RADIATION SAFETY INTERLOCK SYSTEM FOR SACLA (XFEL/SPRING-8)

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Abstract

SACLA (SPring-8 Angstrom Compact free electron Laser), which comprises an 8 GeV linear accelerator and undulators, was constructed. Its radiation safety interlock system was designed to protect personnel from radiation hazards. This system controls access to an accelerator tunnel and monitors safety devices. It controls permission signals for accelerator systems in accordance with safety conditions. When a safety condition is not satisfied, the system turns off the permission signal, thereby terminating the electron beam. In particular, when the bending magnets controlling the beam transport route are not properly excited, the system must terminate the beam within 16.6 ms. Therefore, as part of this system, a beam route interlock was constructed to rapidly evaluate the correctness of the beam route. We developed a new optical module to transmit the permission signal at high speeds, over a long distance. The system achieved a response time of less than 6.7 ms.

INTRODUCTION

SACLA was constructed at the SPring-8 site. It generates high-intensity X-ray lasers using an 8 GeV linear accelerator and undulators. Beam commissioning began at the end of February 2011 [1]. The layout of SACLA is shown in Figure 1. The electron beam is generated by an electron gun (GUN) with a repetition rate of up to 60 Hz. The beam is accelerated to 8 GeV by the following series of RF accelerator cavities: pre-buncher (238 MHz), booster (476 MHz), L-band (1428 MHz), S-band (2856 MHz), and C-band (5712 MHz). The accelerated beam is switched by a switching magnet into two beamlines: BL1 and BL3. The beam is injected into the undulator to generate X-ray lasers that are transported to the experimental facility. Finally, the electron beam is bent toward a beam dump by a dump magnet and then safely disposed.

To protect personnel from radiation hazards, the radiation safety interlock system (safety interlock system) was designed and constructed [2] [3]. The safety interlock system manages access control and monitors safety devices. It controls permission signals for accelerator systems in accordance with safety conditions. When permission signals are turned off, the operations of the GUN, beam chopper, and RF are inhibited.

The safety interlock system needs to be reliable and stable. In addition, the system requires specific functionality, as described below.

First, fast beam termination is required. When the electron beam deviates from the beam dump, the electron beam generates unexpected radiation. Therefore, when this situation is detected, the next beam injection should be avoided, i.e., the safety interlock system needs to terminate the electron beam within 16.6 ms.

The other specific functionality concerns the transmission line of the permission signal. SACLA is a large facility whose total length is approximately 700 m. The accelerator section is approximately 400 m long. Within the klystron gallery of this section, 73 RF systems are distributed and placed. Thus, the permission signal must be transmitted over a long distance to a large number of accelerator systems. Moreover, to achieve fast beam termination, a high transmission speed is required.

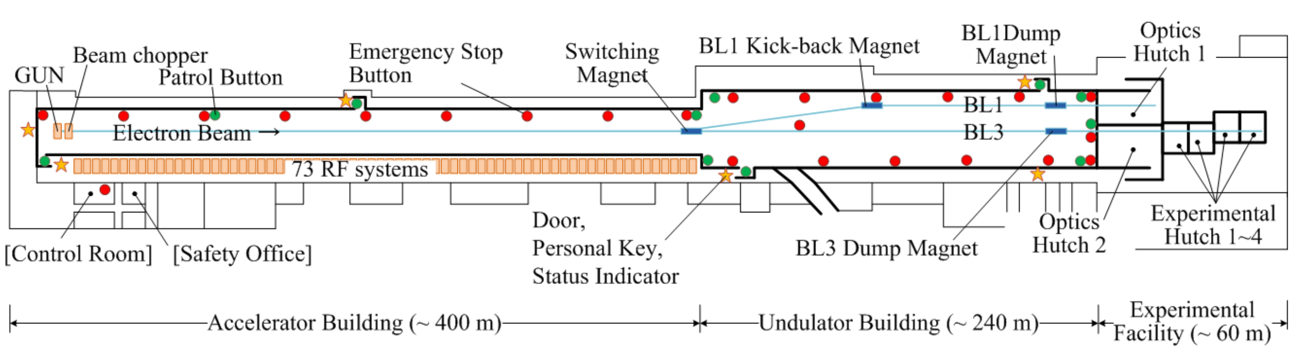

Figure 1: Layout of SACLA and the equipment related to the radiation safety interlock system.

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SAFETY INTERLOCK SYSTEM

Overview

We constructed the safety interlock system which consists of the following three interlock systems and a permission transmission system: a central interlock system (CIS), an emergency interlock system (EIS), and a beam route interlock system (BIS). Figure 2 shows a schematic view of the safety interlock system.

The CIS supervises the doors of the accelerator tunnel, personal keys, patrol buttons, status indicators, the safety signal from the beamline interlock system, and other safety systems, such as the radiation monitoring system. The CIS provides the access control to the accelerator tunnel, search confirmation, and indications about the accelerator operation.

The EIS monitors the emergency stop buttons. When an emergency stop button is pushed, all permission signals are turned off.

The BIS supervises the current of the electromagnets. To ensure that the electron beam is discarded into the beam dump, the BIS evaluates the beam route based on the excitation status of four electromagnets: the BL1 and BL3 dump magnets, the switching magnet, and the kickback magnet. If the dump magnet is not properly excited, the electron beam deviates from the beam dump core. In this case, the BIS turns off the permission signal for the GUN and the beam chopper within 16.6 ms.

The permission transmission system transmits the permission signal to the GUN, beam chopper, and 73 RF systems distributed over 400 m.

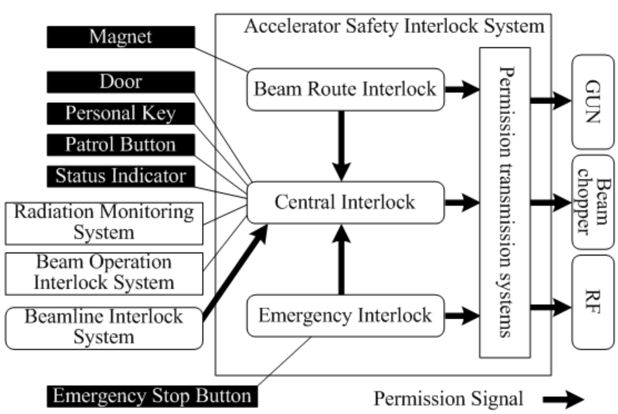

Figure 2: Schematic of the radiation safety interlock system.

The safety interlock system is required to be reliable and stable. At the SPring-8 site, programmable logic controllers (PLCs, Mitsubishi) have been used to construct interlock systems for 5 accelerators and over 50 beamlines [4]. PLC networks (MELSECNET/H) have also been utilized to input/output status signals from distant locations. We have operated them for over 14 years. PLCs present very few problems during their operation. Based on our experience, PLC-based systems are highly reliable and stable. Thus, to take advantage of these attractive characteristics, we based the CIS, EIS, and BIS development on PLCs.

Beam Route Interlock System

The BIS requires fast beam termination. However, this is difficult to achieve using PLC networks because the communication time is slower than the required response time. In addition, the PLC processing time depends on the size of the ladder program. Thus, we designed the BIS shown in Figure 3.

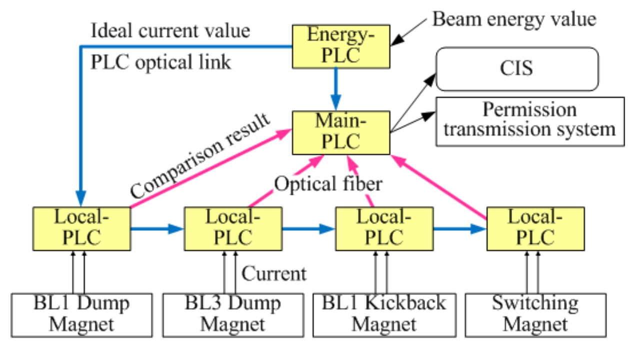

Figure 3: Schematic of the beam route interlock system.

We used several PLCs: Energy-PLC, Main-PLC, and Local-PLCs. The Energy-PLC and Main-PLC were installed in the safety office. The Local-PLCs were installed in the rack located near the power supply of the magnet approximately 600 m from the safety office. An optical PLC network used for data communication in slow control applications was used to connect the PLCs. The Energy-PLC executes high-load tasks, such as calculating the ideal currents for the magnets. The ideal current values are delivered to the Local-PLC via the PLC network. The Local-PLC inputs an analog signal proportional to the current of the magnet and compares the ideal value with the measured value. Then, the comparison result is sent to the Main-PLC. Because PLC networks cannot transmit signals within a few milliseconds, we used a direct fiber optic I/O connection between the Local-PLC and Main-PLC. The Main-PLC evaluates the beam route based on the comparison results and generates the permission signal.

We measured the response time of each device. The response times of the Main-PLC and the Local-PLC were both less than 3.0 ms.

Permission Transmission System

The permission signals for the GUN, beam chopper, and RF systems are generated by each interlock system. To achieve fast beam termination, the permission signals for the GUN and beam chopper must be stable and must have fast transmission speeds. Conversely, the permission signal for the RF systems is required to transmit over long distances and to a large number of systems. Therefore, PLC networks or metal cables cannot be used in the transmission line.

Thus, we developed a new optical module to transmit the permission signals and used it to construct the permission transmission, as shown in Figure 4. There are three permission transmission lines for the GUN, beam chopper, and RF systems. Permission signals are sent from the CIS, first, to module (A), and then, to module (C) via module (B). Module (C) outputs the signals to the target devices. Permission signals are transmitted from the EIS and BIS by inputting them to module (B) of the GUN and RF systems.

Two optical-fiber cables were used to connect the modules and ensure signal transfer. One of the fibers was used to send a static signal and the other was used to transmit the pulse signal (1 kHz) of the heartbeat. The transmission line for the RF systems used a total of 76 modules, and the total length of the optical fiber was more than 1.5 km.

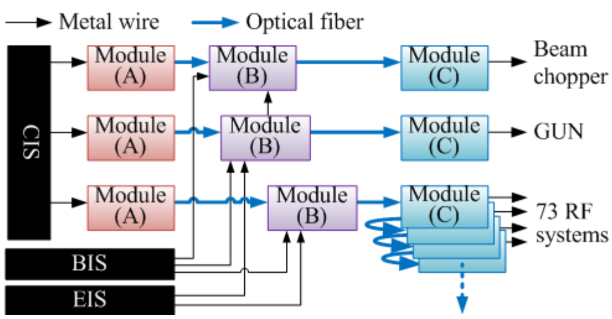

Figure 4: Schematic of the permission transmission system.

Figure 5: The newly developed module with a rack-mount unit of size 2U.

Figure 5 shows the developed module. A complex programmable logic device (CPLD) was utilized to reduce the processing time. To avoid noise, the circuit board was carefully designed. The modules are connected in a daisy-chain scheme and the distance between modules can be extended to up to 1 km. In the case of RF systems, the measured transmission delay time was less than 0.3 ms.

To verify reliability and stability, we conducted several tests, such as the electrical fast transient/burst test (international standard IEC 61000 4-4) and the long time operation test in the SCSS test accelerator [5]. The module passed all the tests.

MEASUREMENT OF RESPONSE TIME

We tested the total response time of the BIS and the permission transmission system. We chose the Local-PLC for the BL3 dump because it had the longest wiring from the Main-PLC. We measured the response time from the interlock action of the Local-PLC to outputting a permission signal from the module for the beam chopper. Figure 6 shows the 10,000 measurements obtained. The slowest response time measured was 6.7 ms, clearly satisfying the target value of 16.6 ms.

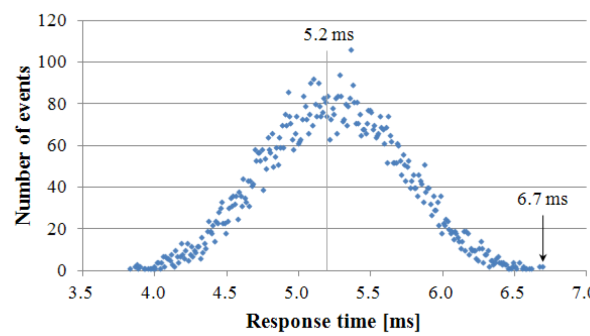

Figure 6: Total response time of the BIS and permission transmission system. The average response time was 5.2 ms with a standard deviation of 0.8 ms. The slowest value measured was 6.7 ms.

CONCLUSION

We constructed a radiation safety interlock system for SACLA. To stop the electron beam injection within 16.6 ms, an interlock system using multi-PLCs and an optical module were developed. The optical module was able to transmit a permission signal over a long distance to numerous accelerator systems. The radiation safety interlock system achieved a response time of less than 6.7 ms. The operation of the system commenced at the end of February 2011.

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