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THE SUPERCONDUCTING UNDULATOR CONTROL SYSTEM FOR THE EUROPEAN XFEL

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Abstract

The European XFEL development program includes the implementation of an afterburner based on superconducting undulator (SCU) technology for the SASE 2 hard X-ray permanent-magnet undulator (PMU) system. The design and production of the first SCU prototype, called PRE-SerieS prOtotype (S-PRESSO), together with the required control system, are currently underway. The architecture, key parameters, and detailed description of the functionality of the S-PRESSO control system are discussed in this paper.

PROJECT OVERVIEW

As an initial step to realize the SCU afterburner project [1], the S-PRESSO module [2] will be manufactured by Bilfinger Noell GmbH, characterized, and installed at the European XFEL facility. The project entails the incorporation of six SCU cells into the existing SASE 2 undulator line. They are planned to be installed right after the last PMU cell.

The overview of the future tunnel installation is presented in Fig. 1.

Superconducting Undulator Cold Mass

Each SCU unit houses two pairs of two-meter-long superconducting undulator coils, with the superconducting coils-based phase shifter (PS) and Helmholtz coils (HH) in between. The whole assembly together with the number of correction and shimming coils constitutes an SCU magnet system, which is incorporated into a mechanical structure (cold mass) whose function is to keep tight mechanical tolerances to assure the quality of the magnetic field. The cold mass is enclosed in the cryostat and cooled down to 4 K by means of the second stage of three cryocoolers. The electron beam chamber (EBC) is cooled by the second stage of another three cryocoolers. The first stage of all six cryocoolers is used to keep the desired temperature of ~50 K in the cryostat. Figure 2 shows the schematic view of the S-PRESSO magnet system, while Table 1 compiles the main parameters of S-PRESSO.

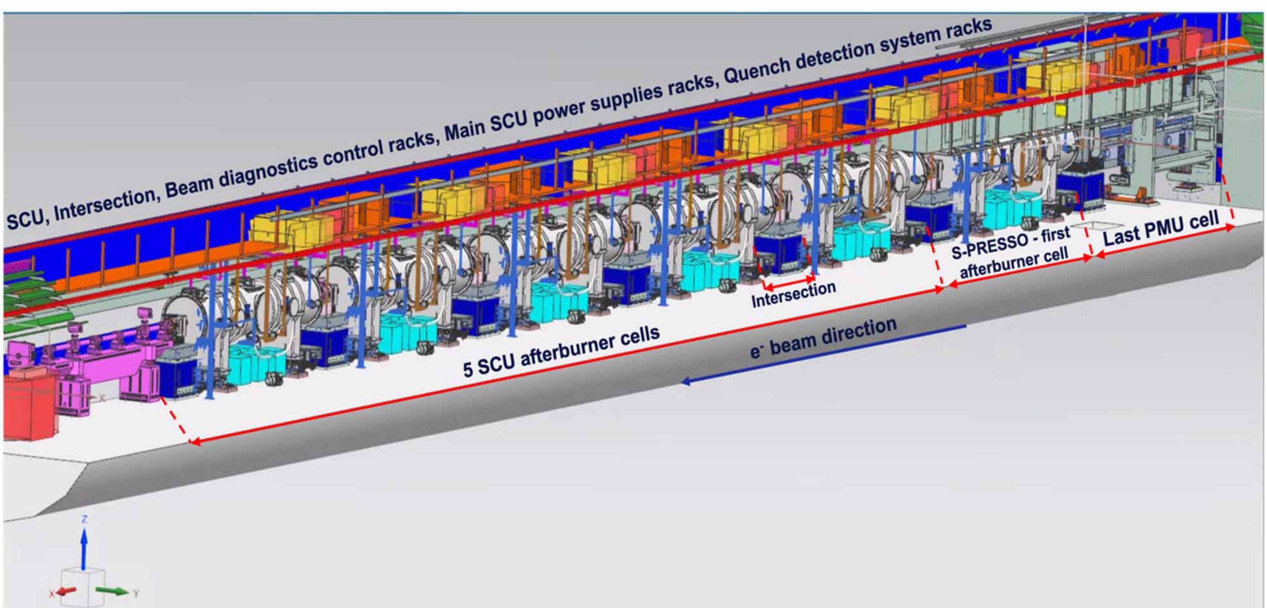

Figure 1: General overview of the SCU afterburner components installation in the tunnel including the control racks.

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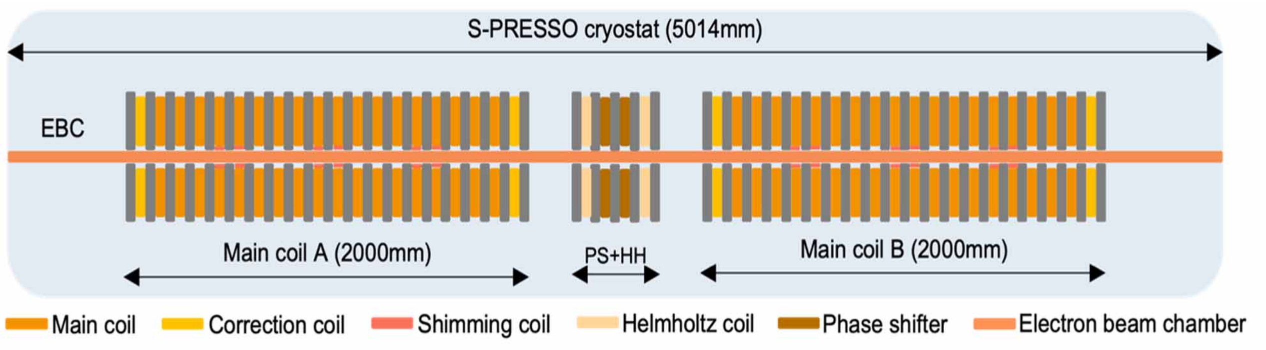

Figure 2: Simplified schematic view of the S-PRESSO magnet system.

Table 1: S-PRESSO Design Main Parameters

Parameter	Value	Unit
Period length λ_U	18	mm
Max. magnetic field	1.82	T
K value	3.1	
Vacuum gap	5	mm

S-PRESSO CONTROL SYSTEM

For a reliable operation of S-PRESSO and the future five SCU modules in the tunnel as a part of the existing undulator line, the same undulator control system architecture is planned to be implemented [3]. This concept is designed based on the Beckhoff automation solution using the TwinCAT Programmable Logic Controller (PLC) development environment. The decision was taken due to the reliable and sustainable operation of the existing undulator systems over the last six years as well as the fact that the SCU afterburner undulator cells must be integrated into the existing undulator system. As it is implemented in the existing undulator systems, the concept contains two main subsystems: the global and the local control system each covering their dedicated goals which are described in [3, 4]. The hardware component of the local control system is shown in Fig. 3. The local control system hardware layer is based on the Beckhoff Automation GmbH industrial solution. The S-PRESSO Control Rack (SCR) was designed and will be prototyped at the beginning of 2024. The layout of SCR is presented in Fig. 4: The following hardware subsystems are included in the layer called “Basic components needed for the undulator operation in the tunnel” mentioned in Fig. 3:

- Connection to the intersection control rack (ICR) over the EtherCAT interface.
- Camshaft mover control - 5 axes.
- Control of four correction coil power supplies, which will also be used for the heaters on the cold mass and shield, to warm up the system.
- C6925-0030 Accu-Pack, for Industrial PC (IPC) safe shutdown in case of power loss or glitch.
- Switch off/reboot neighbor SCR.
- Fire detection system with the SCR door switches monitoring function.

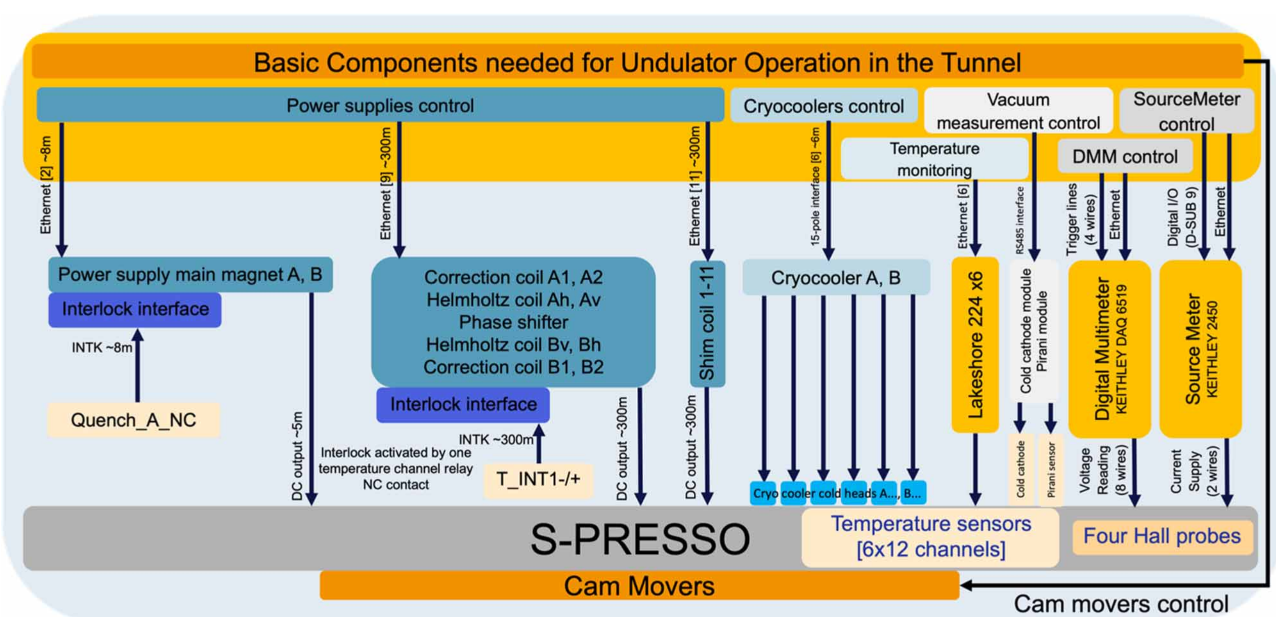

Figure 3: Simplified diagram of the S-PRESSO local control system in the tunnel.

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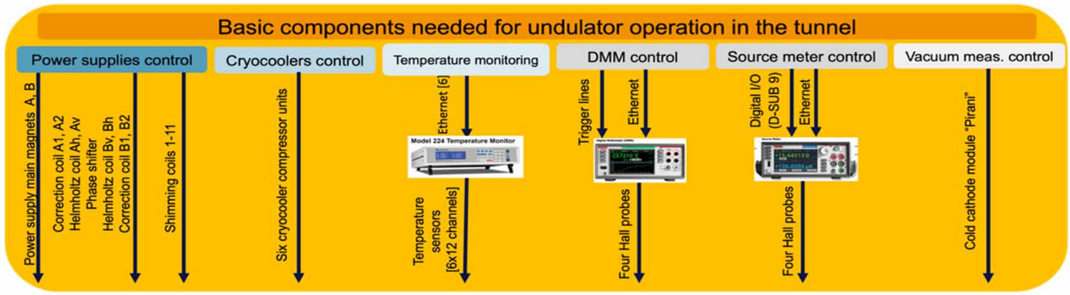

Figure 4: Layout of the S-PRESSO (SCR) control rack.

Table 2: S-PRESSO Main Components Intended to be Integrated into the Local Control System

System Description	Interface
Two PSs main magnet A, B	Ethernet
Two main PSs QD systems	Interlock signal
Two PSs correction coil A1, A2	MicroTCA/Ethernet
Two PSs correction coil B1, B2	MicroTCA/Ethernet
Two PSs Helmholtz coil Ahor, Aver	MicroTCA/Ethernet
Two PSs Helmholtz coil Bhor, Bver	MicroTCA/Ethernet
PS phase shifter coil	MicroTCA/Ethernet
Eleven PSs shimming coils 1-11	MicroTCA/Ethernet
Six temperature Monitors (Lake Shore Model 224)	Ethernet
Two turbo pump controllers	RS485
Six cryocooler compressors	15-pole interface
Vacuum measurement controller	RS485
Four Hall probes up/downstream	Direct wired

The main intersection components controlled via the ICR are permanent magnet-based phase shifters, quadrupole mover, and air coils. The 5-axis camshaft mover is a mechatronic system, that allows adjustments of the undulator with respect to a reference axis. The local control system is designed to merge several main specifically S-PRESSO-related subsystems. The main components with their interfaces and protocols including the hardware needed for monitoring the crucial parameters for the save operation are compiled in Table 2.

All control system racks that contain hardware components of the local control system such as SCR, ICR, Diagnostics Control Rack (DCR), as well as the S-PRESSO main Power Supply Rack (SPSR) and S-PRESSO Quench Detection Rack (SQDR) will be installed on the support structure above the S-PRESSO cell in the same way as it is done for the PMU cells. The overview of the tunnel installation is presented in Fig. 5.

To be able to operate the undulator system either from the accelerator or the experiment side, there is an interface implemented using the Distributed Object-Oriented Control System - DOOCS software framework, which is built for creating accelerator-based control system applications [5]. The existing undulator end-user GUI is made use of the Java DOOCS Data Display – JDDD framework [5]. Since the SCU afterburner will become a part of the SASE2 undulator system, the same architecture is planned to be implemented.

Power Supplies

The precise control of the main and auxiliary power supplies (PS) to set and monitor the current in the SCU coils, which in fact leads to generating the desired on-axis magnetic fields, is the core part dedicated to the S-PRESSO local control system. In total, there are two main and twenty auxiliary power supplies which have to be precisely and synchronously controlled. The parameters of the main power supplies are listed in Table 3.

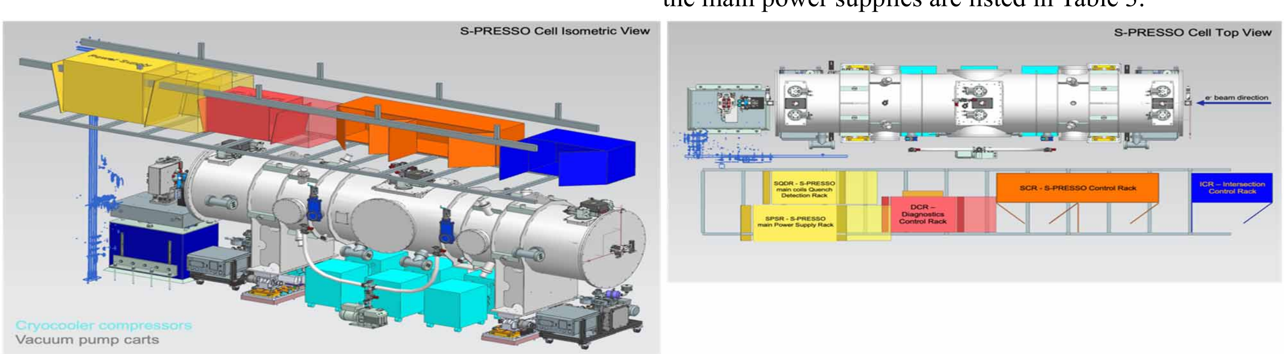

Figure 5: Overview of the S-PRESSO installation in the tunnel. The following control racks will be involved in the operation of the S-PRESSO cell: S-PRESSO main coils Quench Detection Rack (SQDR), S-PRESSO main Power Supply Rack (SPSR), Diagnostics Control Rack (DCR), S-PRESSO Control Rack (SCR), Intersection Control Rack (ICR).

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Table 3: S-PRESSO Main Power Supplies Parameters

System Description	Interface
Infeed	1 infeeds 3x400 V ±10%, 50… 60 Hz, 13.9 kW, max. input current 20 A. 1 infeed 24 VDC 1W or 1x230 V (QD)
Maximum output power	14.4 kW
Efficiency	>90% @ full load
Cooling	water cooled
Composition	one 1000 A, 10 V module
Max. output current	1000 A
Max. output voltage	10 V
Current drift stability	< 5 ppm/FS (30 min) < 10 ppm/FS (24 hours)
Current Reproducibility	< 20 ppm/FS
Temperature Dependence	< 2 ppm/°C
Voltage ripple	< 0.04% of Vout @ 300 Hz

The main power supplies with the quench detection (QD) systems are a third-party component that will be a part of the S-PRESSO delivery, while the auxiliary power supplies will be provided by DESY (Deutsches Elektronen-Synchrotron). The auxiliary power supplies are typically controlled via the open and modular electronics standard MicroTCA, which permits high-performance and reliable data processing and control operations to be carried out at large-scale scientific research facilities. For the S-PRESSO functioning and integration into the SASE 2 undulator line, the synchronous operation of the main and the auxiliary power supplies within the sub-second precision is required. To complete this task, an implementation of a combined EtherCAT field bus with the computing architecture MicroTCA solution is currently under discussion.

Quench Detection Systems and Interlock Signals

In the case of a quench, which is a termination of electromagnet operation, that happens when a section of the superconducting coil switches into a normal (resistive) state, the power supply's output is deactivated via its interlock signal. The stored energy is dissipated within the coils which in the case of the main ones are protected by a set of dedicated diodes implemented in order to reduce the quench voltage. A set of potential taps is arranged to detect a quench within the magnet system. Voltage taps and relay channels of temperature monitors constitute the most critical safety components of the interlock system. The voltage taps are fed into the quench detection units, which in turn are hardwired to the corresponding main power supply. The relay channels of temperature monitors are also hardwired to the main power supplies. Those signals are used as interlocks in the two following specific conditions: when the operational temperatures have not been achieved or when there is a temperature increase that could potentially result in a quench. The Interlock loop incorporating NC contacts from quench detection and relay channels of temperature monitors protects the main coils, while the auxiliary coils are protected via the corresponding interlock channel activated by one of the NC temperature channel relays only.

CONCLUSION AND OUTLOOK

The conceptual design as well as the software and hardware architecture layout of the local and global control systems of the SCU afterburner project are currently being finalised. As an outcome, the S-PRESSO control rack (SCR) is designed by Beckhoff Automation GmbH in collaboration with Bilfinger Noell GmbH and the European XFEL GmbH. The same type of Intersection components as for the existing undulator system will be used for the SCU afterburner project including their control system, which will be integrated into the SCU local control system. The main components are permanent magnet-based phase shifters, quadrupole mover, and air coils as well as the intersection control rack which encloses the necessary control system hardware. The control system is designed based on more than six years of experience operating the existing undulator systems, planning the smooth integration of the first SCU module, S-PRESSO, during the regular maintenance period without interruption of the facility operation. During the approximately six-month shutdown period, which is scheduled for 2025, the necessary infrastructure for the SCU afterburner project is planned to be installed in the tunnel.

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