TURBO GENERATORS FOR POWERING THE HV-SOLENOIDS AT THE HESR ELECTRON COOLER

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Abstract

Many experiments at the planned High Energy Storage Ring (HESR) require magnetised electron cooling [1]. One of the challenges in the future HESR electron cooler is the powering of HV-solenoids.

In this report we discuss two approaches which are currently under discussion. In both proposals, turbo generators should be used. We also present a possible alternative way to drive these turbo generators. Instead of a compressor, the turbo generators could be powered with an Organic Rankine Cycle (ORC) like process.

INTRODUCTION

An essential project at the Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt is the HESR storage ring, which is dedicated to the field of high energy antiproton research. The HESR has a circumference of 575 m and can operated in two modes, the “High Luminosity" (HL) and “High Resolution" (HR) mode. The experiments are carried out in the PANDA detector [2]. Some experimental demands are summarised in Table 1 [3]. To meet these requirements

Table 1: Experimental Demands of the HESR

	HL	HR
Momentum range	$1.5 - 15\ \frac{\text{GeV}}{\text{c}}$	$1.5 - 9\ \frac{\text{GeV}}{\text{c}}$
Peak luminositiy	$2 \cdot 10^{32}\ \frac{1}{\text{cm}^2\text{s}}$	$2 \cdot 10^{31}\ \frac{1}{\text{cm}^2\text{s}}$
Momentum resolution	$\frac{\Delta p}{p} = 10^{-4}$	$\frac{\Delta p}{p} = 10^{-5}$

for the high resolution mode, magnetised electron cooling with a 4.5 MeV, 1 A electron beam is necessary to counteract the emittance blow up due to scattering processes. An intention for the HESR is an upgrade to the Electron Nucleon Collider (ENC). The ENC will allow experiments with polarised electrons and protons [4], which also need magnetised electron cooling. In that case, an 8 MeV, 3 A electron beam is needed. In order to solve critical technical issues, the Helmholtz-Institut Mainz promotes collaborations with other Institutes such as Forschungszentrum Juelich (FZJ), Budker Institute of Nuclear Research Novosibirsk (BINP), Russia and Lehrstuhl fuer Technische Thermodynamik und Transportprozesse (LTTT), University Bayreuth. One of the challenges is the powering of HV-solenoids. The HV-solenoids are located on different electrical potentials inside a high voltage vessel, which is why they needed a floating power supply. At the moment, two different concepts are being discussed. In the first design, many small HV-solenoids are powered by a cascade transformer, which is powered by turbo generators. In the second proposal, few big HV-solenoids are powered directly by turbo generators.

HIGH VOLTAGE VESSEL

An important element of the elctron cooler device is the high voltage vessel, whose principal design is illustrated in Figure 1. The main components are the DC-thermionic elec-

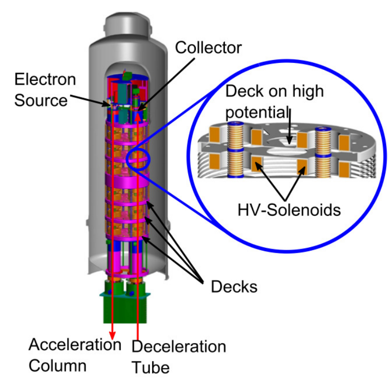

Figure 1: Principal design of the high voltage vessel [5].

tron source, the collector, the acceleration and deceleration tube. The acceleration/decleration voltage is provided by a high voltage column, which is built in a modular way and consists of decks. Every deck has a defined electrical potential. To guide the electrons from the gun to the interaction section, where the cooling process takes place, and back to the collector, a homogeneous magnetic field is necessary. It is generated with solenoids, the so-called HV-solenoids, which are mounted on the decks. This results in various requirements to the power supply for the HV-solenoids. Because the decks are on a fixed electrical potential, the power supply for the HV-solenoids must not be grounded. Ideally, the cooler should operate continuously for time scales of several months to allow for a reasonable scheduling of HESR experiments. Therefore, a high reliability, particulary of the powering system for the HV-solenoids, is a must. Due to the fact that the high voltage vessel is filled with sulphur hexafluoride, all components must be compatible with that. In addition to the HV-solenoids, there are more devices on the HV platform, which also need powering, e.g. vacuum pumps.

POWERING OF THE HV-SOLENOIDS

Currently, two different concepts are being discussed, which were proposed by the BINP in a frame of a design study. In both concepts, the power supply should be built in a modular way. While the 2 MeV COSY Cooler at

Forschungszentrum Juelich [6] serves as a basis for the first concept, for the second concept the swedish design, which had orinally been planned by the Svedberg Laboratory, Upsala University [5], was taken as a model.

Cascade Transformer

A well known and tested technology to power the HV-solenoids is a cascade transformer, which is already in use at the COSY cooler. At COSY, a cascade transformer is used to power the HV-solenoids and to generate a potential difference of 60 kV between the individual decks. However, the energy range of a cascade transformer is limited to 2.5 MeV [7], which is why a single cascade transformer is probably difficult to realise for the HESR/ENC. Instead of a single cascade transformer, two modularised cascade transformer should be used, as is sketched in Figure 2. The first

Figure 2: Powering the HV-solenoids with a cascade transformer. The left image shows the whole modular power supply, the right drawing shows two modules. The magnetic field is generated by several small HV-solenoids that are mounted along the acceleration/deceleration tube. The HV-solenoids are powered by a cascade transformer. A second cascade transformer generated the acceleration/deceleration voltage. Both cascade transformers are feeded by a turbo generator, whose AC power is adjusted by a chopper at a frequency of 20 kHz for the cascade transformer.

cascade transformer generates the acceleration/deceleration voltage, the second powers 22 HV-solenoids (11 per tube). The potential difference between the individual decks is 60 kV, in total the cascade transformer generates an acceleration/deceleration voltage of 600 kV. In order to achieve the full energy of 4 MV or 8 MV respectively, the modules will be cascaded. Every HV-solenoid consumes a power of 130 W, for the generation of the high voltage a power of 600 W is needed. This results in a total power consumption of 3.5 kW per module. But not only the HV-solenoids require a floating power supply: the power supply for the input side of the cascade transformers must not be grounded either. Therefore, a turbo generator, an assembly of a turbine and a generator, are foreseen to feed the cascade transformers. The turbine is powered by a gas under high pressure, ideally sulphur hexafluoride, consequently driving the generator. In order the minimise the losses during the energy transfer, the mid coil of the cascade transformer is powered. Thus the maximum power which must be transferred through a coil is only 1.75 kW (up and down) instead of the full 3.5 kW. A further advantage which is obtained with the use of turbo generators is that the expanded gas from the turbine can be used for cooling the HV-solenoids.

Although this technology is well known and established, there are also disadvantages:

- All the electronics and HV-solenoids are located on different electrical potential, which is why for the controlling a radio network system, e.g. ZigBee, is required
- Despite the simple structure, the construction is relatively complex due to many connection elements (maintenance)
- Limited space for the vacuum system, BPM, corrector coils etc.

For these reasons, an alternative approach is in discussion,which also allows an easier access the case of repairs.

High-Voltage Column with Unit Elements

In this approach, the power supply should also be built in a modular way, but instead of a cascade transformer which distributes the power to 22 small decks (or HV-solenoids respectively), only one deck, a so-called Separation Box, per module should be used (Figure 3). Each Separation Box sits

Figure 3: Direct powering of the HV-solenoids with a turbo generator. The left image shows a drawing of the entire module with electron gun and collector. On the right two modules, consisting of a Separation Box and two HV-solenoids are shown. The high voltage is generated e.g. by a Cockcroft Walton generator (not shown in the image).

on a defined electrical potential. The potential difference between two Separation Boxes is 600 kV, the distance is 0.7 m. Every Separation Box contains all the electronics of a module. Furthermore, two HV-solenoids are mounted per Separation Box. In this design, the HV-solenoids are composed of four coils. To smooth the variations of the magnetic field, the coils are surrounded with iron. The power consumption of one HV-solenoid is in the range of 1.5 kW to achieve a sufficient value of the magnetic field. A first

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estimation for the required total power per module is 3.6 kW. But also in this design, a floating power supply is necessary to feed the HV-solenoids. As in the first design proposal, turbo generators should be used. But in contrast to the first approach, the turbo generators feed the HV-solenoid and all the other electronics inside the Separation Box directly. For the generation of the acceleration/deceleration a Cockcroft-Walton generator can be considered.

The second design approach allows easier construction and maintenance. Disadvantages are a higher power consumption and the arrangement of the HV-solenoids that demands more attention to the beam optics due to small variations of the magnetic field along the beam axis.

GREEN ENERGY TURBINE

For both concepts, a suitable turbo generator is essential. A research for proper turbo generators has identified the GREEN ENERGY TURBINE (GET) (Figure 4) form the company DEPRAG [8] as a potential candidate, which works with dry air. Further properties of the GET are listed in Table 2.

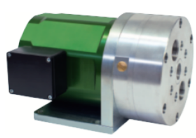

Figure 4: Green Energy Turbine (www.deprag.com).

Table 2: Properties of the GET

Property	Value
Power	5 kW
Pressure (in)	4 bar
Pressure (out)	1 bar
Mass Flow	$4\ \frac{m^3}{min}$

ORGANIC RANKINE CYCLE

A critical point in both concepts is the generation of the pressurised gas. As the high voltage vessel is filled with sulphur hexafluoride, the preferred gas is SF_6, since this reduces the problems e.g. in the case of leaks. Based on the data of the GET, the efficiency was roughly estimated to 12.5 % for a compressor power (air) of 40 kW . If we assume the same specification of the GET for SF_6 as driving gas, a compressor power of 28 kW is required. This results in an efficiency of 18 %, but that is probably an overestimation. However, a low efficiency means high operational cost. Alternatively a Organic Ranking Cycle (ORC) like process could be applied in the case of SF_6. The working principle of an ORC is illustrated in Figure 5. In the first step, the liquid SF_6 is pumped to a heater. In the heater, the SF_6 is heated at constant pressure, so that it vaporises. The vaporised SF_6 expands afterwards in the turbine, which drives

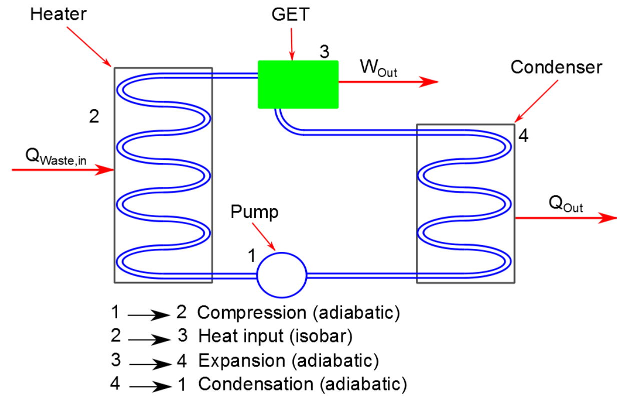

Figure 5: Working Principe of an Organic Rankine Cycle process.

the generator. In the last step the SF_6 is condensed. The advantage in contrast to the compressor is that residual heat of other device at FAIR can be used, which would otherwise be wasted. Hence the operational costs could be reduced significantly.

FURTHER ROAD MAP

Following the design study, a set-up for a single module for the finally preferred design should be built at BINP, with the GET as turbo generator. For the characterisation of the GET, a test set-up at HIM is in preparation. In this set-up, the GET will be powered with air, in and the compressor consumes a power of 40 kW. In addition to the output power, the reliability in continuous operation, the temperature of the expanded gas etc. can also be tested.

For the ORC, a feasibility study in cooperation with the University of Bayreuth is planned. The feasibility study will also determine whether and how the GET must be modified to use of SF_6 as a driving gas.

REFERENCES

[1] PANDA Collaboration, Physics Performance Report for PANDA, Strong Interaction Studies with Antiprotons.

[2] http://www-panda.gsi.de/framework/detector.php

[3] A. Lehrach et al.,"Beam Performance and Luminosity Limitations in the High Energy Storage Ring (HESR)" , STORI'08, Lanzhou, China.

[4] A. Lehrach et al., "The polarized electron-nucleon collider project ENC at GSI/FAIR", 19th International Spin Physics Symposium (SPIN2010), J. Phys: Conf Series 295, 012158 (2011).

[5] "HESR Electron Cooler Design Study", University Uppsala, 2009.

[6] D. Skorobogatov et al.,"The Power Supply System for the Accelerating Column of the 2 MeV Electron Cooler for COSY", RuPAC 2012, WEPPC032, Saint Peterburg, Russia.

[7] J. Dietrich et al., "New Developments in High Energy Electron Cooling", RuPAC 2012, TUCH02, St. Petersburg, Russia.

[8] www.deprag.com