generation of high magnetic field is still limited by technical issues like quench detection. A novel quench detection technique is developed using Rayleigh backscattering interrogated optical fibers (RIOF). In particular, the technique is based on the comparison of Rayleigh backscattering signals of a reference and perturbed state. A spectral shift quantifies the mismatch between the two conditions, which depends on temperature and strain changes between the two compared states. Several HTS coils have been fabricated, instrumented and tested. Results show that RIOF is a viable choice for quench detection. In addition to demonstrating that the system works as a detector of normal zones, strain, the experiments also show the different advantages of the fiber optic system over a conventional voltage based one. In particular, optical fibers are co-wound with HTS wire using different integration schemes. Experiments at temperatures as low as 4.2 K have been performed and show that RIOF is operable at 4.2 K with no fundamental differences relative to higher temperature operation. The combination of high spatial resolution and high speed allows for rapid detection and localization of hotspots. Additionally, RIOF allows for a fine calculation of the instantaneous normal zone propagation velocity as a function of time, along with the normal zone size as a function of time. These capabilities, along with a deeper understanding of the minimum propagating zone (MPZ), enable the use of a criterion based on the MPZ to identify unstable (propagating) normal zones, instead of the conventional threshold voltage.

Submitters Country:

United States

Wed-Af-Po3.11 / 1034**Quench energy in ITER conductors for different magnetic field perturbations with JackPot and THEA combined models**Tommaso Bagni¹ ; Arnaud Devred^{None} ; Arend Nijhuis¹

¹ *University of Twente*

The electromagnetic-thermal model for Cable-in-Conduit Conductors JackPot-ACDC and THEA (Thermal, Hydraulic and Electric Analysis of superconducting cables) are combined for prediction of the stability of ITER Central Solenoid conductors. The combination of both models allows to predict the effect of any type of magnetic field perturbation in time relevant for the magnet coils during the plasma operation scenario of the reactor. At present there is no experiment to test the stability of the ITER Nb3Sn conductors under such conditions. Only limited experimental data on Minimum Quench Energy (MQE) defining the conductor stability are available but the time and magnetic field amplitude settings are quite different from the actual ITER operating conditions. Nevertheless such tests are useful as a basis to calibrate and benchmark the codes. JackPot+THEA allows to determine the MQE for any magnetic field change in time and to fully describe the involved electromagnetic phenomena on strand level detail in terms of local power dissipation and (peak) electric field. Thermally the computation is still on a global scale identifying the quench initiation and propagation. The predictions from the combined codes are in good agreement with the experiments and provide a solid basis for extrapolative scaling of CICC's stability under plasma operating conditions.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

Netherlands

Tue-Mo-Or12 / 837

Quench propagation and degradation limits of pre-strained HTS tapes with a spot heater

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Quench propagation and degradation properties are critical in quench detection and protection of high temperature superconductor (HTS). It is essential to understand the strain influence on quench propagation velocity (QPV) and degradation limits in HTS in practical applications since there are unavoidable for pre-strain and deformation in its manufacture and operation. In the present work, the quench propagation and degradation behaviors of critical property for pre-strained high temperature superconducting composite tapes are investigated experimentally during a heater triggered quench process. The distributed voltage taps, low-temperature strain gauges and thermal couples are attached on the tape to measure the QPV, strains and the quench degradation limits. In addition, the numerical predictions are presented to discuss the inherent relationship between the pre-strains and quench behaviors of the pre-strained HTS tape. It shows a reasonable consistent with the experimental data. Preliminary results indicate that the QPV increases and the degradation limits decrease for large pre-strained tape with tension deformation. The correlation between detection strain and hot point temperature is analyzed and discussed in detail. The potential applications with pre-strained HTS tape on the quench detection and protection are also discussed.

Submitters Country:

China

Mon-Af-Po1.10 / 799

Quench propagation measurements on 2 km MgB2 coil up to 4 T.

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Cea Saclay, in collaboration with the French SMI Sigmaphi, have fabricated a 50 kg solenoid with 2 km of Columbus MgB2 rectangular wire (3*0.7 mm²). The magnet was powered with 100 A at about 10 K and reached 4.2 T on the wire, with an external magnetic field of 3 T. A comparison between the protection and stability theoretical study and experimental results is presented. The quench propagation measurements have been performed at various temperatures, coil currents, and external fields. More than 20 quenches have been triggered using quench heaters mainly around the nominal design condition (10 K; 4 T and 50 A/mm² of overall conductor current). These measurements values are compared to the results of the design calculations. The differences with the numerical model are analyzed and a possible explanation of these differences is given by not taking into account eddy currents and ground insulation thickness. The validation of the experimental parameters is necessary for designing the protection of high field MgB2 magnets magnet in the frame of our development program. The performances of recent MgB2 wires allows us to reach magnetic fields over 5 T.

Submitters Country:

France

Wed-Af-Or24 / 292

Quench protection of HTS coil composed of multiple pancake-coils by changing current distribution in pancake-coils

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Co-author(s): Akane Kojima¹; Yoshiki Fuchida; Tomoaki Takao¹; Naohiro Matsuda¹; Osami Tsukamoto¹

¹ Sophia University

Sure quench protection of HTS coils is essential for their sustainable operations. The most probable cause of quench damages is the over-heating at the highest temperature spot (hot-spot) of the coil wire during the quench protection sequence. Therefore, to avoid the damage, generated heat in the hot-spot of the coil conductor has to be decreased by quick decrease of a current flowing in the hot spot area. A common and basic method to protect an HTS coil from quench is a detect-and-dump type active method. By modifying this method, the authors propose a method to reduce hot spot temperature *THS* of a magnet composed of multiple pancake-coils by changing current distributions in the pancake coils at a quench event by a passive method. In a coil composed of multiple pancake-coils, amplitude of the perpendicular magnetic field components to wide faces of HTS tape wires is different by the position of a pancake coil in the whole coil. Critical current I_c of HTS wire is dominated by the perpendicular magnetic field component and I_c decreases for high perpendicular magnetic field component and a quench starts most probably in pancake coils of low I_c . When a quench is detected in a pancake coil of lower I_c , the current in the lower I_c coil is transferred to the other coils of higher I_c by resistive shorting the higher I_c coils. In the paper, current distributions of each of a pancake coil are analytically obtained and effectiveness of the method is investigated by a numerical simulation of a model coil. In the simulation study, it is shown that hot-spot temperature is decreased and that the coil can be safer from quench damages by the proposed method, comparing with the ordinal detect-and-dump method for a given value of quench detection voltage.

Submitters Country:

Japan

Thu-Af-Po4.09 / 1115

Quench protection of an MgB₂-based MDS magnet system

Author(s): Marc Dhallé¹**Co-author(s):** Chao Zhou¹; Giovanni Grasso²; Herman ten Kate¹; Jaap Kosse; Marcel ter Brake¹; Matteo Tropeano³; Wouter Kühlkamp¹¹ *University of Twente*² *Columbus Superconductors SpA*³ *Columbus Superconductors, SpA*

This paper discusses the design of the quench protection for a conduction-cooled MgB₂ magnet system that will be used for magnetic density separation (MDS). First, an extensive literature review is made of currently available quench detection and - protection methods, which are discussed in a structured way in terms of merits and challenges. Next, the measured normal zone propagation velocity and minimum quench energy of MgB₂ wire produced by Columbus SpA are reported and used as input for pseudo-analytical modeling of the maximum hotspot temperature and coil voltages. These simulated quench characteristics are then combined with the literature review to select the most adequate quench detection and - protection strategies.

The work is part of the research programme "Innovative Magnetic Density Separation for the optimal use of resources and energy" with project number P14-07, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

Submitters Country:

Netherlands

Tue-Af-Po2.03 / 836

Quench simulation of a DEMO TF coil using a quasi-3D coupling tool

Author(s): Quentin Le Coz¹**Co-author(s):** Daniel Ciazynski¹; Matti Coleman²; Valentina Corato³; Benoit Lacroix¹; Sylvie Nicollet¹; François Nunio⁴; Roser Vallcorba⁴; Louis Zani¹¹ *CEA/IRFM*² *EUROfusion*³ *ENEA*⁴ *CEA/IRFU*

In the framework of the EUROfusion DEMO project, studies are conducted in several European institutions for designing the tokamak magnet systems. In order to generate the high magnetic fields required for the plasma confinement and control, the reactor should be equipped with superconducting magnets, the reference design being based on Cable-In-Conduit Conductors (CICC) cooled at cryogenic temperatures by forced circulation of supercritical helium.

In order to be compatible with DEMO requirements, a proposed toroidal field (TF) winding pack (WP) design should satisfy the criteria in operation and off-normal conditions. Quenches are studied to ensure that the proposed conductor design and associated quench protection system guarantee the integrity of the magnet; it is of most importance since it is a matter of safety and protection of the device.

Quench propagation in a coil is a 3-dimensional problem. For this reason, a transient pseudo-3D modelling tool was developed for coupled thermal and thermo-hydraulic calculation in a tokamak superconducting coil. The coupling tool is based on a set of 1D models of the cable using the THEA code, considering the helium flow, thermal conduction in the strands and propagation of the quench along the conductor; the 2D transverse thermal diffusion across turns and pancakes is modelled using

the Cast3M code, considering the conductor jacket and insulation, and eventually casing structures, on a selected set of cross-sections along the D-shape coil.

The aim of the analysis is to assess the quench behaviour of the CEA proposal for DEMO TF coil. The hotspot temperature, as well as the maximal pressure and normal length evolution are evaluated on a realistic quench scenario, emphasizing the impact of transverse heat diffusion.

Submitters Country:

FRANCE

Wed-Af-Po3.03 / 885

Racetrack-shaped large single pancake coils wound with 1 km-long REBCO-coated conductors

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Co-author(s): Hiroshi Miyazaki¹ ; Taizo Tosaka¹

¹ *Toshiba Corporation*

Large-scale racetrack coils wound with two kinds of REBCO-coated conductors were developed and tested. The two conductors had different critical currents, thicknesses and also allowable delamination stresses respectively for comparison. The total wire length of the fabricated two coils was 978 m and 945 m, and the overall size was 0.57 m x 1.14 m and 0.51 m x 1.08 m. The coils were impregnated with epoxy resin as bonding material to maintain the coil shape. Nevertheless, a racetrack-shaped coil is easily deformed at the straight parts, since the retention force due to the winding tension in the straight parts is not as high as in the semicircular parts so that it is difficult to achieve consistent dimensional accuracy. And a non-uniform resin between turns will cause the unexpected thermal stresses. Therefore the coil windings were being compressed continuously using a compression roller during the winding processes. The winding thickness in both of the semicircular parts and the straight parts showed approximately the same values within 0.5 mm, indicating that good dimensional accuracy was obtained consistently. Furthermore, the n-values of the two coils were sufficiently high as 24 and 23, respectively, in a voltage range from 10^{-9} to 10^{-8} V/cm at 77 K, which indicates that the coils had no damaged area in the windings.

Submitters Country:

Japan

Mon-Af-Po1.12 / 1070

Ramping Injector Power Supply for Dipole Magnets

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Co-author(s): Lou van Lieshout

¹ *Ampulz*

For the upgrade of the booster of the European Synchrotron Radiation Facility in France, an IGBT based ramping current injection system for the dipole electromagnets has been developed, delivered and commissioned. The main function of the dipole power supply is to drive the necessary voltage for an accurate 4 Hz triangular current wave injection in the electromagnets with peak value of current 1600 A. The inductance of the dipole magnets is 180 mH and their ohmic part 0.56 Ohms. The maximum peak to peak voltage ripple at the specified 6.4 kHz ripple frequency is required lower than 40 V peak to peak which leads to extremely low current ripple. Special requirement for the 4 Hz ramped current injection system was the design for reliability of 90 million load cycles before maintenance. The dipole power supply has been realized by 2 synchronized identical water-cooled units

in series connected. Each unit is realized by a 5-level neutral point clamped topology with a passive output filter and it is fed by a 12-pulse rectifier system. FPGA digital control is implemented for the controlled voltage source which results to precise high current injection in the dipole magnets. The synchronized operation of the two units offers in total 9-level output voltage which, in combination with the oversampled digital feedback control, leads to high dynamic performance. The ramping injector power supply also offers IGBT switching frequency 4 times lower than the ripple frequency in the magnets and proper thermal behavior in its nominal operation for high power cycling capability. Test results are available.

Submitters Country:

Netherlands

Tue-Af-Or18 / 1037

Ramping Turn-to-turn Loss and Magnetization Loss of HTS No-Insulation Coils due to Non-uniform Current Distributions (Overview)

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² *University of Bath*

³ *BNL*

⁴ *SuperPower Inc.*

No-insulation HTS (particularly REBCO) coil which has great merits of self-protection owing to current-bypassing across turns, are of great interests for high field insert magnet. Meanwhile it has delay issues during energization (current ramping). We have extensively studied ramping behaviors under various conditions and found out its dependence on turn-to-turn contact resistivity, coil size and turns number. It is found that increasing turn-to-turn resistivity does reduce the ramping delay, particularly when it's close to 8000 u-ohm cm². Moreover, we have studied ramping loss which including both magnetization loss and turn-to-turn loss in the NI HTS coil, and the latter is ~10 times more than the former. As many HTS coils stacked in a magnet system, such ramping behaviors become very complexity due to both the mutual inductance and turn-to-turn current bypassing. We have symmetrically studied ramping behaviors in the multiple-coils system and simulated non-uniform current distributions, as well as detailed calculation of the non-uniform ramping loss of all the coils and their inductive interaction. It is not only a timely report on the NI HTS coil development, but also a good time to discuss what the next steps are towards a mature technology. Remaining open questions will be reviewed and demanding issues will be discussed particularly.

Submitters Country:

USA

Mon-Mo-Or3 / 463

Real-time functional diagnostics of superconducting magnets using acoustic techniques

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Functional diagnostics of superconducting magnets is essential for ensuring their safe and reliable operation and understanding performance limitations. Among various known diagnostic approaches, acoustic techniques being non-invasive and inexpensive carry a significant potential that is not yet fully explored. Firstly, acoustic emissions provide direct access to magnet mechanical disturbance spectra, allowing localization, and in some cases identification of the type of disturbances leading to premature quenching, training and memory phenomena. Next, they allow for real-time structural monitoring of mechanical integrity, contact stiffness and coupling between magnet structural parts. Finally, early detection of heat release in coil windings during current ramping and quench development can be accomplished using active acoustic sensing of local variation of the Young's modulus. Acoustic detection of hot spots using this principle is complementary to the conventional voltage-based quench detection, and can be especially useful for high-temperature superconductor magnets exhibiting slow quench propagation. We demonstrate how the described range of diagnostic capabilities can be achieved with in-house developed package of passive and active acoustic analysis and sensor hardware. We present a novel "acoustic heartbeat" monitoring tool, allowing for in-depth real-time analysis of disturbance types, structural integrity and heat release in the magnet. Validation of our tool during testing of the canted-cosine-theta Nb3Sn dipole and ReBCO tape stacks will be discussed.

Submitters Country:

USA

Wed-Af-Po3.08 / 828

Realization and commissioning of WAVE Neutrons a Wide Aperture Vector Magnet for Neutron scattering experiments delivered Turn Key

Author(s): Raphael Pasquet¹

Co-author(s): Alexandre Bataille²; Antoine Dael; Arnaud Madur²; Christophe Berriaud²; Christophe Lecrenn¹; Damien SIMON³; David RAMAUGE¹; Emmanuel Voisin⁴; Frederic Molinie⁵; Frederick Forest⁶; Gaston Exil⁷; Guy Aubert²; Jean-louis Meauriot⁸; Nicolas Huttin¹; Pascal Lavie²; Philippe Bredy²; Pierre-eric Maillard¹; Sylvain Antoine⁹; Thomas Robillard¹⁰; morgan DELBECQ¹¹

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⁹ *Unknown*

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WAVE is a one tesla superconducting vector magnet for neutron scattering experiments. It will expand the range of experimental scattering possibilities by being able to applying a 3D magnetic field in any orientation, completely independently from orienting the sample in diffraction condition. WAVE will be used as a sample environment on neutron scattering instruments relevant for magnetism studies and thus available to a large community of users. This equipment is based on an innovative design (patent FR12 62 070, US extension 14/105,711), the magnet is made of 16 coils, all with a vertical axis, the homogeneity of the field is better than 1000 ppm. The design concept of WAVE, consists of NbTi wire wound solenoids imbedded in an aluminum box, indirectly cooled by a thermosiphon loop of liquid helium which is liquefied by a 2-stage cryocooler. An additional 1-stage cryocooler cools down the thermal screen and the current leads. This equipment has a very wide aperture which is crucial for neutron diffraction (220° horizontal, ±10° vertical with a warm

sample bore of 100 mm). The WAVE neutrons magnet system fabrication contract has been awarded to SIGMAPHI group. In this context, we present in this paper all the realization work performed by our company to deliver a complete turn-key magnet system comprising the magnet with its cryostat, its cooling system, its dedicated power supplies and quench detection system. We also report in this paper the results of the factory acceptance tests as well as the preliminary site acceptance tests performed at CEA during the last few months.

Submitters Country:

France

Wed-Af-Or27 / 943

Recent Magnet and Material Development at the Pulsed Field Facility – NHMFL

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¹ LANL

² NHMFL - FSU

³ NHMFL-FSU

The National High Magnetic Field Laboratory's Pulsed Field Facility at Los Alamos National Laboratory develops and provides state-of-the-art ultra-high field pulsed magnets for scientific research. The facility houses several types of non-destructive pulsed magnets which can provide the peak magnetic fields ranging from 60 T to 100 T with different pulse length for users. This presentation will highlight the recent developments for the pulsed magnet technology at our facility. In addition, we also want to share invaluable lessons learned from recent failures of the magnets and discuss the possible solutions to improve magnet performance.

Submitters Country:

USA

Thu-Mo-Or30 / 647

Recent Progress of Application-Oriented DI-BSCCO Wires

Takayoshi Nakashima¹ ; Shin-ichi Kobayashi¹ ; Goro Osabe² ; Tomohiro Kagiya¹ ; Kouhei Yamazaki^{None} ; Masashi Kikuchi^{None} ; Souichirou Takeda^{None} ; Tomoyuki Okada^{None}

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² Sumitomo Electric Industries, LTD

Sumitomo Electric has been developing silver-sheathed Bi2223 multi-filamentary wires, DI-BSCCO (Dynamically-Innovative BSCCO). The wires have been improved various properties in response to growing demands from application products and projects.

For high magnetic field applications targeting to more than several tesla, DI-BSCCO wires need to endure the intense hoop stress and maintain high engineering critical current (Je). Lamination with Ni-Cr alloy tapes has proved to be a more feasible way to solve these challenges compared to stainless steel lamination. Combination of the thin (0.030 mm-thick) Ni-Cr alloy tapes and the previously reported lamination technique "pre-tension" has significantly enhanced the mechanical properties of the DI-BSCCO wires. For example, critical double bending diameter at room temperature ~ 35 mm, critical tensile stress at 77 K ~ 440 MPa, and critical tensile strain at 77 K ~ 0.5 %. The DI-BSCCO wires laminated with the Ni-Cr alloy tapes were formerly called Type HT-XX (~2014) and have been officially named Type HT-NX (2015~). In terms of more practical use, the applicative DI-BSCCO

wires have been generating new needs for a variety of evaluations and technical challenges to be addressed. In this talk, the detailed performances of the currently available wires and the updated R&D activities will be shown.

Submitters Country:

Japan

Tue-Af-Po2.08 / 12

Recent progress in development of high performance CICC for CFETR magnet

Jinggong Qin^{None}

The CFETR, "China Fusion Engineering Test Reactor", is a new tokamak device. Its magnet system includes the Toroidal Field (TF), Central Solenoid (CS) and Poloidal Field (PF) coils. The main goal of this project is to build a fusion engineering tokamak reactor with fusion power of 50-200 MW and self-sufficiency by blanket. The maximum field of CS and TF will get around 15 T, which is much higher than that of other reactors. Tremendous investigations have been made in the development of high performance CICC for CFETR magnet in the last two years. High temperature superconductors and new designs for CICC were considered. Firstly, one CICC referred to ITER CS was developed for CFETR Central Solenoid Model Coil (CSMC), and tested at SFC in 2016, showing similar behavior as ITER CS with good performance. Furthermore, two small-size Bi2212 conductors with 42 wires were developed, heat treated at 1 and 50atm, separately. As the result, the one heat-treated under 50 atm shows higher I_c by a factor of 2. Based on the investigations, Bi2212 prohibits big potential to develop the full size CICC for CFETR CS and TF magnet. Moreover, one CICC with new design was proposed, manufactured and tested. This new CICC presents with higher stiffness but less strand damage inside as advantages, after the test at Twente University for stiffness (77 K) and AC loss. The stiffness shows similar behavior to ITER CS conductors. In this paper, the recent progress in development of high performance CICC for CFETR magnet are introduced and described in details, in terms of manufacture, test results, and their analysis.

Submitters Country:

China

Tue-Af-Or16 / 250

Recommissioning and upgrades to the FNAL muon g-2 magnets

Karie Badgley¹

¹ *Fermilab*

The recently recommissioned Fermilab muon g-2 experiment is aiming to determine the anomalous magnetic moment of the muon to 140 ppb. To achieve this level of precision, the magnetic field seen by the muon must be known at a fraction of a ppm level, which puts limits on the required magnetic field uniformity. This paper provides an overview of the g-2 magnet systems; the inflector magnet, the main ring magnet, and the 200 active compensation coils. After mechanical adjustments and shimming were performed on the magnet pole tips, the remaining integrated field errors were measured using NMR probes. These remaining higher order multipoles are reduced using the compensation coils. Three charcoal panels were also removed from the cryogenic vacuum system to prevent magnet quench due to pressure spikes. Installation and testing of the inflector magnet, as well as work toward a new inflector, will also be discussed.

Submitters Country:

United States

Thu-Af-Po4.10 / 305

Reduction effect of irregular magnetic field due to screening-current in copper-plated multifilamentary REBCO tape

Atsushi Ishiyama¹ ; Yuichi Ozone¹ ; Hiroshi Ueda² ; Tomoaki Koizumi² ; SeokBeom Kim² ; So Noguchi³¹ Waseda University² Okayama University³ Hokkaido University

The research and development on the applications of REBCO superconducting coil to the high field magnets for NMR, MRI, accelerator and so on are in progress. In these application, the magnets need to create highly homogeneous and temporally stable field. However, the screening currents lead to the serious problem in REBCO magnets for the applications required very high field quality. Then, multi-filamentary REBCO tapes are expected to reduce the screening current induced magnetic field in the REBCO coil. The multi-filamentary REBCO tape is plated the copper for mechanical strength and thermal stability. And, the coupling currents are induced between filaments in REBCO tape during excitation. In REBCO coil using copper-plated multifilamentary REBCO tape, the transverse resistivity between filaments in REBCO tape is important factor for thinking about the behavior of magnetic field and current distribution. In previous study, we developed three-dimensional numerical simulation code using finite element method (FEM) and fast multipole method (FMM) to calculate the spatial and temporal behavior of screening current distribution in REBCO coil. The validity of the developed numerical simulation was confirmed by comparison with the experiments. In this study, we focused on the transverse resistivity between filaments in REBCO tape and investigated the current distribution in the multifilamentary REBCO tape by using our developed simulation code. We discuss on the effects of transverse resistivity of multifilamentary REBCO tape on the diffusion process of screening current and the spatial and temporal behavior of the magnetic field.

Submitters Country:

Japan

Thu-Af-Po4.10 / 1155

Reduction of the screening current field in HTS coils wound by using Soldering-Stacked-Square (3S) REBCO wires

Author(s): Zhuyong Li^{None}**Co-author(s):** Fei Gu ; Daoyu Hu ; Timing Qu ; Zhiyong Hong ; Zhijian Jin

1-mm wide REBCO tapes have been produced through continuous fine cuts from a 5-mm wide one. Soldering-Stacked-Square (3S) wires were assembled by these narrow tapes and used for coil winding. The screening current field (SCF) introduced by the magnetization inside HTS wires were greatly reduced due to the narrower geometry of 3S wires. The remnant field caused by SCF were measured to be 40-70% less than a comparison coil wound by using normal 4-mm tapes, when both coils were discharged from 5 A, 10 A and 30 A at 77 K. These results conformed well with simulations based on H-formulation, which showed clear different screening current patterns inside 3S wires and normal tapes. This work shows a new way to reduce SCF of HTS coils, which will be of great importance for HTS magnets requiring high field stability and homogeneity.

This work was supported in part by the National Natural Science Foundation of China (Project 51577119).

Submitters Country:

China

Tue-Af-Po2.10 / 431

Refinement and application of a generic CFD toolkit covering the heat flows in combined solid–liquid systems to investigate thermal quench limits of superconducting magnets

Author(s): Fouad Aabid¹**Co-author(s):** Rob Van Weelderren ¹¹ CERN

The recently developed robust multi-region numerical toolkit for the modelling of heat flows in combined solid–liquid systems ¹ is extended to cover larger temperature domains, crossing the superfluid to normal helium state transition, and to include NbTi cables that feature open electrical insulation, porous to superfluid helium. The aim is to be able to probe for superconducting magnets their thermal design details' influence on the temperature margin. The model enhancements are discussed and the model is applied to analyse the results of a particle beam loss test in a LHC main dipole ¹. We show and quantify which of the built characteristics of the superconducting magnet, such as electrical insulation and interlayer fishbones, are most influential on the local temperature margin and hence the quench level seen by the magnet.

¹ Development and application of a generic CFD toolkit covering the heat flows in combined solid–liquid systems with emphasis on the thermal design of HiLumi superconducting magnets, Gennaro Bozzaa, Ziemowit M. Malechab, Rob Van Weelderren, Cryogenics, Volume 80, Part 3, December 2016, Pages 253–264 Chats on Applied Superconductivity 2015 University of Bologna, Italy, 14-16 September 2015

¹ Bound-free pair production in LHC Pb-Pb operation at 6.37 Z TeV per beam, J.M. Jowett, M. Schumann, B.Auchmann, C. Bahamonde Castro, M. Kalliokoski, A. Lechner, T. Mertens, C. Xu, Proceedings of IPAC'16, Busan, Korea, May 2016, Pages 1497-1500, ISBN 978-3-95450-147-2

Submitters Country:

Switzerland

Mon-Af-Po1.10 / 1234

Remarkable difference in thermal runaway behavior between a Ni-alloy reinforced Bi-2223 coil and a REBCO coil

Author(s): Yu Suetomi¹**Co-author(s):** Yoshinori Yanagisawa ¹ ; Hiroki Mochida ² ; Kentaro Kajita ³ ; Tomoaki Takao ³ ; Hideaki Maeda ⁴¹ RIKEN² Sophia University, RIKEN³ Sophia University⁴ riken

A Ni-alloy reinforced Bi-2223 conductor (Bi-2223) enables the construction of a compact high field magnet due its high mechanical strength. However, its thermal runaway behavior has not been investigated. The purpose of this paper is to investigate (a) the thermal runaway behavior and (b) the subsequent degradation of a Bi-2223 coil. For this purpose, a five-turn pancake with an artificially degraded section was made and tested at 77 K. The different behavior between the Bi-2223 coil and a REBCO coil will be discussed.

The degraded section in the middle turn continuously generates heat, resulting in a premature thermal runaway. In a case of the Bi-2223 coil, the thermal runaway initiation current for the paraffin impregnated coil (adiabatic) was 117 A, 105 % of I_c , while that for a dry coil (cooled) was 158 A, 142 %. The corresponding heat generation was 4.4 W and 28 W, respectively. In the case of REBCO coil, the thermal runaway current for a paraffin impregnated coil was 53 A, 54 % of I_c , while that for a dry coil was 90A, 92 %. The respective heat generation was 1.7 W and 5.3 W. Thus, from a viewpoint of thermal runaway, the Bi-2223 coil is several times more tolerant than the REBCO coil. Based on numerical simulations, such a high tolerance is due to the lower n-index and higher T_c of Bi-2223. For the Bi-2223 coil, fatal degradation did not appear until the temperature exceeded 483 K, i.e. the melting temperature of the solder bonding a Bi-2223/Ag and a Ni-alloy. This temperature is higher than that of a REBCO coil, 340 K. Thus, the Ni-alloy reinforced Bi-2223 coil is superior to the REBCO coil from a view point of thermal runaway tolerance and permissible temperature rise.

1 Yanagisawa, et al., SUST075014, 2012.

Submitters Country:

Japan

Thu-Af-Po4.08 / 678**Repair method of locally defective or damaged coated conductor using the superconducting patch****Author(s):** Rock Kil Ko¹**Co-author(s):** No Hyun Woo¹ ; Kim Gwan Tae¹ ; Ha Dong Woo¹¹ *Korea Electrotechnology Research Institute*

We have proposed a method for effectively repairing locally defective or damaged HTS coated conductors produced during manufacturing HTS coated conductor or coil winding for magnet applications using superconducting patch. The superconducting patch was fabricated by separating the metal substrate from the commercial HTS coated conductor using the interface delamination phenomenon. And it has high J_c (engineering critical current density) coated conductor with simple structure of "stabilizing layer / superconducting layer / stabilizing layer". This idea is that a reduced critical current can be recovered by attaching a superconducting patch to the defective or damaged coated conductor. In this presentation, a detailed introduction to the idea and experimental results to investigate its feasibility are discussed.

Submitters Country:

Republic of Korea

Wed-Af-Po3.10 / 1082**Research and Analysis on Impulse Discharge of EAST Cryogenic Axial Insulation Breaks**Cheng Wu^{None} ; Wanjiang Pan^{None} ; Yi Cao^{None} ; Huang Chen^{None}

The cryogenic axial insulation breaks (IBs) are key components of the superconducting magnet system for the EAST device, which play an important role of the liquid nitrogen and liquid helium insulation channel. In order to ensure the safe operation of the IBs during the working life of the EAST device, experimental research and analysis on impulse discharge performance should be carried out, including structural analysis, impulse discharge test in air and helium condition.

Submitters Country:

China

Mon-Af-Po1.12 / 308

Research of Active Regulation for High-Stability Flat-Top Pulsed High Magnetic Field

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Pulse generator is one of the common power supply for flat-top pulsed magnetic field for its advantages of large energy storage and flexible control. However, some characteristics of pulse generator, such as nonlinearity and time-varying, limit the effect of measures by optimizing control strategy to improve the stability of flat-top. On the base of pulse generator power supply system for flat-top pulsed magnetic field at Wuhan National High Magnetic Field Center (WHMFC), a scheme of parallel active regulator composed by cascade H-bridge converter is proposed in this paper. PI feedback control with Carrier Phase Shifted Sinusoidal Pulse Width Modulation (CPS-SPWM) is adopted by the regulator to adjust the ripple during the flat-top. A 50 T/140 ms flat-top pulsed magnetic field with the ripple less than 100 ppm is achieved through system modeling and simulation. An optimal control strategy combining selective PI control and repetition control is proposed to restrain the circulating current between pulse generator and active regulator. Selective PI control is designed for the regulator that the ripple at flat-top is divided into two parts by 20 Hz low pass filter. One part with the frequency under 20 Hz is regulated by ripple tracking control and the other is regulated by PI control. Repetition control is used for the pulse generator to optimize the triggering angle of the rectifier. In order to verify the effectiveness of the optimal control strategy for high-stability flat-top pulsed high magnetic field with the active regulator, experimental data about the triggering angle of rectifier is employed into the simulation model, and the result shows that circulating current between pulse generator and active regulator has been suppressed effectively.

Acknowledgements: The National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.

Submitters Country:

China

Mon-Af-Po1.12 / 314

Research of a new DC breaker based on the electromagnetic forming technology for Battery power supply of long pulsed magnet

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In Wuhan National High Magnetic Field Center, a new explosive DC breaker switch based on the pulsed electromagnetic forming (EMF) technology is developed to shut down the Battery Bank power supply for protecting the long pulsed magnetic field system when terrible fault happens. The switch is reformed from the aluminum wire electrical explosive switch of the Laboratoire National des Champs Magnétiques Intenses in France. The new DC breaker switch consists of pulsed magnet (EMF coil), aluminum tube (the main contact of DC breaker) and its supporters. The switch uses pulsed magnetic field to apply repulsion produced by induced eddy current to expand the aluminum tube, which can be broken at the weaknesses of V-shaped slots in a very short time. The concept of repulsion is based upon inducing currents flowing in the contrary directions in the pulsed magnet (EMF coil) and in the aluminum tube, which, according to Ampere law, results in repulsion forces between the pulsed magnet and the tube. By combining the advantages of the aluminum wire electric explosive DC breaker and the electromagnetic forming (EMF) technology, the analytical model

based upon the solution of Maxwell is built by the software COMSOL Multiphysics to simulate the distribution of magnetic flux, magnetic force, tube deformation and their interactions. Both simulation and primary experimental results show that the design of the new DC breaker with compact volume and easy maintenance is feasible. In addition to the pulsed high magnetic field facility, the breaker can also be applied to numerical potential industrial fields.

Submitters Country:

China

Wed-Af-Po3.06 / 679

Research on MgB₂ armature windings in fully superconducting AC machine

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Fully superconducting machine is the one that can take the most advantages of superconducting materials with dramatically improving the magnetic loading and electrical loading at the same time. However, intense R&D effort is giving priority to partially superconducting machines not only for their lower manufacture difficulty but also higher feasibility compared to fully superconducting machines. Fully superconducting machines are in trouble with high ac losses during the operation for too much power is consumed to take away all these heat losses and make an unacceptable low efficiency for the entire system. What is more, air-core structures are preferred to use in fully superconducting machines, which caused strong Lorenz force on the superconducting windings. Such stress field will cause a threat to superconducting coils by significant performance degradation. Although with many difficulties, the researches of fully superconducting machines never stop especially when relatively low ac loss superconducting materials such as fine filament NbTi, YBCO, and MgB₂ were developed. Much work was done in trying new superconducting materials, proposing novel topologies, designing new cryostat structure and supporting structure to decrease the ac loss or heat leakage. Yet, the research on the superconducting magnets especially the superconducting armature windings in fully superconducting ac machine are lacked. MgB₂ is believed to be one of the most promising superconducting materials with acceptable expense, low ac losses, high customizability. In this paper, a 10 MW fully superconducting machines employing MgB₂ on both field windings and armature windings for offshore wind turbine is designed. The full paper will focus on the influence of the magnetic field and Lorentz force on the MgB₂ armature windings in this machine. Some solutions are tried to lower the ac losses and the affection of magnetic force on the armature windings at various operation conditions.

Submitters Country:

China

Tue-Af-Po2.10 / 644

Research on Temperature Rise and Temperature Control for Giant Magnetostrictive Transducer

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Terfenol-D has giant energy density (25kJ/m³) and relatively high thermal conductivity (13.5w/(m·k) at 20°C). It is the core component of giant magnetostrictive transducer (GMT) which has been widely used in the field of ultra-precision machining and precision fluid control technology. However, when GMT operates under 6000Hz high frequency magnetic field, hysteresis loss, eddy current loss and copper loss of excitation coil lead to serious temperature rise. The temperature of Terfenol-D rod can reach above 120°C without a cooling device. The temperature rise of Terfenol-D rod seriously affects the precision of GMT. So, it is necessary for GMT to analyze temperature rise and temperature control under high frequency. This paper includes two parts: (1) Based on the theory of Jiles-Atherton model, Maxwell's equations, Newton's law and Fourier's heat transfer equation, a nonlinear electromagnetic-mechanical-thermal multi-field coupled finite element model for GMT is established. The temperature rise characteristics and output responses of GMT are analyzed. (2) Based on the convection heat transfer theory and the thermal compensation method, a new combined temperature control device is presented. It consists of two main structures which are servo valves for compulsive oil-cooling and thermal compensation mechanism of nonmagnetic stainless steel. According to the theoretical and experimental researches, when the velocity of the fluid is greater than 0.5m/s, the temperatures of Terfenol-D rod can be controlled within 21.7°C under the excitation field of 6000 Hz. The temperature error can be limited below 0.5°C, and the axial output displacement error by temperature rise can be controlled less than 0.65 μm. These studies can effectively guide the design and application of GMT under high frequency magnetic field.

Submitters Country:

China

Tue-Af-Po2.06 / 723

Research on a Coreless Superconducting Linear Machine for Electromagnetic Catapult

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¹ *Southeast University*

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Electromagnetic catapult has been considered as a part of launch vehicle system as it can lower the recurrent cost for space exploration. Superconducting magnets are considered for levitation firstly and they can lift over 150 times their weight. Much work including building numerical models has been done to analyze the thrust properties of HTS LSM but few of them are interested in thrust ripple. This paper derives the air gap flux density and studies the influence of harmonic component on no-load induced voltage and steady thrust. Compensation coils which can generate an opposite flux density to the harmonic flux density are designed to eliminate the fifth harmonic flux density. Since the motor is coreless, the waveform of the air gap flux density is exactly the same as the waveform of MMF. The magnitude of the nth harmonic flux density is expressed. With the increase of n, only the fifth harmonic is significant. The fifth harmonic can be reduced by increasing the width of excitation coils when α increases from 0 to $\pi/6$. However this method is not effective enough because the ratio is 4% when α is $\pi/6$. The winding method of the armature is distributed winding because the thrust of the distributed winding model is larger than the concentrated winding model. The distributed winding method of the armature is implemented. Thrust produced by the mover is derived. The steady thrust has contains a period ripple whose frequency is 6 times of that of induced voltage. To reduce thrust ripple, compensation coils are used to generate a flux density which is opposite to the fifth harmonic flux density excited by excitation coils. The air gap flux density is analyzed with different width of excitation windings. The ratio of the thrust ripple is reduced.

Submitters Country:

China

Thu-Af-Po4.06 / 1147

Research on a field-modulated tubular linear generator with quasi-Halbach magnetization for ocean wave energy conversion

Author(s): Tao Xia^{None}**Co-author(s):** Haitao Yu¹; Rong Guo¹; Xiaomei Liu²; Lei Huang³¹ *School of Electrical Engineering, Southeast University*² *Southeast University*³ *Southeast University*

With the energy crisis and environmental problems becoming increasingly prominent, the utilization of renewable energy is showing an accelerated attention. Compared with wind and solar power, ocean wave energy has many advantages such as high energy density, large amount and being easy to forecast. Direct-drive ocean waves energy conversion system(WEC) has a simple structure and higher efficiency, and this make it an effective way to extract energy from ocean waves. But the average speed of ocean wave is generally slow. This will lead the traditional linear generator with disadvantages of large weight and low power density. In order to solve this problem, the permanent-magnet field-modulated tubular linear generator is proposed, which can accelerate the speed of the traveling magnetic field by the teeth in the primary. Hence, it will lead it to higher power density and energy conversion efficiency. Simultaneously, equipped with quasi-Halbach magnetized permanent-magnet, it can improve the air gap magnetic density and reduce the volume and weight of the generator to some extent. In this paper, a proposed FMPMTLG with 10 pole-pairs and 9 primary teeth is investigated and designed. Meanwhile, a corresponding quasi-Halbach PMTLG is also designed to compared with the proposed machine. For the sake of fairness, these two machines are optimized with the same axial length, overall diameter, air-gap length and magnet volume. From the individual results of the FEA, it can be seen that the efficiency of the proposed machine is higher than the traditional PMTLG excluded the mechanical and stray loss. And due to the more pole-pairs, the cogging force of the FMPMTLG is lower than the traditional one. The proposed machine achieves lower voltage regulation for the weakened reactive effect. The tubular linear generator with quasi-Halbach magnetization has manufactured for the experimentation to verify the validity of the theoretical analysis.

Submitters Country:

China

Thu-Af-Po4.06 / 1118

Research on an Asymmetric-primary Hybrid-excitation Maglev Axis-flux Generator for the Vertical Axis wind Turbine

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The floating wind power generation is an important trend of the wind power generation on the sea, paid more attentions by the researchers around the world. The direct-drive vertical axis wind turbines (DVAWT) gives an important development direction for the floating wind power generation. In order to improve the starting performance and output power of the DVAWT, a hybrid excitation maglev axial-flux generator with asymmetric primary is proposed in this. Two-sided asymmetric primary is adopted to obtain maglev force and improve the starting performance, and hybrid excitation is used to adjust the suspension force and output power in real time for the stable output. Firstly, the operation principle of the proposed hybrid excitation maglev axial-flux generator is introduced, and the magnetic field distribution is analyzed by using 3D finite element method (FEM). The cogging

torque produced by the teeth-slot effect between stator and mover may cause the mechanical vibration and ripple of electromagnetic force. Two axial-flux generators with different pole slot ratio are optimized and compared. In addition, the parameters in the static or the dynamic state are calculated and studied, and the laws of the parameters effecting the motor performance are grasped, and the optimizing method to weaken the cogging torque are obtained. Secondary, the levitation force is obtained and analyzed under different primary currents. Based on the on-load performance, a hybrid excitation method is proposed and is compared with only PM working. Lastly, considering the levitation force and output power, coordinated strategy of primary armature current and excitation current is proposed. By using 3D FEM, the output voltage, out power and voltage-regulation factor under different wind speed are obtained and analyzed. All the results show the proposed generator has advantages of Stable levitation force, controlled power, low voltage-regulation factor, and is well suit for vertical axis wind turbine.

Submitters Country:

China

Tue-Af-Po2.06 / 1200**Research on control system of a novel coil assisted reluctance motor****Author(s):** Aimin Liu¹**Co-author(s):** Peng Sun¹ ; Jiachuan Lou¹¹ *Shenyang University of Technology*

The novel coil assisted reluctance motor is a kind of high torque DC motor combined with traditional permanent magnet brushless DC motor and switched reluctance motor. The motor with double sets of armature windings and the central coil (field winding) which is installed between two-stator-rotor by axial excitation has a 9\6 symmetric double salient pole structure. Based on the special structure of the motor, a two group of power module with one power supply is designed to control the amount and direction of the phase voltage and exciting current, and to adjust magnetic field as magnetic flux density is not saturated. In the case of being constant for the phase voltage, the speed and torque can get the corresponding change separately by increasing or decreasing the excitation current. When the load is constant, increasing the field current and reducing armature voltage can get the effect of saving energy. Because of inherent torque ripple problem of doubly salient motor, after simplifying mathematical model of the motor, a three phase-six state control mode on the basis of the standard angle control mode is put forward—increase the conduction phase during commutation, according to finite element analysis of ANSYS/MAXWELL. And a new speed-torque closed loop control mode is formed by adding a field current control to achieve the aim of increasing starting torque, minimizing commutation torque ripple and extending speed range. Finally the reliability and feasibility of the control method is verified through the simulation and experiment respectively. The load capacity of the motor has been greatly improved and the motor runs more calmly.

The project is supported by National Natural Science Foundation of China (51377107).

Submitters Country:

China

Thu-Af-Po4.05 / 919**Research on demagnetization-resistant structure of synchronous motor performance using Nd-permanent magnets reduced heavy rare earth metals**Dong-woo Kang¹

¹ Keimyung University

In order to reduce the heavy rare earth element, permanent magnet are continuously developing. Especially, maintain of high coercive force is a very important technology in motors that mainly use high currents. In addition, since the price of heavy rare earth element is high, the use of the rare earth element is minimized so that the price competitiveness of the motor is obtained. In this paper, we have developed the permanent magnet type synchronous motor for Idle Starter & Generator. To increase the output density of the motor, a study was made on a structure capable of generating the maximum magnetic flux per unit volume. In this process, various structures and permanent magnets were applied to compare the characteristics of simulation through FEM. In the case of motors using permanent magnets, it is essential to verify the demagnetization of the permanent magnet by the inverse magnetic field. In particular, in a system requiring high-speed operation, the field control must be performed due to the limitation of the voltage that can be supplied. At this time, demagnetization of permanent magnets can be easily generated. Therefore, in this paper, we analyze various situations in which permanent magnets can be demagnetized by simulation and verify them by test. Finally, we present the results of the study on the demagnetization-resistant structure to minimize the demagnetization of permanent magnets even if the magnet is applied by minimizing the Dy among the heavy rare earth elements.

Submitters Country:

Republic of Korea

Mon-Af-Po1.12 / 648

Research on operation strategy of the pulse generator power system energizing the out coil of the 100 Tesla magnet

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¹ Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology

A magnet composed by three coaxially nested coils has been developed to generate 100 Tesla pulsed magnetic field at the Wuhan National High Magnetic Field Center (WHMFC). The flywheel generator system has great energy storage density and can control the waveform of the magnet current, therefore the outer coil is energized by a 100 MVA/100 MJ flywheel pulse generator. To reduce the magnet heat and solve the generator output voltage overshoot, the power supply system works in the inverter state after rectification. As the pulse generator power system has rich harmonics and unbalanced three-phase voltage, the speed of adjusting inverse angle and the value of the maximum inverse angle is critical to avoid the inverter failure. In this paper, an appropriate speed of adjusting inverse angle and the optimal inverse angle are derived in detail, which is based on the simplified schematic and some assumptions. Considering that the spike voltage caused by the change of inverse angle affects the safety and stability of the power system, a method of reducing peak voltage by changing excitation voltage is proposed, which restrained peak voltage effectively. When the inverter time exceeds the protection value, the switchgear trips and cuts off the power supply with the magnet into the freewheeling state. simulations and experiments show that this proposed operation mode including rectification, de-excitation, inverter and tripping can meet the power supply needs of the outer coil, improve the efficiency of the pulse power and ensure the safe and stable operation of the system.

Submitters Country:

China

Thu-Af-Po4.06 / 1148

Research on the linear tubular motor with multilayer flux-concentrating permanent magnets for direct-drive ocean wave conversion

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With the rapid develop of energy crisis and environmental problems, the utilization of renewable energy is attracting an increasing attention in the world. Compared with the wind and solar power, ocean wave energy has many advantages, such as high energy density, large amount and being easy to forecast, etc. Therefore, a various ocean wave energy extraction systems have been proposed and established in recent years. Direct-drive ocean energy conversion system(WEC) has a simple structure and higher efficiency, which merely comprised of linear generator and buoys without any medium-devices. However, the traditional linear generator in WEC usually has disadvantages of large weight and low power density due to the average low speed of ocean waves. In order to solve this problem, the linear tubular motor with multilayer flux-concentrating permanent magnet is proposed. The permanent magnets are arranged evenly and alternately in the axial direction, and the produced flux-concentrating effect can improve the air gap magnetic flux and power density obviously. The multilayers of permanent magnets could make the magnetic flux more sinusoidal distribution. When the WEC operates in the sea, it encounters extreme weather sometimes. The huge force generated by the incident ocean waves may destroy the magnets. But the proposed machine is to embed permanent magnets into silicon steel, this structure would enhance the mechanical strength to withstand the storm to some extent. Using the FEA, the performances comparison between the traditional and proposed machine has identified that the last one has the advantages of high torque capability and power density. The experimental tests on the prototype machine in a wave tank have been conducted to verify the validity of FEA results.

Submitters Country:

China

Wed-Af-Po3.05 / 206

Research on the thermal characteristics of permanent magnet linear motor operated in short-time duty cycle

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There is an increasingly demand for the electric machine with the characteristics of high power density, high speed and high temperature. While the first problem on the road to reach these objects is to solving the temperature rise of electric machine. There is a very closed relationship between heat transfer problems and various application conditions of motors. Larger continuous constant-load operation motors are commonly operated with specific capacity load in a continuous duty. While in some conditions, motors need to be operated with higher capacity load in an intermittent duty, which need to be analyzed from the angle of heat transfer. when motor operated with short-time or intermittent duty, the load capacity usually changes with the time, the operation time may change from few seconds or several minutes, so the output torque may be research up to several times of the rated torque, so the current density may be very high. In this article, a high power density PMLM with the ultimate current density of 12 A/mm² is designed, which can be used to research the thermal characteristics of this PMLM operated in short-time or intermittent duty with normal operating characteristics. A finite element model is built to calculate the temperature of this PMLM, the loss and thermal parameters are calculated by the electromagnetic and fluid field. Finally, the relationships among the current density, peak temperature, thermal recovery time and duration time

are analyzed. The general temperature change laws of PMLM with different current densities and duties are obtained and verified by the experiment, which is important in designing and analyzing the thermal characteristics of the permanent magnet linear motor.

Submitters Country:

China

Mon-Af-Po1.09 / 700

Resistance of splices in the LHC Main Superconducting Magnet Circuits at 1.9 K

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¹ CERN

The electrical interconnections between the LHC main magnets are made of soldered joints (splices) of two superconducting Rutherford cables stabilized by a copper busbar. In 2009, a number of splices were found not properly stabilized and could have burnt through in case of quench at high current. The LHC was therefore operated at reduced energy and all Rutherford-cable joints were continuously monitored by a newly installed layer of the Quench Protection System (QPS). During the first Long Shutdown (LS1) in 2013-14 the high-current busbar joints were consolidated to allow a safe operation of the LHC at its design energy, i.e. 14 TeV center-of-mass. The SMACC project (Superconducting Magnets And Circuits Consolidation) has coordinated the consolidation of the 10170 13 kA busbar splices. Since 2015 the LHC runs at the energy of 13 TeV center-of-mass. This paper will briefly describe the QPS data analysis method and will present the results and comparisons of the Rutherford-cable splice resistance measurements at 1.9 K before and after the LS1, based on an unprecedented amount of information gathering during long-term operation of superconducting high-current joints. A few outliers that were still found after the splice consolidation will also be shortly discussed.

Submitters Country:

switzerland

Wed-Af-Po3.11 / 829

Robust REBCO coated conductor with metal stitching stabilizer

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Co-author(s): No Hyun Woo¹; Gwan tae Kim¹; Dong-Woo Ha¹; Kim Seog Whan¹; Jo Young Sik¹

¹ Korea Electrotechnology Research Institute

REBCO coated conductor has architecture of metal substrate/ buffer layers / REBCO layer/ metal over-layers. Multilayer thin films are deposited on metal substrate by various deposition or coating technique. From this structures, films delamination and interfacial failure in coil applications are caused by thermal mismatch strains and potentially high Lorentz forces. We have proposed advanced structures of REBCO coated conductor for improving the mechanical properties and electrical stabilities using the micro-holes and fill technique. Micro-holes were made by laser drilling on the surface of the REBCO coated conductor and filled with conducting metal such as Ag, Cu and Solder to act as metal channel for connecting with both side of metal over-layers. And also it play a role as electrical and thermal channel for quench energy dispersion. So we were named "Metal Stitching

Stabilizer". In this presentation, a detailed introduction to the robust coated conductor with metal stitching stabilizer and experimental results to investigate its feasibility are discussed.

Submitters Country:

Republic of Korea

Tue-Af-Or18 / 128

Role of electrostatic charges in the calculation and measurement of AC losses in superconducting coils.

Fedor Gömöry¹

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Dissipation of energy in a superconducting coil generating magnetic field that varies in time could be evaluated locally as the product of electrical field and current density. The effect of electric field exerting force and accelerating the electric charge carriers that transport the current is commonly incorporated into AC loss calculation by inserting a realistic current-voltage dependence e.g. in form of a power law. A direct experimental confirmation of this computation approach would require the placement of a suitable sensor inside the conductor forming the coil winding. Therefore such approach to AC loss analysis is ruled out for real superconducting coils. On the other hand one can measure the total voltage appearing at the coil winding. We prove that this voltage is in fact the electrostatic field produced by the electric charges accumulated at the conductor non-uniformities like the coil terminations. Practical aspects of this approach are demonstrated analysing a series of thought experiments on objects with increasing complexity.

Submitters Country:

Slovakia

Wed-Af-Po3.12 / 666

Rotor Losses Research of Brushless Doubly-fed Machine with Hybrid Rotor

Author(s): Fengge Zhang¹ ; Guangwei Liu¹

Co-author(s): Yutao Wang¹ ; Siyang Yu¹ ; Shi Jin¹

¹ *Shenyang University of Technology*

Brushless doubly fed machine (BDFM) is a new type of adjustable-speed machine developed in recent years. It has broad application prospects in the field of variable frequency speed regulation and wind power generation. However, the traditional loss calculation method is no longer applicable due to the special structure and complex magnetic field distribution of BDFM. A novel hybrid rotor structure which has better coupling ability than the commonly used rotor structures such as cage rotor, wound rotor and reluctance rotor is presented but it also increases the difficulty of rotor loss calculation. In this paper, in order to calculate the rotor loss accurately, the time-stepping finite element mathematical models of rotor iron loss and copper loss of BDFM with hybrid rotor are established by considering the influence of skin effect, harmonic magnetic field and eddy-current loss. Based on the mathematical model of iron loss, the spatial distribution and time-variable value of magnetic flux linkage are obtained, and then the iron losses of rotor (hysteresis loss, eddy-current loss and added loss) is calculated. Based on the mathematical model of copper loss, the copper loss is determined by three main factors which is the bar conductor current, skin effect coefficient and DC resistance of bar conductor. In addition, the bar conductor current is calculated by magnetic vector

potential, and the skin effect coefficient is identified by referring to the calculation method of induction machine cage winding. In order to verify the validity and feasibility of proposed mathematical model, the simulation model of BDFM with hybrid rotor is established and analyzed, and the results of simulation and calculation are consistent. Thus, this mathematical model provides a theoretical basis for the rotor losses research of BDFM with hybrid rotor.

This work is supported by the National Natural Science Foundation of China under Grant 51537007.

Submitters Country:

China

Wed-Af-Po3.06 / 571

Rotor Structure Design and Optimization of MW-class Brushless Doubly Fed Generator for Offshore Wind Turbine

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Co-author(s): Fengge Zhang¹ ; Siyang Yu¹ ; Shi Jin¹

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Brushless doubly fed generator (BDFG) has a broad application prospect in variable speed constant frequency offshore wind power generation system, in recent years, MW-class generators for offshore wind turbine has been becoming the hot-spot of research. Due to the large volume of MW-class generators, if the solid rotor is used, there will be some difficulties in the process of transportation and installation. In order to reduce the rotor weight, in this paper, three rotors used for BDFG, which are consist of rotor spider, magnetic separation layer and magnetic barrier part, are designed, and the web number of three rotor spiders are 3, 4 and 5 respectively. The idle state and rated operation condition of the three rotors are simulated by FEA, according to analyzing the simulation results, it can be known that at the idle state and rated operation condition, the maximum stress is mainly distributed on the junction between support ribs and shaft, and its value is far less than the allowable stress value of materials, the maximum deformation is distributed on the outer edge, and can meet the operation requirement of the generator. Comparing the maximum deformation, it can be seen that the maximum deformation of the rotor with four webs is smaller than that of the rotor with three webs by 20.62%, and the maximum deformation of the rotor with five webs is smaller than that of the rotor with four webs by 15.62%, through comprehensive consideration, the rotor with four webs is selected. Finally, the super-synchronous and sub-synchronous operation conditions of the selected rotor are simulated, the maximum stress and deformation are all within the range of the allowable values, the reliability of the designed rotor is further verified.

The work is supported by Key Project of National Natural Science Foundation of China (51537007).

Submitters Country:

China

Thu-Af-Po4.02 / 58

STATUS OF CEA MAGNETS DESIGN METHODS AND TOOLS AND APPLICATION TO EU DEMO MAGNETS DESIGN

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In the framework of the design activities conducted in EU for dimensioning the future fusion demonstration reactor (DEMO), extensive analyses were led through in the EUROfusion context, aiming at ultimately defining the design of the DEMO magnets system. In this objective CEA has developed ad-hoc pre-dimensioning tools and associated methods in order to size the different magnets: Toroidal Field (TF) coils, Central Solenoid (CS) and Poloidal Field (PF) coils. Once pre-dimensioned the magnet concepts undergo an evaluation process deriving from detailed analyses with more elaborated tools and methods. The latter being more time consuming, the whole process benefits from a most accurate as possible pre-dimensioning process. The tools address various aspects driving the operational limits of the magnets while energized in the tokamak, related to electromagnetic, thermic and mechanic phenomena.

In the present paper we mainly expose the latest developments achieved on the pre-dimensioning tools and the methods employed for obtaining a reliable macroscopic semi-analytical representation of the magnets. The assessing of the pre-dimensioning tools on reference configurations (e.g. ITER) will be also described. An outlook will be shown on the tools used for evaluation step and their possible integration. For both types of tools a discussion will be provided on the methods and criteria retained and the comparisons with reference analyses (e.g. detailed finite elements analyses on hotspot criterion).

The application of the above described tools on the DEMO configuration issued by EUROfusion will be shown, and their outcome as proposals for magnet design for: - The TF system, considered with pancake winding geometry; - The CS, considering modular geometry (6 modules) and pancake winding; - The PF system, composed of 6 coils. Discussions on the sensitivity of each system to design parameters / criteria will be provided, extended to some tentative recommendations on DEMO magnets design approach.

Submitters Country:

France

Tue-Af-Po2.10 / 701**STEAM: A Hierarchical Co-Simulation Framework for Superconducting Accelerator Magnet Circuits****Author(s):** Lorenzo Bortot¹**Co-author(s):** Bernhard Auchmann¹ ; Idoia Cortes Garcia² ; Alejandro Manuel Fernandez Navarro³ ; Michal Maciejewski⁴ ; Marco Prioli¹ ; Sebastian Schöps⁵ ; Arjan Verweij (Program Chairman)¹ ; Matthias Mentink¹ ; Emmanuele Ravaioli⁶¹ CERN² Technische Universität Darmstadt³ Centro de Investigaciones Energéticas Medioambientales y Tecnológicas⁴ Technical University of Lodz(PL)⁵ Technische Universität Darmstadt⁶ LBNL

Numerical simulations play a crucial role in understanding transient phenomena occurring within circuits of superconducting accelerator magnets. Numerical methods are extensively used during both the electromagnetic and mechanic design. Furthermore, simulations support the quench protection system design, bringing insights on the quench behaviour and contributing to prevent potentially irreversible consequences.

Accelerator magnet circuits are intrinsically multi-physics, multi-scale, and multi-rate systems. The

currently available multi-physics simulation tools tend to cover only a specific subset of physical domains, given that no high-performance tool can cover the full range of phenomena within a single model. Therefore, circuits are traditionally decomposed in simpler parts, represented in domain-specific models refined by expert knowledge. As a consequence, the domains' reciprocal influences are neglected, possibly leading to incorrect results.

In this paper we present STEAM, a Java-developed framework which implements a hierarchical co-simulation scheme. The key feature is a dedicated common interface which enables the exchange of information between multiple models, arranged as modular and independent sub-units. The consistency between the solutions is ensured by the convergence of the co-simulation algorithm, which applies the waveform relaxation method. The framework implements a scalable and extendable architecture, which ensures that any new sub-unit can be easily interfaced. Then, the STEAM collaborative environment enhances the synergy between the different sub-units which can be actively used in a modular approach, depending on the required simulation scenario.

The STEAM capabilities are applied to the inner triplet circuit for the High Luminosity LHC at CERN, assuming a quench scenario in one of the low-beta Nb3Sn quadrupole magnets (MQXF). The system is deconstructed and co-simulated by means of dedicated models which account for the quench initiation and propagation, the reaction of the quench protection system, the electro-thermal behaviour of the magnet, and the electrical transient in the external circuit. Results are analysed, and further applications are proposed.

Submitters Country:

Switzerland

Tue-Af-Po2.02 / 1242

Sector DC Dipoles Design for the Beam Test Facility Upgrade

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The Beam Test Facility (BTF) is part of the DAΦNE accelerators system, of INFN Frascati National Laboratory (LNF). It is a transfer-line optimized for selection, attenuation and manipulation of electrons and positrons extracted from the DAΦNE LINAC. An upgrade of the line is scheduled by the end of 2018 in order to reach a beam energy of 920 MeV (with respect to the actual 750 MeV) and a new branch of the actual transfer line, in order to have two different beam lines into two separate test apparatus.

The layout of the new transfer line foresees seven new quadrupoles and a beam deflection of 135 degrees achieved through a 15 degrees fast ramped dipole and three DC sector dipoles particularly two with 45 degrees and one 35 degrees bending angle.

The design of the magnets has been completely performed at INFN, including electromagnetic, mechanical, thermal and hydraulic aspects. Electromechanical Enterprise partner were involved in the design phase in order to optimise the manufacturing process. This effort leads to a complete set of detailed CAD drawings that can be directly used from industrial partners to build the magnets. The goal is to boost the manufacturing of prototypes and small series from Small and Medium Enterprises. Magnetic measurements will be later performed at our Institute.

This paper is focused on the realization of the two 45 degrees H-shape dipoles and on the 35 degrees C-shape dipole. All the three dipoles have a full iron yoke and they are characterized by a high flux density that reach the maximum value of 1.7 T in a pole gap of 35mm. This requirement is due to the combination of beam energy and geometrical constraints of the hall that will host the line that limits the allowable curvature radius at 1,8 m.

Submitters Country:

Italy

Mon-Af-Or9 / 1103

Self-heating effect in HTS coils

Author(s): Marc Dhallé¹**Co-author(s):** Anne Bergen¹; Erik Krooshoop¹; Herman Ten Kate²; Konstantyn Yagotyntsev¹; Marcel ter Brake¹; Markus Bauer³; Martin Keller³; Nir Tzabar¹; Sander Wessel¹¹ *University of Twente*² *CERN*³ *THEVA Dünnschichttechnik GmbH*

A straightforward analytical model is presented that describes the observed slow thermal drift of the conduction-cooled ReBCO coils developed for the EcoSwing project. In the vicinity of their critical surface, both the temperature and the voltage across these coils drift upwards in response to a current step, on a time-scale ranging from minutes to hours. Eventually, such drift results either in a quench or a new equilibrium temperature. EcoSwing aims to demonstrate the world's first superconducting low-cost, light-weight wind turbine drivetrain. In order to validate the rotor pole design, THEVA produced a series of sub-scale test-poles which reflect the actual layout of the full-scale poles. Several of these sub-scale coils were tested at the University of Twente in terms of superconducting behavior and thermal housekeeping. The voltages across the coils were measured over time at various current levels and base temperatures ranging from 55K-77K. To explore the thermal drift effect described above, an analytical model was devised based on self-heating of the winding pack. The model, which essentially combines a simple heat-balance equation with a non-linear power term, shows how the detailed ratio between initial heating and cooling leads to two sharply separated types of eventual outcome, either stable or unstable. The heat capacity of the coil does not influence this outcome, although it does determine the time scale. Model predictions were compared to experimental data, showing excellent qualitative and relatively good quantitative agreement. As such, the model provides a better understanding in the thermal behavior of conduction-cooled HTS coils and may be used to guide their design. EcoSwing has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No656024. Herein we reflect only the author's view. The Commission is not responsible for any use that may be made of the information it contains.

Submitters Country:

The Netherlands

Thu-Af-Po4.09 / 1182

Self-monitoring, SMART REBCO coated conductors

Author(s): Federico Scurti¹**Co-author(s):** Srivatsan Sathyamurthy²; Martin Rupich³; Justin Schwartz⁴¹ *NCSU*² *American Superconductor Corporatio*³ *American Superconductor Corporation*⁴ *NC State University*

The development of second generation (2G) high temperature superconductor (HTS) wires has allowed for achieving performance levels that are suitable for numerous applications and allow for the generation of the high magnetic field required in applications like future particle colliders. In fact, 2G HTS technology is currently being employed in fault current limiters (FCLs), energy storage devices, motors and generators, different cable configurations and high field magnet applications. Any technology based on HTS, however, still suffers from the fact that conventional quench detection techniques result insufficient and ineffective when applied to HTS based systems. A novel way to

address the quench detection challenge is represented by Rayleigh backscattering interrogated optical fibers (RIOF). The ultimate way to integrate optical fibers into coils is to embed them directly in the conductor. Here the quench detection challenge in HTS has been addressed by developing conductors that are able to self-monitor their status, detecting incipient, local transitions to the normal state. The feasibility of a 2G HTS wire incorporating an optical fiber has been demonstrated. The embedded optical fiber is interrogated by Rayleigh backscattering and therefore presents all the advantages of the RIOF approach, with the addition of ultimate sensitivity and complete cancelation of reduction in winding packing density. In fact, with the development of such a coated conductor, the optical fiber doesn't take up any additional space in a magnet, leaving the magnet design completely unchanged. Straight samples and small coils of SMART conductor have been characterized and used in quench experiments, showing the potential of the SMART conductor technology.

Submitters Country:

United States

Thu-Af-Po4.05 / 385**Sensorless Control of Bearingless Permanent Magnet Synchronous Motor Based on MRAS**Huangqiu Zhu¹ ; Yizhou Hua² ; Chenyin Zhao^{None}¹ *Jiangsu university*² *Jiangsu University*

In the past two decades, bearingless permanent magnet synchronous motors (BPMSMs) have been researched widely. Because of the advantages of high efficiency, long operation life, no friction, and so on, the BPMSMs have the prospects to be widely applied in high-speed and high-precision mechanical processing and many other industrial fields. In the control system of the BPMSM, in order to obtain a good suspension performance, the accurate rotor radial displacement detection is necessary. However, the displacement sensors used in the BPMSM system not only increase the cost and the shaft length but also decrease the reliability of the BPMSM. Therefore, the research on rotor radial displacement sensorless control technology is of great significance. In this paper, a rotor radial displacement sensorless control method of the BPMSM based on the model reference adaptive system (MRAS) is proposed. This method not only has higher accuracy and better robustness than the open loop estimation method, but also has simpler structure and lower cost than the high-frequency signal injection method. Firstly, the principle of radial suspension force generation and the mathematical models of the BPMSM are introduced. Secondly, the suspension force windings current model and the actual BPMSM itself are applied as the adjustable model and the reference model, respectively. Then, the adaptive mechanism based on the Popov's hyperstability theory is derived. The BPMSM rotor radial displacement sensorless control system is designed afterwards. Finally, the comparative simulations and experiments between the proposed method and an open loop estimation method are carried out. The results show that the maximum error between the actual rotor radial displacement and the estimated displacement is 0.005mm, while the data in the open loop estimation method is 0.008mm. In addition, the changes of the parameters in the reference model have little impact on the estimation result.

Submitters Country:

China

Tue-Mo-Or13 / 554**Series Production of ITER TF Coil Winding Pack in Japan****Author(s):** Norikiyo Koizumi¹

Co-author(s): Kunihiro Matsui¹ ; Tsutomu Hemmi¹ ; Hideki Kajitani² ; Mio Nakamoto¹ ; Minoru Yamane¹

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National Institutes for Quantum and Radiological Science and Technology, (QST), as Japan Domestic Agency in ITER, has responsibility to procure 9 ITER Toroidal Field (TF) coils. QST completed series production of the first seven double-pancakes (DP), all of which are for the first TF coil. The target tolerance of impregnated DP, 2 mm flatness, was achieved in all these DPs. These DPs were stacked and ground insulation was wound around the stuck DPs. The impregnation of these stuck DPs to form winding pack (WP) is being prepared. In addition, series production of DPs for later TF coils are being proceeded. Including the first TF coil DPs, Winding of 26 DPs, heat treatment of 21 DPs, fabrication of 16 radial plates (RP), transfer of 16 DPs and cover plate (CP) welding of 13 DPs were completed until end of Feb. 2017. Challenging tight tolerances in conductor length, +/-0.01%, was achieved to enable transfer of heat-treated conductor into RP groove. 1 mm flatness was achieved in RP, whose height and width are 13 m and 9 m. In addition, about 2.5 mm flatness was achieved after CP welding by optimizing welding sequence. The flatness of 2 mm could be achieved for all DPs completed and DPs for the first WP was successfully implemented. These results justify that series production of TF coil DP in Japan is going well.

Submitters Country:

Japan

Tue-Af-Po2.10 / 348

Shielding Current Analysis in High-Temperature Superconducting Film and Its Application

Author(s): Teruou Takayama¹

Co-author(s): Ayumu Saitoh¹ ; Atsushi Kamitani¹

¹ *Yamagata University*

For the purpose of contactlessly measuring a critical current density in a high-temperature superconducting (HTS) film, the contactless methods such as the inductive method, the hall probe method, and permanent magnet method have been developed. These methods are applied to the distribution measurement of the critical current density for the case with large-area samples such as an HTS wire or tape. On the other hand, they are also used to the defect detection of the HTS bulk or film. As a contactless method for measuring the critical current density, Claassen et al. have proposed the inductive method. By applying an AC current to a small coil placed just above an HTS film, they monitored a harmonic voltage induced in the coil. They found that, only when a coil current exceeds a threshold current, the third-harmonic voltage develops suddenly. They conclude that the critical current density can be evaluated from the threshold current. Incidentally, this method has been successfully employed as the distribution measurement of the critical current density the detection of a crack. The purpose of the present study is to develop a finite element method code for analyzing the time evolution of the shielding current density in a multiple-layered HTS film containing a crack and simulate the superconducting devices. For example, the inductive method was reproduced numerically in the previous study. The results of the computations show that when the coil approaches any cracks, the estimated value of the threshold current always decreases. Furthermore, even when the outer diameter of the coil is in contact with the edges, the accuracy of the inductive method is slightly degraded.

Submitters Country:

Japan

Wed-Af-Po3.10 / 1136

Simulation Analysis of Typical Defects on superconductor cable

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Any insulation defects will produce partial discharge, resulting in the gradual deterioration of the insulating material surrounding the defect and may eventually lead to serious accidents. In order to study the risks of the typical construction defects on the superconductor cable, this paper analyzes the typical failure mechanism of defect and then using the finite element method to study the electric field of superconductor to determine the distortion of the electric field around each typical defects. The results show that the presence of the air gap on the primary insulation will lead to the distortion of electric field about 3.29 times; the residual impurities on the main insulation due to construction will cause the distortion of electric field about 2.35 times; the uneven peeling of the semi-conductive layer will lead to distortion of the electric field around 2.68 times. Three typical defects cause a large distortion of the electric field, which will easily lead to partial discharge occurs, but the potential level of the risk is not the same, the findings can be used to guide the construction and cable fault analysis for the superconductor cable.

Submitters Country:

China

Tue-Af-Po2.12 / 809

Simulation and Experiment of HTS Coils with a New Structure as Inductors in STRETCH Meat Grinder Circuit

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Inductive pulsed power supplies attract attention from lots of research institutions and scholars since the energy density of inductors is approximately one order of magnitude higher than that of capacitors. Institute for Advanced Technology (IAT) proposed an inductive pulsed power topology named Slow Transfer of Energy through Capacitive Hybrid (STRETCH) meat grinder. In recent years, HTS wire has become sufficiently available to build prototypes and practical instruments. Combining the features of STRETCH meat grinder circuit with the advantages of HTS, we put forward a new structure of HTS coils with transposition method to gain higher pulsed current output. As HTS wire has the advantage of low losses, STRETCH meat grinder modules with HTS coils help to reduce the requirements for the primary power supply, which contributes to the decrease of weight and size of pulsed power system. In the paper, we introduce the design and modeling progress of the new coil structure in detail. Simulation results show that transposition method actually can make current in HTS tapes of parallel-wound coil tend to even distribution. By using the coils with new structure in STRETCH meat grinder, maximum pulse current amplitude of several hundred amperes can be obtained with a high current multiplication factor. Besides, experiments were taken to verify the feasibility of the proposed coil structure.

Submitters Country:

China

Thu-Af-Po4.10 / 147

Simulation of Screening Current Reduction Effect of External AC Magnetic Field on Multi-turn REBCO Pancake Coils

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Screening currents induced in superconducting wires are well known as a critical issue upon NMR/MRI magnet operations. It invokes an irregular field and downgrades the magnetic field homogeneity of NMR/MRI magnets. Especially, in REBCO magnets, screening currents have a strong effect on an on-axis magnetic field due to the shape of REBCO tapes. Therefore, in order to reduce the screening current-induced magnetic field, Kajikawa et al. proposed a method of applying an external AC magnetic field in parallel to the REBCO tape's surface. The reason why the screening currents induced in REBCO coils have such considerable effect is that both positive and negative screening currents are separately distributed on the short edges of REBCO tape having more than 1000 aspect ratio. Then, by applying an external AC magnetic field, both the currents are separately re-distributed along the long tape edges. As a result, the screening current-induced magnetic field is decreased. A validity of this shaking field method was presented in experiments and numerical simulations. In the previous papers, we have presented the simulated shaking field effect on a single-turn REBCO tape. However, when multi turns of REBCO coils have to be considered, the identical magnetic field is not necessarily applied to all the turns due to their mutual interaction. In addition, their behaviors depend on the frequency and magnitude of AC magnetic field. Therefore, it is difficult to know the most effective condition of AC magnetic field. In the extended paper, we will present current distributions on the cross sections of multi-turn REBCO coil computed by 2D finite element method when an external AC magnetic field is applied with various kinds of conditions. We will also discuss about the field homogeneity created by re-distributed currents after applied shaking field.

Submitters Country:

Japan

Wed-Af-Po3.08 / 403

Simulation of Thomson Parabola spectrometer for charged particle diagnostics in the PETAL+ project

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The PETAL (PETawatt Aquitaine Laser) laser facility is a high energy multi-petawatt laser, which is able to generate pulses of up to 3.5 kJ energy with a duration of 0.5 to 5 ps. This petawatt laser will be coupled with the ns pulsed beams of the LMJ (Laser MégaJoule). Such facility will provide unique tools for inertial confinement fusion (ICF) physics. PETAL is located in the site of the CEA/CESTA in the Barp, close to Bordeaux. The Petal+ project is aiming at designing and constructing the first diagnostics of the PETAL laser for the characterization of the Target Normal Sheath Acceleration (TNSA) particle source. Among them, SEPAGE (Spectrometre Electrons Protons A Grande Energie) is a two Thomson Parabola (TP) diagnostic and will measure the electron, proton & ion energy spectra in the direction perpendicular to the PETAL target. This paper presents the simulation by Finite Element Method of these two Thomson Parabolas: High Energy (HE) and Low Energy (LE) which work simultaneously. Each TP involves the use of a magnetic field generated by a pair of permanent magnets and an electric field generated by a potential difference across a pair of electrodes.

Submitters Country:

France

Tue-Af-Po2.09 / 165

Simulation of the ITER Toroidal Field Coil Case welding distortion using Finite Element Method

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⁸ fusion for energy

The first European superconducting Winding Pack (WP) and the first set of Coil Cases (TFCC) for ITER are going to be delivered in 2017. The TFCC are steel structures which provide structural integrity to the WP, contribute to neutron shielding capacity, provide support to operating forces and offer interface connections with the rest of ITER machine. The TFCC assembly is formed by four main parts, two sectors with U-shaped section and two closure plates, which, after being welded together, enclose the WP. Each TFCC weights about 150 t and present wall thicknesses from 60 to 120 mm. The presence of distortions when welding such thick structures is particularly problematic in our components requiring tight tolerances and with several interfaces with other components of the tokamak. In order to compensate distortions, extra-material is present in the critical areas to allow post-welding machining. The amount of extra-material has to be optimized to reduce machining time and therefore cost of the components. So, the evaluation of the welding-caused-distortions is essential in order to confirm the extra-material strategy. In this scenario, a complete experimental and virtual campaign has been set up to predict and minimize the deformation of the TFCC during welding. First, welding coupons were welded in representative configurations. Then, this data was used to build a preliminary modelling approach, using ANSYS® software, which was then benchmarked against a 'blind test' coupon and three TFC-like mock-ups of 1 m long. Finally, a full FEM model is under construction using the previous lessons-learned, to predict the deformation of the coil structures during the welding process. This paper describes the numerical and experimental activities carried out so far, being EnginSoft S.p.A the developer of FEM models, SIMIC S.p.A the responsible of welding processes and data acquisition, and Fusion for Energy the contractual and technical supervisor.

Submitters Country:

Spain

Thu-Af-Po4.08 / 1065

Simulation of the delamination behaviors in the 2G HTS tape with consideration of thermal stress

Author(s): Yujie Duan^{None}; Yuanwen Gao^{None}

Co-author(s): Youhe Zhou

Key Laboratory of Mechanics on Environment and Disaster in Western China, The Ministry of Education of China, Lanzhou The 2G HTS tapes have been widely used in the magnets, cables and superconducting magnetic energy storage (SMES) systems with its outstanding electromagnetic characteristics. As a typical multi-layer composite structure, the superconducting tape is delaminated easily by the strong electromagnetic force and the thermal stress. A numerical model of the peel test is built to research the effect of thermal stress on the peel strength by inserting a mixed-mode traction-separation law near the superconducting layer. The model can be implemented to simulate all mode type (mode I, mode II and mode III) fractures and to prevent recover once the occurrence of the delamination. The plastic properties of the constituent materials and the dependence of the peeling angle are taken into account in this model. The thermal stress-strain state is analyzed firstly after cool down from room temperature to operating temperature (77 K or 4.2 K). Then the numerical simulation of the peel test procedure is presented to get the peel strength. Finally, the effect of the thermal stress on the peel strength is analyzed. This study should be useful to the promotion of the manufacture technology of the 2G HTS tape.

Acknowledgments: The authors appreciate the financial supports from the National Natural Science Foundation of China (11572143, 11372120 and 11421062).

Submitters Country:

China

Tue-Af-Po2.09 / 514

Simulation studies of mechanical stresses and trapped field in annular REBaCuO superconducting bulk magnet for NMR spectrometer during field-cooled magnetization

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Co-author(s): Keita Takahashi¹; Tomoyuki Naito¹; Yousuke Yanagi²; Yoshitaka Itoh²; Takashi Nakamura³

¹ *Iwate University*

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Nuclear magnetic resonance (NMR) spectrometer with high resolution using superconducting coils is a powerful apparatus to analyze complex molecular structure or to develop new drugs. Recently, a compact and cryogen-free NMR spectrometer with a medium resolution of 200 MHz (4.7 T) has been developed using annular REBaCuO superconducting bulks, in which the NMR spectra of ethanol with a full width at half of the maximum (FWHM) of 0.1 ppm (21 Hz) were achieved¹. The magnetic resonance imaging (MRI) was also investigated using the same apparatus. In the apparatus, the annular REBaCuO bulks are magnetized by field-cooled magnetization (FCM), in which large hoop and radial stresses are experienced and the bulks are sometimes fractured for higher applied field. The metal ring support must be considered to avoid the bulk break. In this paper, we performed the numerical simulation of the mechanical stresses (hoop stress and radial stress), together with the electromagnetic properties (trapped field and induced persistent current density) in the actual annular REBaCuO bulks reinforced by aluminum alloy ring during FCM from 4.7 T and 9.4 T at 50 K using the finite element method (FEM). The hoop stress became the maximum at the innermost edge of the uppermost ring bulk at intermediate step in FCM and increased with increasing applied field. The thermally compressive stress was also applied to the annular bulks during cooling to operating temperature because of the difference of thermal contraction coefficient between bulk and aluminum alloy ring. The actual total hoop stress due to both cooling and FCM was analyzed and the possibility of the mechanical fracture was discussed. A new method to reduce the total hoop stress is proposed. 1 T. Nakamura, D. Tamada, Y. Yanagi, Y. Itoh, T. Nemoto, H. Utumi and K. Kose, *J. Mag. Reson.* 259 (2015) 68.

Submitters Country:

Japan

Tue-Af-Po2.02 / 1169

Simulations, measurements and sorting of THOMX ring bending magnets.

Author(s): Cynthia Vallerand¹ ; Fabrice Marteau²**Co-author(s):** Alexandre Loulergue³ ; Christelle Bruni⁴ ; Iryna Chaikovska⁴ ; Jordi Marcos⁵ ; Josep Campmany⁶ ; Marie-Emmanuelle Couprie² ; Valenti Massana⁷¹ *Linear Accelerator Laboratory*² *Synchrotron SOLEIL*³ *SOLEIL*⁴ *LAL*⁵ *ALBA*⁶ *Cells*⁷ *CELLS*

The THOMX facility is a compact ring source based on Compton Back Scattering (CBS), under construction at LAL in Orsay (France). Due to high constraints as its compactness (18 meters long storage ring), the low electron energies (ranging from 50 to 70 MeV), the non-linear beam dynamics, the limited beam storage (60ns per turn), THOMX accelerator has to face many technical challenges. One of them concerns particularly ring dipole magnets, having small curvature radius, which have to be designed to ensure a large dynamic aperture preserving the machine performances. The manufacturing of all dipoles is now finished and they have been magnetically characterized by using a Hall probe bench. From the analysis of magnetic field maps, multipole components, excitation curve, field uniformity and magnetic length have been extracted. In this paper, the dipole design, the set-up and magnetic measurement results will be presented and discussed, as well as the sorting issue in preparation of the commissioning of ThomX facility.

Submitters Country:

France, Spain

Mon-Af-Po1.08 / 899

Single-strand excitation for examining current sharing and ICR in cored and non-cored Nb₃Sn Rutherford Cable at 4.2 K up to 12 Tesla

Chris Kovacs¹ ; Mike Sumption¹ ; Ted Collings²¹ *The Ohio State University*² *MSE, The Ohio State University*

A rig was fabricated to test single-strand excitation and current sharing in Nb₃Sn Rutherford Cables. Measurements were performed on a 40 centimeters length of 27-strand cored and non-cored cables which were mounted on a U-shaped holder. Samples were reacted and epoxy impregnated using magnet-like protocols. Current was injected into a single strand at varying I/I_c and a heat pulse was used to initiate current sharing. Current-distribution was measured using voltage taps. These measurements were performed as a screening for cable and cable preparation protocol for larger scale measurements.

Submitters Country:

USA

Tue-Af-Po2.02 / 1240

Sirius - Details of the new 3.2 T Permanent Magnet Superbend

James Citadini¹ ; L.N.P. Vilela^{None} ; R. Basilio^{None} ; M. Potye^{None}¹ *Brazilian Synchrotron Light Laboratory*

An all permanent High Field Superbend Dipole is proposed for the new Sirius optics can now provide hard X-rays in a critical energy of 19 keV. In the new design, the superbend has a much stronger magnetic field with a 3.2 T peak and it is composed of two low field parts designed with a transverse gradient on each side of the high field pole. The full magnet is joined into a single permanent magnet named BC and a floating pole links all three parts. The low field poles, the floating poles and the return flux in the back can be adjusted to correct the integrated dipole and quadrupole components. The magnetic and mechanical design, assembly, magnetic measurements and production strategy will be presented.

Submitters Country:

Brazil

Wed-Af-Po3.10 / 75

Size effect on the strength of Cu-Ag microcomposites by accumulative drawing and bundling process

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Cu-6wt.%Ag micro-composites were fabricated via casting and accumulative bundling and drawing (ADB) process. The evolution of microstructure and crystal orientation during the compositing process was observed. The mechanical properties and conductivity characteristics of the materials were investigated. And the mechanism for the mechanical properties was discussed.

Submitters Country:

China

Mon-Af-Po1.05 / 368

Soft Sensing Modeling of Rotor Displacements Based on Continuous Hidden Markov Model

Huangqiu Zhu¹ ; Hao Gu² ; Yuemei Qin¹¹ *Jiangsu university*² *Jiangsu University*

In the traditional magnetic bearings, displacement sensors are used to estimate position of rotors, which increase size and cost of magnetic bearings, and decrease its dynamic performance. The soft sensing technology can not only solve the problems above, but also eliminate the mutual coupling of motion equations, which makes the design of controller easier. As a result, soft sensing technology for high speed and high precision occasion arouses wide public attention. Currently, a variety of soft sensing methods have been proposed, however, there are still some problems need to be solved, such as complexity of structure, strict requirements for controllers, excessive reliance on precise mathematical model, and so on. Thus, a soft sensing modeling based on continuous hidden Markov model (CHMM) is proposed in this paper. It has no additional signal input and signal processing circuits. Furthermore, it has higher prediction accuracy and shorter computing time than other machine learning soft sensing methods. Firstly, the structure and operation principle of a 3-degree-of-freedom hybrid magnetic bearing (3-DOF-HMB) are described, and the nonlinear mathematical model of the 3-DOF-HMB in large air-gap is derived by using equivalent magnetic circuit method. Secondly, combining the well prediction ability of CHMM, a position prediction model is built by collecting representative current-displacement data, meanwhile, basic Baum-Welch parameters reevaluation formula is improved to optimize parameters of the CHMM prediction model. Then, a soft sensing credibility evaluation index is proposed for real-time monitoring. Finally, mean squared error (MSE) is taken as model evaluation index to compare the predictive ability of proposed CHMM and other soft sensing methods. The simulation results show that the MSE value of the CHMM prediction model is obviously smaller than that of other soft sensing models. The effectiveness of the proposed soft sensing method based on CHMM is verified by experiments.

Submitters Country:

China

Mon-Af-Po1.11 / 60**Speed up the cooling process of superconducting magnets by applying a large cooling capacity Stirling cryocooler****Author(s):** Xin Qiao¹**Co-author(s):** Daming Sun¹; Ya Xu¹; Qie Shen²; Ning Zhang²; Jianzhong Wang³¹ *Institute of Refrigeration and Cryogenics of Zhejiang University, Key Laboratory of Refrigeration and Cryogenic Technology of Zhejiang Province*² *Institute of Refrigeration and Cryogenics of Zhejiang University, Key Laboratory of Refrigeration and Cryogenic Technology of Zhejiang Province*³ *Jiangsu Cryote Cryogenic Technology Co.,Ltd*

Abstract: Superconducting magnets have been widely applied in MRI, superconducting motor, power storage and transmission, etc. The mass of superconducting magnets is often large in applications, so the cooling down process is frequently slow. A new method to speed up the cooling process by applying a large cooling capacity Stirling cryocooler is studied. The present cooling system consists of a Stirling cryocooler, a cryopump, and other accessories, using helium gas as the circulating cryogen. A single-stage Stirling cryocooler is developed and it can provide 1048 W cooling power at 77 K with a relative Carnot efficiency of 26.9 %. Under ideal conditions, the cryocooler is able to cool a 30-ton superconducting magnet from 77 K to 40 K in 59.7 hours, which is faster than the traditional one with GM cryocooler. Considering the heat transfer temperature difference and heat leakage, the Stirling cryocooler needs 23 days to cool a 30-ton superconducting magnet from 300 K to 40 K. Moreover, compared with the cooling process with liquid nitrogen, this method makes the operation cleaner and simpler.

Submitters Country:

China

Wed-Af-Po3.11 / 940

Stability and Normal Zone Propagation in a conduction cooled racetrack coil wound of YBCO Coated Conductor Tape – FEM Modeling

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We present a Finite Element Method (FEM) analysis of stability, heating and quench propagation in a conduction cooled race track coil at 20 K. The coil was assumed to be wound using YBCO coated conductor tape either non-insulated or insulated by a kapton tape. An anisotropic continuum model of the winding for thermal propagation, with input parameters taken from experiments, was developed and adopted in computations. Both coils – with non-insulated as well as kapton insulated tape - have the same critical current. The coil with non insulated tape needs more YBCO tape but can operate at lower current. As a consequence of this the non-insulated coil has a higher operational temperature margin. The coil wound using the non-insulated tape also shows a higher degree of electromagnetic stability because of possible current sharing among the turns within the winding. Stress-strain modeling showed that due to a strong anisotropy of J_c in YBCO film, the critical current of the coils is not limited by mechanical stresses, but by the radial magnetic field component in the winding, i.e. by the field component parallel to c-axis of YBCO film. Cooling time of the non-insulated coil is shorter than that of the insulated one.

Submitters Country:

USA

Wed-Af-Po3.11 / 1024

Stability of Superconducting Magnet and Wire Insulations

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In order to improve the stability of the superconducting magnets, e.g. MRI magnets, the NbTi superconducting wires were used to wind magnets without electrical insulation layers. The magnets were made with different induction values. As comparisons, the same kinds of wires with insulation layers were used to wind magnets of similar induction values. The magnets were tested at 4.2 K in a LHe bath. The results were analyzed and theoretically investigated. The results reveal that non-insulation winding is beneficial to the magnet stability. However, the long charging and discharging period make it unacceptable for the technique to be put into practical applications.

Submitters Country:

China

Wed-Af-Po3.03 / 327

Stability simulation of a new ring-shaped YBCO coated conductor sheets magnet

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High field magnets built using low temperature superconductors are currently approaching their upper field limit of 25T or so. Applications of (RE=Y, Gd)BCO coated conductors for the generation of high magnetic fields are increasing sharply, this while (RE)BCO coated conductors themselves are evolving rapidly. This present study simulates the stability of a new magnet made of ring-shaped YBCO coated conductor sheets. The current sharing temperature, minimum quench energy (MQE) and normal zone propagation velocity (NZPV) are calculated by using the power law model. Without winding process and bending strains, this HTS magnet made of superconductor sheets is considered to have advantages of good stability, simple structure, easy fabrication and minor effect of flow capacity.

Submitters Country:

China

Tue-Af-Po2.08 / 436

Stacked tape HTS conductors for Fusion Magnets

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A prototype conductor for Fusion magnets rated for about 60 kA at 5K, 12 T has been fabricated. The conductor is composed by a flat cable in a steel conduit; the flat cable consists of twisted and soldered stack of tapes in round copper profiles which are cabled around a flat central former. Initially the performances of the coated conductor tapes used for the cable manufacturing were fully retained; during a long campaign cumulating about 2000 electromagnetic cycles and a warmup-cooldown cycle a progressive degradation of the performances was observed on both conductor legs. After the test the samples were dismantled and the jackets removed; the visual inspection of the strands revealed cracks in the soldering between the copper profiles; in three out of four cases the cracks were located at the cable edges. After disassembling the cables the critical current of the strands was measured at 77 K: a reduction was found not only in the loaded flat side of the cable, but also (and more evident) on the edges of the cable. Transverse pressure cycling test were performed at 77 K on various short test strands and it was confirmed that bent strands degrades more than straight ones; the hardness of the copper shell also affects the performances. Guidelines for the next prototypes have been suggested.

Submitters Country:

Switzerland

Thu-Af-Po4.05 / 387

Starting Control Strategy of Bearingless Permanent Magnet Synchronous Motor

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A bearingless permanent magnet synchronous motor (BPMSM) is a new type of motor, which inserts functions of the magnetic bearings into the traditional permanent magnet synchronous motor, and realizes the steady suspension and rotation of rotor at the same time. Because of its advantages, such as high efficiency, high power factor, good control performance, no mechanical contact, non-wear, non-lubrication, and so on, the BPMSM has been used in high-speed hard disks, flywheel energy storages, satellites, aircraft gyro systems and other fields. Therefore, the BPMSM becomes one of the popular research directions in the field of special drive in recent years. The accurate initial rotor orientation is the foundation of smooth start and stable operation for the BPMSM. Firstly, the operation principle of the BPMSM is analyzed and the mathematical models of radial suspension forces and torque are deduced in this paper. Secondly, to realize rapid steady starting, a new initial rotor orientation method is proposed based on command current control. The rotor initial position is orientated by instruction current sequence, and the positioning step angle is designed and optimized. Then based on DSP TMS320F2812, the experiment platform including the corresponding hardware and software system are designed. Finally, the six-step and three-step initial orientations for the BPMSM are tested and compared. The test results show that the three-step orientation can accurately accomplish the initial positioning, and realizes the quick and stable starting for the BPMSM.

Submitters Country:

China

Tue-Af-Po2.04 / 244

Static and transient magnetic design of a Septum magnet for ThomX accelerator

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ThomX is a Compton source project in the range of the hard X rays (40 / 90 keV). The machine is composed of an injector Linac and a storage ring where an electron bunch collides with a laser pulse accumulated in a Fabry-Perot resonator.

The injection and extraction of the beam in the storage ring is managed by an UHV eddy current septum magnet. This eddy current septum magnet has to generate a full sinus pulse, 150 mT peak and 130µs period. Magnetic and thermal 3D models, have been performed on OPERA FEA Software (ELEKTRA and TEMPO solvers), to analyse the transient behavior of the magnet. Results of this modelling are presented.

Submitters Country:

france

Wed-Mo-Or19 / 27

Status and realization of an high efficiency transport beamline for laser-driven ion beams

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Laser-target acceleration represents a very promising alternative to conventional accelerators for several potential applications, e.g. in nuclear physics and medicine. However, some extreme features, such as a wide energy and angular spread, make optically accelerated ion beams not immediately suitable for multidisciplinary applications. Therefore, in addition to improvement of laser-target interaction, a large effort has been recently devoted to development of specific beam-transport devices in order to obtain controlled and reproducible output beams. In this framework, a three years contract has been signed between INFN-LNS (IT) and Eli-Beamlines-IoP (CZ) to provide the design and the realization of a complete transport beam-line, named ELIMED, dedicated to the transport, diagnostics and dosimetry of laser-driven ion beams. The transport beamline will be composed by three sections for the collection, selection and final shaping of the transported beams. The collection section is made of a set of super-strong high field quality permanent magnet quadrupoles with large acceptance to minimize beam losses and a gradient of 100 T/m over a 36 mm net bore able to correct the angular dispersion and focus laser driven ions up to 70 MeV/u. The beam selection is done by a double dispersive mode magnetic chicane made of C-shaped electromagnetic dipoles able to select beams with a high resolution and to work as an active energy modulator. The final beam shaping is done by two correctors and two electromagnetic quadrupoles. In this contribution the actual status of the development and realization of these magnetic systems is described.

Submitters Country:

Czech Republic, Italy, France

Mon-Af-Po1.02 / 1131

Status of Design and Manufacturing of PENELOPE neutron trap

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We present the current status of design, testing and manufacturing of the magnet system of the PENeLOPE neutron lifetime measurement experiment, carried out by Babcock Noell GmbH on behalf of and in close cooperation with Technical University of Munich. Ultra cold neutrons produced by the experimental reactor facility in Garching are stored in a large volume magnetic bottle and held confined for periods of several minutes, where the combination of electric and magnetic fields allows basically all protons emerging from neutron decay to be captured by a high efficiency detector. This allows the decay curve to be captured with unprecedented accuracy. The magnetic bottle is formed by a nested array of 24 pairwise oppositely poled superconducting coils with local fields up to 5.5 T providing magnetic confinement for neutron energies up to 110 neV while maintaining an essentially field free trap volume. The coil formers made of 316LN constitute the wall between experimental vacuum and the LHe bath providing the cooling and support the force of the repelling coils. This circumstance and the intricate geometry makes manufacture particularly challenging. The coils are wound and potted on individual formers, which are then assembled to the full magnet structure. This is achieved by means of laser welding. Due to spatial constraints, the welds are as close as 6 mm to the coil windings. With the help of specialized companies we were able to produce 6 mm deep vacuum tight and load bearing structural welds without raising the temperature at the coil's windings above 180°C, which is considered the maximum acceptable temperature for the insulation and potting resin chosen.

Submitters Country:

Germany

Tue-Mo-O10 / 40

Status of Magnet System for CSNS RCS

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China Spallaion Neutron Source (CSNS) accelerators include a 80 MeV Linac, 1.6 GeV Rapid Cycling Synchrotron (RCS) and two beam transport lines. There are nearly 300 magnets for these accelerators, including 24 DC biased 25Hz AC dipole magnets, 48 DC biased 25Hz quadrupole magnets, 16 DC sextupole magnets, 34 AC correcting magnets and 23 injection & extraction magnets for the RCS and other DC magnets for the Linac and the beam transport lines. In this paper, the status of RCS magnets will be presented, which includes the key technologies for the magnet production, some interesting results of the magnetic field measurements and some vital faults in process of the magnet commissioning.

Submitters Country:

China

Tue-Af-Or16 / 72

Status of manufacturing and testing of superconducting magnets for NICA and FAIR projects

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NICA is an accelerator collider complex under construction at the Joint Institute for Nuclear Research in Dubna. The facility is aimed at providing collider experiments with heavy ions up to Gold in the center of mass energy from 4 to 11 GeV/u and an average luminosity up to $1 \cdot 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ for Au⁷⁹⁺. The collisions of polarized deuterons are also foreseen. The facility includes two injector chains, a new superconducting booster synchrotron, the existing 6 AGeV superconducting synchrotron Nuclotron, and a new superconducting collider consisting of two rings, each 503 m in circumference. The planned FAIR synchrotron SIS100 has to deliver high intensity beams in GSI, Darmstadt. This machine will use fast-cycling 4 T/s, 2 T magnets. The NICA booster synchrotron, the NICA collider and the heavy ion synchrotron SIS100 are based on iron-dominated "window frame"-type magnets with a hollow superconductor winding analogous to the Nuclotron magnet. The status of work on the manufacturing and testing of the NICA magnets and the SIS100 superconducting quadrupole and corrector magnets are discussed.

Submitters Country:

Russia

Thu-Mo-Or28 / 333

Status of the 16 T dipole development programme for a future hadron collider

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A next step of energy increase of hadron colliders beyond the LHC requires high-field superconducting magnets capable of providing a dipolar field in the range of 16 T in a 50 mm aperture with accelerator quality. These characteristics could meet the requirements for an upgrade of the LHC to twice the present beam energy (HE-LHC) or for a 100 TeV centre of mass energy Future Circular Collider (FCC). This paper summarizes the activities and plans for the development of these magnets, in particular within the 16 T Magnet Technology Program, the WP5 of the EuroCirCol, and the US Magnet Development Program.

Submitters Country:

Switzerland

Mon-Mo-Or1 / 782

Status of the Activity for the Construction of the HL-LHC Superconducting High Order Corrector Magnets at LASA-Milan

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⁷ *University of Milan / INFN*

INFN is developing at LASA lab (Milano, Italy) the prototypes of five corrector magnets, from skew quadrupole to dodecapole, which will equip high-luminosity interaction regions of the High Luminosity-LHC (HL-LHC). These magnets are based on a superferric design, to allow a relatively simple, modular and easy to construct magnet. This program takes place within the framework of a collaboration agreement between CERN and INFN. In the paper we present an overview of the present activity, from the design, to the construction and test at the operation condition.

Submitters Country:

Italy, switzerland

Tue-Mo-Or13 / 1066

Status of the ITER In-vessel Coils System and Progress on the Qualification of the In-Vessel Coil Conductor

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Following a decision made at the ITER Council in November 2013, two types of In-Vessel Coils (IVCs), namely ELM Coils to mitigate Edge Localized Modes and VS Coils to provide Vertical Stabilization, have been incorporated in the ITER design. Strong coupling with the plasma is required so that the ELM and VS Coils can meet their performance requirements. Accordingly, the IVCs are in close proximity to the plasma, mounted just behind the Blanket Shield Modules. This location results in a radiation and temperature environment that is severe necessitating new solutions for material selection as well as challenging analysis and design solutions. Due to high radiation environment, mineral insulated copper conductors enclosed in a steel jacket have been selected. A key component of the MIC is the mineral insulation which will consist of compressed MgO powder. The insulation provides three main functions, namely structural support of the copper conductor, thermal conduction between the jacket and the copper conductor, and electrical insulation between the jacket and copper conductor. A major advantage of the coil design is the long conductor length which eliminates the need for any internal joints. In-situ winding of the VS coils is asking for a development of a creative solution for the unspooling, straightening, precise winding tools, bending, and metrology processes in a tight and congested environment. The contract for the procurement of the IVC Conductor has been signed with two suppliers for phase 1: Development, Qualification of all processes, final tests and one full conductor length. Phase 2 includes series manufacturing, storage and delivery of all required conductor lengths. The procurement strategy aimed to select multiple contractors for Phase 1 of the project to mitigate the risk on qualification, cost and schedule and to keep the cost within acceptable limits thus maintaining competition for Phase 2.

Submitters Country:

France

Wed-Af-Po3.01 / 49

Stealth superconducting magnet technology for collider IR and injector requirements

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The intersection regions and the beam injection channel of a high-energy collider require magnets that must act strongly upon one beam yet not at all on a closely neighboring beam. Designs are presented for three examples: a septum dipole that serves as a forward spectrometer centered on an ion beam after collision, which must clear an electron beam leaving the IP; a final-focus quadrupole that must provide high-gradient focusing of electrons with large aperture but pass a close-lying ion beam; and a high-gradient quadrupole that must operate in the background field of a spectrometer solenoid. All designs use to advantage a new superconducting cable-in-conduit that provides for compact winding, robust end geometry, and in-cable flow of liquid helium.

Submitters Country:

US

Mon-Af-Po1.06 / 313

Step-current method for improving energy storage density of superconducting magnet

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It has previously observed that superconducting magnets have been conventionally excited by a unified current which limited by the largest perpendicular magnetic field usually on the top of magnet due to anisotropic properties . In this case, the current carrying capacity of these pancake windings except that on the ends of the magnet can't get fully used .This paper provides a new method to improve the energy storage density by applying step-currents on pancake windings according to the different perpendicular magnetic field on the different position. A iteration method is proposed to obtain the critical step-currents. The paper establishes the finite element models of double solenoid magnet and toroidal magnet. The two kinds magnets with step-current are analyzed and the variation trend of the perpendicular magnetic field, central magnetic field, critical currents, storage and mechanical stress are given to verify its feasibility.

Submitters Country:

China

Tue-Af-Po2.09 / 654

Strain characteristics of Ic in brass laminated GdBCO CC tapes under various temperature and magnetic field conditions

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The 2G coated conductor (CC) tapes exhibit greater potential in magnet and coil applications because of their high critical current density, J_c and good mechanical properties along longitudinal direction. Differences in fabrication processes, architecture, and layer materials in REBCO CC tapes produce different mechanical and electromechanical behaviors under magnetic field B , temperature T , and with applied strain ϵ . For practical applications of HTS CC tapes to magnets, the understanding of critical current, I_c behavior under B , T , and ϵ is necessary. In this paper, the $I_c(\epsilon)$ characteristics of brass foil laminated RCE-DR processed GdBCO CC tapes under various temperature and magnetic field conditions have been examined. As results, it showed that the brass laminated CC tapes showed no significant difference as compared to Cu-stabilized CC tapes in magnetic field dependence of I_c at various low temperatures. The ϵ_{irr} of brass laminated CC tape increased with decreasing temperature from 77 K down to 20 K, and showed some increased values when compared with the cases of Cu-stabilized ones. This behavior was resulted of thermal hardening effect of brass foils to the CC tapes decreasing temperature that caused some increase in its yield strength. Finally, the strain sensitivity and magnetic field dependence of I_c in brass-laminated CC tapes decreased with decreasing temperature from 77 up to 20 K, resultantly increasing the ϵ_{irr} value.

* This work was supported by a grant from the Power Generation & Electricity Delivery Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) funded by the Ministry of Trade, Industry and Energy, Republic of Korea (No. 20131010501800). This work was also partially supported by a grant from National Research Foundation of Korea under Grant NRF-2014-002640. This work was also carried out as an activity of Collaborative Research (No. 16H0051) of HFLSM, IMR, Tohoku University, Japan.

Submitters Country:

Korea

Tue-Af-Po2.09 / 488

Strain response of superconducting magnets during excitation and quench training based on FBG and cryogenic strain gauge measurements

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ABSTRACT: The mechanical characteristics and behaviors of two superconducting magnets with different low temperature superconducting materials and configurations during excitation and quench training processes are investigated experimentally and numerically in the present work. One is a racetrack magnet made of NbTi/Cu with the maximum magnetic field of 4 T. Another is hybrid superconducting magnet with field up to 10.5 T, which is fabricated with Nb₃Sn/Cu and NbTi/Cu concentric solenoids. Since the high field in the superconducting magnets provides a huge Lorentz forces, the maximum stress in the coils is significant even up to 180 MPa. To measure the stress-strain responds in the two SC magnets, a serial of Fiber Bragg Grating (FBG) sensors and cryogenic strain gauges (CSG) are utilized and attached onto the NbTi/Cu racetrack magnet and Nb₃Sn/Cu solenoid. It is found that both the FBG and CSG can record the strain responds for the SC magnets during excitation and quench training processes with high precise and repeatability. Compared to the CSG with compensation bridge, the FBG exhibit more attractions like smaller size, immunity to electromagnetic interferences, non circuits compensation and sensing performance of internal strain. We further analyze the electromagnetic and deformation fields in the two SC magnets based on FEM to show good predictions on their multi-field behaviors in comparison with the measurements.

Submitters Country:

China

Wed-Af-Po3.11 / 1050

Strand level modeling on AC loss and current distribution of prototype EU DEMO TF conductors

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The development of the Toroidal field coils of the upcoming European DEMO reactor is under the coordination of the EUROfusion Consortium. The Swiss Plasma Center (SPC) and ENEA-Fusion produced two new cable concepts, RW1 (react and wind) and WR1 (wind and react) with rectangular cross section, inspired by existing concepts of Nb3Sn Cable-in-Conduit Conductors (CiCCs). The prototypes have been tested for DC transport current and AC loss in the EDIPO facility (SPC) and for inter-strand contact resistance and AC loss at the University of Twente. The code JackPot-ACDC developed at the University of Twente is used to model the conductor geometry and to study the electro-magnetic behavior. The experimental results are used to calibrate and benchmark the simulations. The analysis of coupling loss and current distribution shows the impact of the magnetic field orientation on the rectangular shape of the samples, focused on possible issues on the stability and performance of the conductors. One notable outcome of the study is the level of maximum allowable coupling loss in the conductors, depending on the magnetic field orientation, based on the peak electric field threshold defined for the ITER CS conductors in previous JackPot studies.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

Netherlands

Wed-Af-Po3.04 / 172

Stress Analysis of Canted–Cosine–Theta Superconducting Dipoles Coils During Winding , Cooling and Charging for Rotating Gantry

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Abstract– Superconducting Proton cancer therapy rotating gantry is becoming widespread due to its efficient treatment, compact size, low cost, it is increasingly important to promote rotating gantry in medical center. Canted–cosine–theta(CCT) superconducting dipoles can be used to reduce sizes of rotating gantry for proton cancer therapy. The paper introduce single mandrel structural and multidimensional computer numerical control (CNC) winding coils for improving winding accuracy. The superconducting wires were ultrasonic welded on the layer. To control mechanical deformation, the pre-stresses were applied to conductor and overbanding of each coil is considered during winding process. The allowable pre-stresses of whole processes including winding, cooling and charging were confirmed by finite element calculations in ANSYS . The effectiveness of winding pre-stress and material anisotropy on stress in superconducting coils are also discussed.

Submitters Country:

China

Thu-Af-Po4.05 / 660

Stress Analysis of Induction Motor Core Considering Anisotropic Magnetic and Magnetostrictive Properties

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In order to control and reduce the electromagnetic vibration of induction motors, the stress in motors cores, which is the inherent reason of vibration, should be computed accurately. Stress in induction motors is mainly generated from Maxwell electromagnetic force between the stator and rotor under the rotational magnetization excitation. The non-oriented silicon steel in motors shows different magnetic characteristics between rotational magnetization excitation and the alternating one, which has remarkable effect on the magnetic field and stress computation. However, the influence of rotational magnetic characteristics has not been considered in the past studies of motors vibration. This paper tests magnetization properties of non-oriented silicon steel sheet under different rotational magnetic field to support the stress computation. Based on the measured constitutive relations, an electromagneto-mechanical coupled numerical model for induction motors is presented. Under the rotational magnetization excitation, stress distribution on the motor cores is calculated. In order to study the influence of rotational magnetization characteristics on the stress distribution of motors cores, another model, which uses magnetic characteristics under alternating magnetization excitation instead of the rotational ones, is calculated, too. By comparing the computation results, it can be seen that the rotational magnetization characteristics greatly influence the stress distribution of motors cores.

Submitters Country:

China

Wed-Af-Po3.03 / 512

Stress-Strain Analysis in a 10 T non-Insulated GdBCO HTS Coil for the 25 T All-superconducting NMR Magnet

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A 25 T all-superconducting magnet, consisting of a 10 T GdBCO high temperature superconducting (HTS) insert and 15 T low temperature superconducting outer coils, is now in progress at Institute of Electrical Engineering, Chinese Academy of Sciences. Predicting the stress/strain distributions inside the HTS insert during its fabrication and energization accurately is one of the key issues to avoid the high field superconducting magnet's failure. In this paper, an improved finite element method was adopted to analyze the dynamic stress/strain distributions in the HTS insert, in which the effects of bending strain, pretension during winding, thermal contraction while cooling down, and the electro-magnetic force induced by the screening current and the transport current were taken into considerations. The thermal disturbance originating from the AC losses while its energization were also considered to analyze the stability of the HTS insert. To increase the simulation accuracy, the magnetic field dependency of critical current for each turn was incorporated into the calculations. And also, the related experiment was carried out to verify the simulation. The calculated results and experimental data were compared and discussed detailedly in the paper.

Submitters Country:

China

Tue-Af-Po2.09 / 383

Stress-strain behaviors of a Nb₃Sn Superconducting prototype solenoid for ECR magnet during winding, cooldown and energizing processes

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The fourth generation of Electron Cyclotron Resonant (ECR) ion source is currently built for the LEAF facility at the Institute of Modern Physics of Chinese Academy of Science, which is expected to operate at a heating radio frequency at 45 GHz. To confine the plasma scales with RF frequency, a sextupole-in-solenoid superconducting magnet made of Nb₃Sn is established for generating a strong magnetic field with peak value even in excess of 10T. In this study, we focus on the mechanical behaviors of the prototype of middle solenoid superconducting magnet wound and reacted with 1.43 mm diameter Nb₃Sn wire during winding, cooldown and energizing process. As one of key unit coil of the complicated magnet, the prototype middle solenoid has a total field as high as 12.3T (100% I_c), and its coil is experienced to the max stress up to 140 MPa (mag. forces). By the way of recoding the strain responds at locations along the circumferential directions of the solenoid and structure support with the cryogenic strain gauges, the measurements on the strain-stress state during the manufacture and operation processes, as well quench behavior are conducted. For purpose of precise measurement and comparison, the fiber Bragg grating method is also used. The numerical simulations with FEM for solving the Maxwell's equations and the equilibrium equations of the solenoid and structure support are performed for their electromagnetic and mechanical characteristics under operation conditions. The assembly stress, cryogenic thermoelastic strain and magnetoelastic stress in the solenoid during different processes are obtained experimentally and numerically. We further make comparisons between the experiment measurements and FEM analysis results to show a quite good agreement.

Submitters Country:

China

Wed-Af-Po3.09 / 481

Strong flux pinning caused by phase distribution characteristics in (Ba, K)Fe₂As₂ films

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We report that the strong flux pinning of (Ba, K)Fe₂As₂ thin films is induced by the superconducting phase distribution characteristics. Depending on the growth conditions, our thin films have distribution diversity which can induce various superconducting properties. The activation energy is one of the parameters representing pinning forces. We compare the activation energy of two different distributions, which has 16780 K and 5900 K, respectively. The sample of higher activation

energy forms a mesh-textured-like distribution which has delta-Tc pinning mechanism while the lower activation energy sample has an intrinsic pinning mechanism. Moreover these distributions are achieved from EPMA elemental mapping which modified by overlay method. We conclude that superconducting phase distribution have strong relation to the flux pinning potential in the (Ba, K)Fe₂As₂ films.

Submitters Country:

South Korea

Wed-Af-Po3.09 / 946

Strong, round and rectangular HTS wires based on the Bi2212 superconductor

Alexander Otto¹

¹ *Solid Material Solutions, LLC*

Reinforced round and rectangular, Bi2212 -based, high temperature superconducting wires are being developed for use in transposed cables, coils and magnets that are problematic with wide HTS tapes, and that need to operate beyond the limits of low temperature superconductors. These wires exhibit in excess of 500 MPa stress tolerances and current densities (Jc's) that exceed 2000 A/mm² at > 16T field and 4.2 K, making them suitable for use in transposed cables, coils and magnets that are problematic with wide HTS tapes, and that need to operate beyond the limits of low temperature superconductors. This paper describes advances in the bonding of very high modulus strips to portions of the 2212/Ag wire surfaces so as to greatly improve their strength while also still enabling the subsequent coil winding and reaction formation of high Jc 2212 inside the multifilament 2212/Ag wire cores. Our program has recently established long length production capability for the rectangular form of this wire and the round wire form is now at an advanced stage of architecture and process development. Strong rectangular wires have been produced and tested with reinforcement levels for 300, 400 and 500 MPa stress tolerance levels, in straight, coiled and cabled forms, with the results validating that usefully high operating current densities and target levels of strengthening are achieved with low cost materials, scalable processes, and now, with a simple reaction step that produces high Jc 2212 in gas at 1 atm pressure instead of in gas at 50 atm overpressure conditions previously employed. Considerable progress has also been achieved on the development of technologies for the practical application of these wires to both wind-and-react and react-and-wind usage regimes.

Submitters Country:

USA

Mon-Mo-Or3 / 589

Structural Behavior of KSTAR CS Magnet during Plasma Operation

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An analysis model was developed to evaluate the axial pre-compression for the central solenoid (CS) magnet of KSTAR. The model represents the preloading relatively well in assembly, cool-down

and current charging conditions. However, the model for cool-down condition needs to be modified for the accurate estimation of preloading. The smeared material properties of the CS winding pack were reevaluated. The electromagnet forces of the coils are evaluated during plasma operation conditions like large plasma current and long pulse H-mode discharges. The structural analysis of the CS magnet is performed using the updated model and the analysis result is compared to the measured strains. The analysis methodology and the model have been consistently updated to increase the reliability of the analysis through these processes. Studies on the structural behavior of the CS magnet are expected to provide guidelines for future KSTAR operation in spite of insufficient preloading.

Submitters Country:

Republic of Korea

Thu-Af-Po4.05 / 616

Structural Design Methodology of BLDC Motor Considering Response Time of Phase Current

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The Brushless DC (BLDC) motor is getting more widely used in home appliances, vehicle and industry for its easy control method and low cost. For proper control of the BLDC motor, it is designed to have trapezoidal Back-EMF wave form and the square wave current is applied to its phase current which has instantaneous switching in its wave form. Although, in low speed or low phase current, the instantaneous switching in phase current does not affect the performance of the motor, but, as the rotating speed of BLDC motor rises, it is getting difficult for the phase current to response the instantaneous switching of the square wave. And the distortion of phase current affects the performance of the BLDC motor, such as torque ripple and efficiency. The time constant of phase current in BLDC motor is proportional to the inductance and inverse proportional to the resistance of the motor.

To improve the response time of the phase current, the inductance is necessary to be decreased and the resistance is necessary to be increased. As resistance of motor is affected by the number of turns and dimensions of slots, these are important parameters in design of BLDC motor with fast response phase current. In the same way, as inductance of motor is affected by the number of turns, degree of magnetic saturation and the airgap, including magnet thickness, these are important parameters in design of BLDC motor with fast response phase current. In this study, the design methodology of BLDC motor with fast response phase current is proposed through the comparison between differently designed BLDC motor with same specification. Both motor has designed to have same performance in ideal current source but shows different characteristics in voltage source and PWM control whose phase current waveform could be distorted in instantaneous switching sequence.

Submitters Country:

Republic of Korea

Wed-Af-Po3.10 / 224

Structural optimization methodology of the 2-D inner-leg cross-section for the Toroidal Field Coils of fusion reactors

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¹ ENEA

A novel methodology is proposed for the structural optimization of the inner-leg cross-section of Toroidal Field (TF) coils of DEMO fusion reactor to achieve significant improvements in the structural response of the component. The original Winding Pack (WP) configuration, used as starting point of the optimization process, despite being compliant in terms of the electro-magnetic behavior, causes the entire component cross-section to be far beyond structural limits, because of intensive peak stress concentrations. Moreover, a standard optimization approach, aimed to lower these stress peaks, is nearly impossible, even on modern computer platforms, because of the expensive computational cost of each single Finite Elements analyses, resulting in unaffordable optimization times. Within this frame, in this work, borrowing numerical concepts and techniques from the aerospace industry, the mentioned prohibitive optimization problem is made computationally solvable, in reasonable optimization times.

Submitters Country:

Italy

Thu-Af-Po4.01 / 424

Study of a Sextupole Round Coil Superferric Magnet

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The LASA Lab. (INFN, Milan) is developing a new type of superferric magnets suitable to arbitrary multipole order which we refer to as Round Coil Superferric Magnets (RCSM). It is based by the previous proposal of I. F. Malyshev and V. Kashikhin. This type of magnets is suitable for strain-sensitive superconductors, because it only uses a single round coil, which has a large bending radius, to create the magnetic field. The round yoke with arbitrary multipoles is able to create the desired harmonic component for the magnet. A preliminary electromagnetic design of such magnet in sextupole configuration was presented, using MgB2 superconducting tape for the coil. In this paper we present the advances in study for the construction of the prototype. We analyze the electromagnetic properties of the coil and of the round multipole iron yoke, focusing on the optimization of the principal multipole harmonic desired. We also study the mechanic and the protection for quench, considering a new type of MgB2 superconducting cable for the coils.

Submitters Country:

Italy

Tue-Af-Po2.09 / 642

Study of bending behavior in Nb3Sn strands

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The superconducting property of Nb₃Sn strands is very sensitive to strain. The transverse electromagnetic loading has been considered as a major origin of the degradation of Nb₃Sn cable-in-conduit conductor (CICC) due to the periodic local bending. The degradation of each strand due to this bending should be evaluated to calculate the performance of a CICC. Thus, an analytical model considered with the plastic deformation of copper and filament breakages was developed. The calculated results show good agreement with strain distribution measured by the neutron diffraction for uniformly bent Nb₃Sn strands. In addition, the critical current calculated by this model shows agreement with the test results.

Acknowledgement: The neutron diffraction experiments were conducted at the MLF of J-PARC with the proposal number of 2012B0017.

Submitters Country:

Japan

Tue-Af-Po2.03 / 100

Study of the Hotspot Temperature during Quench in the Non-Planar Coils of W7-X

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The quench protection system of the non-planar coils of the Wendelstein 7-X stellarator was laid out over fifteen years ago. At that time, the assessment of the hot spot temperature by a basic adiabatic model was done using design values for material and operation parameters. After the operating experience in 2016, the hot spot temperature is re-assessed with the thermal-hydraulic program THEA, using the actual values for delay and dump time. The electrical resistivity of the conduit alloy is measured over the whole range of temperature and in magnetic field on relevant samples of conductor, exposed to the hardening heat treatment after winding. The results are fed into Thea. Parametric variations are studied in the calculations, e.g. testing the effect of the operation current, quench initiation zone and dump resistor. The results suggest that the hot spot temperature of the conduit in case of quench is safely within the allowable values even in case the dump voltage is reduced compared to the initial design value.

Submitters Country:

Switzerland

Mon-Af-Or8 / 382

Study on Counter-rotating Dual Rotors Radial Permanent Magnet Motor for underwater vehicle Propulsion

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A novel Permanent-magnet Machine with Counter-rotating Dual Rotors (PMCDR) is proposed in order to improve operation performance of underwater vehicle anti-rotation propulsion system. It can be substantially simplify system structure, decrease volume, reduce mass and cost, moreover, improve reliability without brush and slip-ring. The idea and principle of electromagnetic design are provided in order to meet power angle characteristic corresponding to uniform or similar between Inner Rotor Permanent-magnet Machine Unit (IRPMU) and Outer Rotor Permanent-magnet Machine Unit (ORPMU). Magnetic field, Stator yoke flux density, air gap flux density, inductance, no-load back-EMF and torque angle characteristic are obtained through the finite element method. A prototype has been designed, built, and tested. The method of detecting no-load back-EMF with search coils is proposed. The validity is verified by FEA results and experimental measurements.

Submitters Country:

P. R. of China

Thu-Af-Po4.05 / 600

Study on Design of a Novel Magnetic Field Modulation Linear Primary Permanent Magnet Synchronous Motor

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In this paper a novel magnetic field modulation linear primary permanent magnet synchronous motor (LPPMSM) is proposed, which is originated from brushless electrically excited synchronous machine (BEESM). LPPMSM have short primary (rotor side), long secondary structure. The primary side consists of an iron core with salient teeth wound with 3-phase armature windings and permanent magnets (PMs) mounted on the surface of stator teeth, and second side only combined by magnetic barrier. The three-phase AC armature windings and PMs have different number of poles, when the motor is operated with steady-state, the armature windings form a traveling magnetic field in the air gap of the motor, and a constant static magnetic field generated by permanent magnets. The two magnetic fields are modulated by secondary magnetic barrier, which bring out indirect coupling, and the electromagnetic torque formed in the rotor. In the city rail transit drive motor application, this novel magnetic field modulation LPPMSM compared with the traditional linear synchronous motor, the dosage of armature windings or permanent magnets can be reduced, and the secondary structure is simple and reliable, which saves material cost and maintenance cost; compared with the traditional linear motor, it can improve the efficiency and power factor of motor. This paper introduces the structure characteristics and operation mechanism of this kind of motor, LPPMSM with a 12+8 pole was designed. The effect of pole-arc coefficient and salient pole height on coupling capacity of magnetic barrier was researched, and the values of pole-arc coefficient and salient pole height were obtained. The Maxwell-2D model was established and no-load operation was analyzed by the finite element analysis (FEA), the flux plot, the flux density and no-load EMF were obtained. The results prove the feasibility of the design of LPPMSM.

Submitters Country:

China

Wed-Af-Po3.08 / 1046

Study on Electromagnetic Force Distribution and Copper Fatigue Performance in Electromagnetic Strengthening with Axial Compression

Li Qiu^{None} ; Yijie Yu^{None} ; Liang Li^{None}

The surface compressive stress can improve the work piece fatigue performance effectively and the existing strengthening technologies can increase the work piece fatigue life in varying degrees. However, they would lead to some negative results such as uneven residual stress and poor surface quality. In order to solve these problems, the electromagnetic strengthening technology with axial compression is firstly proposed in this paper. In this process, the surface compressive stress is generated by a pulsed electromagnetic force; specifically, both the radial and axial compression on a copper bar is obtained by a designed tool coil. A transient electromagnetic-structure coupling model is established by COMSOL software. On this basis, the electromagnetic force distribution of a pure copper bar is analyzed, and then the tool coil structure is optimized. Secondly, the deformation behavior of the pure copper bar is analyzed, and the corresponding residual stress distribution is obtained. Finally, the original and strengthen sample with tensile and fatigue property is tested respectively and the effectiveness of the electromagnetic strengthening method with axial compression is verified.

Submitters Country:

China

Tue-Mo-Or11 / 1007

Study on Electromagnetic Force Distribution and Material Forming Performance in Electromagnetic Tube Expansion with Concave Coils

Author(s): Li Qiu^{None} ; Yijie Yu^{None} ; Qi Xiong^{None} ; Changzheng Deng^{None}

Co-author(s): Liang Li

In the electromagnetic tube expansion process, both electromagnetic force and workpiece deformation are axisymmetric. Hence, the forming performance of tube is better than that of sheet and then electromagnetic tube expansion is widely used in industry processing. However, the cylindrical coil is always applied to generate the electromagnetic force in electromagnetic tube expansion process at present, the radial electromagnetic force in the tube end is less than that in the tube middle because of the end effect, with the result that the workpiece deformation could not meet the industrial requirements. In order to obtain more uniform radial electromagnetic force in the axial direction, electromagnetic tube expansion method with concave coils is proposed in this paper. Firstly, the effect of coil structure parameters on the radial electromagnetic force distribution is studied. Secondly, the concave coils for a given workpiece is designed to meet the workpiece deformation requirements. Finally, the advantages of using concave coils in electromagnetic tube expansion are verified by comparing the workpiece forming performance of cylindrical and concave coils.

Submitters Country:

China

Mon-Af-Po1.06 / 762

Study on Integral Transformer / Reactor for Improving Power Density

SU YONG KIM¹

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With the development of industries worldwide, the use of industrial electricity is increasing. In addition, as household income increased, the number of products using electric energy increases,

and the amount of electricity used at home is rapidly increasing. To solve the increased power usage, the ESS(Energy Storage System) is attracting much attention in terms of efficient energy use. The ESS consists of various components such as battery, BMS (Battery Management System), PCS (Power Conversion System) and PMS (Power Management System). And PCS is the largest weight and volume among these components. The reason is the reactor for the high-frequency filter and the transformer for electrical insulation, but which are essential in the ESS. In the future, reduction of weight and volume of PCS is essential for the spread of ESS, especially for home-use ESS. Therefore, this paper proposes a new concept of transformer and reactor that can reduce the weight and volume of PCS. Its main idea is that the winding of the reactor is used together with the primary winding of the transformer. In such this configuration, the high frequency included in the current flowing in the primary winding is filtered through the reactor core, and the flux generated by the primary current of the transformer is coupled to the secondary winding through the transformer core, Can be performed at the same time. And it shows the performance of the proposed structure by comparing the efficiency and power density when using the conventional commercial reactor and transformer respectively and using the integral transformer / reactor.

Submitters Country:

the Republic of Korea

Wed-Af-Po3.08 / 1230

Study on Magnetic Field of Stacked Permanent Magnets in Magnetic Liquid Inclination Sensor

Author(s): Wenrong Yang¹

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Aiming at the magnetic field requirement of magnetic liquid full inclination sensor for spherical shell structure, this paper presents a kind of stacked permanent magnet. Using the finite-element method, magnetic field intensity distribution of different stacked forms of permanent magnet is studied. Furthermore, a stacked form which optimizes the linearity between the magnetic field intensity and the inclination angle is proposed. The spherical shell is filled with magnetic liquid and permanent magnet, and the stacked permanent magnet is suspended in the magnetic liquid by the second-order buoyancy. When the sensor is oblique, the stacked permanent magnet remains stationary relative to the gravity field. Thus the magnetic field excited by the permanent magnet remains stationary. But the spherical shell rotation. At first, the transformation of the inclination angle and the azimuth angle signal into electrical signal is realized measuring the change of the magnetic field intensity after shell inclination. Then, through the magnetic field strength measurement experiment, the linear function relation between the magnetic field intensity and the inclination angle is obtained by the curve fitting method, and the calculation formula of the inclination angle is deduced. The calculation principle of the azimuth angle is studied by theoretical analysis, the relationship between the three-axis component of the magnetic field intensity and the azimuth angle is proved by experiment, and the calculation formula of the azimuth angle is deduced. Finally, experiments are designed for testing the performance of the sensor. The experimental results show that the design of the stacked permanent magnet as the tilt angle sensor magnetic field source to meet the measurement requirements.

Submitters Country:

China

Tue-Af-Po2.07 / 550

Study on Operation Charactersitcis with Flux-Lock Type SFCL

considering Interruption of Circuit Breaker in Power Distribution System

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This paper suggests a configuration and an operation scheme of the flux-lock type superconducting fault current limiter (SFCL) which is composed of multi-coils winding on same iron core considering interruption capacity of the protection devices such as the circuit breaker (CB) and recloser (RC) in power distribution system. To limit fault current and meet the protection coordination with reducing the burden of superconducting (SC) element in the flux-lock type SFCL, the method containing a commutation line and a resistance were used. Recently, the power system has become more complex such as the mesh or the loop network power systems to supply continuously power demand. However, the change of the configuration of the power system made some problems in which the fault current exceeds the short-circuit capacity of the CB when a fault occurs in the power system. To protect the power system with a SFCL to meet rated interrupt capacity of the CB, the fault current should be limited by the SFCL depending on its operation settings in an instantaneous and a delay time. Therefore, the analysis on the operation method of the SFCL considering the magnitude of the fault current to meet rated breaking capacity of protection devices could be investigated through some case studies using computer simulation.

Submitters Country:

Rep. of Korea

Thu-Af-Po4.05 / 922

Study on Vibration Characteristics of Permanent Magnet Synchronous Motor with Demagnetization of Permanent-magnets

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This paper discusses a motor that was designed to satisfy the size constraints of system by using ferrite magnet and has the same performance as rare-earth magnet motor. In general, the size of the motor is increased in order to meet the same performance of motor using a ferrite magnet, because of its very low energy density compared to the rare-earth magnet. Thus this paper researched the ferrite magnet structure for compensating the low magnetic energy density and satisfying motor size constraint. Especially, in the case of ferrite magnets, since the demagnetization phenomenon is easily occurred at low temperature, the demagnetization analysis is carried out considering the low temperature. In addition, when the permanent magnet's demagnetization is generated, the magnetic flux density of the airgap is different from the initial design. Such deformation of the magnetic flux changes the vibration characteristics of the motor and thereby affects the noise characteristics. Therefore, in this paper, the vibration characteristics of motors according to the demagnetization of permanent magnet are analyzed. Finally, we adopted the magnetic flux concentrated rotor design. Therefore, it analyzed and optimized the structure of motor using finite element method for motor structure that can increase productivity by enabling magnetization well in a mass production system, prevent the problems of demagnetization in the actual use environment of motor, and secure the stiffness of rotor. To verify the study result through an experiment, magnetizer was made to confirm magnetization characteristics and output and efficiency were checked through motor dynamo test.

Submitters Country:

Republic of Korea

Wed-Af-Po3.06 / 1151

Study on a Novel Transverse-flux Tubular Linear Permanent-magnet Generator for Stirling Engine

Author(s): weibo zhong¹**Co-author(s):** Haitao Yu ¹ ; Minqiang Hu ² ; Zhenchuan Shi ¹ ; Rong Guo ¹¹ *School of Electrical Engineering, Southeast University*² *Nanjing Normal University*

Stirling engine is a cycle piston engine with high efficiency. The motion characteristics of Stirling engine are the same as those of the linear generator. Through the integrated design of Stirling engine and linear generator, it can realize the high efficiency conversion of heat energy to electric energy. Based on the traditional permanent magnet linear generator and Stirling engine structure, a novel transverse flux tubular linear permanent magnet generator for use Stirling engine is proposed. Compared with the traditional permanent magnet linear generator, the efficiency and dynamic performance of the proposed generator is improved obviously. The structure of the proposed generator is given out. The proposed generator is mainly composed of primary and secondary. The primary of the proposed machine consists of two modules. They are named outer stator and inner stator, respectively. The structure of the stators is extremely similar to the conventional three-phase induction machine. There are twelve teeth and twelve slots on the stator. Coil spans the tooth. The two sides of coil are embedded in two adjacent slots of the core. The secondary of the proposed machine consists of twenty-four PMs and a bracket with a plurality of slots. The PMs are embedded in the slots of the bracket. The polarity of two adjacent PMs is opposite. The transient Finite-element method (FEM) is implemented to study the performance of the proposed generator. The back-EMF at sinusoidal speed is obtained by 3-D transient FEM. The wave of the back-EMF is sinusoidal under sinusoidal speed condition. This can greatly reduce the difficulty of the power post-processing. All the results indicate that the proposed generator is suitable for the application of Stirling power system.

Submitters Country:

China

Wed-Af-Po3.06 / 595

Study on fault-tolerant control of open-winding brushless doubly-fed wind power generator

Author(s): Shi Jin¹ ; Guangwei Liu¹**Co-author(s):** Long Shi ¹ ; Liancheng Zhu ¹¹ *Shenyang University of Technology*

Brushless doubly-fed generator (BDFG) has the advantages of reliable structure, easiness in implementing variable-speed constant-frequency, small converter capacity, and so on, which has a broad application prospect in large offshore wind power generation. There are two sets of windings with different pole numbers on the BDFG stator, which are respectively called the power winding for generation and the control winding for excitation. The coupling relationship between the two sets of stator windings is implemented by the special rotor. For the high reliability requirement of offshore wind power generation system, the control winding of BDFG being designed as open winding structure is proposed, that is, all the six terminals of control winding are drawn out to connect with dual converters. This topology structure can independently control each phase current of control winding, which can improve the fault redundancy capability of generation system, have more flexible control mode and further reduce the converter capacity to half of the original. For the special structure of open-winding BDFG, a novel fault-tolerant control strategy based on direct power control (DPC) is proposed. DPC derived from direct torque control can independently control the active and reactive powers of BDFG, and has simple structure, strong robustness and good real-time. From

the DPC idea, the switching voltage vector selection table should be re-established according to the fault information of dual converters. This control method can enable the brushless doubly-fed wind power generator system to be normal operation under the fault of dual converters, and implement the maximum power tracking control at the same time. The feasibility and validity of the proposed fault-tolerant control strategy based on direct power control for the open-winding BDFG can be analyzed and verified by simulation and experiment. The work is supported by Key Project of National Natural Science Foundation of China (51537007).

Submitters Country:

China

Thu-Af-Po4.09 / 334

Study on the Quench Protection of the HTS magnet with iron core for a 1MW DC Induction Heater

Author(s): Ping Yang¹

Co-author(s): Derong Qiu¹

¹ *Shanghai Jiao Tong University*

The energy efficiency of novel high temperature superconductor (HTS) direct current (DC) induction heating method can approach to 90%, due to the loss-free of superconducting coil in DC operation. Now a MW-scaled HTS DC induction heater is designed and manufactured. The magnet is coupled with iron core, which helps to guide the magnetic flux and generate more suitable magnetic field for preheating. The inductance of magnet with iron is 98 H, which is greater than conventional magnet. Due to the considerable amount of energy stored during persistent mode operation, the protection system is very important. In this paper, a passive protection system is developed for the HTS magnet of the 1 MW DC induction heater. The protection circuit is presented and the Matlab/Simulink-based quench model is developed to optimize the design parameters of the protection circuit. Experiments with different magnet operating current and dump resistor are carried out. The results show that the proposed scheme performs desired characteristics and that the dissipation efficiency and velocity vary depending upon different values of dump resistor. Finally optimization parameters of protecting system are obtained.

Submitters Country:

China

Thu-Af-Po4.08 / 1128

Study on the Transport Current Properties for the 2G HTS Wire Under the Spray Cooling Method

Ho Ik Du¹ ; Hyun Gi Jeong¹ ; Sung Chae Yang¹

¹ *Chonbuk National University*

This study is about the cooling of the superconducting wire by spraying the liquid nitrogen. In this study, the superconducting wire was cooled under the spray cooling condition, and a current flow test was conducted. In addition, the operating range of the superconducting wire was presented under the spray cooling condition of the liquid nitrogen. For this, a low temperature container with a spraying device was fabricated, and the cooling performance of the container was evaluated. The YBCO superconducting wire for the spray cooling test had the Bi-2223/Ag superconducting wire and stainless steel wire as stabilizer layers. The wires were the representative superconducting wires that were

fabricated using the PIT and sputtering techniques. The current flow test was conducted in the normal and over current conditions, and the results were compared with those of the existing immersion cooling method.

Submitters Country:

Republic of Korea

Mon-Af-Po1.04 / 831

Study on the design of a Very-high speed PM Motor/Generator for Electric-Turbo Compounding System

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Very-high speed Permanent Magnet (PM) motor is actively studied and developed for various applications in industries like generators/starters for micro gas turbines, turbo-compressor, vacuum pump and turbine generator. PM motor/generator for Electric Turbo Compounding System (E-TCS), which is the alternative technology that can respond to fuel efficiency regulation by applying an electrical system to the existing hydraulic-turbocharger, is one of the very-high speed PM machinery. When designing the very-high speed motor, the number of poles is selected to be minimized, in consideration of the switching frequency of an inverter, for the reliability of control. Therefore, Surface Permanent Magnet Synchronous Motor (SPMSM) with 2-pole diametrically magnetized permanent magnet is mostly studied as the very-high speed motor. In case of SPMSM, the magnet is retained within a sleeve with non-magnetic material like Inconel718 to obtain a mechanical stabilization. It is caused lots of additional loss by the eddy-current in the sleeve, so that the efficiency is decreased. However, Interior Permanent Magnet Synchronous Motor (IPMSM) with the strong structure, compared to SPMSM, does not need the sleeve. Therefore, this paper proposes the design of 2-pole IPMSM for very-high speed application. In addition, the optimal design of rotor and magnet division are performed with Response Surface Method (RSM) and Finite Element Method (FEM) to develop the output characteristics. The output characteristics between existing SPMSM and IPMSM, proposed in this paper, are compared. And experiment is performed to verify the validity of the proposed design method with a prototype. Consequentially, this paper proposes the new design method of motor/generator for very-high speed application.

Submitters Country:

republic of korea

Wed-Af-Po3.06 / 1116

Study on the no-insulation ReBCO pancake coils for superconducting synchronous machines

Yali Zheng¹

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No-insulation (NI) high temperature superconductor (HTS) coils show a great advantage of thermal stability and self-protection features. The eddy loss has always a problem for the NI technique when it is applied to motors. This paper presents a study on the eddy losses of a NI racetrack coil induced

by harmonic waves, which is designed as the rotor of a synchronous machines. As the current can flow through the turn-to-turn contacts during AC operation, an equivalent circuit network model is used to calculate the eddy losses on the turn-to-turn contacts. In the model, each turn of the coil is subdivided into fine elements, each element is equivalent to circuit parameters, and the whole coil is equivalent to a circuit network. Governing equations are derived from Kirchhoff's voltage and current law. The current distribution inside the NI racetrack coil is calculated, and the eddy losses on the turn-to-turn contact is analyzed. The eddy losses are compared with the AC losses of the NI coil's insulated counterpart, which is calculated by a finite element method (FEM) based on H-formulation. The results is useful for the study and design of HTS motor based on NI technique.

Submitters Country:

China

Wed-Af-Po3.05 / 134

Study on the torque ripple reduction design through varying the air-gap magnetic flux density in the SPM motor

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Co-author(s): SEHYUN RHYU¹ ; JEONGJONG LEE¹

¹ *Korea Electronics Technology Institute*

In this paper, a study was conducted to minimize the torque ripple of a 22 kW compressor motor applied to direct coupled compressor system. In the case of a direct coupling type compressor, the motors and the air ends are directly connected without gears, so that the vibration of the motor greatly affects the life and performance of the compressor. For this reason, an initially designed 22 kW compressor motor was analyzed for torque ripple reduction according to the stator skew and magnet configuration studied previously, and the influence of the two parameters on the torque ripple was analyzed. The relationship analysis of the torque ripple and cogging torque shows that the torque ripple characteristic varies with the cogging torque. Based on the results of the analysis, a new method is proposed to reduce the torque ripple during operation by reducing the cogging torque of the compressor motor. It is a method of reducing the cogging torque by varying the air-gap magnetic flux density. Finally, the final model to be applied to direct - coupled compressors was derived through each method, and the performance evaluation was completed through experiments. Acknowledgements: This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy (No. 201520201065200)

Submitters Country:

Republic of Korea

Wed-Af-Or23 / 458

Summary of test results of MQXFS1 - the first short model 150 mm aperture Nb3Sn quadrupole for the High-Luminosity LHC upgrade

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The development of Nb₃Sn quadrupole magnets for the High-Luminosity LHC upgrade is a joint venture between the US LHC Accelerator Research Program (LARP) and CERN with the goal of fabricating large aperture quadrupoles for the LHC interaction regions (IR). The inner triplet (low- β) NbTi quadrupoles in the IR will be replaced by the stronger Nb₃Sn magnets boosting the LHC program of having 10-fold increase in integrated luminosity after the foreseen upgrades. Previously LARP conducted successful tests of short and long models with up to 120 mm aperture. The first short 150 mm aperture quadrupole model MQXFS1 was assembled with coils fabricated by both CERN and FNAL. The magnet demonstrated strong performance at the Fermilab's vertical test facility reaching the LHC operating limits. This paper reports the latest results from MQXFS1 tests with changed pre-stress levels. The overall magnet performance, including quench training and memory, ramp rate and temperature dependence, is also summarized.

Submitters Country:

USA

Wed-Af-Po3.04 / 189

Superconducting Coil system R&D for a 230 MeV Superconducting Cyclotron

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Started in Jan 2015, a 230 MeV superconducting cyclotron is under construction at China Institute of Atomic Energy for proton therapy. A compact main magnet design with warm iron yokes and a superconducting coil system is adopted to reduce the size, construction and operation cost of the cyclotron. In this paper, the field calculations of the main magnet are briefly described; then the R&D of the superconducting coil system are outlined in detail, including the cryogenics design of the system, the forces and stress analysis of the superconducting coil and support links, the power supply and quench protection design; some preliminary test results are also presented.

Submitters Country:

China

Wed-Af-Or25 / 1198

Superconducting Detector Magnets for CERN's Future Circular Collider

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CERN, in collaboration with its partner laboratories, is presently undertaking a design study of the Future Circular Collider including electron-positron and proton-proton collider variants. A 100 km long circular tunnel is foreseen featuring some 400 m below surface a few caverns for housing general purpose detectors probing e-e+ and p-p collisions. The design effort shall lead to a conceptual design report by the end of 2018 necessary for preparing the next step eventually leading to a new collision machine by medio 2045. The FCC effort comprises options for new detector magnets presently being explored. The design effort, in place since 2014, will show new baseline designs for both the ee+ and pp detector magnet systems. For the pp collisions detector the 14 GJ magnet system features a 10 m diameter, 19 m long, 4 T central solenoid in combination with two 5 m free bore, 3.5 m long 4 T solenoids covering the low angle forward directions. For the ee+ detector the baseline comprises a more classical 0.74 GJ solenoid providing 2 T in a 6.6 m free bore and 8 m length. The peak magnetic field in the coil windings is 4.6 T and 2.5 T, respectively, comfortably within reach of NbTi technology. The design drivers for the magnets set by physics requirements are highlighted and various options for these records breaking magnets are presented.

Submitters Country:

CERN in Switzerland

Tue-Af-Po2.03 / 1171

Superconducting Feeder System For ITER Central Solenoid Module Final Test Facility

Zbigniew Piec¹

¹ General Atomics

General Atomics (GA) is fabricating the ITER Central Solenoid Modules (CSM). The production contract also includes the design and qualification of tooling necessary for fabrication and full current cold testing. Each of the seven modules will undergo final testing at GA to verify performance. GA is currently commissioning the Final Test Facility at the CSM Manufacturing site in Poway, California. The facility includes a number of critical subsystems including the feeder system (FS), supplied by ASIPP, that connects the test chamber to the cryogenic and electrical systems. It includes a coil termination box, high temperature super-conducting current leads, and a feeder duct. The FS carries the current (50kA) and supercritical Helium (4.5K, 5.5 bara) to the CSM and its supporting structure, while monitoring and controlling the temperature, pressure, flow and voltage drop through all elements of the superconducting components. It functions as an integral part of the system to rapidly (6s decay time) dissipate 1 GJ energy stored in the coils, and to protect the cryogenic system. The system is complex, requiring multidisciplinary engineering including High Temperature Superconductivity, cryogenic-temperatures (77, 50, 4.5K), high vacuum (1.0 x 10⁻⁵ Pa), redundant quench detection (Voltage, temperature), high voltage insulation (15 kV), low thermal loads (70 W), and low electrical joint resistance (2 nΩ), Paschen testing, high voltage signal measurements and high current electronics. The system presented significant challenges for design and analysis, complex manufacturing assembly processes, measurement and control, and stringent quality and safety requirements. The positive cooperation between GA and ASIPP resulted in successful design and integration, manufacturing and assembly, factory acceptance testing, transfer to GA, and site acceptance test completed in Feb. 2017. Work supported by UT-Battelle/Oak Ridge National Laboratory under sponsorship of the U.S. DOE Office of Science under Awards 4000103039 and DE-AC05-00OR22725.

Submitters Country:

USA

Thu-Mo-Or32 / 959**Superconducting HTS joints for connecting strong Bi2212 wires**Alexander Otto¹¹ *Solid Material Solutions, LLC*

A Bi2212-based rectangular wire approach has been developed, with up to 500 MPa stress tolerances and useful current densities for building compact solenoid coils that are more problematic to make with wide HTS tapes, and that need to operate beyond the field and temperature limits of low temperature superconductors. Until now, no method has been shown to achieve a superconducting joint between HTS tape ends in coils or wires. In this paper, we describe the development and validation of a first practical approach for producing high critical current superconducting joints between the ends of these strong 2212 wire ends. The joints are produced by applying the unique ability of the Bi2212 superconductor to be melt textured into high J_c , textured and interconnected forms, without the need for the deformation required for 1G-Bi2223, or the need for the flat, solid state epitaxial template required for 2G-ReBaCuO. Robust superconducting joints have been produced with I_c levels that exceed the I_c 's of the wires in the highest field sections of targeted insert coil designs, and that exhibit adequately high stress and axial load tolerances, for example exceeding 200 MPa.

Submitters Country:

USA

Tue-Af-Or16 / 1060**Superconducting Magnets for High Performance ECR Ion Sources**Liangting Sun¹ ; Hongwei W Zhao² ; wei wu¹ ; GianLuca Sabbi³ ; Wang Lu³ ; Daniel Xie³¹ *Institute of Modern Physics, CAS*² *Institute of Modern Physics, Chinese Academy of Sciences*³ *LBNL*

High charge state ECR ion source has become an indispensable machine in heavy ion associated physics research. It has got remarkable advancement in the last several decades. Modern heavy ion accelerator technology needs very intense highly charged heavy ion beams, therefore very high performance ECR ion sources are needed by many large scale heavy ion facilities. So called 3rd generation ECR ion source whose magnet built with the state of the art NbTi technology represents the cutting edge technology of ECR ion sources. Latest nuclear physics research are demanding more powerful ECR ion source, therefore the ECR sourcers are tackling the 4th generation machine which is symbolized by a sophisticated sextupole magnet built with high performance Nb3Sn wires. This paper will present the existing worldwide development of high performance superconducting ECR ion sources, and the challenges in developing such kind of magnet. The development activities of both 3rd and 4th generation ECR ion source magnets at IMP will be discussed in detail.

Submitters Country:

China

Tue-Mo-O10 / 120

Superconducting Undulators Toward Commercial Products

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Babcock Noell GmbH (BNG) and the Institute for Beam Physics and Technology (IBPT) of the Karlsruhe Institute of Technology (KIT) are collaborating in an R&D program focused on the development of superconducting undulators (SCUs). After successfully completing SCU15, a full scale 15 mm period length device installed in ANKA in 2015, the team developed SCU20 a second device with 20 mm period length. The goal of SCU20 is to develop a commercial product. During the conceptual phase over 90% of the components have been redesigned with focus on reproducibility and reliability of the manufacturing process. Moreover the reduction in weight of the cold mass and the optimization of the cooling system, led to faster cooldown and reduced thermal gradients. This contribution describes the performance of SCU20 and the most significant design improvements in comparison to the previous generation device.

Submitters Country:

Germany

Mon-Af-Po1.09 / 262

Superconducting joints made using internal Mg diffusion (IMD)-processed MgB₂ wires

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Magnesium diboride (MgB₂), which has a critical temperature (T_c) of 39 K, is a candidate for use in liquid-helium free magnetic resonance imaging (MRI). Since the discovery of MgB₂, the performance of MgB₂ wires and the manufacturing technology for long-length conductors have dramatically improved. Moreover, the superconducting properties of MgB₂ wires have improved. Wires subjected to internal magnesium diffusion (IMD) processing show particularly high performance compared to Power-In-Tube processed MgB₂ wires. Our group has been developing high-performance IMD wires with J_c and J_e values greater than 100 kA/cm² and 10 kA/cm², respectively, at 4.2 K and 10 T. MRI magnets usually require persistent-mode operation to obtain high-quality images. Therefore, for wide applicability of MgB₂ in MRI, more work is required on the joining process.

We prepared two unreacted IMD wires having a diameter of 0.8 mm. The edge of each wire was compressed by a press machine to flatten it into a tape shape. After one side of the tape was polished, two tapes were packed into a metal tube and pressed again to form a joint. The IMD wire with the joint was heat-treated at 670°C for 6 h. We performed I_c measurements using the probe method and observed the specimens by scanning electron microscopy (SEM) after the measurements. The maximum I_c values in the wire were depressed 10% compared to those of a normal IMD-processed wire for each investigated magnetic field. However, the I_c values of the joint part at 3 T were equal to the I_c values of normal IMD wire at 10 T, suggesting that this joint was effective for use at magnetic fields weaker than 3 T. SEM observations revealed several B-rich compounds. We will report further improvements of the IMD technique.

Submitters Country:

Japan

Mon-Af-Po1.08 / 593

Superconducting properties and microstructure of high performance Nb₃Al wires fabricated by RHQT and mechanically alloyed methods

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Co-author(s): Y Zhang ; CC Hsin ; PY Li ; C Ke ; G Yan ; XS Yang ; XF Pan ; Feng Y ; Z Yu ; CH Cheng

High-performance Nb₃Al superconducting wire has wide potential applications in high-field magnets, magnetic confinement fusion, high energy particle accelerator, etc. However, km-grade Nb₃Al wires with high-performance are still not available to the large-scale engineering application due some fabrication problems and intrinsic physico-chemistry properties. In this paper, we reported the comparison study on the superconducting properties and microstructure of Nb₃Al superconducting wires fabricated with two different techniques: The first is an in-situ powder-in-tube (PIT), which were made by using the mechanically alloyed Nb(Al)ss supersaturated solid solution, as well as the low temperature heat-treatment at 800 -950 C; and the second is a jelly-roll Nb₃Al precursor long wire followed with different rapid heating and quenching (RHQ) heat-treatments. We found that both mechanical alloying and RHQ methods can produce the Nb(Al)ss supersaturated solid solution phase, however, the performance of the consequent Nb₃Al wires are quite difference. The wires fabricated by RHQ method has a much better T_c and J_c than those prepared by mechanical alloying technique. Microstructure and compositional analyses reveal that these two methods results quite different microstructure and local chemical composition in nanometer scale, which may affect the superconductivity and flux pinning behavior in the Nb₃Al wires.

Submitters Country:

China

Tue-Af-Or17 / 376

Superconducting properties of 2G HTS wires with artificial pinning centres fabricated using production scale PLD equipment

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State of the art high field and ultra-high field magnets demand HTS conductors with ever-increasing critical current. SuperOx is conducting an industrial R&D effort, in order to improve the performance of 2G HTS wire in magnetic field by introducing perovskite artificial pinning centres into the HTS film matrix. This paper will report the results of critical current measurements of BaZrO₃ and BaSnO₃ doped GdBCO 2G HTS wires fabricated using a production scale PLD system at the 100-200 Hz laser pulse frequency. Angular dependencies of the critical current of the samples were measured by the 4-probe transport technique at 77 and 65 K in 1 T magnetic field and derived from magnetic hysteresis curves measured in PPMS in the 4.2-77 K temperature range and 0-9 T magnetic field range. The crystal structure and texture parameters of the HTS layer and perovskite inclusions were characterised with XRD. The HTS layer microstructure and morphology were studied with TEM. TEM studies revealed the typical microstructure with BaZrO₃ and BaSnO₃ nano-rods incorporated into the GdBCO film matrix, with an average nano-rod diameter of about 5 nm. There was

a systematic shift in T_c to lower temperatures with increasing dopant concentration. All doped samples exhibited much lower angular anisotropy of in-field critical current and higher lift factors than undoped samples. Doped samples had higher minimum critical current for all field orientations than undoped samples at 65 K and at lower temperatures. These results demonstrate a positive impact of artificial pinning centres introduced into 2G HTS wires fabricated at production throughput. In the on-going work we will optimise the PLD growth parameters, in order to maximise the improvements in specific temperature and field conditions, and verify the reproducibility of the improvements in production wires.

Submitters Country:

Russia

Mon-Af-Po1.08 / 1244

Superconducting properties of Nb₃Al wires prepared with rapid heating, quenching and transformation method

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An apparatus is constructed for Nb₃Al short wires heat treatment with rapid heating and quenching (RHQ) method. Multifilamentary Nb/Al precursors are fabricated by rod-in-tube (RIT), powder-in-tube (PIT) and jelly-roll (JR) processes. These precursors are RHQ heat treated in the apparatus and then transformation heat treated at 800 °C for 10 h in a vacuum furnace. Transport and magnetization tests are performed to investigate the superconducting properties of the various short wires. The influences of RHQ time and maximum temperature on superconducting properties are also investigated. The highest onset TCs for RIT, PIT, JR wires are 17.2 K, 16.8 K, 17.5 K respectively. Microstructural observations show that wires prepared by JR method has homogeneous and stoichiometric A15 phase. The calculated JC based on Bean model for JR wire is 1100 A/mm² @10 K, 2 T, which is the best of the three wires. All the results show that JR method is the most suitable method to prepare Nb₃Al precursor for RHQT heat treatment.

Submitters Country:

China

Mon-Af-Po1.06 / 1100

Superconducting properties of Prototype Pancake Coil using MgB₂ Cable

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⁴ *Chubu Electric Power*

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⁶ KEK

⁷ Tohoku Univ.

MgB₂ wires with $T_c \sim 39$ K has been developed for the applications such as various coils. Considering hydrogen society in the future, MgB₂ coils for the Superconducting Magnetic Energy Storage (SMES) devices under conduction cooling are worth serious consideration. First, the authors evaluated critical current density in commercially available MgB₂ wires as a function of magnetic field and temperature (I_c - B - T) under conduction cooling. I_c of these MgB₂ wires aligned in straight and curve lines under an external magnetic field up to 3.5 T by superconducting magnets was measured at 20-30 K. And then, the authors analyzed bending strain of MgB₂ cable and coil, and designed double-pancake coils for several tens of kJ class SMES system. Finally, the authors produced a prototype pancake coil (200 mm inner diameter, 269 mm outer diameter, and thickness 7 mm) experimentally and evaluated coil properties under an external magnetic field. These results suggest can allow us to construct the robust energy storage system using MgB₂ wires.

Acknowledgements: This work was supported by Advanced Low Carbon Technology Research and Development Program (ALCA) of Japan Science and Technology Agency (JST).

Submitters Country:

Japan

Wed-Af-Po3.10 / 1112

Superconducting properties of YBaCuO bulk ceramics using melt process

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Superconducting properties of CeO₂ doped and undoped YBCO superconductors were evaluated to investigate the effect of pinning center on the magnetization properties. The variation ΔM with doping was maximum for 5 wt% doping and decrease with further doping. The result indicates that ΔM is proportional to the number of magnetic flux lines passing through the sample. The CeO₂ was converted to fine BaCeO₃ particles which were trapped in YBCO superconductor during the reaction sintering. The trapped fine particles, BaCeO₃ may be acted as a flux pinning center. Numerous pinning centers existing in the CeO₂ doped sample react with the external magnetic field and trap the magnetic flux. This research was supported by the Korea Electric Power Corporation [Grant number: R16XA01].

Submitters Country:

Korea

Wed-Af-Po3.05 / 1132

Superconducting synchronous motor With HTS stacked tape armature

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This paper addresses a comprehensive electromagnetic and thermal model of the superconducting synchronous motor that was successfully designed and fabricated at University of Cambridge. In this motor, the stator is a conventional 3 KW, three phase with copper windings and is controlled by a v/f

control method, while the rotor consists of 100 layers of 72x40 mm stacked-tape superconducting pseudo-bulks. A racetrack-like copper coil is implemented around the rotor in order to provide required background field required for magnetizing of the stacked tapes. Furthermore, the cooling of the motor is based on the conduction cooling in which it is by a pair of internal liquid nitrogen circuits providing cooling to the superconductors and the bulk rotor independently. Finally, the motor was constructed and the experimental results were verified by simulation.

Submitters Country:

UK

Wed-Af-Po3.12 / 561

Suppression of Flux Creep in HTS Coil by Applying Low AC Magnetic Field

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¹ *Kyushu University*

High temperature superconducting (HTS) wires such as first generation Bi-2223 Ag-sheathed tape and second generation rare-earth-based coated conductor have been developed and become commercially available. When the HTS coils wound using these wires are energized, the in-plane screening currents induced in the windings due to the perpendicular components of locally applied magnetic fields not only slightly decrease the magnitudes of central magnetic fields but also drastically degrade their uniformity. The effective methods to eliminate the screening-current-induced field in the HTS coil have been proposed and validated experimentally. In these methods, cyclic magnetic fields with the amplitudes larger than the full penetration field are applied to the HTS windings using additional coils located around them. The elimination of the screening-current-induced field would enable us to ensure the field homogeneity required especially in future HTS magnet system for nuclear magnetic resonance or magnetic resonance imaging. Furthermore, the temporal stability of the central magnetic field would also be required for their realization. In this study, the suppression of flux creep in the central magnetic field of an HTS coil is experimentally validated by applying a low AC magnetic field using additional coils. The HTS coil is fabricated using a Gd-based coated conductor, and a pair of the additional coils wound using copper wires, which are connected in series in the opposite direction, are located coaxially inside and outside the HTS coil. These coils are immersed in liquid nitrogen, and the time evolutions of the central fields in the axial direction after the excitations of the HTS coil and during the subsequent applications of AC fields with the additional coils are observed using a Hall probe. The influences of the amplitude of AC field, frequency and number of AC cycles on the flux creep in the HTS coil are investigated experimentally.

Submitters Country:

Japan

Tue-Af-Po2.02 / 396

SwissFEL Beam Dump Dipole Spectrometer Simplistic Design Backed by Accurate Magnetic Field Measurements

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The SwissFEL project at the Paul Scherrer Institute (PSI) has entered its final phase with most of the magnets having been measured and installed. The beam dump dipole in the Injector-Linac 1 section

of the SwissFEL facility serves not only to dump the electron beam but also acts as a spectrometer. Optimisation of the magnet pole profiles and pole ends, in order to achieve a good field region homogeneity of $1E-4$, is nowadays a common approach when designing magnets utilised at places where a high magnetic field quality is necessary. This design route leads to very compact magnets with complex pole geometries that are more expensive to manufacture than magnets of simple geometries. Regardless the magnet quality, the magnetic field measurements are the ultimate test before getting magnets into operation. At PSI, the magnetic field mapping by Hall probes has a relative accuracy of $1E-4$ and below. With such an accuracy the beam dump dipole geometry optimisation could be somewhat relaxed. It is for these reasons that we have adopted a simpler design concept for this dipole. The magnet design rationale, the results of the magnetic field measurements and the beam ray-tracing analysis are presented in depth.

Submitters Country:

Switzerland

Mon-Af-Po1.04 / 770**SynRM Rib optimal Design method for High-Power Density****Author(s):** Jae-Kwang Lee¹**Co-author(s):** Sol Kim² ; Ju Lee³¹ *hanyang university*² *Electrical Information Department, yuhan university*³ *Hanyang University*

Recently, As environmental problems such as global warming have appeared, MPES (Minimum Energy Performance standard) that regulates the efficiency of industrial induction motor is being implemented centered on developed countries. MPES limits the use of induction motors less than a certain efficiency to improve the energy efficiency. There are cases where the use of induction motors below IE4 level is restricted. Unfortunately, the research to improve the efficiency of induction motors have reached saturation point. As an alternative, the research of SynRM was activated. the SynRM has a merit of economical advantage compared to an induction machine because it does not use a permanent magnet, and it also has a merit in durability with a simple structure. the operating principle is that using reluctance torque generated by the difference between d-axis and q-axis inductance. Generally, the d-axis,q-axis inductance was directly connected in the output of the SynRM. Generally, output density of SynRM is proportional to the number of layers. However, if the number of layers is increased, the mechanical strength becomes weak, so high-speed rotation becomes impossible. In this paper, we propose a design method of 3D printing manufacturing method and SynRM designing method. First we have designed many layers for SynRM that has maximum output density but also has minimum mechanical strength. To compensate for the mechanical strength, 3D printing structure is placed inside the layer. In the case that made only using iron core, it is impossible to drive cause by mechanical stress. but the 3D printing structure is placed inside the core, it is confirmed that the 3D printing structure is dispersed in the stress concentrated on the iron core. To prove this design technique, the motor is manufactured and tested. As a result, the validity of the design method was verified.

Submitters Country:

Republic of korea

Tue-Af-Po2.05 / 1212**THE SCANNING MAGNETS FOR PROTON THERAPY AT SAPT****Author(s):** Jia Bolei¹

Co-author(s): Ouyang Lianhua ¹

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A new proton scanning system for the treatment of cancer has been accomplished for Shanghai Advanced Proton Treatment (SAPT). It includes two separate dipole magnets, each controlling horizontal and vertical directions independently. According to the design requirements, the dimensions of the magnets were determined and the local and integrated field quality optimized. The static magnetic field analysis was completed for spatial distribution, the interference between two the dipoles, the optimization of the poles, and the verification of the scanning scopes. The dynamic behaviors of the two dipole magnets were analyzed, and approaches to reduce the effects of eddy current and hysteresis were taken. Both the static and dynamic magnetic field measurements were carried out, and the measurement results showed that the design goals were reached. This paper describes the design, manufacture, and test of the scanning magnets.

Submitters Country:

China

Tue-Af-Po2.09 / 734

Tail Component Qualification for the EU ITER PF Coils

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Co-author(s): Kevin Smith ; Carlo Sborchia ; Fabrice Simon ; Roberto Penco ; Giorgio Vercelli ; H. Wu ; Z. Zhang ; François Chastel

¹ *Fusion for Energy*

The ITER Poloidal Field (PF) magnet system is composed of six circular coils, consisting of winding packs (WP) made up from a stack of Double Pancakes (DP) wound of NbTi cable-in-conduit superconductor. The largest coil has a diameter of 24 meters, the heaviest weighs 400 tons, and they are designed to produce a total magnetic energy of 4 Giga Joules at a maximum magnetic field of 6 Tesla for 30,000 inductively driven plasma pulses. The ends of the conductors (in the outer-most coil turns) of the top and bottom DPs are coil terminations which are connected to the superconducting bus bars of the feeders, being these conductor exits one of the structural weakest points of the coils. The main function of the tail is to reinforce this region by linking the outer-most termination to the last-but-one turn, thus guaranteeing the transfer of longitudinal tensile force, through an electrically insulated mechanical connection featuring a fiberglass strap. The PF Coils are subject to electromagnetic forces induced from their own magnetic field and the magnetic field generated from the rest of the ITER magnet system, the thermal stresses during cooldown and warmup cycles and DC/AC high voltage levels. Therefore, the tail components shall withstand these conditions while staying within the geometrical boundaries imposed by the conductor dimensions, in order to avoid any protrusion on the winding pack surface. This paper aims to describe the adopted solution throughout its lifecycle, from the design validation, by the electromagnetic and mechanical analyses, to the design qualification of the set of imposed requirements through the manufacture and testing of a set of full-size mock-ups.

Submitters Country:

France

Tue-Mo-Or13 / 583

Tcs Measurement Result of ITER Toroidal Field Insert Coil Tested in 2016

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⁵ *ITER Organization*

Performance of the ITER toroidal field (TF) coil conductor has been measured in the SULTAN facility with 3.6 m straight configuration and joints at the sample top and bottom. However, this test condition includes large gradients of magnetic field along the conductor length caused by its only 0.45 m high field length. This condition, which is not present inside the ITER TF coils, could lead to an increased drop of Tcs: current sharing temperature. In order to study the TF conductor performance without such large field gradient, a TF Insert Coil (TFIC) was tested in the CSMC facility in Naka Fusion Institute, Japan. The TFIC is a single layer 8.875-turn solenoid coil wound from ITER TF conductor. The coil diameter is 1.44 m and the conductor length is around 40 m. The TFIC has been tested from October 2016 to March 2017 and its Tcs was measured through 1,000 electromagnetic cycles and then several times of warm-up and cool-downs from room temperature to cryogenic temperature. In parallel with the TFIC test, Tcs measurement with similar procedure was also carried out in the SULTAN with a TF conductor sample, which was cut from the one for the TFIC during its fabrication, and both Tcs results were compared. The result showed that the Tcs of the TFIC was around 0.7 K higher than that in SULTAN mainly caused by hoop stress in the coil, and the change in Tcs through the electromagnetic cycles was almost identical in both cases. However, the Tcs results after the warm-up and cool-downs were different for each case and the TFIC showed smaller Tcs degradation than the SULTAN sample. The result of the Tcs measurements and following analysis are reported in this presentation.

Submitters Country:

Japan

Thu-Af-Pl9 / 1256

Technical Visits, Banquet and Closing of MT25

Thu-Af-Po4.08 / 359

Temperature Evolution of Pinning Force in GdBaCuO Coated Conductors with Artificial Pinning Centers

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In this report we present results of analysis of pinning force as well as pinning energy in PLD $GdBa_2Cu_3O_{7-x}$ coated conductors doped by $BaSnO_3$ and $BaZrO_3$. Concentrations of both additions in the studied samples have varied from 0 to 18 mole per cent. For all samples we measured magnetization curves in the range of temperature 4,2-77 K and magnetic field up to 14 T. Dependencies of critical current on applied magnetic field $j_c(H)$ were obtained from magnetization curves

based on Bean model. Analysis of pinning force was carried out based on the Dew-Hughes approach $F_p/F_{p-max} = b^p(1-b)^q$ ($b = B/B_{irr}$) by used Kramer's plot $J_c^{0.5} B^{0.25}$ for determination of irreversibility field B_{irr} . We found that the normalized pinning force tends to change both functional dependency and peak position as the temperature varies. This result indicates the change of pinning mechanism with decreasing temperature.

Submitters Country:

Russia

Thu-Mo-Or29 / 1176

Temperature dependent behaviour of a barrel-type HTS dynamo

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HTS dynamos are a class of superconducting flux pump, which have attracted significant recent interest as novel current sources for HTS magnet coils. They employ a series of permanent magnets which mechanically traverse a coated conductor stator, giving rise to a time averaged output emf. Previous work has shown that the maximum achievable output current of an HTS dynamo is determined by the width of the coated conductor stator wire. This presents the question – what happens if a topologically-continuous stator is employed which does not have well-defined edges? In this work we report on the experimental characterisation of an HTS dynamo employing a cylindrically-continuous HTS stator, which is excited by a concentrically mounted rotor containing a permanent Nd-Fe-B magnet. The entire device is mounted in a temperature controlled cryo-cooled vacuum chamber, enabling characterisation of dynamo performance at temperatures down to 40 K. We find that device temperature affects the optimum operating speed of the device, but has little effect on the maximum current which can be achieved. Our results also indicate that this device architecture is capable of achieving output currents exceeding 1 kA, whilst incurring minimal thermal losses. This opens the tantalising possibility of kA-class power supplies for cryo-cooled benchtop magnets.

Submitters Country:

New Zealand

Wed-Af-Po3.11 / 1049

Temperature evolution in ITER CSU2 coil module during 15MA plasma scenario

Tommaso Bagni¹ ; Arnaud Devred^{None} ; Arend Nijhuis¹

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The JackPot-ACDC model, an electromagnetic-thermal model for Cable-in-Conduit Conductors and THEA, a thermo-hydraulic model for superconductors can be combined to reproduce and predict the behavior of a conductor under any current and magnetic field variations. JackPot+THEA is used to model the most demanding turns of the CSU2 module quadra-pancake of the ITER Central Solenoid. The chosen Nb3Sn conductor section is about 150 m long from helium inlet to helium outlet, which are placed respectively in the most inner and outer turns of the pancake. The conductor temperature margin and electric field levels are compared with those obtained at minimum quench energy

(MQE) simulations and experiments in order to evaluate possible critical issues. The results confirm sufficient stability of the conductor section, both from electrical and thermal point of view. The temperature evolution during the 15MA plasma scenario is also analyzed to evaluate the feasibility of concatenate multiple scenarios without interruption due to accumulative heat storage in the helium slug, necessary for continues energy production for future fusion power plants.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Submitters Country:

Netherlands

Mon-Af-Po1.06 / 906

Test Winding of a 1-T Class Force-Balanced Coils Using High Temperature Superconducting Tapes

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Co-author(s): Toru Ueki¹ ; Akira Ninomiya¹ ; Shinichi Nomura¹ ; Tsuyoshi Yagai² ; Taketsune Nakamura³ ; Hirotaka Chikaraishi⁴

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High-temperature superconducting (HTS) tapes are expected to improve small sized high field magnets such as superconducting magnetic energy storage (SMES). The authors proposed the force-balanced coils (FBC) concept as a feasibility option for SMES. Although the FBC can minimize the mechanical stresses induced by the electromagnetic forces, the FBC has three-dimensional complex shapes of helical winding. Therefore, when the tensile strain, the bending strain and the torsional strain simultaneously apply to the HTS tapes, the critical current of the HTS coils decrease. The objective of this work is to clarify the critical current property of HTS tapes for the applying complex mechanical strain due to the winding process, winding configuration and electromagnetic forces through the development of a 1-T class HTS model helical coils based on the FBC concept. As a first approach, the authors developed a prototype winding machine whose motion was optimized to prevent from decreasing the critical current of the HTS tapes during winding process. The authors fabricated the one-turn helical coils wound onto the pure torus surface without the winding slot using YBCO and BSCCO wire. From the excitation test results with liquid nitrogen cooling, the authors confirmed the feasibility of the helical winding techniques without a decrease in the critical current. As a next step of this work, the authors are planning to carry out the test winding onto the winding slot whose shape has helical coil trajectory. In this case, the complex mechanical strain will directly apply to the HTS tapes compared with the winding case using the pure torus surface. This work discusses the critical current property dependence on the winding technique of the HTS coils thorough the test winding results and a numerical analysis of the applying mechanical strain.

Submitters Country:

Japan

Tue-Mo-Or13 / 394

Test of ITER-TF joint samples with NIFS test facilities

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Co-author(s): Norikiyo Koizumi² ; Tsutomu Hemmi² ; Hideki Kajitani² ; Tetsuhiro Obana¹ ; Suguru Takada¹ ; Shinji Hamaguchi¹ ; Hirotaka Chikaraishi¹ ; Kazuya Takahata¹ ; Kunihiro Matsui²

¹ *National Institute for Fusion Science*

² *National Institute for Quantum and Radiological Science and Technology*

Qualification tests of the ITER Toroidal Field (TF) conductor joints have been carried out by testing short joint samples with test facilities in National Institute for Fusion Science. The joint sample consists of two short TF conductors with the length of 1,535 mm, which is restricted by the conductor test facility with 9 T split coils and 100 kA current leads. Each conductor has two joint boxes at both ends. The lower joint is a testing part that is full size joint of the TF coil, where the cables is compacted from the void fraction of 33% to 25% on the length of 440 mm, the same as the final twisting pitch length. The total length of the joint box is 675 mm including the transition region of cable compaction. In order to attain the original conductor part of 300 mm length for setting voltage taps at three positions, the length of upper joint box is shortened to 560 mm, where the joint length of the cables and copper sleeve is shortened to 325 mm. The voltage drops between L-leg conductor and R-leg conductor are measured with six voltage taps per position per conductor while holding currents for three minutes at 1, 15, 30, 45, 60, 68 kA. The joint resistance of the lower joint is estimated from the increase of the average voltage drop among the six taps against the currents. Five joint samples were tested until 2016, and all the samples satisfied the requirement of the joint resistance less than 3 nano-ohms. The method of the measurement is explained and the voltage distribution among the voltage taps is discussed.

Submitters Country:

Japan

Tue-Af-Po2.07 / 344

Test of a Prototype Inductive Superconducting Fault Current Limiter Using No-insulation Coil

Derong Qiu¹ ; Zhuyong Li^{None} ; Wei Wu^{None} ; Zhen Huang^{None} ; Zhiyong Hong^{None} ; Zhijian Jin^{None}

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No-insulation (NI) coil made of 2G HTS tape has many advantages over insulated coil that it has higher engineering current density and self-protection characteristic. While there are few researches of NI coil in AC power application due the charging/discharging delay of NI coil. In this paper, we apply NI coil into inductive superconducting fault current limiter (iSFCL) as the secondary shielding coil and fabricate a prototype iSFCL. The NI coil works in inductive mode that there no longer exists charging/discharging delay. The basic electromagnetic characteristics of the prototype iSFCL are tested, such as the voltage drop during normal operation and the current limiting characteristic. Additional experiment is also conducted to testify the better thermal conductivity of NI coil can shorten the quench recovery time of the iSFCL, which is beneficial to the reclosure of the power grid.

Submitters Country:

China

Wed-Af-Po3.07 / 474

Test of the SMES working as a Power Buffer in a Multiple DC Distribution Power Network by Using the Real Time Digital Simulator

Author(s): Jianwei Li¹

Co-author(s): Weijia Yuan¹ ; Min Zhang¹

¹ *University of Bath*

The multiple DC power networks with introduction of distributed generations (DGs) and energy storage system (ESSs) have been drawing much attention in recently. Compared with the conventional AC system, the DC network has many advantages. Nevertheless, the power balancing between the various DC components has been realised as one of the key issues of the DC network. The penetration of the renewable energy may lead to the instantaneous power mismatching between the DGs and ESSs, which makes the situation worse. This study proposes a novel solution by introducing a superconducting magnetic energy storage (SMES) into the DC network. A hardware in the loop test circuit is developed coupling with the RTDS to verify the performance of the SMES in the DC system. The results show that the SMES works as a power buffer with large power capacity either absorb or release the mismatching power in the DC system so that to compensate power fluctuations.

Submitters Country:

United Kingdom

Wed-Af-Or23 / 818

Test of the first MQXFA prototype by LARP and status of the US High Luminosity LHC Accelerator Upgrade Project preparation

Amalia Ballarino¹; Bernardo Bordini¹; Daniel Cheng^{None}; Eddie Frank Holik^{None}; Emmanuele Ravaioli²; Eugenio Cavanna^{None}; Ezio Todesco¹; Fred Nobrega³; GianLuca Sabbi²; Giorgio Ambrosio³; Giorgio Apollinari⁴; Giorgio Vallone¹; Guram Chlachidze³; Heng Pan²; Herve Prin¹; Hugo Bajas¹; Jesse Schmalzle⁵; Joseph F Muratore⁵; Juan Carlos Perez¹; Lance Cooley³; Marta Bajko¹; Maxim Marchevsky^{None}; Miao Yu³; Michael Anerella⁵; Paolo Ferracin¹; Peter Wanderer^{None}; Piyush Joshi⁵; Rodger Clayton Bossert¹; Ruben Horacio Carcagno^{None}; Soren Prestemon²; Steve Krave³; Stoyan Stoynev⁶; Susana Izquierdo Bermudez¹; Tiina-Mari Salmi⁷; Vittorio Marinozzi⁸; Xiaorong Wang⁹

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⁴ *Fermi National Accelerator Lab. (US)*

⁵ *Brookhaven National Laboratory*

⁶ *FNAL (US)*

⁷ *Tampere University of Technology, Finland*

⁸ *University of Milan / INFN*

⁹ *Lawrence Berkeley National Laboratory*

The US LARP (LHC Accelerator Research Program), in collaboration with CERN, has started developing prototypes of the low-beta Quadrupoles (MQXF) for the High Luminosity Upgrade of the LHC at CERN. These large aperture (150 mm) high gradient (133 T/m) quadrupoles will use Nb₃Sn conductor to replace the present 70-mm aperture NbTi quadrupoles.

The first LARP prototype (MQXFA1) has coils with 4 m magnetic length produced at BNL and FNAL. The Al-shell based structure was assembled at LBNL. Test at 1.9 K is in progress at BNL. This test is an important milestone toward the full approval of the High Luminosity LHC Accelerator Upgrade Project (HL-LHC-AUP), which will fabricate and test the upgraded Q1 and Q3 elements of the LHC Inner Triplets, using CERN supplied cryostats.

In this paper we present the status of MQXFA1 test, the status of the HL-LHC-AUP project preparation, and the plan for next steps.

Submitters Country:

USA

Thu-Af-Po4.03 / 202

Test results of the first superconducting undulator prototype at the SSRF

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Development of a superconducting undulator prototype is ongoing at the SSRF. The 50-period superconducting magnet of this prototype is based on NbTi/Cu conductors. The period length is 16 mm. The magnetic gap is 9.5 mm and the vacuum gap is 7.5 mm. The peak value of the magnetic fields on beam axis is 0.67 T with the operation current of 400 A. Cooling system includes 4 cryocoolers and independent cooling circuits for magnet and the beam vacuum chamber. In this report we present the main parameters, components, and the R&D process of this prototype. Methods and results of the stand-alone test are also included in detail.

Submitters Country:

China

Wed-Af-Or23 / 777

Test results of the short models MQXFS3 and MQXFS5 for the HL-LHC upgrade

Antonella Chiuchiolo¹ ; Daniel Cheng² ; Emmanuele Ravaioli² ; Ezio Todesco¹ ; Friedrich Lackner¹ ; GianLuca Sabbi² ; Giorgio Vallone¹ ; Guram Chlachidze³ ; Hugo Bajas¹ ; Juan Carlos Perez¹ ; Lance Cooley³ ; Luca Bottura¹ ; Marta Bajko¹ ; Miao Yu³ ; Paolo Ferracin¹ ; Susana Izquierdo Bermudez¹ ; Xiaorong Wang⁴

¹ *CERN*

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³ *Fermilab*

⁴ *Lawrence Berkeley National Laboratory*

For the luminosity upgrade of the Large Hadron Collider at CERN, the installation of new generation of lower beta* quadrupole magnets is foreseen on each side of the ATLAS and CMS experiment insertions zones. The new magnets are based on Nb3Sn technology and designed to achieve a field gradient of 132.6 T/m within a 150-mm aperture reaching a peak field of 11.4 T at the conductor level. In 2016 and 2017, the first two 1.5 m long magnet models, called MQXFS3 and MQXFS5, have been successfully tested at 4.2 K and 1.9 K in the two new High Field Magnet (HFM) test benches designed to respond to the HL-LHC magnets new requirements in terms of size and magnet performance.

This paper first presents in details the main features of the tested magnets in terms of conductors, magnet instrumentations and magnet integration in the SM18 HMF facilities. A second part is then dedicated to the magnet training behaviour and to the investigation on the quench location which may limit the magnet final performance. The last part describes the specific tests performed to validate the magnet protection schemes (quench detection, Quench Heater and CLIQ systems) and the main outcome of the test results.

Submitters Country:

Switzerland

Thu-Af-Po4.05 / 1238**Test title**Srinivas Vanapalli¹¹ *University of Twente*

Test abstract

Submitters Country:

Netherlands

Thu-Af-Po4.03 / 918**Testing of the superconducting magnets for the SIS100**Anna Mierau¹ ; Egbert Fischer^{None} ; Kaether Florian² ; Christian Roux² ; Alexander Bleile¹ ; Vassily Marusov² ; Piotr Szwangruber² ; Harald Weiss² ; Sergei Kostromin³ ; Hamlet Khodzhbagiyani³¹ *GSI*² *GSI Helmholtzzentrum für Schwerionenforschung GmbH*³ *Joint Institute for Nuclear Research*

The SIS100, a novel heavy ion synchrotron, is the main accelerator of the FAIR complex, which is currently constructed at Darmstadt, Germany. Around 500 superconducting magnets have been contracted for the SIS100 at industry or collaboration partners. All these magnets have to be tested at cryogenic temperature in order to verify and guarantee their performances before their installation in the accelerator tunnel. Test stations, sophisticated measurement equipment, and the required infrastructure are developed and built up at GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany and Joint Institute for Nuclear Research, Dubna, Russia. We report on the production status of the magnets and the testing strategy, according developments, and the status of preparations at the test stations.

Submitters Country:

Germany

Wed-Af-Po3.03 / 962**Tests in Standalone Mode of the EuCARD 5.4-T REBCO Dipole Magnet.**Maria Durante^{None} ; Franck Borgnolutti¹ ; Denis Bouziat² ; Jean-Marc Gheller² ; Frederic Molinie³ ; Philippe De Antoni²¹ *CEA*² *CEA Saclay*³ *DAPNIA*

A HTS insert dipole magnet made of REBCO tapes was fabricated at CEA Saclay in 2016. The design of the insert was produced in the framework of the EuCARD High Field Magnet program and its fabrication was continued within a collaboration agreement between CEA-Saclay and Cern. The goal of the HTS insert project is to assess the potential of HTS material to generate a magnetic field

of 5.4 T at 4.2 K in the 13 T background field of the 100-mm aperture FRESCA2 Nb₃Sn dipole magnet. The insert winding is made of three double-layer racetrack coils, wound from 12 mm wide YBCO tapes stabilized with beryllium copper ribbons. Prior to being installed in the aperture of FRESCA2, at CERN, the insert will be tested in standalone at both 77 K and 4.2 K at CEA-Saclay. After a recall of the insert design and main parameters, this paper will report on insert manufacturing and on the cold tests results in standalone.

Submitters Country:

France

Tue-Af-Po2.03 / 1210

The Charging and Discharging characteristics of a YBCO Metal-insulation coil

Jun Ma^{None}

The high temperature superconducting (HTS) No-insulation (NI) coils have the self-protecting ability and good thermal stability because of the absence of turn-to-turn insulation. However, the charging time is too long compared with Insulated coils, since the current path is changing all the time during the charging and discharging process. In order to optimize the performance of No-insulation coil, a trade off was made: A metal layer was inserted as an interlayer of the coil to increase the turn-to-turn resistance between the neighboring YBCO tapes. This method could speed up the charging and discharging process of the new invented coils, defined as Metal-insulated Coils, which can produce a more easy-to-use coils for practical applications. The test results and analysis will be presented in detail in the essay.

Submitters Country:

U.K

Wed-Af-Po3.04 / 1086

The Design and Manufacture of the 90 degree bending Magnets for Proton Beam Therapy

liu zhihong^{None} ; wu jiefeng^{None}

Proton beam is an effective means of radiotherapy for tumors. During the transmission of the proton beam from the accelerator to the treatment head, the direction of the beam is usually changed by the magnetic field generated by dipole magnet. A variety of magnets are arranged in a radiotherapy system using a rotating gantry for proton beam transmission. The 90 degree magnet is placed above the treatment head that move with the rotation of the gantry and concentric with the rotating gantry. The iron core of the magnet is often stacked with silicon steel sheets with high magnetic permeability and low loss. The outer coil is wound with oxygen-free copper conductor with water cooling in the middle. This article will describe the details of design and manufacturing process of a 90-degree bending magnet on the proton therapy rotating gantry.

Submitters Country:

china

Tue-Mo-O10 / 341

The Design of Magnetic Needles for Improving Magnetic Field Measurement System

Author(s): Yun-Liang Chu¹

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To measure magnetic field with Hall probe, the accuracy needs to be considered synchronously. Therefore, the improvements of measurement system are presented, including the magnetic needles and a zero-field shielding were simulated by OPERA. The design of magnetic needles with N-N type is significant that the misalignment of magnet could be calibrated. The doping area of Hall probe was sensitive, whose position should be defined before measuring. Also, a zero-field shielding is used to reset the value of magnetic field to zero. However, the data of simulation is reported in this paper.

Submitters Country:

Taiwan

Thu-Af-Po4.04 / 803

The FuSuMaTech initiative: Synergy with Industry and Impact on the Future Superconducting Magnet Technology

Author(s): Antoine DAEL¹

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¹ *CEA*

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The CERN's projects, HL-LHC and FCC, will create a big push in the state of the art of High-Field Superconducting magnets. The performance of superconducting materials such as Nb3Sn and HTS will be developed to yield higher performance at lower costs and the construction materials and techniques will be advanced. In the context of Energy's savings, Industry is experiencing a renewed interest in the domain of industrial superconductivity with fault current limiters, wind generators and electric energy storage. Medical Research shows a strong interest in High-Field MRI, especially for the brain observation. Considering the social impact of the HL-LHC project and FCC study, CERN and CEA have established a Working Group on Future Superconducting Magnet Technology (FuSuMaTech). The working group has explored a large spectrum of possible synergies with Industry, and proposed a set of R&D&I projects to be conducted jointly between academics and industry. To keep the leading position of Europe, the most efficient way is to support common activities of industry and academic partners on the common concerns in view of overcoming the technological barriers. The FuSuMaTech initiative aims, to create the frame of collaborations and to provide common tools to all the European actors of the domain. The FuSuMaTech initiative is a dedicated and large scale silo breaking program which will create a sustainable European Cluster in applied Superconductivity. It will enlarge the innovative potential especially in High Field NMR and MRI, opening future breakthroughs in the brain observation. Based on practical case studies, the FuSuMaTech Phase 1 is the first step of the FuSuMaTech initiative. It will consist in preparing the detailed description of R&D&I actions, the administrative and legal conditions and the funding scheme for the future. This paper summarizes the initial R&D axis, and the roadmap foreseen to germinate the proposed collaborative developments.

Submitters Country:

France Switzerland Italy UK

Thu-Af-Po4.05 / 665

The Investigation of Cogging Torque Reduction Technologies

Author(s): YC Kim¹**Co-author(s):** Ju Lee ¹¹ *Hanyang University*

Cogging Torque is essential torque component on permanent magnet motor having teeth and slots and also this is an important characteristic of some applications such as electrical steering motor which requires precision position control and lower acoustic noise. There had been investigated variety techniques to reduce cogging torque during several decades and most of them show common feature for some reduction of motor performance.

In industrial fields, many engineers have been tried to reduce cogging torque, but this is not simple problem to find root cause because it could be affected by many factors and its unbalance. In this paper, the definition of cogging torque will be explained again with some equations as theoretically, and the variety of design techniques for low cogging torque will be summarized with theory and calculation result by finite element method. And also, the strength and weakness of each method will be compared. And then all the potential factors will be defined through logic tree analysis for rotor and stator respectively, the sensitivity of cogging torque by each factor will be analyzed. The correlation study between design factors and cogging torque will be used the result of finite element method considered realistic situations because of many design factors. And the sensitivity analysis will be used by statistic method. In the end of paper, the cogging torque including each harmonic order will be summarized with major factors. This paper will provide some tips for the solution of cogging torque failure problem in the actual field.

Submitters Country:

South Korea

Thu-Af-Po4.11 / 187

The Mu2e Solenoid Cold Mass Position Monitor System

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The Mu2e experiment at Fermilab is designed to search for charged-lepton flavor violation by looking for muon to electron conversions in the field of the nucleus. The concept of the experiment is to generate a low momentum muon beam, stopping the muons in a target and measuring the momentum of the conversion electrons. The implementation of this approach utilizes a complex magnetic field composed of graded solenoidal and toroidal fields. The location of the solenoid cold mass relative to external fiducials are needed for alignment as well as monitoring coil movements during cool down and magnet excitation. This paper describes a novel design of a Cold Mass Position Monitor System that will be implemented for the Mu2e experiment.

Submitters Country:

USA

Wed-Af-Po3.07 / 990

The Number of Magnet Poles Decision Method of Magnetic Gear for Torque Ripple Reduction

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Mechanical gears, which are employed in the many fields of modern industry, are used mostly for power-transmitting mechanical devices. However, because the mechanical gear operates, in principle, by the engagement of gear teeth, it is difficult to avoid problems such as friction loss from physical contact, noise, and vibration. To address this problem, magnetic gears have been proposed as a substitute for mechanical gear trains owing to advantages like noise reduction, utility of maintenance, and low friction loss due to non-contact power transmission. Since the N and S poles always coexist in the permanent magnet, the poles of the permanent magnets must be composed of an even number. The characteristics of these permanent magnets limit the gear ratio configuration according to the combination of pole numbers of the magnetic gears. If the number of poles of the inner rotor is fixed to four poles and the number of poles of the outer rotor is arranged from four poles to twenty poles, the gear ratios are displayed at 0.5 intervals from 1: 1 to 5: 1. That is, when the number of poles of the inner rotor is 4, the gear ratio of the adjacent pole ratio combination is different by 0.5. Even if the gear ratio is immediately adjacent, it can be seen that the ripple value is up to 10 times or more. However, there are certain rules for this difference. In this paper, we have confirmed the regularity of the torque ripple according to the gear ratio. Therefore, the research result of this paper can provide design guideline that are essential for calculating the torque characteristics suitable for the application field in the design stage of the magnetic gear.

Submitters Country:

Rep. of Korea(South)

Wed-Af-Po3.02 / 1153

The PF1 coil electrical joint test results

Author(s): Egor Marushin^{None}**Co-author(s):** Andrei Mednikov ; Dmitry Stepanov¹ ; Igor Rodin¹ ; Oleg Kovalchuk¹ JSC "NIEFA"

The Poloidal Field (PF1) coil is one of six PF coils of the ITER magnet system. It represents a stack of eight double pancakes (DP). Each DP is wound from niobium-titanium "cable-in-conduit" conductors (CICC). All DPs are connected into a single electric circuit using electrical joints, which have a 'shaking hands' configuration. The new joint design was agreed by the ITER Organization (IO). It was required to upgrade the existed techniques and equipment. The work acceptance criterion is a resistance of less than 5 nOhm in the range of operating temperatures and magnetic fields. The upgrading was done in the following parts: (1) the superconductor cable preparation including masking of the double twist pitches; (2) electroplating of the strands; (3) inserting of the cable inside the termination box; (4) soldering cable inside the box and between two termination boxes. To check its operability the full size joint sample was manufactured and tested. The final electrical test was performed on CRPP "SULTAN" test facility (Switzerland). The results of the tests during manufacturing and electrical test are mentioned in this paper.

Submitters Country:

Russia

Thu-Mo-Or29 / 993

The Study of Pulsed Strong Magnetic Field Measurement System based on Distributed Magnetic Field Sensors

Zhenhua Li¹ ; Li Qiu^{None} ; Wenhui Zheng^{None} ; Shuang Zhao^{None} ; Zhenxing Li^{None}¹ *China Three Gorges University, College of Electrical Engineering & New Energy, Yichang, China*

Currently, how to measure the magnetic field accurately is a difficulty in the study of high magnetic field. This paper proposes a measurement method for pulsed magnetic field based on distributed magnetic field sensors. The method adopts multiple magnetic field sensors based on Rogowski coil to measure the value of the magnetic field. The magnetic field sensor is a single cube structure, of which three sides are closely linked and perpendicular to each other. The sensors are made up by the technology of printed circuit board. Each side is covered with copper, and then forms three little coils. Each coil induces magnetic field changes in the x, y, and z direction, respectively. The output of the coils reflects the value of magnetic field in correspondingly measured direction. Thus, the value of magnetic field of monitoring points can be obtained by comprehensively processing of the output of the three magnetic field sensors. After obtaining signals of the magnetic field sensors, this paper adopts a data analysis method based on subsection FFT with window functions to extract useful signal among the output signals of the sensors accurately. This paper will focus on the study of sensing mechanism and method of distributed magnetic field measurement. And then researches the disturbances of magnetic field measurements, by means of establishing model of magnetic field sensor in the simulation software, such as the temperature and humidity changes, the electric field etc. Besides, the corresponding data compensation algorithm to ensure the accuracy of measurement results will also be studied, and then the accuracy can be improved.

Submitters Country:

China

Thu-Mo-Or28 / 1197

The US Magnet Development Program for High Field Accelerator Magnet R&D

Soren Prestemon¹¹ *Lawrence Berkeley National Laboratory*

The 2014 Particle Physics Project Prioritization Panel (P5) Report identified a critical need for transformational high field dipole magnet R&D, focused on improving performance and reducing the cost per T-m. This need was subsequently reiterated in the HEPAP Accelerator R&D subpanel report. In response, the DOE Office of High Energy Physics has initiated an ambitious program to aggressively pursue superconducting accelerator magnet development with the primary goals of minimizing training and minimizing the required operating margin. Breakthroughs in magnet performance, particularly in training and operating margin requirements, will require further understanding and control of the underlying physics mechanisms. The US MDP leverages developments in modeling, materials, and diagnostics that are critical to advancing magnet technology. An outline of the program objectives, a review of the status of these elements, and a summary of the underlying program milestone roadmaps that serve to focus R&D efforts will be presented.

Submitters Country:

USA

Thu-Af-Po4.08 / 854

The angular and Field Dependence of the Critical Current of commercial YBCO coated conductors

Xiuchang Zhang¹ ; Jianzhao Geng¹ ; Chao Li¹ ; Boyang Shen¹ ; Tim Coombs¹¹ *University of Cambridge*

Many applications of YBCO tapes operate under external magnetic fields, hence it is necessary to investigate the in-field angular dependence of the critical current density of the coated conductors. In this paper, five commercial YBCO tapes with different microstructure that produced by three different manufacturers are chosen, which have width of 2mm, 4mm, 6 mm or 12mm. The in-field critical current density characteristics $J_c(B, \theta)$ of the selected commercial YBCO tapes are comprehensively measured under various magnetic fields and orientations. Afterwards, the obtained five experimental data sets are successfully fitted using an extended Kim model which considers the material anisotropy. In certain cases, a rational function is integrated into the fitting equations, which can effectively reduce the average errors of the fitting results to 2% or even lower. Based on the derived fitting functions of the YBCO tapes, a FEM model is built in COMSOL for calculating AC losses of the superconducting wires. The validity of the model is proved through comparison with the Norris analytical solution. Moreover, we consider the accuracy of this model is higher than the Norris equation since the influence of self-field is taken into account. Our results can be helpful for prediction of critical current and AC losses of devices that composed of electromagnetically interacting YBCO tapes.

Submitters Country:

United Kingdom

Tue-Af-Po2.04 / 1235

The conceptual design and analysis of the background magnet for a conductor test facility

Author(s): linyu sun¹**Co-author(s):** Pengyuan Li ; Haihong Wei¹ *Southwestern Institute of Physics*

To achieve steady-state operation, the magnetic field can be up to 15T or even more to confine the plasma inside vacuum chamber in demo-fusion device. For conductor tests under such a high-magnetic field, a conductor test facility is required, and a conceptual design of the magnet which is used to generate background field is in process. The preliminary design and the results of electromagnetic and structural analysis are presented.

The background magnet consists of three sets of concentric superconducting coils, divided into two split pairs, upper and lower coils. With 120mm vertical distance between them, the space is used to place test samples. To obtain 15T of magnetic field required, the design value needs to be more than 16T, and the coils of those sets are wound with different superconducting tapes, NbTi, Nb3Sn and REBCO. The NbTi coils are on the outside of the magnet, with a maximum field of about 8T at 75A. The Nb3Sn coils are located in the middle of the magnet, generating a magnetic field of 6.4T when the current is 18kA. The REBCO coils are inserted in the center of the magnet, and the peak field is 2.1T. The radial gap between the three sets of coils is 40mm. In order to reduce the amount of superconducting tapes and operating costs, the size of the magnet is optimized, and the heights of the three sets of coils are 600mm, 450mm, and 300mm respectively. The total magnetic field of the magnet is about 16.5T when all coils reach their rated currents, and the 0.6% homogenous field length is 500mm along the axis of the magnet. All coils are cooled with liquid helium at 4.2K. The stress in the middle of the magnet is up to 128MPa, and the outer surface of the magnet should be reinforced.

Submitters Country:

China

Thu-Af-Po4.08 / 643

The effect of compositional ratio of SmBCO coated conductor on the superconducting properties.**Author(s):** Gwan-tae Kim¹**Co-author(s):** Ho-sup Kim¹; Dong-woo Ha¹; Rock-kil Ko¹¹ *Korea Electrotechnology Research Institute*

Sm_{1+x}Ba₂Cu_{3+y}O_{7-d} (SmBCO) coated conductors were fabricated by reactive co-evaporation method in the EDDC (Evaporation using Drum in Dual Chambers) deposition chamber. The structure of SmBCO coated conductor was Ag/SmBCO/LMO/MgO/Y₂O₃/Al₂O₃/Hastelloy. The deposition system was composed of dual chambers: reaction chamber and evaporation chamber. Superconducting materials of Sm, Ba, and Cu were evaporated in the evaporation chamber and deposited on the substrate mounted on the drum while the deposited elements reacted with oxygen and turned into SmBCO superconducting phase in the reaction chamber. The samples with different composition ratios were prepared, and we measured the angular dependence of critical current under high magnetic field and the field dependence of critical current. We found out that the magnetic field dependence of critical current was highly dependent on the composition ratio of SmBCO film. The broad peak at $\Theta = 0$ (B//c-axis) in the angular dependency of critical current was observed, which means that c-axis correlated pinning center was formed in SmBCO film. The elemental mapping of the high-J_c SmBCO coated conductor was measured by TEM-EDX. We confirmed secondary phases and Sm/Ba anti-site phase which take the role of pinning centers.

Submitters Country:

KOREA

Wed-Af-Po3.09 / 297

The impact of conductor Jacket material to the performance of Bi-2212 round wire**Author(s):** Chao Dai¹**Co-author(s):** Jinggang Qin¹ *Institute of Plasma Physics, Chinese Academy of Sciences(ASIPP)*

Using Bi-2212 round wire to manufacture the cable-in-conduit conductor (CICC) is promising and challenging. One of the difficulties is due to its reaction environment, high-temperature and oxygen atmosphere. Many metals or alloys would be oxidized severely in this environment. Another disadvantage is that, the chemical elements in some kinds of alloy could react with Cu element in Bi-2212 powder, which causes the Cu element loss and the performance degradation of Bi-2212 wire. These make choosing jacket material for Bi-2212 CICC difficult. In this paper, several kinds of alloy which could withstand the heat treatment environment of Bi-2212 round wire were chosen to study their chemical compatibility with Bi-2212 wire. The thin tapes of the alloys were wrapped around Bi-2212 wire and reacted together, then the critical current, n index and residual resistivity of reacted samples were measured. Different impact of each alloy to the Bi-2212 wire were compared and analyzed in the paper.

Submitters Country:

China

Mon-Af-Po1.12 / 745

The implement of control and date acquisition system for the 100 T pulsed high magnetic field facility at WHMFC

Jiangtao Shi¹ ; Xiaotao Han^{None} ; Jianfeng Xie^{None} ; Wang Yixuan¹ ; Liang Li¹¹ *Huazhong University of Science and Technology*

A facility, which will generate 100 T pulsed high magnetic field, is under development recently at Wuhan National High Magnetic Field Center (WHMFC). The pulsed magnet is composed of three coils, and driven by four power supplies of three types. The outer coil is driven by the battery bank of 1620 lead-acid batteries connected in series with the 100 MVA / 100 MJ pulsed generator, The middle and inner coils are respectively energized by 1.6MJ and 18MJ capacitor banks. In order to control synchronous discharging of different types of power supply, an Integration Control and Data Acquisition System (ICDAS) has been developed. The ICDAS is developed based on the NI CompactRIO system, which adopts three-layer structure. The programmable FPGA is used as the lowest level with the characteristics of fast response. The control logic and strategy implemented on FPGA provides timing triggering signals, failure protection and data acquisition. The real-time layer serves to perform data collection, storage and conversion. Human machine interface (HMI), which accepts parameter inputting and displays the experimental results, is achieved on PC layer. A real-time communication system is established based on TCP/IP protocol between the HMI and the existing control subsystems of the power supplies, by which the HMI sends control command to the control subsystems and monitors the status of the subsystems to achieving the coordinated control sequences of the four power supplies. The ICDAS has been put into practice in the 100T facility, and implemented synchronic control and data acquisition of three-type power supplies. A magnetic field of 70 T has been achieved and the discharge experiment of 100 T is planned to be carried out this year according to the work plan of WHMFC.

Submitters Country:

China

Mon-Af-Po1.08 / 591

The influence of heating treatment on NbTi superconducting wires with Cu5Ni alloy matrix

Author(s): Xing Qin¹**Co-author(s):** Qiang Guo¹¹ *Western Superconducting Technologies.,Ltd*

NbTi superconducting wires with Cu5Ni matrix can be applied in High Intensity Heavy-Ion Accelerator Facility(HIAF) magnets for the low hysteresis loss and high critical current. On account of the application in the high frequency magnetic field ,a new requirement for this type of NbTi superconducting wires,which is $J_c \geq 2500 \text{ A/mm}^2$ at 5T&4.2K and $Q_h \leq 40 \text{ mJ/cm}^3$ at 3T&4.2K,is needed more study. In this paper,two kinds of superconducting wires with 12960 and 10800 Nb47Ti filaments respectivelywere designed and fabricatedvia three times assembling. The diameter of NbTi filament is 4~4.8 μm . The Cu5Ni alloys acted as inter-filament matrixaim to reduce inter-filament coupling currents loss.Oxygen-free copper outside is used to be stabilization matrix and the Cu/Sc ratio is 1.8~1.9 . Every heat treatment process is 385°C for 40h and the influence of heat treatment times on properties were investigated. For the wire with 10800 filaments, J_c at 5T and 4.2K is about 2300A/mm² and Q_h at 3T and 4.2K is about 38 mJ/cm³ after three times aging heat treatment. J_c increases with the heat treatment times increasing and achieves about 2669 A/mm² after five times

heat treatment. For the wire with 12960 filaments, the same influence of heat treatment times on J_c has been observed. But Q_h at 3T and 4.2K is below 35mJ/cm³ for the finer filaments deformation than the wire with 10800 filaments. Both kinds of wires can meet the requirements after four or five times heating treatment.

Submitters Country:

China

Mon-Af-Po1.10 / 464

The latest observations from results of comprehensive computer simulation of the NHMFL all-superconducting 32T magnet quench tests

Author(s): Andrey Gavrilin¹

Co-author(s): Hubertus Weijers¹; Patrick Noyes¹; David Hilton¹; Dmytro Abramov¹

¹ *NHMFL - FSU*

The 32T all-superconducting user magnet comprised of a REBCO tape pancake-wound dual-coil insert and an LTS multi-coil outsert has been tested at the NHMFL. The magnet protected-quench behavior was simulated using a custom-written Fortran computer code. The simulation results and their sensitivity to the input data are discussed. The effect of insert quench protection system parameters on the protection efficiency was also analyzed. The simulation results are compared with the measurements in the insert coils during deliberate quenches.

Acknowledgement: This work was supported in part by the U.S. National Science Foundation under Grants No. DMR-0654118, DMR-1157490, DMR-0923070 and the State of Florida.

Submitters Country:

USA

Tue-Mo-Or11 / 220

The limits of space radiation magnetic shielding

Author(s): Riccardo Musenich¹

Co-author(s): Valerio Calvelli²; Martina Girauda³; Marco Vuolo⁴; Filippo Ambrogini⁵; Roberto Battiston⁶

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² *U*

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A major problem of long duration manned missions in the deep space is the flow of high energy charged particles of solar (SPE) and galactic (GCR) origin. SPEs have short duration but can be extremely intense and can lead to acute, even lethal, effects. GCR flux is much less intense but is continuous, isotropic and more energetic; it increases the risk of carcinogenesis and can affect the nervous and cardiovascular systems, limiting missions duration to few months. It is commonly believed that the problem of space radiation can be solved by surrounding the spacecraft habitats with large superconducting magnets, even though a considerable technological effort would be required.

However, magnetic shielding has several basic limitations which restrict the reduction of the radiation dose. As an example, particles in the high energy region of the GCR spectrum, that cannot be deflected out of the cabin by the magnetic shield, have a significant biological effect. Moreover, the interaction of cosmic rays with magnet and spacecraft materials generates secondary particles which have a major effect on the radiation dose. The physical and technological constraints of space radiation magnetic shields are discussed in the paper. Despite such limitations, a superconducting magnet could completely eliminate the risk due to SPE. Moreover, it could reduce the GCR adsorbed dose enough to make acceptable the risk of developing long term diseases after a return trip to Mars.

Submitters Country:

Italy

Tue-Af-Po2.07 / 271**The optimal design of superconducting coil withstanding short-time large current impact in VSC-HVDC****Author(s):** Zhifeng Zhang¹**Co-author(s):** Feng Qianqian²; Haonan Wang²; Liye Xiao³; Qingquan Qiu⁴; Zhang GuoMin⁵¹ *Institute of Electrical Engineering Chinese Academy of Sciences*² *Institute of Electrical Engineering Chinese Academy of Sciences*³ *Institute of Electrical Engineering, Chinese Academy of Sciences*⁴ *Applied Superconductivity Key Lab, Institute of Electrical Engineering, CAS, Beijing, 100190, China* ²*University of Chinese Academy of Sciences, Beijing, 100190, China and University of Chinese Academy of Sciences, Beijing, 100190, China*⁵ *Institute of Electrical Engineering Chinese Academy of Science*

With the voltage source converter-based high voltage DC power transmission (VSC-HVDC) is widely developed, the short-circuit fault current is one of serious factors to influence the security and stability of the VSC-HVDC operation. Comparing with AC fault current, the DC fault current rise faster and the peak value is higher due to the DC short-circuit damping is very smaller. At same time, the DC breaker must cut off the short-circuit in 3-5 ms to avoid damaging the converter and other device of the VSC-HVDC. So a superconducting coil, working as fault current limiting device, will withstand large impact current in short time. The resistance change characteristic of YBCO tape is experimental studied under large current impact in different insulation and operating temperature. The relationship of resistance and current, temperature of the YBCO tape is modeled by the test results. A 10kV/1kA superconducting coil is optimal designed, in which the maximum impact current up to 10kA in 5 ms. The results help implement the application of superconducting fault current limiter in VSC-HVDC.

Submitters Country:

China

Mon-Af-Po1.05 / 173**The performance of magnetic suspension and motor/generator of a bearingless BLDCM for flywheel energy storage system**Yichen Liu¹; Huangqiu Zhu²; Lei Huang¹¹ *Jiangsu University*² *Jiangsu university*

With the development of science and technology, the irreconcilable contradiction between the energy crisis, the environmental pollution and the rapid increasing industrial demands are more and more prominent. Due to the advantages, such as clean and maintenance-free in the whole life cycle, the flywheel energy storage system has been attracted increasingly attentions for many applications, such as aerospace and electric vehicle in recent years. The brushless DC motor (BLDCM), as one of the most important parts, is usually adopted in the flywheel energy storage systems. However the traditional mechanical bearings have the disadvantages, such as friction, wear and tear, and producing dust pollution easily, thus limiting the speed and the operation life of the motor. Therefore, the flywheel energy storage system, which is composed of a 2-DOF bearingless BLDCM, has been present to achieve the high- or ultrahigh- speed running. In this paper, based on the typical 12-slot 4-pole double-winding bearingless BLDCM, the principle of the radial suspension force generation has been stated firstly. And the mathematical models of the radial suspension force and motor electromagnetic torque have been established in the next section. Then the motor/generator control system and suspension force control system of the bearingless BLDCM for the flywheel energy storage systems is introduced emphatically. Next, the simulation model of the bearingless BLDCM control system is established in the Matlab/Simulink software. And the experiment platform is built in the paper either. The simulation waveform and experiment waveform, which include displacements of rotor, show that the rotor shaft can be stably suspended without the mechanical contacts. The speed waveform and the generating waveform are also posted in the paper. Form the experiment results, the performance of the magnetic suspension and motor/generator for bearingless BLDCM is favorable which verifies the validity of the proposed flywheel energy storage system.

Submitters Country:

CHINA

Thu-Af-Po4.04 / 952**The trapped magnetic field of a joint-less second-generation high temperature superconducting coil.**Yali Zheng¹¹ Luoyang Normal University

The joint-less coil is wound by ‘wind-and-flip’ technique. Due to the absence of resistive joint, the coil enable the current to flow in an absolutely superconducting closed loop, therefore it can load a DC current persistently without power supply. Therefore, the coil shows a great potential on MRI/NMR, permanent magnet and rotor magnet of HTS machines. This paper is to study the trapped magnetic field of a joint-less second-generation high temperature superconducting (HTS) coil. A numerical model based on H-formulation is built to analyze the underlying mechanism of trapping field. A joint less coil with 40 turns is fabricated and zero field cooling tests are performed on it. Comparison is conducted on the trapped magnetic field from measurements and simulations. The numerical model is validated by the good agreement between them. Then the physical mechanism of trapping field is elucidated by the model. The influence of external field amplitude, critical current and external field reduction rate on the trapped field is analyzed.

Submitters Country:

China

Wed-Af-Po3.11 / 1135**Thermal Quench Characteristics of 2G HTS Race Track Field Coil with Kapton Polyimide Insulation and Smart Insulation Materials****Author(s):** Ho Min Kim¹ ; Chang Ju Hyeon¹

Co-author(s): Huu Luong Quach ¹ ; Hyung-Wook Kim ² ; Seog-Whan Kim ² ; Young-Sik Jo ² ; Ji Hyung Kim ¹

¹ *Jeju National University*

² *Korea Electrotechnology Research Institute*

As a turn-to-turn insulation material on second generation high-temperature superconducting (2G HTS) coils, the smart insulation (SI) with a metal-insulator transition (MIT) materials, which have a resistivity variability on temperature, i.e., resistivity of MIT materials is decreased with temperature increase, may enhance not only the thermal stability but also current control performance of 2G HTS coils. Thus, it is expected to redeem No-insulation winding technique which has a delay of target magnetic field by bypassed current. This paper presents thermal quench characteristics of 2G HTS race track coil insulated with Kapton polyimide insulation (KPI) and SI materials, respectively for the rotor field winding of 1-HP-Class HTS rotating machine integrated with a contactless HTS excitation device. The constant-current experiment with heater activation and an over-current experiment with pulse current were performed to investigate thermal behaviors in quench state of respective 2G HTS coil insulated with KPI and SI materials and to verify the standout thermal performance of SI material as a turn-to-turn insulation. Finally, the applicability of SI material on 2G HTS coil system was discussed on the basis of above experimental results.

Acknowledgement: This work was supported in part by the Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), grant funded by the Ministry of Trade, Industry & Energy, and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP), Republic of Korea. (Nos. 20164030201230 and 2016R1A2B4007324)

Submitters Country:

Republic of Korea

Wed-Af-Po3.11 / 390

Thermal Stable Analysis on Superconducting Magnet stacked by REBCO Annulus Plates

Author(s): Yanbing Hou^{None}

Co-author(s): Yinshun Wan ; Xi Yuan ; Yan Li

This paper presents a conceptual configuration of superconducting magnet made from REBCO annulus plates, which can operate in close-loop mode excited by flux pump. The thermal stability of the superconducting magnet is numerically simulated by Comsol software for different stacked structure of REBCO annulus plates. The simulation include the minimum quench energy (MQE), the quench propagation velocity (QPV) and sharing temperature with different inserted conductor plates between REBCO annulus plates. The results are essential for quench detection and protection for this kind of superconducting magnet.

Submitters Country:

China

Tue-Af-Po2.11 / 470

Thermal analysis for a fast AC field controlled HTS switch for flux pumps

Jianzhao Geng¹

¹ *University of Cambridge*

Direct current carrying Type II superconductors present a DC electric field under external perpendicular AC magnetic field. This effect can also be considered as an equivalent dynamic resistance. The minimum field magnitude required to generate the dynamic resistance is less than the fully penetration field of the superconductor, which is much less than its upper critical field. Thus the superconductor can remain superconducting, leading to fast recovery times and meaning that it is feasible to use dynamic resistance to add a controlled impedance into the system. In this work, we built a demonstrator using a section of YBCO coated conductor controlled by an external AC field of a wide frequency range. We tested the electric field limit and response time of the system. Thermal analysis concerning the AC field controlled switch is conducted. The work may be indicative for designing AC field switches for flux pumps or SMES systems.

Submitters Country:

UK

Wed-Af-Po3.11 / 146

Thermal and Electromagnetic Simulation of Multi-stacked No-Insulation REBCO Pancake Coils on Normal-state Transition by PEEC model

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¹ *Hokkaido University*

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Many researchers have a great interest in applying no-insulation (NI) REBCO pancake coils to high field magnets used for NMR, MRI, and accelerator applications, because NI REBCO pancake coils have a high thermal stability. When a local normal hot spot appears in an NI REBCO pancake coil, the operating current can flow from the turn to the adjacent turns so as to avoid the hot spot. In other words, an NI REBCO pancake coil has a self-protection against a burnout. The high thermal stability of NI REBCO pancake coils has been demonstrated in experiments, and it is recognized as very stable HTS coils. However, it does not mean that an NI REBCO magnet never quenches. In fact, the quench of NI REBCO magnet has been identified in several experiments. Based on the above background, we have developed a numerical simulation to confirm the current and thermal behavior of a single NI REBCO pancake coil during a normal-state transition using a partial element equivalent circuit (PEEC) model. However, in practical applications, multi NI REBCO pancake coils are usually stacked. If one of pancake coils transitioned into a normal state, it would deteriorate the stability of the other pancake coils. Actually, in experiments, it was confirmed that a quench in one pancake coil invoked sequential quenches in the other pancake coils. To develop further valuable applications, the stability of multi-stacked NI REBCO pancake coils should be verified in detail. Therefore, we developed a numerical simulation for multi-stacked NI REBCO pancake coils to confirm a quench process. In this paper, we present the simulation results of multi-stacked NI pancake coils on a normal-state transition by the PEEC model. A sequential-quench phenomenon is reproduced in the numerical simulation, and its mechanism is observable.

Submitters Country:

Japan

Tue-Af-Po2.11 / 111

Thermal and electric analysis of the flux pump to apply conduction cooled superconducting magnet

Woo Seung Lee¹ ; Kwang Myung Park¹ ; Yoon Do Chung²

¹ JH Engineering Corp.

² Suwon Science College

Current leads of a superconducting magnet are one of the largest heat source to the superconducting magnet cryo-system. A flux pump is one possible way to remove the current leads by replacing conductive connection to magnetic coupling. However, the heat loss of the flux pump should be analyzed in order to apply to conduction cooled magnet because of little temperature margin in conduction cooled system. In this research, the thermal link for the linear type flux pump applied conduction cooled magnet is investigated. The heat generation of the linear type flux pump is calculated based on the AC loss theory. Temperature stability of a thermal link for the flux pump system is analyzed with different design parameters. A design of thermal link for the flux pump of conduction cooled magnet is suggested by summarizing the results of analysis.

Submitters Country:

Korea, Republic of

Mon-Af-Po1.11 / 656

Thermal characteristics of a prototype HTS quadrupole magnet for In-flight fragment separator of RISP

Author(s): Seokho Kim¹

Co-author(s): Heecheol Park¹; Changhyung Lee¹; Dongmin Kim¹; Kideok Sim²; Hyun Chul Jo³; Do Gyun Kim³; Sukjin Choi³

¹ Changwon National University

² Korea Electrotechnology Research Institute

³ Rare Isotope Science Project, Institute for Basic Science

A prototype HTS (High Temperature Superconductor) quadrupole magnet of In-flight fragment separator was developed and successfully tested to generate field gradient of 9 T/m. This paper describes thermal characteristics of the quadrupole magnet. The magnet is composed of four race-track coils and each coil consists of two double pancake coils with ReBCO wires and stainless steel tape for turn-to-turn metallic insulation. The magnet is cooled by circulation of gaseous helium below 40 K instead of the conventional liquid helium cooling because the magnet will be used at an intensive neutron radiation region. The gaseous helium is generated by a separate cooling system composed of a cryogenic blower and three GM cryocoolers. To cool down and remove the heat penetration, helium channels are installed on the surface of coil bobbins and they are connected to the external cooling system. The test was conducted to find out the optimum operational parameters of the cooling system since the coil temperatures depend on the inlet temperature, the pressure and the mass flow rate of gaseous helium. By adjusting the helium pressure (5~8 bar) and the mass flow rate (5~10 g/s), it was possible to keep the magnet temperature below 40 K while the magnet generated the field gradient of 9 T/m by transporting the rated current of 330 A.

Acknowledgment: This work was supported by the Rare Isotope Science Project of Institute for Basic Science funded by Ministry of Science, ICT and Future Planning and NRF of Korea (2013M7A1A1075764)

Submitters Country:

Republic of Korea

Thu-Af-Po4.05 / 407

Thermal limit curve calculation for squirrel cage induction motor based thermal equivalent circuit

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IEEE Standard 37.96-2000, Guide for AC Motor Protection, recommends the use of overcurrent relays for overload and locked rotor protection. Because of the familiar use of overcurrent protection, little attention is paid to the nature of motor thermal limit curves and their relation to winding temperature in an induction motor. Although thermal limit curves are defined in IEEE Standard 620-1996, Guide for the Presentation of Thermal Limit Curves for Squirrel Cage INduction Machines, the guide gives no information as to how the curves are constructed. Some existing papers introduced equation of thermal limit curve based a single time-constant model. But a single time-constant model cannot be accurate exactly because there are at least two time-constants in the thermal response of a motor. In this paper, modeling of 3-dimensional thermal equivalent circuit for rotor is conducted. Thermal equivalent circuit consists of rotor bar embedded in the slot, end-ring, rotor teeth and yoke. rotor bar is divided into n-segments in the radial direction, where n is large enough so that rotor winding loss distribution considering skin effect phenomenon can be calculated at locked rotor and accelerating conditions. All of the thermal resistance and capacity are defined as a function of temperature because specific heat, thermal conductivity and heat transfer coefficient depend on temperature. For each time step, temperature calculation algorithm calculate resistances, heat capacity and rotor bar losses with the temperature value of the previous time step and calculate temperature of following time step. And experimental results of temperature rise in the rotor bar will be compared to the calculation results. Thermal limit curves are constructed based on the thermal equivalent circuit calculation results. Locked rotor and accelerating thermal limit curve calculation diagram will be explained on the full paper.

Submitters Country:

Republic of Korea

Tue-Af-Po2.10 / 573

Thermo-Magnetic Mechanical stability study of the MICE Spectrometer Solenoids

Author(s): Heng Pan¹

Co-author(s): Soren Prestemon¹ ; Steve Virostek² ; Holger Witte³ ; Alan Bross⁴

¹ *LBNL*

² *Lawrence Berkeley Lab*

³ *Brookhaven National Laboratory*

⁴ *Fermilab*

The muon ionization cooling experiment's (MICE) purpose is to design and engineer a section of a cooling channel capable of giving the desired performance for a Neutrino Factory. Two spectrometer solenoids in the MICE cooling channel provide a uniform magnetic field for two five-plane scintillating fiber trackers to analyze the evolution of the muon beam emittance in the cooling channel. The MICE spectrometer solenoids contain five superconducting solenoids with different structural parameters. The five coils are wound on a single 6061- aluminum mandrel that forms the cold mass. A series finite element models were developed to analyze the thermal-mechanical behaviors of the cold mass: A 2D finite element structural model was created in ANSYS to analyze the static stresses development of the cold mass over the steps of winding to excitation; A 3D Opera model is used to evaluate the quench protection performance. The paper provides the static thermal load of the magnet, describes the static mechanical analyses performed and reports on the comparison between quench voltage measurements during training runs to those predicted from the 3D finite element analysis.

Submitters Country:

USA

Thu-Af-Po4.02 / 618**Thermo-hydraulic analysis of The KSTAR PF cryogenic loop using SUPERMAGNET CODE****Author(s):** HyunJung Lee¹**Co-author(s):** Sangjun Oh²; Jung Laurent¹; Dong Keun Oh²¹ *National Fusion Research Institute*² *NFRI*

Operation stability study for a large-scale superconducting magnet is of particular importance to protect the magnet from permanent damage. Especially, for a fusion magnet, severe heat load by AC loss needs to be effectively removed during operation to achieve required temperature margin. A unique feature of KSTAR PF (poloidal field) magnet is that all the liquid cryogen inlets and outlets of PF1~4UL (PF upper and lower) coils are located at high field region. Therefore, major heat loads are localized both at the inlets and outlets, so that a drastically reduced or even no temporal cryogen flow is frequently observed at the inlets of PF1~4UL coils. This kind of temporal blockage of cryogenic loop can seriously affect the thermos-hydraulic analysis of a superconducting magnet system. As a preliminary study on this issue, we discussed thermos-hydraulic analysis results of the KSTAR PF cryogenic loop by using the SUPERMAGNET code. The numerical simulations were also compared to empirical results.

Submitters Country:

Korea republic of

Thu-Af-Po4.02 / 1162**Thermohydraulic analyses on CEA concept of TF and CS coils for EU-DEMO****Roser Vallcorba¹; Benoît Lacroix²; Quentin Le Coz²; Louis Zani²; Daniel Ciazynski²; Alexandre Torre²; François Nunio¹; Sylvie Nicollet²; Valentina Corato³; Matti Coleman⁴**¹ *CEA Saclay*² *CEA Cadarache*³ *ENEA*⁴ *EUROfusion*

In the framework of the European fusion program for energy, EUROfusion funds the studies for the future fusion power demonstrator reactor DEMO. CEA is involved on the conceptual design of the superconducting conductors for the Toroidal Field (TF) and Central Solenoid (CS) magnets. The CEA design proposal corresponds to Wind and React Nb3Sn pancake-wound coils using Cable-In-Conduit Conductors (CICC) cooled at about 4.5 K by forced flow of supercritical helium. The present paper presents the latest thermohydraulic analyses performed on both TF and CS conductors. Two TF conductor designs have been analyzed, with nominal current of 111 kA and 88 kA respectively. The analyses were performed in normal (burn) and off-normal (quench) conditions. Burn simulations focused on the central and lateral pancakes, heat load corresponding to neutron heating. The central pancake is the most critical one regarding the magnetic field while the lateral one receives a more important heat load from the casings. The influence of case cooling on temperature margin (DTma) was analyzed by means of a dedicated 2D Cast3M model. The DTma sensitivity to driving parameters

such as conductor pressure drop, friction factor and heat exchange correlations was analyzed. The impact of inter-turn thermal coupling on temperature margin was also assessed. In addition, the simulation of a sequence of several burn/dwell is presented. Quench studies on TF conductors have been explored in several scenarios corresponding to events that can lead to a quench: heat deposition due to a plasma disruption, cryogenic malfunction and fusion power excursion. Regarding the CS conductor, burn analyses are exposed on the latest design featuring a nominal current of 53.7 kA, focusing on the impact of AC losses and of dwell duration.

Submitters Country:

France

Wed-Af-Po3.10 / 34**Thermomechanical behavior of the HL-LHC 11 tesla Nb3Sn magnet coil constituents during reaction heat treatment**Christian Scheuerlein¹ ; Friedrich Lackner¹ ; Frederic Savary¹ ; Birgit Rehmer² ; Monika Finn² ; Christian Meyer²¹ CERN² Federal Laboratory for Materials Research (BAM)

The superconducting magnets for the LHC High Luminosity upgrade (HL-LHC) are built using Nb3Sn technology, which implies a reaction heat treatment when the conductor is at final shape. During the reaction heat treatment the Nb3Sn coil is surrounded by a fixture that restricts the coil volume changes. The knowledge of the evolution of the thermo-mechanical properties of the coil materials and of the reaction fixture during the heat treatment is required in order to predict the coil geometry and stress state by Finite Element simulations. We have measured the Young's and shear moduli of the HL-LHC 11 T Nb3Sn magnet coil and reaction tool constituents with the non-destructive dynamic methods resonance and impulse excitation during in situ heat cycles in the temperature range -60°C to 700°C. The 4.2 K elastic properties are obtained by fitting and extrapolating these results. The thermal expansion of the coil components was measured by dilation experiments.

Submitters Country:

Switzerland

Thu-Af-Po4.08 / 200**Threshold value analysis of YBCO tapes under transient over-current impulse**Shizhuo Liu¹ ; Dong Xia¹ ; Qingfeng Liu¹ ; Qingquan Qiu¹ ; Zhifeng Zhang¹ ; Guomin Zhang¹

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The superconducting tapes are widely used in fault current limiters for AC power systems. However, they are still in the study in the HVDC situation as it has a lot of differences compared with the AC situation. In the AC situation we have 45ms-60ms to shut down the circuit breaker so the current flows through the superconducting tape would be two or three times of the critical current of the superconducting tapes. And the heat would be absorbed a lot by the liquid N2 in this 45ms-60ms. Whereas we need the circuit breaker shut down in 4ms-10ms in HVDC situation. Less time means more over-current and less heat transfer. This paper would explore the threshold value of the YBCO

tapes in DC over-current situation and the heat transfer law between the tapes and the liquid N₂. The experiment of the DC over-current impulse under the conditions of different times could obtain the relationships between time and the threshold value of over-current. The relationships between heat transfer and the threshold value could be obtained by the experiment under the different cooling conditions. Then we can get the heat transfer law in combination with the experiment results and the temperature-resistance curve. Then the threshold value of the over-current could be calculated at a given time and cooling conditions. The results have the reference for the design of the superconducting fault current limiter (SFCL).

Submitters Country:

China

Tue-Af-Po2.06 / 710**Torque Actuator Control considering Nonlinearity of Magnetic Saturation****Author(s):** Kyoung-Jin Joo¹**Co-author(s):** Sung-Hong Won²¹ *Hanyang Univ.*² *Dong Yang Mirae Univ.*

Various types of motors have been proposed for the conventional 3-axis multi-Degree-of-Freedom (D.O.F) drive, but there are limitations in the research because of the disadvantages such as complicated structure considering system frame and difficulty of manufacturing. In addition, conventional actuators have disadvantages in that the electromagnetic operating range is limited by the size of permanent magnets and the coil, or the winding utilization rate is low. Therefore, in this paper, a Torque Actuator (TA) of rotary type which is capable of generating a large tilting torque and having a simple and stable rotating shaft and supporting structure for load connection, is designed. The TA is designed and manufactured in the form of a coil wound around a ring-shaped core, and an unbalanced air gap is created through the coupling between this core and the housing. The reluctance cogging torque and the unbalanced magnetic saturation of the stator due to such unevenness of salient pole cause a nonlinear proportional relationship between the torque and the current and make the torque control of the actuator unstable. Therefore, in this paper, it is proposed to apply a map of the relationship between the torque and the magnetic flux to control the linearized current and torque for the TA considering the nonlinearity of magnetic saturation. This method will be verified by an experiment comparing before and after the application to the 3-axis rotary TA. The results of simulation and experiment will be explained in detail on the full paper.

Submitters Country:

Republic of Korea

Thu-Af-Po4.05 / 413**Torque Control of IPMSM considering actual controller and driving condition****Author(s):** Ye Jun Oh¹**Co-author(s):** Kyoung-Jin Joo ; Gang Seok Lee² ; Hyungwoo Lee³¹ *Hanyang University*² *Hanyang Univ.*³ *Korea National University of Transportation*

In this paper, we study the robust torque control of wireless tram with independently rotating wheelsets (IRWs). In order to perform robust torque control of Interior Permanent Magnet Synchronous Motor (IPMSM) in the driving condition, D-Q axis current information are required. However, it is difficult to get appropriate current information, because of a lot of current vector exists for required torque. If current vector is calculated in real time, the load of the DSP is increased and it is difficult to consider the driving condition. Therefore, it is more suitable to use the current vector table in the offline. Current vector information should take into account variation of the four variables (speed, torque reference, battery voltage, and temperature) in the IPMSM. Therefore, it requires excessive FEA or experimentation. However, since the linkage flux in the motor contains both speed and battery voltage information, it is possible to simplify it by affecting three variables (linkage flux, required torque, temperature). In addition, if samarium cobalt is used as a permanent magnet, it can be reduced to two variables. FEA has an advantage that nonlinear and cross-saturation effects can be considered. However, FEA is a numerical analysis that assumes various ideal conditions, it is difficult to consider the actual controller and driving conditions. As a result, there is a difference between the FEA and the actual experimental results. In actual motors, there is influence on carrier frequency and dead time, and voltage error of inverter. In this paper, we have studied torque control considering driving condition through motor-inverter co-simulation. Moreover, the influence of the controller can be considered. The results of the experiment show that the co-simulation is more similar than only FEA.

Submitters Country:

Republic of KOREA

Thu-Af-Po4.10 / 585**Torque Maximization Method of Radial Magnetized Surface-Mounted PM Machine Having Sinusoidal Shaped Pole**shuangjiang zhuang¹; yang shen¹¹ *Naval University of Engineering*

This paper presents a torque maximization method to increase output torque without deteriorating the torque ripple in radial magnetized surface-mounted permanent magnet (SPM) machine having sinusoidal shaped pole by using third-order harmonic (Sine+3rd) shaping method. The optimal value of third-order harmonic injected into sinusoidal shaping can be either scanned out by finite element analysis (FEA) or determined analytically. In accordance with the profile of SPM, it can be classified into SPM with arc magnet and SPM with "bread-loaf" magnet. For all slot/pole combinations of SPM machine with radial magnetized arc magnet, it is already found that the optimal value of third order harmonic injected into sinusoidal shaping is fixed and equal to 1/6 of the fundamental one. However, such optimal value is varied with pole pair number (p), magnet thickness and rotor radius for machine having radial magnetized "bread-loaf" magnet. Therefore, the developed Sine+3rd shaping method is not accurate enough and invalid for SPM machine having "bread-loaf" magnet pole. In this paper, an analytical model to obtain the optimal value of third-order harmonic injected into radial magnetized SPM machine with sinusoidal shaped "bread-loaf" magnet is derived to achieve maximum torque without deteriorating torque ripple. The accuracy of developed analytical model is verified by FEA. The analysis reveals that the value of fundamental air-gap flux density for SPM machine having Sine+3rd magnet pole is increased more than 10% in contrast to SPM having sinusoidal shaped pole only.

Submitters Country:

china

Wed-Af-Po3.05 / 214**Torque Ripple Improvement for Ferrite-Assisted Synchronous Reluctance Motors by Using Asymmetric Flux-barrier Arrangement**

Meimei Xu¹

¹ *Jiangsu University*

Ferrite-assisted synchronous reluctance motors (FASRM) provide high torque density and a wide range operation speeds for many applications, ranging from electric vehicle and electric home appliance. However, the main drawback of the FASRM is the high torque ripple. This paper is to propose a method of reducing total ripple by changing the opening angle of flux barrier. The key of this method is to consider the reluctance torque ripple because it is the main source of torque ripple in ferrite-assisted reluctance motors. In addition, the ferrite magnet insertion part is not changes compared with original design, and it is expected that the average torque does not decrease with this design. The detailed configuration of the FASRM is 48 slots and 8 poles, with two flux barriers per poles. The original flux barriers are chosen basic unit and designed in the line of symmetry with the magnetic pole center. This method is realized by changing the opening angle of each pair pole of flux barrier respectively. In the proposed arrangement, the opening of angle of flux barrier is enlarged a particular angle based on the basic unit. For example, the opening of angle of one pole enlarges a particular angle, another pole enlarges double. The proposed method is evaluated by a theoretical analysis and finite-element method (FEM). Through this method, several low-order harmonic of torque could be eliminated. It is shown that the proposed flux barrier design is very useful of improving the torque ripple for ferrite-assisted synchronous reluctance motors. Moreover, it is easy to implement and not sacrifice the average torque.

Submitters Country:

China

Tue-Af-Po2.06 / 683

Torque Ripple Minimization in a PM-assisted Synchronous Reluctance Motor with Different Flux Barrier Rotor

Aamir Nazir¹ ; Guohai Liu²

¹ *Jiangsu University*

² *School of Electrical and Information Engineering, Jiangsu University*

This paper describes an innovative synthesis rotor geometry technique of permanent magnet assisted synchronous reluctance motor (PMAREL) with different flux barrier rotor shapes. The two symmetric rotor optimizations are examined and synthesis to establish the best asymmetric rotor geometry. The research results point out that the synthesis asymmetric rotor geometry is a more satisfying considerable candidate, in terms of torque ripple minimization and compensation of torque harmonics. The 8 pole and 48 integral-slot distributed winding motor with three different flux barriers per pole is adopted. Since the exponential increase of the cost of rare earths magnets, the motors adopting Ferrite magnets instead of rare earth magnet are considered. Initially, the angular position of U type flux barrier end is modified by numerical method and simulated with FEM, subsequently the C type flux barrier rotor structure designed same as U type methodology. Finally, the optimum U and C rotor combined together "U+C" this strategy simultaneously offers the advantages of two motors. In order to compare the performance of symmetric and asymmetric rotor of PMAREL the same dimensions and volume of magnets are used as benchmarks. The all rotor geometries results are compared and verify with finite element model (FEM). The overall 78% torque ripple reduction is achieved by final proposed model as compares to initial model. As well as, a sort of compensation of the torque harmonics is obtained, the corresponding slot harmonic 12 amplitude in initial symmetric model 0.60 N.m and asymmetric model 0.07 N.m. Compares their electromagnetic torque performance, it can be seen that the final model has 5.35% higher torque than the initial model. It is worth notice, the average torque is slightly increased but the torque ripple minimized effectively. Taking into account the asymmetrical positions between different flux barrier magnets have good impact on the motor performance.

Submitters Country:

China

Wed-Af-Po3.09 / 938

Toward using artificial neural network to predict the outcomes of PMP heat treatments in Bi-2212 wiresShijian Yin¹ ; Wan Kan Chan¹ ; Justin Schwartz¹¹ North Carolina State University, Raleigh, USA

Bi2212 multi-filamentary round wire is the only high temperature superconductor that can be fabricated into isotropic round wire and is capable of having high critical current density (J_c). The J_c of a Bi2212 wire depends strongly on the partial-melt processing (PMP) multi-step heat treatment profile used to fabricate the wire. Many studies have tried to understand the cause-and-effect relationships of the parameters of a PMP profile and the resulted micro-structure and phase formations on J_c . The complications of the heat treatment process, however, have hindered these efforts from providing a well-round guideline for optimizing PMPs. As a result, PMP profiles nowadays are usually designed in an empirical manner. Artificial neural network (ANN) is capable to approximate multivariable nonlinear functions at high accuracy by learning from sample input-output data set without knowing the explicit forms of the functions. The aim of this study is to develop an ANN-based model to assist the design of multi-step PMP profiles by predicting the outcomes, such as J_c and key microstructural features like voids, under different parameters at different intermediate PMP sub-steps, which are sequentially dependent with cause-and-effect relationships. To achieve this goal, a proof-of-concept, special ANN is built and a large set of time-dependent data imitating the multi-step PMP parameter-to-outcome relationships is used to train the ANN. The training data, which contain inputs with non-uniform sensitivities, are generated from a 2D finite element thermal model excited with time-dependent heat-flux boundary conditions mimicking real PMP profiles. Cause-and-effect relationships between two adjacent PMP sub-steps are modeled by adding feedback connections in hidden nodes of the ANN and trained with simulation data obtained at each boundary heat-flux sub-step of the thermal model. The results show that the special ANN model is capable of predicting sequentially-dependent outputs in close agreement to the validation and test data.

Submitters Country:

USA

Tue-Af-Po2.10 / 864

Towards real time computation of 3D magnetic field in parametrized Polyhelix magnets using a reduced basis Biot-Savart modelRomain Hild¹ ; Cécile Daversin¹ ; Christophe Prud'homme¹ ; Christophe Trophime²¹ IRMA Strasbourg² LNCMI - CNRS

The Laboratoire National des Champs Magnétiques Intenses (LNCMI) is a member of the European Magnetic Field Laboratory (EMFL). This is the French facility enabling researchers to perform experiments in the highest possible magnetic fields. The numerical modeling jointly developed with the Center of Modeling and Simulation of Strasbourg (Cemosis) plays an essential role in the understanding and the optimization of such magnets. In this context we have implemented a full 3D multi-physics model coupling thermoelectric, magnetostatic and mechanic dedicated to the study of LNCMI resistive high field magnets. We have proposed a parallel algorithm to efficiently compute the magnetic field in the zone of interest for researchers using Biot and Savart law. Validated by dedicated campaigns of measurements, this model has confirmed the 3D behaviour of the magnetic

field which has been observed in some experiments such as magnetic levitation. In order to design, control or perform advanced analysis - e.g. uncertainty quantification, sensitivity analysis - many queries or real-time evaluations of a our 3D finite element models are required. We propose in this paper a reduced basis methodology applied to the Biot-Savart law in order to reduce by several order of magnitudes the computational cost of the 3D finite element model. Not only does it provide an invaluable tool for magnet designers but it also provides direct access to non-expert in numerical simulation for example to visualize the 3D magnetic field maps in real time while changing the current density. The description of this tool will be illustrated by numerical results on real magnet geometries.

Submitters Country:

France

Mon-Mo-Or1 / 167

Training Performance with Increased Coil Pre-stress of the 2-m Model Magnet of Beam Separation Dipole for the HL-LHC Upgrade

Author(s): Michinaka Sugano^{None}**Co-author(s):** Andrea Musso¹; Ezio Todesco¹; Hirokatsu Ohata²; Hiroshi Kawamata²; Kenichi Sasaki²; Kenichi Tanaka²; Kento Suzuki³; Masahisa Iida²; Naoki Okada²; Naoto Takahashi²; Nobuhiro KIMURA⁴; Norio Higashi²; Ryutarō Okada²; Shun Enomoto²; Tatsushi Nakamoto; Toru Ogitsu; Yukiko Ikemoto²¹ CERN² KEK³ High Energy Accelerator Research Organization⁴ HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION, KEK

Large aperture beam separation dipole magnets (D1) need to be developed for the high-luminosity LHC upgrade. The important specifications of this magnet are a coil aperture of 150 mm and field integral of 35 T·m at 12.0 kA and 1.9 K. The coils in the D1 magnet have a single layer structure and are wound with Nb-Ti/Cu Rutherford cables with the width of 15.4 mm. In such a thin and large aperture coil, precise prediction of coil size change during fabrication, cooling and excitation has importance to maintain the coils under appropriate pre-stress and that is a key to realize superior quench performance. KEK is in charge of development of the D1 magnet. The first 2 m model magnet (MBXFS01) was fabricated and tested at cold in 2015 – 2016. Quench current of this magnet reached 105% of the nominal current, however, the ultimate current of 13 kA as an acceptance criteria was not achieved. Measurements of azimuthal coil stress at the pole during excitation suggested that coil stress was completely released at the current much lower than the nominal one and the insufficient pre-stress was thought to be the main reason of unsatisfactory quench performance. After the cold test, MBXFS01 was once disassembled and reassembled after inserting shims to the coil mid-plane to enhance azimuthal coil pre-stress by 40 MPa. In this paper, we will report reassembly of the first 2 m model magnet (MBXFS01b) and the results of the cold test. Influence of coil pre-stress on training performance will be discussed and other test results such as magnetic field measurements and heater tests will be also introduced.

Submitters Country:

Japan

Mon-Mo-Or1 / 823

Training of the main dipoles magnets in the Large Hadron Collider towards 7 TeV operation

Ezio Todesco¹ ; Marta Bajko¹ ; Davide Tommasini¹ ; Jean-Philippe Tock¹ ; Arjan Verweij (Program Chairman)¹ ; Andrzej Siemko¹ ; Rudiger Schmidt¹ ; Lucio Rossi¹ ; Luca Bottura¹ ; Paolo Fessia¹ ; Sandrine Le Naour¹ ; Gerard Willering¹ ; Bernhard Auchmann¹ ; Juan Carlos Perez¹

¹ CERN

During 2016, one quarter of the LHC main dipoles have been powered above the 7.7 T operational field, to reach a field of the order of 8.1 T. These tests were done to confirm the extrapolation of the training behaviour based on a Gaussian tail of the quench distribution. In this paper we show that the training is compatible with the expectations, but on the lower side of the extrapolation. These tests also allowed to assess the quantity of magnets quenching twice during the training, which is shown to happen in a 10% fraction of the production. Moreover, one eighth of the LHC was warmed up to replace a magnet, adding precious information on the magnet behaviour on successive trainings. We then propose an asymmetric distribution to better model the quench distributions. Based on these new elements, we show that around 500 quenches are expected to reach the operational field of 8.3 T for the whole LHC dipoles (corresponding to 7 TeV operational energy). We show that very little correlation is found between the training in the installed magnet and individual test in virgin condition (first cool-down). On the other hand, a better correlation is found with individual test after a thermal cycle (second cool-down); unfortunately, the uneven sampling of these test (done on 10% of the production) did not cover the production showing slower training in the LHC.

Submitters Country:

CERN

Mon-Af-Po1.03 / 565

Transient Behaviors of a 3T 100 mm Stainless Steel Cladding All-REBCO Magnet During Sudden Discharging

Jae Young Jang¹ ; Young Jin Hwang¹ ; Seungyong Hahn² ; Kwanglok Kim³ ; Sangwon Yoon⁴ ; Hankil Yeom⁵ ; Yong-Ju Hong⁶ ; Min Cheol Ahn⁷ ; Jaemin Kim⁸ ; Kang Hwan Shin⁸ ; SangGap Lee¹

¹ Korea Basic Science Institute

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⁸ SuNAM Co., Ltd.

A 3 T 100 mm all-REBCO multi-width (MW) no-insulation (NI) magnet was designed constructed, and currently being tested at the Korea Basic Science Institute. Key features of the magnet include use of "metallic cladding (MC)" REBCO tapes, i.e., a 1-um thick stainless steel cladding layer hermetically surrounds the tape in order to increase the turn-to-turn contact resistance of the NI coils. The magnet successfully reached its full field of 3 T at a designated operating current of 200 A that corresponds to an engineering current density of 353 A/mm² for double pancake coils wound with the narrowest width tape of 4 mm. Recently, the magnet experienced unexpected power supply trips twice during its long-term field mapping experiment at the full field, after which the magnet was fully discharged in 5 seconds. This paper reports the transient behaviors of the magnet in details during the sudden discharge events. Key parameters to have been measured include: (1) terminal voltages of individual 32 double pancake coils; (2) temperatures at the magnet top, middle, and bottom; (3) power supply currents; and (4) center magnetic field. A lumped parameter circuit model was used to analyze the electromagnetic responses during the sudden discharge. The magnet survived without any damage after each trip of the power supply and is currently being operated normally without any performance degradation. The results imply the self-protecting feature of the MC REBCO magnet, which has been experimentally demonstrated in a magnet level for the first time.

Submitters Country:

South Korea

Tue-Af-Po2.07 / 998

Transient Current Limiting Characteristics of Autotransformer Type SFCL using Additional WindingLim Sung-Hun¹ ; Han Tae-Hee² ; Seung-Taek Lim¹¹ *Soongsil University*² *Jungwon University*

The transient current limiting characteristics of auto-transformer type superconducting fault current limiter (SFCL) using additional winding, which consists of one winding with tap changer and two superconducting (SC) elements with the inserting resistance, were analyzed. The feature of the suggested SFCL is that the triggered current level of the SFCL can be adjusted with its tap changer installed in the autotransformer's winding and that it can limit the fault current by triggering either one SC element or two SC elements comprising the SFCL due to the transient amplitude of the initial fault current. As the influential design parameter to affect the triggered current level and the limiting impedance of the SFCL, the coupling coefficient, which depends on the location of its tap changer on the winding of the transformer, was selected and, from its electrical equivalent circuit considering the coupling coefficient, the triggered current level and the limiting impedance of the SFCL were derived and the correlation between two derived SFCL's design parameters was analyzed. Through the analysis on the short-circuit tests for the autotransformer type SFCL with the different coupling coefficients, the available transient current limiting characteristics of the suggested SFCL could be obtained.

Submitters Country:

South Korea

Thu-Af-Po4.08 / 137

Transport properties of commercially available REBCO conductors at 4.2 K**Author(s):** Kazuki Norimoto¹**Co-author(s):** Kiyosumi Tsuchiya² ; Akihiro Kikuchi³ ; Akio Terashima² ; Xudong Wang² ; Mio Uchida¹ ; Shinji Fujita⁴¹ *Sophia University*² *High Energy Accelerator Research Organization, KEK*³ *National Institute for Material Science, NIMS*⁴ *Fujikra Ltd.*

There is a strong demand for higher field magnets in the various field of science. The development of solenoids capable of generating high magnetic fields of 20–30 T has been ongoing in major high-field laboratories in the worldwide. In the field of high energy accelerator, a 20 T dipole magnet is listed as a candidate for the bending magnet of the Future Circular Collider and the proposed muon collider requires solenoids of 30–50 T. Such field strength exceeds the levels achievable by using low-temperature superconductors. Currently, only high-temperature superconductors have the potential to achieve such field levels. However, there have been limited data on the electrical transport properties of REBCO conductors in high field and at low-temperature. Therefore, as a first step to study the possibility of REBCO-based high-field magnets, we have started the critical

current measurements of commercial REBCO conductors in perpendicular fields of up to 18 T at 4.2 K. To perform the measurements of full width conductors (4-mm-wide), we have developed U-shaped sample holders. In these holders, the rather long voltage taps distance of ~30 mm can be taken, and the current transfer length and heating at the current lead joints need not be considered. In this presentation, we will report the transport properties at 4.2 K for conductors from seven different manufacturers (AMSC Co., Fujikura Ltd., SuNAM Co., Ltd., SuperOx Japan LLC, SuperPower Inc., and SWCC Showa Cable Systems Co., Ltd.)

Submitters Country:

Japan

Wed-Mo-Or19 / 448

Tuneable permanent magnets: Power saving solutions for the next generation of high energy accelerators.

Alexander Bainbridge¹ ; Jim Clarke¹ ; Ben Shepherd¹ ; Norbert Collomb² ; Michele Modena³

¹ STFC

² STFC Daresbury Laboratory

³ CERN

Permanent magnet (PM) based systems offer a potential solution to one of the key issues in designing and running modern particle accelerators; the power draw from conventional electromagnet systems. A recent and ongoing collaboration between the CLIC project at CERN and STFC's Daresbury Laboratory has resulted in the ZEPTO (Zero Power Tuneable Optics) project, a drive to reduce the financial and environmental costs of accelerators. We have investigated the feasibility of creating large scale tuneable bending and focusing PM systems, initially for use on the proposed CLIC accelerator. The proposed magnets tune their field by moving components and so only draw power to the motors during the adjustment process, requiring no power during static operation and no cooling at any time. These systems would dramatically reduce the high electricity and water cooling costs introduced by conventional magnets, as well as the associated large scale infrastructure burden. The collaboration has previously reported on two prototype PM quadrupole systems (as presented at MT23)¹. Within the last two years this work has continued into the development of a 1.6 T PM C-Dipole with a tuning range of over 50%. Significant finite-element simulations have been performed to identify an optimal solution and a 1.1 T scaled prototype has been constructed using a single 500x400x200 mm block of NdFeB which slides horizontally to provide tuning. We discuss the design, construction and measurement of the prototype dipole, whilst addressing challenges such as maintaining excellent field homogeneity over a large tuning range and managing the high and strongly varying magnetic forces. The infrastructure and financial implications for accelerator systems are demonstrated using the example of CLIC.

¹ J.A. Clarke et al, Novel Tunable Permanent Magnet Quadrupoles for the CLIC Drive Beam, IEEE Transactions on Applied Superconductivity (4003205,- Volume: 24, Issue: 3, June 2014)

Submitters Country:

United Kingdom

Wed-Mo-Or19 / 124

Twin aperture bending magnets and quadrupoles for FCC-ee

Attilio Milanese¹ ; Marek Bohdanowicz¹

¹ CERN

We report the magnetic design of twin resistive magnets, with a field configuration applicable to large lepton colliders, like FCC-ee. The bending magnets are based on an I-layout, with a common iron yoke powered by two busbars; both pure dipoles and combined function units with an embedded gradient are considered. The quadrupoles present a peculiar geometry, with eight poles but only two coils; their inherent asymmetry is compensated at the pole tip level to provide a good field homogeneity in the bore. For these magnets, the advantage of using a twin design brings – besides a reduction in the number of components and units – a significant power saving, of the order of 50% with respect to a traditional approach – which makes them attractive for use in large machines. The paper also provides an update on the construction of short models, with possibly first results of magnetic measurements.

Submitters Country:

Switzerland

Wed-Af-Or23 / 596**Two-layer 16 Tesla $\cos\theta$ dipole design based on MQXF Low-Beta Quadrupoles**Eddie Holik¹ ; Giorgio Ambrosio¹ ; Emmanuele Ravaoli²¹ *Fermilab*² *LBNL*

High Energy LHC is a study aimed at exploring the possibility to upgrade the present LHC ring to reach 25 TeV total collision energy which requires 16 Tesla dipoles. Upon the conclusion of the High Luminosity Upgrade, the US LHC Accelerator Research Program in collaboration with CERN will have extensive Nb3Sn magnet fabrication experience. This experience includes robust Nb3Sn conductor and insulation scheming, 2-layer $\cos 2\theta$ coil fabrication, and bladder-and-key structure and assembly. By making evolutionary rather than revolutionary improvements and modification to existing technology the feasibility of a LARP-type 16 Tesla dipole is investigated. Preliminary designs indicate that fields up to 16.4 T are possible with current grading and 15.9 T are possible with conductor grading both while satisfying the HE-LHC specifications. Key challenges include accommodating high-aspect ratio conductor, narrow wedge design, conductor and current grading, and especially quench protection of a 16 T device.

Submitters Country:

United States

Wed-Mo-Pl6 / 1250**Two-layer, $\cos\theta$ Dipole for the FCC****Thu-Mo-Or33 / 166****Ultimate Forces of the Grenoble Hybrid Magnet****Author(s):** Hans Schneider-Muntau¹**Co-author(s):** Benjamin Vincent² ; Christophe Trophime³ ; Guy Aubert⁴ ; Pierre Pugnat² ; Yehia Eyssa⁵¹ *S-M CS&T*

² CNRS-LNCMI, Grenoble, France

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We present results of calculations of the ultimate forces for the worst-case scenario, an important safety concern in hybrid magnets. They appear during a simultaneous and immediate burnout of some or all upper or lower resistive coil halves, or shorts between the coils in the mid-plane. Because of their intensity, they have a dramatic impact on the mechanical layout of a hybrid magnet. An electromagnetic shield between insert and outsert, as it is the case for the Grenoble hybrid magnet, takes up part of these forces and reduces them considerably. It makes the calculation of the now time dependent forces rather complex.

The ultimate forces have been calculated for two models: a) conservation of magnetic flux with instantaneous energy transfer from the shorted coils to the remaining parts, and b) conservation of energy of the whole hybrid system, including the power supplies, with energy transfer via mutual axial and radial coupling to the other coils. Only for case a) we find an instantaneous force of 6 MN between resistive magnet and its housing at $t = 0$. The maximum force between resistive magnet and shield appears, when the resistive power supply is switched off at $t = 50/100$ ms: it is 3.7 MN/4.4 MN for case a) against only 1.5 MN for b). The force on the superconducting magnet is reduced from 210 kN for a) to 130 kN for b).

The results underline the usefulness of a shield between insert and outsert to reduce their electrodynamic interaction. They also confirm that the Grenoble Hybrid Magnet is well suited for inserts of much higher power levels.

Our findings have also consequences for the layout of hybrid magnets without shield.

Submitters Country:

France

Tue-Af-Po2.11 / 1236

Ultra-high field HTS flux-pumped magnets

Author(s): Tim Coombs¹

Co-author(s): Jianzhao Geng¹; chao li¹; J.D.D. Gawith

¹ University of Cambridge

Flux pumped ultra-high field magnets have the potential to produce fields which surpass the nearly 20 year old record of 45 T in a DC field Bitter magnet in a relatively cost effective manner. These higher fields will undoubtedly require superconducting cables capable of carrying thousands of amps and the means to deliver those very high currents. Current leads could be used but at currents in the 10s of thousands of amps they represent a very high cost and heating overhead. Higher currents mean lower conductor cost, lower magnet inductances shorter charging times and lower quench voltages. Flux pump technology and the latest dynamic bridge switching method will be key to providing these high currents with minimal heat loads and minimal infrastructure in comparison to expensive high-current power supplies and warm-to-cold current leads. The resultant effect is that the purchase and running costs of high-field magnets will decrease substantially. Crucially also infrastructure costs will be slashed. A flux pumped HTS magnet does not require high current power supplies and current leads neither does it require copious amounts of water cooling to dissipate the waste heat. Thus it is realistic to expect HTS flux pumped magnets to be available which could be installed in any UK (or international) university enabling a radical sea change in the use of high field magnets to support research. Further down the line it is conceivable that HTS flux pumped magnets could enable the creation of practical fusion devices a goal which has eluded us for many years.

Submitters Country:

United Kingdom

Mon-Af-Po1.10 / 148

Unbalanced Torque in High Magnetic Field No-Insulation REBCO Pancake Magnet after Quench

So Noguchi¹ ; Ryosuke Miyao² ; Seungyong Hahn³¹ *Hokkaido University/National High Magnetic Field Lab.*² *Hokkaido University*³ *Seoul National University / National High Magnetic Field Lab.*

A REBCO pancake coils using a no-insulation (NI) winding technique is received attention. An NI winding technique greatly enhances the thermal stability of REBCO pancake coils, and it is desired to be applied to high magnetic field NMR/MRI magnet, etc. The high thermal stability of NI REBCO magnets was confirmed in many experiments and numerical simulations, even though any accident due to mechanical or thermal factors caused a quench of NI REBCO magnets. However, a new problem arised after a quench when an NI REBCO magnet was operated under a high magnetic field. When NI REBCO pancake coils transitions into a resistive state, the operating current bypasses a turn to adjacent turns in the coil-radial direction. That is an inherent feature of NI REBCO pancake coils. The radially bypassing current flows under a high magnetic field, so that the Lorenz force is generated in the coil-circumferential direction. This circumferential force works to the quenched NI REBCO pancake coils as a torque. The coils or joints may be damaged by unbalanced torque. When NI REBCO pancake coils transition into a normal state, most of the operating currents carry in the radial direction. In cases of a large operating current, the large torque has to be considered to protect from damages. Moreover, the larger bore and/or the larger thickness NI REBCO magnets have, such as a high-field whole-body MRI application, the larger torque is generated. So far, an overcurrent test or a quench test of NI REBCO pancake coils under a magnetic field higher than 10 T has not been reported. Hence, there is no report about unbalanced torque generated in NI REBCO pancake coils. In this paper, we will discuss a risk of unbalanced torque generated in high magnetic field NI REBCO pancake coils after quench.

Submitters Country:

Japan

Wed-Af-Po3.09 / 299

Uniaxial Strain Induced Critical Current Degradation of Ag-Sheathed Bi-2212 Round Wire

Author(s): Chao Dai¹**Co-author(s):** Jinggang Qin¹ *Institute of Plasma Physics, Chinese Academy of Sciences(ASIPP)*

The uniaxial strain induced the critical current degradation of Bi-2212 Ag-sheathed round wire was studied at 4.2 K in 14 T background field. The strains applied on the sample are both tension and compression. An additional tensile strain caused by the difference of thermal expansion between Bi-2212 round wire and Ti-6Al-4V was calculated. Results show that a drastic degradation of the critical current occurred when the strain exceeded 0.35% on tension side. And on compression side, the degradation of critical current was almost linear but more gradual than tensile strain. It is foreseen that these results can provide a basis for Bi-2212 conductor and superconducting coil design.

Submitters Country:

China

Mon-Af-Po1.12 / 1165

Upgrade of the Grenoble High Magnetic Field Facility

Author(s): Romain Barbier¹**Co-author(s):** François Debray¹; Rémi Jaymond¹; Benjamin Vincent¹; Jean Dumas¹; Mickael Pelloux¹; Steffen Kraemer¹; Cedric Grandclement¹; Philippe Sala¹; Jean-Louis Demarinis¹¹ LNCMI-EMFL-CNRS

The Grenoble steady magnetic field facility is one of the four high field facilities part of the European Magnetic Field Laboratory. The upgrade of the Grenoble facility has started in 2013 and aims in a first phase at increasing the electrical power from 24 to 30 MW and to develop the high field magnets accordingly. A new 18 MW power converter has been made available to users in 2017 and replaces two of the four 6 MW units. It will be used during the next three years at a reduced 12 MW power imposed by the current power transformer. 18 MW will be available after the commissioning of a new 60 MVA transformer. In 2017 the flowrate pumped from the nearby river will be increased from 1400 to 2000 m³.h⁻¹. A new 36 MW heat exchanger will be installed at the interface between the primary circuit and the deionized water closed loop. The last step will consist of upgrading the 2 remaining 6 MW units. At the end of this operation, 36 MW should be available to feed the magnets. In parallel, the LNCMI is developing a new compact polyhelix insert capable of absorbing 18 MW instead of 12 MW. This insert needs to have the same outer diameter as the 14 helix insert currently in operation so as to fit in existing external bitter magnets. To optimize the energy costs incurred by this upgrade, studies are being conducted to take advantage of the heat generated by the magnets to heat neighboring buildings. The performance of the new power converters will be assessed from the detailed analysis of the stability of the magnetic field and the electrical currents.

Submitters Country:

FRANCE

Wed-Af-Po3.10 / 230

Upper critical and irreversibility magnetic fields and transport properties of bulk K-, Ni-, and Co-doped BaFe₂As₂ pnictides for different granularities and their prospects in magnet design

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A comprehensive study of upper critical (H_{c2}) and irreversibility magnetic fields (H_{irr}) in (Ba_{0.6}K_{0.4})Fe₂As₂, Ba(Fe_{0.95}Ni_{0.05})₂As₂, Ba(Fe_{0.94}Ni_{0.06})₂As₂, Ba(Fe_{0.92}Co_{0.08})₂As₂, and Ba(Fe_{0.92}Co_{0.09})₂As₂ polycrystalline bulk pnictide superconductors for different average grain sizes was made in pulsed fields at the Los Alamos National Laboratory. The magnetic field-temperature (H_{c2}-T) phase diagrams with H_{c2} as high as 65 T at 28 K for the K-doped samples and critical current density (J_c) measurements as high as 105 A/cm² for the smallest, sub micron grain size samples were obtained. The high H_{c2}, H_{irr}, and J_c data shows the suitability of these materials for magnet design as their mechanical strength and random grain alignment show promise in the manufacturing process.

Submitters Country:

USA

Mon-Af-Or4 / 692

Vacuum Pressure Impregnation for Central Solenoid of JT-60SA

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The construction of a full-superconducting tokamak referred as JT-60 Super Advanced (JT-60SA) is in progress under the JA-EU broader approach projects. The magnet system of JT-60SA consists of 18 toroidal field (TF) coils, 4 modules of central solenoid (CS) and 6 equilibrium field (EF) coils.

The diameter, the height, the number of layers and the number of turns of CS module are 2.0 m, 1.6 m, 52 layers and 549 turns, respectively. GKG (Glass-Kapton-Glass) tape was wound around conductor as a turn insulation of CS module. Vacuum pressure impregnation (VPI) process was selected to fix the insulation tapes for CS module of JT-60SA.

During VPI process, CS module needs to be pressed in order to increase the bonding strength between turn insulation and conductor. The total insulation thickness of CS module is very thick of about 70 mm because of large number of layers. It was considered that the insulation thickness was shrunk during VPI process under the pressurized condition and traditional rigid jigs could not deal with this large shrinkage.

We conducted the VPI test using stacked insulation tapes to measure the amount of shrinkage. Amount of shrinkage was evaluated as 15mm for JT-60SA CS module. Displacement of 15mm was too large for traditional rigid jigs to be used for VPI process. We developed jigs with moving system and modified procedure of VPI process. VPI process of CS module was successfully performed, even though there was large shrinkage, by using developed jigs and modified procedure.

In this paper, result of VPI test, developed jigs and modified procedure for VPI of CS module will be described.

Submitters Country:

Japan

Tue-Mo-Or12 / 878

Validation of Quench Protection simulations in High-Field Nb3Sn magnets by comparison with measurements.

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The Future Circular Collider is at the conceptual design phase and one of the main components are the high-field Nb3Sn dipole magnets targeting 16 T of bore field. With very high current densities and high stored energy, the quench protection is an essential part of the magnet design. The quench protection design relies largely on simulations and naturally, the reliability of the software is crucial. The aim of this paper is to validate the simulation tools with measurements on existing high-field Nb3Sn magnets, namely the MQXF5, 11T-models and RMC racetrack models. We consider those experiments where the protection relies on quench protection heaters.

We consider the following simulation approaches (and their combinations): 1. adiabatic model with

thermally independent coil turns and heater delays simulated before experimental validation 2. The model using experimental input for the heater delays, longitudinal quench propagation, fit parameters for turn-to-turn propagation, and quench delay caused by the ac-losses, and 3. scaling law deduced from a few measurement points and magnet's parameters for predicting quenches over the whole range of operation conditions.

The results of the study will be used to assess the suitability of different simulation approaches, and finally to what level of current density and stored energy the designed magnets for FCC can be protected with quench heaters.

Submitters Country:

Finland, Switzerland, United States

Tue-Af-Po2.06 / 880

Variable-voltage-variable-frequency inverter drive of 20 kW class the High-Temperature Superconducting Induction/Synchronous Motor

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We have conducted research and development on a high-temperature superconducting motor, which has been expected as a next generation transportation equipment. Our target motor is so-called high-temperature superconducting induction/synchronous motor (HTS-ISM). The HTS-ISM has the similar structure as a squirrel cage induction motor, but replaces the winding with a HTS wire. Basically, by merely superconducting the secondary winding, the HTS-ISM is promised to have excellent features such as high efficiency and high torque density. Furthermore, all superconducting HTS-ISM currently undergoing research and development are expected to have high efficiency and high torque density. Assuming the actual application of HTS-ISM, it is possible to improve the efficiency of the whole power-train system using the technology of regeneration and inverter loss reduction. In this study, we carry out rotation test of the fabricated 20 kW class HTS-ISM with a variable-voltage-variable-frequency inverter, and investigate transient performance of it. Especially, we concentrate on instantaneous current/voltage waveforms, of which will be affected by the nonlinear current transport properties of the HTS rotor windings. And then, we will give an explanation of such transient phenomenon based upon Magnet-axis vs. Torque-axis coordinate, so that relationship between torque and magnetic flux is clarified. We also study harmonic components of the above-waveforms, by changing the carrier frequency of the inverter. These results would support the realization of the highly efficient power-train system installing the HTS-ISM.

Acknowledgements: This work has been supported by Japan Science and Technology Agency under the program of Advanced Low Carbon Technology Research and Development Program (JST-ALCA) in Japan.

Submitters Country:

Japan

Tue-Af-Po2.06 / 92

Vibration Comparison of Two Fault-Tolerant Flux-Switching Permanent-Magnet Machines

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In order to improve the fault tolerant (FT) capability suitable for high reliability operation, FT teeth and concentrated windings are designed in two FT flux-switching permanent-magnet machines, namely 10/18-pole and 10/19-pole. However, they still suffer from vibration and noise due to radial force fluctuation. This paper compares the vibration characteristic of both machines. Because odd rotor pole is adopted, the 10/19-pole machine offers less pulsating torque than the 10/18-pole one due to its more symmetric back electromotive force and reduced cogging torque. The total harmonic distortion is 3.9% for 10/19-pole machine, and 7.7% for 10/18-pole one. The cogging torque is 0.066 Nm for the 10/19-pole machine, and 0.757 Nm for the 10/18-pole one. The dominant radial pressure harmonic order is just the pole number for both machines. For 10/18-pole machine, only even harmonics are excited, the lowest order of harmonics is 2. For 10/19-pole machine, even and odd harmonics are all excited. Especially, the first order harmonic is unbalance component which can induce distinct vibration. The stator deformation shows that the dominant vibration modes of 10/18-pole machine are 2nd and 4th. However, for 10/19-pole machine, the dominant modes are 2nd and 1st. The 1st mode generates unbalance deformation, hence induces more severe vibration than that of the 10/18-pole one, although the 10/18-pole machine suffers from higher torque ripple. The measured acceleration is about 1.8 m/s² for the 10/19-pole machine, and 0.4 m/s² for the 10/18-pole one. Measurement result is coincided with the predicted one. It indicates that machines with a low torque ripple do not guarantee low vibration. In terms of vibration, the lower-order radial pressure harmonics with high amplitudes have more influence than the torque ripple. Moreover, the unbalance component will aggravate vibration. Detailed results and discussions will be given in full paper.

Submitters Country:

China

Wed-Af-Po3.08 / 682

Vibration of Magnetically Controlled Saturated Reactor under AC and DC excitation

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Magnetically controlled saturated reactors (MCSRs) operate through changing the degree of saturation of the magnetic valve by applying different DC excitations. Due to the special structure and working mode of AC and DC excitation, the vibration of MCSRs is larger than that of the ordinary ones. In recent years, research on MCSRs vibration mainly concentrated on the causes of the MCSRs vibration. However, the core material shows different magnetization and magneto-strictive properties under different DC excitations. Therefore, in order to calculate the vibration of MCSRs accurately, it is necessary to consider the difference of magnetic properties under different DC excitations. But, so far, the vibration of MCSRs based on the measured magnetic properties of different DC excitations has not been studied. In this paper, magnetization and magneto-striction characteristics in silicon steel under different DC excitations are measured. According to the presented electromagnetic-mechanical coupled model for MCSRs, the magnetic field and vibration stress of the MCSR under different DC excitations are calculated. From the computation results, it can be seen that the magnetic flux density, displacement and acceleration of the MCSR are increased with the DC excitation, and the increase degree of the different parts of the reactor is not the same, which provides the theoretical basis for vibration and noise reduction of MCSRs.

Submitters Country:

China

Thu-Af-Po4.04 / 1072**Walk-Through MRI: Affordable Technology for Well-Patient Cancer Screening**Peter McIntyre¹ ; Joshua Kellams² ; Akhdiyov Sattarov¹¹ *Texas A&M University*² *Accelerator Technology Corp.*

MRI is widely used for diagnosis and characterization of many diseases and injuries. It has immense potential for early diagnosis of cancer through well-patient screening, but that potential is largely unrealized because the cost of dye-contrast MRI is \$thousands and it is not affordable to screen well patients. We have employed a new methodology of magnetic design to project a domain of magnetic field outside the structure of a magnet, with 1.5 T field strength and < ppm homogeneity in the volume of interest of a target organ. The patient can then walk into the target location and the before/after images can be acquired in a few minutes time. This provision uniquely makes it possible to reduce the cost/image to be comparable to radiology procedures. Applications for breast, prostate, cardiac, and brain imaging will be discussed.

Submitters Country:

US

Thu-Af-Po4.10 / 19**Waveform conditioning problems in high frequency magnetization of nanocrystalline alloys**Long Chen¹ ; wang youhua² ; Hanyu Zhao^{None} ; chengcheng liu³¹ *Hebei University of Technology*² *hebei university of technology*³ *Hebei university of technology*

As a new kind of magnetic material, nano-crystalline alloys have high permeability and excellent loss characteristics, and measurement of high frequency magnetic properties of nano-crystalline alloys have great significance on the development of high frequency and high power density transformer. Since the permeability is very high, not only the external field even with small values but also the annealing process would influence the measurement results. If there exit a asymmetric stress inside the materials, the magnetic field H can be asymmetric at different flux density levels. In this paper, three topics are mainly discussed: First, the problem of asymmetric distortion of the waveform in the nano-crystalline alloy high-frequency measuring is discussed and analyzed. Second, a newly developed testing system by adding a compensation wingding is introduced. By applying this configuration, the dc bias magnetic field H= can be adjust to zero. Third, When the nano-crystalline alloy is nearly to saturated, the flux density waveform start distortion, a feedback control method based on the circuit model is proposed to keep the flux density B sinusoidal which is very important to calculate the specific losses during the magnetization. Finally, a FT-3KM nano-crystalline sample were measured and analyzed up to 10kHz. The losses are calculated by the field-metric method.

Acknowledgments: This work is supported by the National Natural Science Foundation of China under Grant No.

51377042.

Submitters Country:

China

Wed-Af-Po3.01 / 869

Windability tests of Nb3Sn Rutherford cables for HL-LHC and FCCDariusz Pulikowski¹ ; Friedrich Lackner¹ ; Christian Scheuerlein¹ ; Davide Tommasini¹ ; Frederic Savary¹ ; Mirosław Pajor²¹ CERN² West Pomeranian University of Technology (PL)

In the framework of the development of high field magnets made of Nb3Sn superconductor for projects like HL-LHC and FCC studies, it is needed to refine the understanding of the winding process and its impact of the overall mechanical integrity of the conductor. The mechanical behaviour during winding of the unreacted Rutherford type Nb3Sn cables has been studied experimentally. In order to quantify the windability of the various cable designs the measurement method and a dedicated specimen scanning device has been developed. The validation of the device and achieved repeatability are presented. The first obtained test results for cables for HL-LHC, 11 T dipole RRP®, 11 T dipole PIT and MQXF are shown.

Submitters Country:

Switzerland

Wed-Af-Po3.02 / 636

Winding Deformation Caused by Reaction Heat-treatment for ITER TF coilTsutomu Hemmi¹ ; Hideki Kajitani² ; Kunihiro Matsui¹ ; Minoru Yamane¹ ; Kaori Sakaguchi³ ; Mio Nakamoto¹ ; Toru Saito³ ; Shinji Ando³ ; Katsutoshi Takano³ ; Norikiyo Koizumi¹¹ National Institutes for Quantum and Radiological Science and Technology² National Institutes for Quantum and Radiological Science and Te³ QST

National Institutes for Quantum and Radiological Science and Technology (QST) has responsibility as Japanese domestic agency (JADA) to procure 9 Toroidal Field (TF) coils in the ITER project. The high mechanical and electrical reliabilities have to be ensured for the operation of the ITER for 20 years. For this objective, the Radial Plate (RP) structure is employed to avoid accumulating the electromagnetic loading to the insulation material. Since Nb3Sn is brittle, the bending strain exceeding 0.1% cannot be applied after the reaction heat-treatment. Thus, the conductor is wound to D-shape and then heat-treated before it is transferred into the RP groove. To transfer the heat-treated conductor into the RP groove, the accuracy of $\pm 0.02\%$, which is ± 7 mm on 1-turn of 34 m, in conductor length is necessary after the winding and the heat-treatment. In addition, the winding deformed by the reaction heat-treatment has to be transferred into the RP groove within the bending strain of $\pm 0.1\%$. The winding deformation caused by the reaction heat-treatment was evaluated. This paper shows the evaluated winding deformation and the bending strain calculated to transfer the winding into the RP grooves.

Submitters Country:

Japan

Wed-Af-Po3.02 / 490

Winding R&D for CFETR Central Solenoid Model Coil

Author(s): Houxiang HAN^{None}**Co-author(s):** Dapeng Yin ¹ ; Yu WU ¹ ; Jingang Qin ; Yi SHI¹ ASIPP

The central solenoid (CS) model coil is being developed to verify the large-scalar superconducting coil manufacture technology for China Fusion Engineering Test Reactor (CFETR) in ASIPP (Institute of Plasma Physics). The CS model coil composed of Nb₃Sn (inner and outer coils) and NbTi (upper, middle and lower coils) hybrid superconducting magnet can reach to 12 T maximum magnetic field. All of five coils are the pancake coil composed of pancakes concentric circular turns, pancake joggles and upper & lower leads. For pancakes concentric circular turns, the minimum diameter is 1500 mm, the maximum diameter 3544.8 mm and the maximum height is 1545.4 mm. The high precision for coil continuous winding must be acquired, the innermost and outermost circular turn surface profile tolerance is 0.5 mm and the turn insulation gap tolerance is 2.6(0/+0.5) mm. The winding R&D activities, including the continuous winding for the pancakes concentric circular turns, the forming on-line for the pancake joggles, have been conducted to optimize and finalize the coil design and do the coil winding technology verification and improvement. The winding & forming for a 4×4 mock-up coil of the Nb₃Sn inner coil have been finished.

Submitters Country:

China

Tue-Af-Po2.07 / 1192

Winding Technology And Experimental Study On Superconductive Fault Current Limiter

chen liang^{None}

The development of 500 kV saturated iron core superconductive fault current limiter(SFCL) is in progress. The magnet consists of 88 high temperature superconducting(HTS) double pancake coils with an inner diameter of 1940 mm and outer diameter of 2040 mm. Double pancake coil plays an important role in 500 kV SFCL, the structure and winding process have great influence on current carrying capability and reliability of the coil. In this paper, the key technology of winding process of the world's largest HTS coil was introduced, which included critical current measurement of HTS tapes under radial bending, insulating treatment of double pancake coil and the former, winding of the coil and welding of the joints. The V-I curve of the HTS coil was also investigated under the condition of liquid Nitrogen in self magnetic field. The experimental results show that the double pancake coil have good properties and the processes are reliable and suitable for manufacturing 500 kV SFCL. The study will not only provide important references for large HTS coils fabrication, but also accumulate experience and data for other similar engineering practices. Key words: Saturated iron core superconductive fault current limiter, double pancake coil, coil winding process, welding procedure, HTS coil V-I curve.

Submitters Country:

China

Wed-Af-Po3.11 / 937

YBCO pancake coil wound using an electrically non insulated tape: current sharing, stability, quench, and NZP measured at 4.2

K and 10 T

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YBCO coated conductors are candidates for using in a number of High Energy Physics applications, like e.g. high field solenoids for muon colliders. A new approach in making YBCO magnets has been suggested recently, where the coils are neither insulated nor epoxied. It is believed that in this approach, the coil is much easier to protect, because once a given zone becomes normal, the lack of insulation lets it share its current to the next winding layer down. Essentially, the various coil windings are no longer completely in series once a normal zone forms. In principle, the current can be shared across the whole winding, thus essentially serving both to re-route the current, but also to distribute the energy, as quench heaters would in a normal active protection scheme. In the present work we have measured current sharing, stability, quench and normal zone propagation in such a YBCO pancake coil at 4.2 K in liquid helium bath. The experiments have been done in applied magnetic fields up to 10 T at transport currents of a certain percentage of the coil critical current. The coil winding was instrumented for voltage and temperature measurements at several places around the winding, such that both radial and azimuthal quench propagation could be measured. A heater was placed on the inner-most part of the winding. Heat pulses of various powers and durations were generated to measure quench and NZP. Obtained results are compared with our previous measurements on a coil wound using a kapton insulated YBCO tape.

Submitters Country:

USA

Wed-Af-Po3.10 / 102

Zylon aging and light resistance

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Zylon fibres are used at the National High Magnetic Field Laboratory for structural reinforcement of high field pulse magnet coils. We have studied the fibre properties with respect to the aging effect and light resistance. The high modulus and strength values were associated to the crystalline and texture. Long time exposure to lab-light was found to decay the crystallinity, increase disorder, and introduce more defects (micro-voids). No function group breaking was observed under light-aging.

Submitters Country:

United States

Mon-Mo-Or2 / 259

[Invited] Commissioning of the 36 T Series-Connected Hybrid Magnet at the NHMFL

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The National High Magnetic Field Laboratory (NHMFL) has commissioned a 36.1 T magnet with homogeneity and stability of 1 ppm over a 10 mm diameter spherical volume to be used for solid state NMR. Most NMR magnets use single strands of superconducting wire carrying a few hundred amps and persistent joints and switches. This magnet uses a 20 kA superconducting cable in a steel conduit for the outer part of the magnet and copper-alloy sheet metal for the inner part of the magnet.

While >15 hybrid magnets have been built worldwide, they typically have a field uniformity of ~250 ppm/cm DSV and stability might be no better than 10 ppm. To attain 1 ppm uniformity, current density grading was employed in the resistive coils to cancel the z² term. In addition coils were shifted after the first map to reduce the z¹ term. Ferroschims and resistive shims were installed in the bore to attain 1 ppm over 10 mm. The large inductance of the superconducting coil reduced the ripple 5-fold compared with all-resistive magnets. A pick-up coil based stabilization system reduced the high frequency ripple and an NMR lock reduced the low-frequency drift to attain 1 ppm stability.

Submitters Country:

USA

Tue-Mo-Or14 / 86

[Invited] HTS field coils with robust design for a superconducting wind turbine generator

Author(s): Markus Bauer¹

Co-author(s): Raphaela Burzler¹; Veit Große¹; Martin Keller¹; Anne Bergen; Marc Dhallé²; Sander Wessel²; Konstantin Yagotintsev²; Nir Tzabar³

¹ THEVA Dünnschichttechnik GmbH

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The EU-funded EcoSwing project aims at demonstrating the world's first superconducting low-cost and lightweight wind turbine generator. This generator will use field coils based on second generation (2G) HTS wire which are manufactured using Pro-Line HTS tapes. During the development subscale test coils with different number of turns were produced and tested in liquid nitrogen as well as cooled by conduction in vacuum and variable temperature. Design details and test results will be reported. After the successful test of these subscale coils the design for the generator coils could be finalized and a first full size coil was manufactured for the type testing. The generator coils have an overall length of 1.4 m and incorporate several hundred meters of tape for realizing about 200 turns. The type test proved that the performance of the coil at operating temperatures and magnetic fields reached the desired values so that the series production of coils for the generator was started. The current status of this production will be shown together with results of type and routine testing.

This work was supported by the European Union's Horizon 2020 research and innovation program under grant agreement No. 656024.

Submitters Country:

Germany

Mon-Af-Or6 / 141

[Invited] High Field Twin-aperture Dipole Magnet R&D for SPPC Pre-study

Qingjin XU¹ ; Kai Zhang² ; Chengtao Wang³ ; Yingzhe Wang³ ; Da Cheng³ ; Ershuai Kong⁴ ; Qing Li⁵ ; Quanling Peng³ ; Feipeng Ning³ ; Fusan Chen^{None} ; Zian Zhu⁶ ; Wen Kang⁷ ; Xiangqi Wang⁸

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⁸ University of Science and Technology of China

A high field twin-aperture dipole magnet is under development as the key technologies R&D for high energy circular colliders like SPPC. The magnet is designed with combined Common-coil and block-type configurations. The main field is 12 T with 20% operating margin at 4.2 K. The aperture diameter is 30 mm. The fabrication and experimental test is divided into 3 steps: 1) 4 flat racetrack NbTi coils and 2 flat racetrack Nb3Sn coils are firstly fabricated and tested, to evaluate the fabrication process and stress management of Nb3Sn coils. 2) 2 more Nb3Sn coils are fabricated and tested together with the 1st 2 Nb3Sn coils, to provide 12 T main field in the top and bottom apertures with the diameter of 20 mm. 3) 2 racetrack ReBCO coils with flared ends are fabricated and inserted into the 4 Nb3Sn coils, to provide 12 T main field in the top and bottom apertures with the diameter of 30 mm. The main design parameters, structure, fabrication process and preliminary test results of the magnet will be presented.

Submitters Country:

China

Mon-Af-Or4 / 844

[Invited] JT-60SA Magnet System Status

Author(s): Sam Davis¹

Co-author(s): Antonio Cucchiario² ; Christophe MAYRI³ ; Daigo Tsuru⁴ ; Enrico Di Pietro⁵ ; Gaël Disset³ ; Gian Mario Polli² ; Haruyuki Murakami⁴ ; Jean Louis Marechal⁶ ; Kaname Kizu⁴ ; Katsuhiko Tsuchiya⁴ ; Kei Masaki⁴ ; Manfred Wanner⁷ ; Mario Verrecchia¹ ; Nandor Hajnal¹ ; Paolo Rossi² ; Patrick Decool⁶ ; Pietro Barabaschi¹ ; Valerio Tomarchio⁸ ; Walid Abdel-Maksoud⁶

¹ Fusion for Energy

² ENEA

³ CEA Saclay

⁴ National Institutes for Quantum and Radiological Science and Technology

⁵ F4E

⁶ CEA

⁷ Fusion For Energy

⁸ Fusion For Energy (F4E)

The JT-60SA experiment will be the world's largest superconducting tokamak when it is assembled in 2019 in Naka, Japan (R=3m, a=1.2m). It is being constructed jointly by institutions in the EU and Japan under the Broader Approach agreement. Manufacturing of the six NbTi equilibrium / poloidal field coils, which have a diameter of up to 12m, has been completed. So far 14 of the 18 NbTi toroidal field coils, each 7m high and 4.5m wide, have also been manufactured and tested at 4 K in a dedicated

test facility in France. The first three of four Nb₃Sn central solenoid modules have been completed, as have all of the copper in-vessel error field correction coils. Installation of the toroidal field magnet, around the previously welded 340° tokamak vacuum vessel and its thermal shield, started at the end of 2016. The TF magnet will in turn support the EF and CS coils.

This presentation will summarise some of the highlights of the JT-60SA magnet system design and manufacturing achievements as well as briefly describing the tests performed on the coils and the status of their assembly.

Submitters Country:

Germany

Mon-Mo-Or2 / 884

[Invited] Progress in the Construction of the 43 T Hybrid Magnet at LNCMI-Grenoble

Pierre Pignat¹

¹ CNRS-LNCMI, Grenoble, France

By combining resistive polyhelix and Bitter inserts with a large bore superconducting outsert, the new hybrid magnet in construction at LNCMI-Grenoble will produce in a first step, an overall continuous magnetic field of 43 T in a 34 mm warm bore aperture. After a brief reminder of the specificity of hybrid magnets, namely the strong electromagnetic and mechanical couplings between resistive and superconducting coils, the main specificities of the proposed design are presented. The superconducting coil will provide a nominal magnetic field of 8.5 T in a 1.1 m cold bore diameter relying on the novel development of a Nb-Ti/Cu Rutherford Cable On Conduit Conductor (RCOCC) cooled down to 1.8 K by a bath of superfluid helium at atmospheric pressure. The novelty of the RCOCC concerns the in-laboratory assembly and induction soft-soldering of the Rutherford cable on a Cu-Ag hollow stabilizer allowing a strict control of the interstrand contact resistance. A stainless steel reinforced copper shield inserted between the superconducting and resistive coils will allow reducing the coupling currents induced within the RCOCC as well as the extreme mechanical force exerted on the superconducting coil. After successful thorough reviews of the Grenoble hybrid magnet design anticipating possible upgrades of the maximum magnetic field produced, this project is now well engaged in its construction phase. The status of this project is presented together with the next milestones.

Submitters Country:

France

Tue-Mo-Or11 / 522

[Invited] Recent Progress of Superconducting Induction Heater with HTS magnets in Korea

Jongho Choi¹ ; Sangho Cho² ; Minwon Park³

¹ Supercoil Co., Ltd.

² TECHSTEEL Co., Ltd.

³ Changwon National University

Large-scaled induction furnaces for non-ferrous metal billets operated at commercial frequency have an energy efficiency of only 50-60% due to the considerable loss from the copper coils used to generate the magnetic fields. Efforts to improve their efficiency are hampered by physical limits. A DC induction heating using HTS magnets has been suggested for achieving higher energy efficiency. A

10kW-class prototype for an HTS DC induction heater was developed in 2013. Changwon National University and TECHSTEEL will have completed a project to develop a 300 kW-class superconducting induction heater(SIH) with HTS magnets in 2017. This project was supported by Korean government.

In the operation of an HTS magnet, ensuring thermal stability against uneven quench is the most important factor. The metal insulation winding method using stainless steel allows the HTS magnet to maintain a great thermal stability by distributing the quench energy evenly and minimize the charging and discharging time. In this paper, we are going to introduce a 300 kW-class SIH and its performance test results. The HTS magnets were fabricated and excited under the conduction cooling condition, successfully. Now, the SIH with the HTS magnets are being fabricated and tested to heat up the metal billets including both the ferrous and non-ferrous metal billets. The performance test results will be applied for the commercial product of SIH.

Submitters Country:

Korea

Thu-Mo-Or28 / 957

[Invited] The EuCARD2 Future Magnets Program for particle accelerator high field dipoles: review of results and next steps

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The EuCARD-2 collaborative programme (2013-2017) is part of the European long term development aimed at exploring magnet technology operating at 16 T to 20 T dipole field for the next CERN collider projects. The collaboration had as a main focus the development of a 10 kA-class superconducting, high current density cable suitable for accelerator magnets, to be tested in small scale coils and magnets capable to deliver about 5 T when energized in stand-alone mode, and 15-18 T when inserted in a 12-13 T background magnet. After evaluating various possibilities, for the conductor we selected REBCO tapes assembled in a Roebel cable. The EuCARD2 programme has come to an end with the successful test of the 10 kA class conductor. The YBCO tape has demonstrated a record critical current density 4.2 K, 20 T and the conductor exceed 12 kA in a 6 m long unit wound in a small coil (FM0.4) and has shown almost no current degradation in special test under 400 MPa of transverse pressure. The coil test, spanning the 4 to 80 K temperature range, has also shown that we can rely on current transfer among cable strands and new systems have been tested and partly validated to detect the transition onset early. The test results of an accelerator-quality magnet of novel design (Feather_M2) with various types of conductor are reported, as well a test of a classical costheta design. The HTS accelerator magnet work plan beyond EuCARD2, supported by a task in the H2020-ARIES program aiming at doubling the J_c at 20 T in the tape, and including investigations of new designs as well as a series of technology developments will also be presented. This work has been partly supported by the EC through FP7-EuCARD2 GA n.312453

Submitters Country:

Switzerland

Mon-Mo-Or2 / 1025**[Invited] The commissioning of a hybrid magnet at CHMFL**

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Guangli Kuang^{None}

A superconducting magnet with large inner diameter of 920 mm was developed for an outsert of a hybrid magnet at the High Magnetic Field Laboratory of Chinese Academy of Sciences (CHMFL). The superconducting magnet was successful tested and produced 10 T on November 5, 2017, and the hybrid magnet combined with the superconducting magnet and also an insert resistive magnet was also successful tested and produced 40 T on November 13, 2017. The superconducting magnet consists of 3 nested coils and made of 4 kinds of Nb3Sn cable-in-conduit conductor. It is cooled by forced flow helium at 4.5 K. During the commissioning of the outsert superconducting magnet, a series of performance tests have been carried out, including the AC losses test, the current dumping test and so on. This paper reviews the important specifications and design features for the outsert superconducting magnet, and also discusses the test results of the first commissioning.

Submitters Country:

China