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PHYSICS AND TECHNIQUE OF ACCELERATORS

Magnet Power Supply System for the Storage Ring of the SKIF Common Use Center

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Abstract—The power supply system for the electromagnets of the electron storage ring of the SKIF common use center (CUC) includes five types of stabilized current sources totaling 2259. The maximum output current of the power supplies is from 3 to 800 A, the output power is from 70 to 300 kW, and the permissible instability of the output current is from 10 to 100 ppm. For reliable operation of the light source, it is necessary to ensure the stability of the parameters of the current sources, high reliability of operation, and the fast replacing failed power supply source within the same type.

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INTRODUCTION

The storage ring of the SKIF common use center (CUC), with an electron beam energy of 3 GeV, a horizontal emittance of 73 pm rad, and a perimeter of 476 m, is designed to generate intense and bright beams of synchrotron radiation. The magnetic system of the storage ring must ensure the circulation of the beam with an ultralow emittance, compensation of natural chromatism with a large dynamic aperture, correction of the orbit, optics, etc. [1]. The features of the magnetic system are large gradients of quadrupole and sextupole lenses requiring individual power supply (each lens is powered by a separate source) and a high density of magnets in the longitudinal direction. Therefore, the requirements for the quality of the magnetic field are high, and a large number of power supplies for electromagnets with high stability of output parameters are required.

The main power parameters of the magnets are given in Table 1. Dipole magnets are powered in series: all magnets of the same type are powered from the same power source. The remaining magnets are powered individually: each magnet is powered by a separate power source.

1. POWER SOURCES FOR DIPOLE MAGNETS

To power the dipole magnets, three unipolar power supplies with a common structure are used. Power sources differ in power transformers, which determine the maximum output voltage and power, as well as the number of power converters, which determine the maximum output current. The most powerful power supply is used for the BDA family of magnets (Fig. 1).

The maximum output current of the power supply is 800 A; the maximum output voltage is 375 V. The output current is regulated by four step-down pulse converters operating at a frequency of 20 kHz; the maximum output current of the converter is 200 A; the maximum voltage is 400 V. A DC transformer operating at the second harmonic is used as a measuring sensor. The power transformer of the power supply is located in a separate room; the rest is placed in three cabinets with dimensions of 800 × 1000 × 2200 mm^3. The first cabinet contains the switching circuits of the power transformer, the second cabinet houses the power input circuit and converter modules, and the third cabinet houses the output circuits and control electronics.

2. POWER SOURCES OF QUADRUPOLES

All quadrupoles are powered by unipolar sources with a maximum output current of 500 A and a maximum voltage of 20 V (Fig. 2). The output current is regulated by pulse-width modulation of the input voltage by a bridge inverter with a frequency of 20 kHz; a DC transformer developed by the Institute of Nuclear Physics is used as a measuring sensor [2]. Control and

Table 1. Main power supply parameters of magnets

No.	Name		Qty	I, A	U, V	$\frac{\delta I}{I}$, ppm	$\frac{\Delta I}{I}$, ppm
1	Dipole magnets	BDC	32	597	6.54	3	50
		BMA	32	426.1	6.43	3	50
		BDA	64	800	4.43	3	50
2	Quadrupoles	QFA	32	327.59	17.56	10	100
		QDA	32	327.59	17.56	10	100
		AFA	128	327.59	11.14	3	50
		AFC	32	327.59	11.14	3	50
		QFB	32	327.59	11.79	10	100
3	Sextupoli	SFA	32	104.2	3.5	10	100
		SDA/SDB/SDC	160	104.2	4.8	10	100
		SFB/SFC	64	104.2	5.4	10	100
4	Dipole correctors in permanent magnets		16	782	7.51	10	100
5	Stand-alone correctors	CX	32	7	5.2	30	500
		CY	32	7	5.2	30	500
		Skew	32	10	29	30	500
6	Corrective windings in sextupoles	SFA	192	3	1.8	30	500
		SDA/SDB/SDC	960	3	1.95	30	500
		SFB/SFC	384	3	2.25	30	500
7	Dipole correctors in dipoles	BDC	32	3	2.7	30	500
		BMA	32	3	2.7	30	500

(I) Maximum current, (U) maximum voltage, ($\delta I/I$) root mean square value of the permissible level of current ripple in the band from 1 Hz to 1 kHz, and ($\Delta I/I$) permissible drift of the output current in 24 h.

management are carried out via Ethernet from a built-in controller containing the required number of DACs, ADCs, and input/output (I/O) module registers. The blocks are made with water cooling in the Euromechanics design with overall dimensions of 432 × 415 × 178 mm^3.

3. POWER SOURCES OF CORRECTORS

To power stand-alone correctors located in rectilinear gaps, bipolar sources with maximum parameters of ±10 A and ±50 V are used. The power supply developed for the European X-ray free electron laser

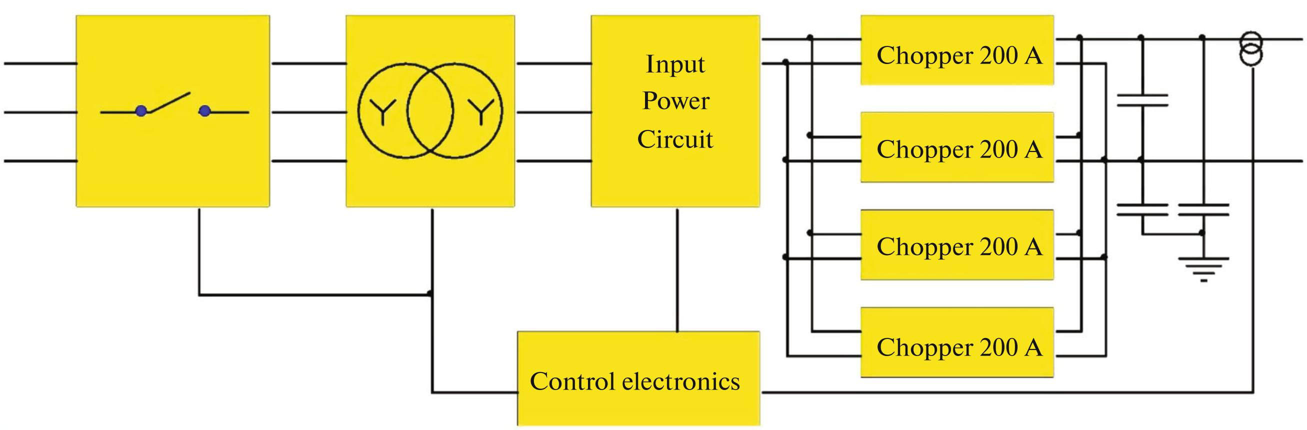

Fig. 1. Block diagram of the power supply for dipole magnets of the BDA family. Composition of the converter: input power transformer with a switching circuit and a circuit for monitoring the heating of the windings; input charging circuit consisting of a circuit for the smooth charging of capacitor banks and a power rectifier; four converter modules connected in parallel of an identical design, which are a capacitor bank, a step-down converter to IGBT, and an output LC filter; output summing circuit with a current meter; and control and protection system.

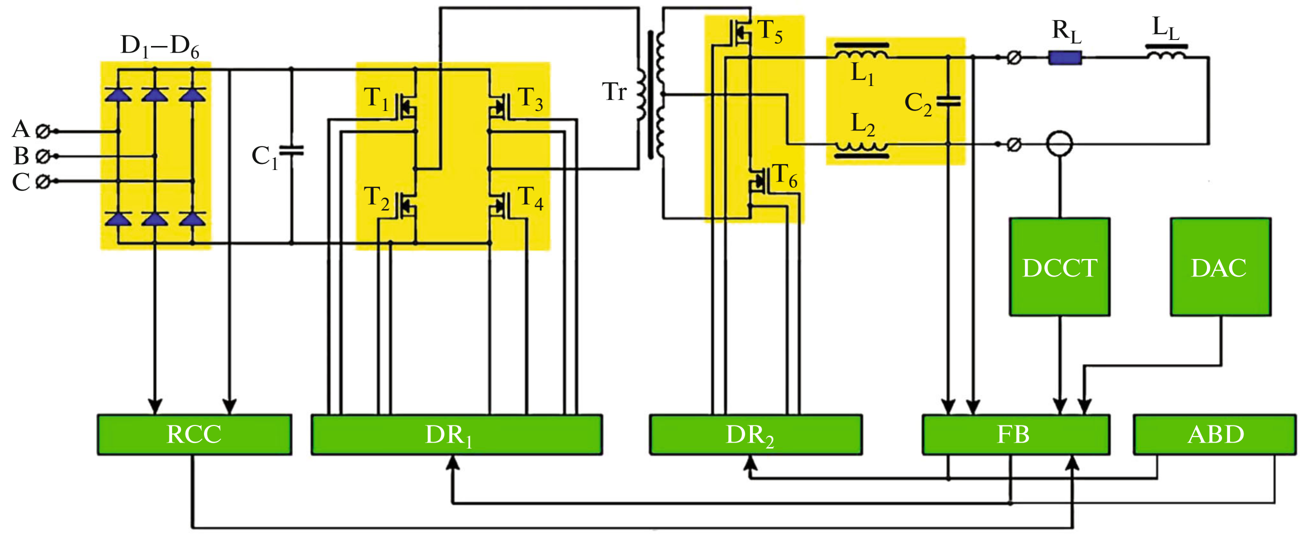

Fig. 2. Structural diagram of the quadrupole power supply. D_1–D_6, three-phase rectifier; T_1–T_4, bridge inverter; Tr, transformer; T_5–T_6, synchronous rectifier; L_1, L_2, C_2, low pass filter; R_L, L_L, load (quadrupole); DCCT, DC transformer; DAC, digital-to-analog converter; RCC, ripple compensation circuit; DR_1, DR_2, drivers of semiconductor switches; FB, feedback module; and ABD, blocking and signaling device.

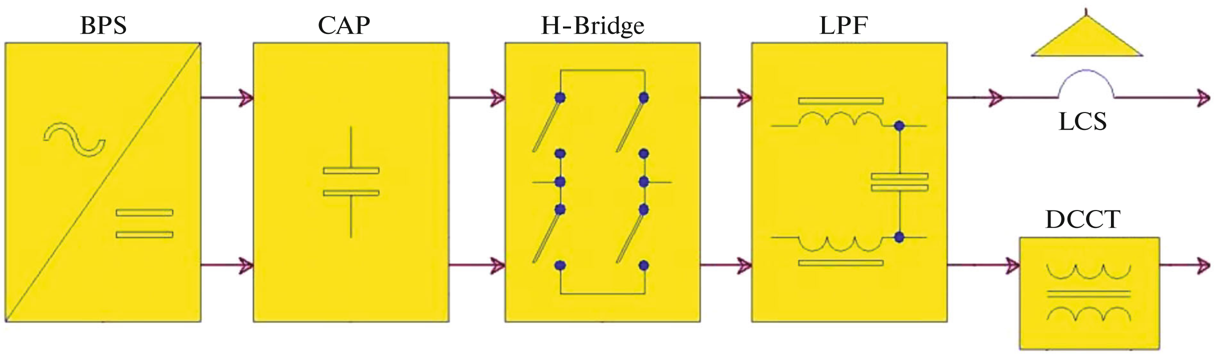

Fig. 3. Block diagram of power supplies of ±10 A. BPS, buffer power supply; CAP, capacitive battery; H-Bridge, bridge inverter; LPF, low pass filter; LCS, noncontact Hall effect current meter; and DCCT, DC transformer.

(XFEL) [3] was taken as the basis for the development. The block diagram is shown in Fig. 3.

The power supply is made according to the double conversion scheme: the AC mains voltage is converted to DC using a buffer power supply and then the DC voltage is converted to DC by a bridge inverter, which regulates the output current at a frequency of 100 kHz. The power supply is designed in the form of a crate in the Euromechanics design with overall dimensions of 432 × 355 × 133 mm^3 and has natural air cooling.

The remaining correctors are made in the form of additional windings wound on each pole of the sextupoles. In addition, each winding is powered from a separate source, which makes it possible to perform dipole, quadrupole, and skew-quadrupole corrections on one lens by setting different currents in the lens windings. Such correctors are powered from bipolar sources with maximum parameters of ±3 A and ±24 V. The structure of power sources is similar to the structure of ±10 A sources and differs in multichannel design: six bridge inverters are powered from one buffer source.

Power supplies have digital feedback. Control and management of power supplies is carried out via the SPI interface from the built-in controllers, which include an I/O module, a processor-interface module (PIM), and a processor module (PM) of the VAR-SOM-MX8MN type manufactured by Variscite. The MBB board is designed to coordinate the interaction interface between the power source and the processor part of the device (PM and PIM); the PM board provides the device with Linux OS, which allows one to implement the lower level of the control system on the basis of the controller. The PIM board has an Ethernet interface for quick interaction with control server.

The speed is necessary for the use of correctors in the closed orbit stabilization system; according to the data from the beam position sensors, it is planned to close the slow feedback through the server in the band often no less than 10 Hz. To quickly correct the beam position in the frequency band up to 10 kHz, 64 standalone correctors on a ferrite magnetic circuit will be used, and their power supply is planned from linear current sources.

4. POWER SOURCES OF SEXTUPOLES AND DIPOLE CORRECTORS IN PERMANENT MAGNETS

To power the sextupoles and dipole correctors in permanent magnets, commercially available AC-to-DC converters are used. The output current is stabilized by an external controller, to which a noncontact current meter is connected. The controller regulates the output current by changing the reference to the voltage converter.

5. CONCLUSIONS

The design of the power supply system for magnets has been completed and prototypes of power sources have been manufactured; tests are underway. The serial production of power supplies has begun, the completion of which is scheduled for 2023. Once the engineering facilities of the SKIF CUC are ready, the installation and launch of the power supply system will begin.

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