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PHYSICS AND TECHNIQUE OF ACCELERATORS

Pulse Power Supply System for Solenoidal Lenses of Linear Induction Accelerator LIU-20

A. A. Krylov[a], *, M. S. Dmitriev[a], O. V. Belikov[a], Sh. R. Singatulin[a], A. A. Morsin[a], and D. S. Vinnik[a]

[a] *Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia*

**e-mail: A.A.Krylov@inp.nsk.su*

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Abstract—Budker Institute of Nuclear Physics of SB RAS has great experience in building power supplies used for accelerator applications where requirements for precise pulsing current are key features. The power supplies based on a capacitor discharge principle and typically with thyristors as switching element. The described power supply system consists of four charging units and a custom designed controller, it ensures the precision charging of the storage capacitors up to 1200 V of any polarity and switching it to the winding of the magnetic element.

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INTRODUCTION

Linear Inductor Accelerator (LIA-20) is designed to provide several electron bunches with current up to 2 kA and energy up to 20 MeV. It has an extended linear structure about 75 m with 42 accelerating modules. In the process of stage-by-stage acceleration, electron beams focused by the magnetic field of solenoid-type lenses. The lenses are powered by pulsed power supply that provides 1 kA, 3 kGs, 2 ms sinusoidal pulse. Each power supply is a high- voltage device based on capacitor storage and antiparallel thyristors commutator, and each channel has it's own delay, therefore starting moment arranged in time with accuracy better than 0.1 us. The slow control is realized using CAN-BUS, all control units are based on VME uniform crate and placed along the installation.

GENERAL STRUCTURE AND PARAMETRS

High voltage chargers crates are ideally suited for mobile and stationary usage by it's compact construction and universal rack form factor. Up to four slots for HV capacitor chargers can be digitally controlled by the custom crate controller. Each module is connected to the backplane of the crate by a din 41612 specific connector, which delivers module power supply and control signals provide by controller board. As it can be referred from block diagram above, the power system comprises basic components: external AC/DC (500 W), charger units (100 W), capacitor storage with semiconductor switch and set of controllers. Depending on the specifics of the task, the operator can interact with the power supplies through various scenarios. Individual modules are widely used at the accelerator complexes of the INP and have a detailed description in published articles.

DOUBLE POLARITY CAPACITOR CHARGER

A flyback topology was chosen as voltage converter of the charger. Flyback works well with a capacitive loads and makes it easy to obtain high output voltages. Unlike alternative solutions, the flyback charger charges the capacitive load with constant power rather than current. As a result, the storage is charged faster at the same nominal power. The converter of the developed charger uses state of the art GaN power transistor and output SiC Schottky diode, which allows the circuit to operate efficiently at high operating frequency of 250 kHz. Higher frequency increases energy discretization of the storage charge and, as a result, increases the charge accuracy. To overcome the main drawback of the flyback topology, which is possible overvoltage of the switching transistor caused by the energy accumulated in the leakage inductance of the coupled inductor, a non-dissipative LC snubber was implemented in the developed device. This snubber recovers the energy stored in the leakage inductance, thereby increasing the efficiency of the converter. The output bridge commutator was used to switch output voltage polarity of the device. With the bridge commutator there is no need to double whole converter's primary side and snubber circuit in order to get both polarities as it made in the competitor devises.

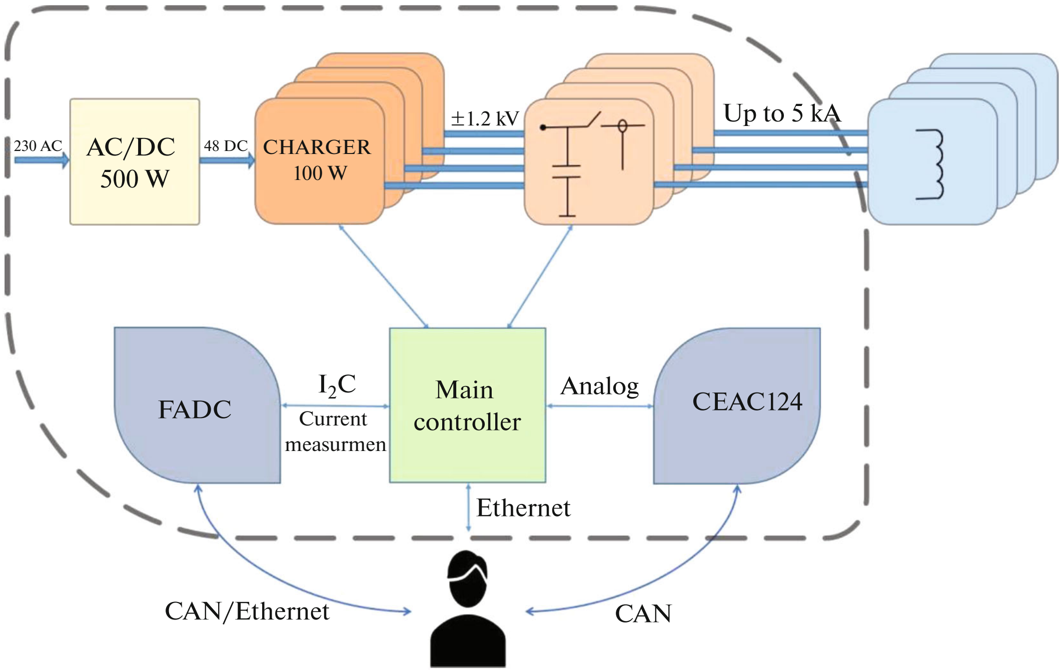

Fig. 1. Structural schematic of power supply system.

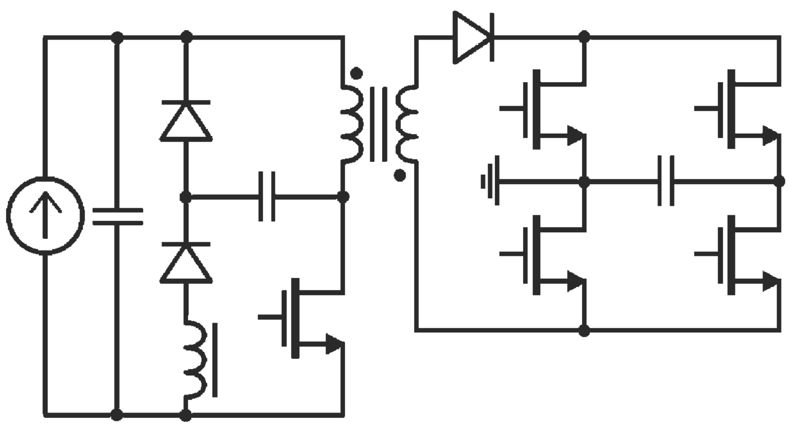

Fig. 2. Double polarity charger topology.

To ensure the stability of the storage charge up to the task voltage, a digital voltage comparator on the ADC is used in the device. The voltage measurement system in the developed device has the following structure: voltage divider–signal buffer–ADC. To improve accuracy, the measuring system provides digital filtering of ADC signals, which consists in storing last eight measurements in the controller registers and then averaging them to smooth out the "jumping" of the least significant bits inherent to the SAR ADC used. Also, to eliminate the influence of electromagnetic interference on measurements, when the voltage of the storage capacitors reaches the value of the task voltage, the controller switches to a mode in which the stages of charging and measurement alternate. Thus, the power converter is switched off and does not generate interference during the measurement. There is a spare backup voltage measurement system in the crate. Analog signals from the buffers on the charger boards

Table 1. Power supplies parameters

Number of channels	4
Repetition frequency, Hz	<1
Maximum amperage, A	5000
Maximum voltage, V	±1200
Current stability, %	<0.05
Charging power (per channel), W	100

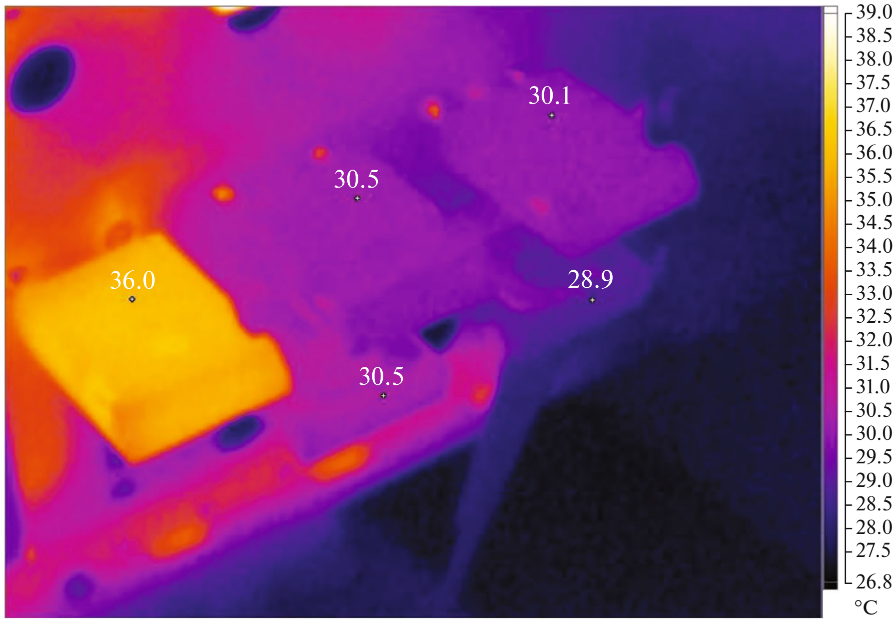

Fig. 3. Thermal measurement without active cooling.

are also transmitted to the controller board, which has an additional ADC.

The maximum efficiency of the converter is 91% (measured in the optimal mode). The overall efficiency of the charger is 76% (measured during a real storage charge cycle). The main losses of the charger occur on the switching elements—the power switch and the output diode. To further increase efficiency, SiC MOSFET transistors were used in the bridge commutator of the device. SiC semiconductor devices have low values of parasitic capacitances, therefore, less energy is lost on these components when recharging parasitic capacitances with a high output voltage. Thermal imager measurements showed almost complete absence of heating of high-voltage SiC switches and SiC Schottky output diode, compared to Si IGBT transistors and Si ultrafast diode. Unlike silicon IGBT transistors, there is no need to install a heat sink on a bridge commutator when using silicon carbide MOSFETs.

CONTROLLER

To service the chargers and the power switches, a control unit has been designed based on CPLD of the MAX V series and the MCU with ARM 32-bit Cortex-M4 core. The use of a CPLD allows us to add 32-bit counters for channel synchronization, simplifies work with a set of independent PWMs, simplifies work with high-speed peripherals (5 ADC with digital filters), and makes it possible to use quick interlocks. Within the charge controller, several features have been added to increase the ease of use and allow for more thorough

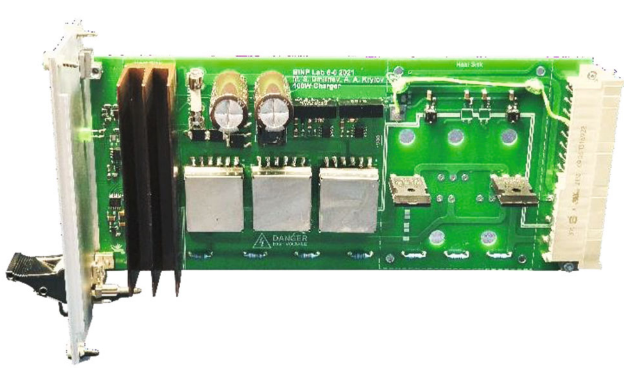

Fig. 4. Double polarity capacitor charger module.

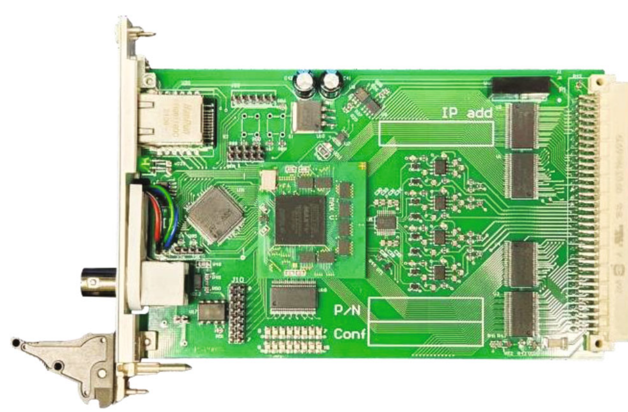

Fig. 5. Main controller module.

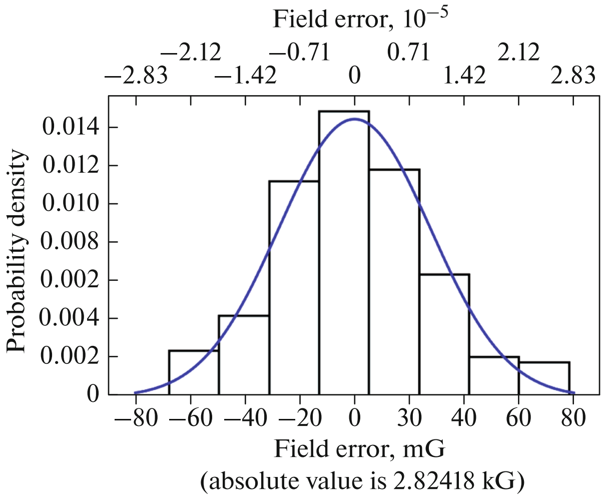

Fig. 6. Field stability measurements with active cooling rack.

testing. MCU runs a web server for monitoring and interacting with power supplies. The controller supports several scenarios for remote control of sources. It can be reference voltage levels, I2C serial bus, Ethernet, and external Bluetooth module.

TEST RESULTS

The stability of charge with the developed devices was checked by measuring the peak value of the magnetic field in a solenoid magnetic lens during the storage discharge onto the lens. Tests were carried out at a charging voltage of 750 V—a mode close to real exploitation on the accelerator. The standard deviation of the field in the test lens was: 61.6 mG (21.8 ppm) in a crate with passive air cooling and 27.7 mG (9.8 ppm) using active air cooling (the fan panel in the rack above the charger crate), with an average absolute field values of 2.82383 and 2.82418 kG, respectively.

Start-up of Linear Induction Accelerator was taken place at Russia in 2019. At present, the power supply system has been launched and is successfully operating with the beam. The power supply system fully satisfies the declared parameters, and easily adapts to the new operating modes of the accelerator. Nowadays, the power supply system is being replicated for new accelerator complexes and is used at local measuring stands at the BINP.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.