CORRECTOR MAGNET POWER SUPPLIES OF THE EUROPEAN XFEL

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Abstract

The total length of the European XFEL is 3.4 km. The electron beam parameters are corrected by about 300 corrector magnets, each powered by an individual power supply. BINP performed the development, production and delivery of the power supply system for the corrector magnets. For the powering of the corrector magnets, seven types of precision power supplies with output currents of up to 10 A and output voltages of up to 70 V were developed.

INTRODUCTION

The European X-ray Free-Electron Laser (XFEL) is designed for generation of synchrotron radiation with an intensity of 27 000 bunches per second, a wavelength of 0.05 to 4.7 nm, and a peak brightness of $5\cdot10^{33}$ ph/(s·mm^2·mrad^2·0.1% bandwidth). To attain the above parameters it is necessary to have an electron beam of extreme quality [1]. The XFEL structure comprises a linear superconducting accelerator with a maximum electron energy of 17.5 GeV, several photon tunnels with undulators, and experiments halls. The total length of the tunnels is 5.77 km (Fig. 1). The XFEL magnetic system structure includes 296 corrector electromagnets:

- Injector tunnel (XTIN) – 13 pcs.
- Entrance shaft (XSE) – 12 pcs.
- Linac tunnel (XTL) – 122 pcs.
- Shaft 1 (XS1) – 35 pcs.
- Distribution tunnel 1 (XTD1) – 32 pcs.
- Distribution tunnel 2 (XTD2) – 44 pcs.
- Distribution tunnel 3 (XTD3) – 22 pcs.
- Distribution tunnel 4 (XTD4) – 7 pcs.
- Distribution tunnel 5 (XTD5) – 9 pcs.

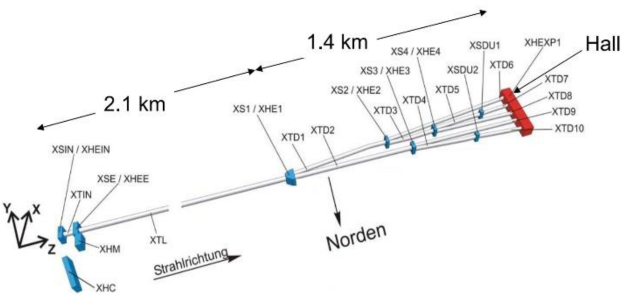

Figure 1: XFEL nomenclature.

In accordance with the requirements to the magnetic system, each corrector electromagnet shall be powered by a separate precision current source (magnet power supply, MPS). The MPS required parameters are given in Table 1.

Table 1: Requirements to Corrector Power Supplies

Parameter	**Specified Value**	**Unit**
Output current, max.	± 5 / 10	A
Output voltage, max.	± 70 / 60	V
Minimum current setting step	< 4	ppm
Short-term current deviations (up to 1 sec)	< 10	ppm
Long-term current deviation (1 sec to several years)	< 100	ppm
Temperature coefficient of output current drift	< 6	ppm/K
Output current non-linearity	< 20	ppm
Efficiency of power part	> 90	%
Mean time between failures (MTBF)	> 100 000	hrs

STRUCTURE OF POWER SUPPLIES

The power supplies for the XFEL corrector magnets are divided into two groups, with maximum output currents of 5 A and 10 A. Since the corrector electromagnets have different resistances, power supplies with different maximum output voltages were required. The result is seven types of the power supplies, the maximum values of their output parameters shown in Table 2.

Table 2: Maximum output currents and voltages of power supplies.

Power supply	**Maximum output current, A**	**Maximum output voltage, V**
MPS-5-24	5	24
MPS-5-48	5	48
MPS-5-72	5	72
MPS-10-15	10	15
MPS-10-30	10	30
MPS-10-45	10	45

The circuitry design relies on double pulse conversion (Fig. 2).

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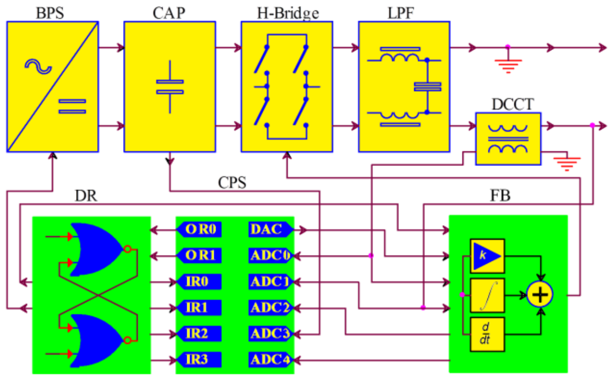

Figure 2: MPS structure. BPS – Bulk power supply, CAP – Capacitor, H-Bridge – H-Bridge inverter, LPF – Low-pass filter, DCCT – Direct Current-Current Transformer, DR – Digital Regulator, CPS – Controller Power Supply, FB – Feedback module, OR – Output register, IR – Input register, DAC – Digital-to-analog converter, ADC – Analog-to-digital converter.

The alternating voltage of the mains is converted into a DC voltage using a BPS, which consists of several Alternating current - Direct current (AC-DC) converters. The maximum output voltage of the power supply is set by the BPS module. The output current regulation is performed via pulse-width modulation of the output voltage of the H-Bridge inverter with a frequency of 100 kHz. The carrier frequency ripples are suppressed by a passive second-order filter, LPF. There is a Direct Current-Current Transformer, which is used in the main loop of the current feedback. The required accuracy of the output current is provided by the Feedback module, which includes a proportional link and an integral one. Mains ripples (50 ÷ 300 Hz) are suppressed with an additional loop of the voltage feedback. The output current regulation constants are set using a mezzanine in dependence on the power supply load parameters. The inductance of the coils of the XFEL corrector magnets varies from 100 mkH to 15 H. Four types of mezzanines were selected for this range of loads; they are installed in the Feedback module.

The DR module is used to generate the PWM signal. The value of the output voltage of the H-Bridge inverter is defined by two PWM channels: the first and second PWM channels set the high pulse and low pulse duration, respectively. Therefore, we have three voltage values in the H-Bridge Inverter output voltage oscillogram (Fig. 3): $+U_{BPS}$, $-U_{BPS}$ and 0 V. This method of forming a PWM signal allows us to have low ripples of the power supply output voltage at low output currents.

The power supply is controlled by an embedded controller CPS [2] via the CANbus interface. The controller includes an 18-bit digital-to-analog converter (DAC), a 6-channel 24-bit analog-to-digital converter (ADC), and input and output registers of discrete signals.

Figure 3: Oscillogram of H-Bridge Inverter output voltage.

CONSTRUCTIVE OF SUPPLY SYSTEM FOR CORRECTOR MAGNETS

All the power supplies are implemented in 432×355×133 mm^3 Euromechanics crates (Fig. 4).

Figure 4: Magnet power supply.

The structural parts are designed as modular devices. Some modular devices are made as universal, for different types of power supplies. The commutation of the modular devices is done by the Motherboard.

The power supply system for the XFEL corrector magnets consists of 48 2000×800×600 mm^3 Varistar racks (Pentair/Schroff). One rack comprises up to seven power supplies for the corrector magnets, a reserved power supply, and a redundancy system crate. The redundancy system [3] is intended to reduce XFEL downtimes caused by malfunction of the power supplies. The redundancy system crate enables remote replacement of any of the seven power supplies by the spare one.

CONCLUSION

The Power Supply Prototypes were successfully tested in Novosibirsk and Hamburg. The compliance with the requirements to power supplies for the XFEL corrector magnets was tested at BINP and DESY. The compliance with CE certification standards was checked at the EMC Laboratory "TUV NORD" (Hamburg) [4]. After all the

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tests, a permit to manufacture the power supplies was signed.

387 power supplies for the corrector magnets have been produced, tuned and delivered to XFEL:

- 296 power supplies to feed corrector magnets.
- 48 power supplies to work in the redundancy system
- 43 spare power supplies

The power supply system for the corrector magnets has been assembled and tested.

ACKNOWLEDGMENT

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