DESIGN OF THE ACCELERATOR SAFETY INTERLOCK SYSTEM FOR XFEL IN SPring-8

M. Kago, T. Matsusita, N. Nariyama, C. Saji, R. Tanaka,
JASRI, XFEL Joint Project /SPring-8, Hyogo, Japan
Y. Asano, T. Fukui, T. Itoga, RIKEN, XFEL Joint Project /SPring-8, Hyogo, Japan

Abstract

The accelerator safety interlock system (ASIS) for the X-ray free electron laser (XFEL) at SPring-8 protects personnel from radiation hazards. We developed an ASIS consisting of three interlock systems: a central interlock system (CIS), an emergency interlock system (EIS), and a beam route interlock system (BIS). The CIS and EIS monitor the safety equipment status and emergency stop buttons, respectively. The BIS monitors the consistency between the predefined electron beam route to the downstream insertion devices and the actual transport route. If the state is unsafe, these systems do not permit accelerator operation and they stop the electron beam. The ASIS is required to stop the electron beam within 16.6 ms. Therefore, we developed an optical module to transmit high-speed stop signals.

INTRODUCTION

The X-ray free electron laser (XFEL) facility at SPring-8 is currently under construction. Figure 1 shows the plan of the XFEL building and installation location of the equipment. The electron beam is injected from the 500 kV electron gun (GUN) and is boosted to 8 GeV by the linear accelerator. The boosted electron beam is switched to the beamline (BL) with a bending magnet. The maximum repetition frequency of the electron beam is designed to be 60 Hz, and the bending magnet switches the direction of the electron beam between BL1 and BL3. In the final plan, the electron beam is switched among five BLs, which are indicated by dashed lines in Fig. 1. The switched electron beam is injected into the undulator to generate XFEL radiation and is dumped at a beam dump. In addition, the XFEL-to-Storage ring beam transport line (XSBT), which connects from the XFEL linac to the existing 8 GeV storage ring at SPring-8, is now under construction.

The accelerator safety interlock system (ASIS) has been established with the objective of protecting personnel from radiation hazards. It controls the permission signal for the accelerator and monitors the access to the machine tunnel. If the conditions are unsafe, the ASIS denies permission to the accelerators and stops the electron beam.

BASIC CONCEPT OF ASIS

The ASIS is based on the following concepts:

- It must be fail-safe so that even in the case of a single fault, the system goes into a safe beam-inhibiting state.
- It requires double structure of the logic and signal translation.
- It must monitor the equipment related to the machine tunnel, the emergency stop buttons, and the electron beam route. We have designed three independent systems that monitor the equipment.
- If the electron beam route is unsafe, it must stop the electron beam within 16.6 ms (=1/60 Hz), since the next electron beam must be stopped.
- It controls 73 radio frequencies (RFs) and the GUN by giving the permission signal.

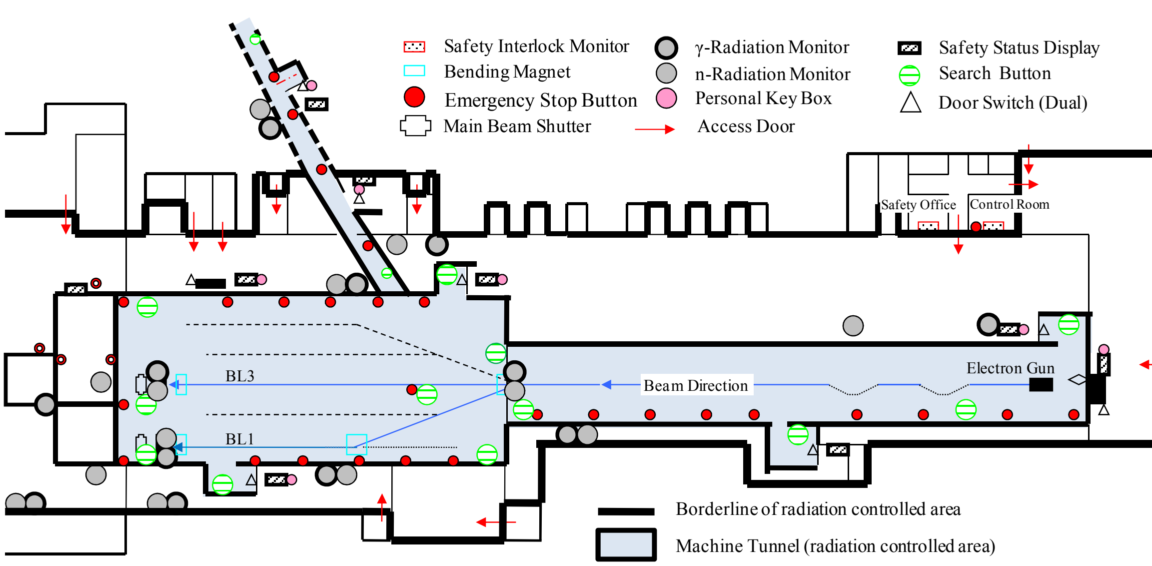

Figure 1: XFEL building and installation location of equipment.

SYSTEM LOGIC

The ASIS has three safety states: "STOP," "READY," and "RUN." These states are switched by a system key and the safety condition. These states control the access to the machine tunnel and the accelerator operation.

The "STOP" State

In this state, accelerator operation is not permitted. And personnel can access the machine tunnel. A person who enters the machine tunnel should take a key from the personal key box (PK-BOX) set up near the access door. While in the tunnel, one must carry the key.

The "READY" State

This state does not permit accelerator operation. Access to the machine tunnel is denied to all but the person who carries the system key.

Before starting accelerator operation, a search is launched to verify that no one is present in the machine tunnel. As the tunnel is searched, buttons are pushed to indicate that the area was visited by the search team. After successful completion of the search, the ASIS permits the switch to the "RUN" state.

The "RUN" State

When the ASIS switches to this state, a warning message is announced in the machine tunnel by an audible alert and a red flash, and no one is permitted to enter the tunnel. When the safety conditions given below are met, accelerator operation is permitted after 1 min.

- All access doors of the machine tunnel are closed.
- All access doors of the machine tunnel are locked.
- All keys of the PK-BOX are returned.
- All emergency stop buttons are energized (not pushed).
- The tunnel search is completed (all search buttons are pushed).
- All radiation monitors are normal.
- The electron beam route is safety.
- All BLs are safety.

If any access door is opened or unlocked, if any key of the PK-BOX has not been returned, if any emergency stop button is pushed, or if any search button is pushed, this state is transited to the READY state, and the search operation needs to be carried out again. If the radiation monitor, beam route, or BL is faulty, this state is retained, and only the accelerator operation is not permitted.

SYSTEM CONFIGURATION

The ASIS consists of a central interlock system (CIS), an emergency interlock system (EIS), and a beam route interlock system (BIS). The system configuration is shown in Figure 2. All three systems are implemented on a programmable logic controller (PLC). The three independent interlock systems communicate with each other by inputting/outputting hardwired signals or using an optical module. If any system trips, or if any system is unsafe, the permission signal from the system must be off and the electron beam is inhibited.

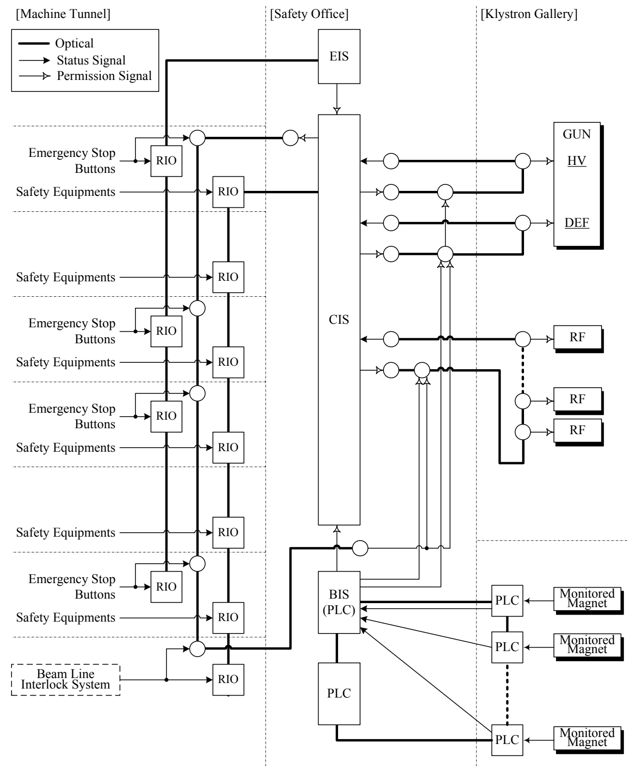

Figure 2: ASIS configuration.

Central Interlock System (CIS)

The CIS, which is the main interlock system in the ASIS, monitors machine tunnel security. The PLC of the CIS is installed in the safety office and is connected to remote input/output (RIO) devices via fibre optic cables. The CIS hardware comprises door switches, search buttons, safety status display, PK-BOX, main beam shutter, radiation monitors, and a control panel. The CIS monitors/controls these safety equipment, changes the safety state, and gives the permission signal to controlled equipment.

Emergency Interlock System (EIS)

The EIS is established to monitor the emergency stop buttons, which are located in the tunnel at intervals of about 50 m, because these stop buttons are important equipment for general safety and radiation safety, and are monitored regardless of the status of the accelerator operation. If the buttons are pushed, the EIS does not give permission to the GUN and RF. In addition, as a general safety procedure, the EIS turns off the low-voltage (LV) of GUN, the LV of RF, and the power supply of the magnet via other interlock system.

Beam-route Interlock System (BIS)

The BIS monitors the consistency between the predefined electron beam route to the downstream insertion devices and the actual transport route by inputting the current of the bending magnet at the beam switching points. The monitored magnet consists of the switching magnet, the kickback magnet of the BL, and the beam dump magnet of the BL.

The BIS consists of many PLCs. Each PLC sends and receives data by linking to the PLC network. Two PLCs are installed in the safety office; the other PLCs are installed in the control racks of the magnets that control the beam route. The first PLC in the safety office accepts the energy of the accelerator operation through the graphic panel. The values of the current of the magnets are calculated and transmitted to the PLC for the magnet. The PLC for the magnet compares the calculated current with the actual current of the magnet. If the result is over ±1%, the PLC outputs an error signal to the second PLC in the safety office. The second PLC checks the conformity of the electron beam route, and if the beam route is unsafe, it does not permit accelerator operation and stops the electron beam. This process of stopping the beam is a high-speed one; it is essential that the electron beam be stopped within 16.6 ms.

DEVELOPMENT

Optical Module

The optical module has been developed to transmit the permission signals for the GUN and for all RFs at a high speed. There are three types of optical modules: the A type interfaces with the PLC, the B type relays between the modules and inputs the signal from the external instruments, and the C type outputs the permission signal to the controlled equipment. Figure 3 illustrates the relation between these modules.

Each module sends and receives signals through two fibre optic cables. One of the cables is used to send and receive a static signal to achieve a high-speed transmission. The other is used to transmit a pulse signal (1 kHz) to the watchdog to achieve reliability. Both signals are the permission signal. When the accelerator operation is permitted, the static signal and the pulse signal turn on. When either signals trips, the trip state is held until a reset signal is transmitted.

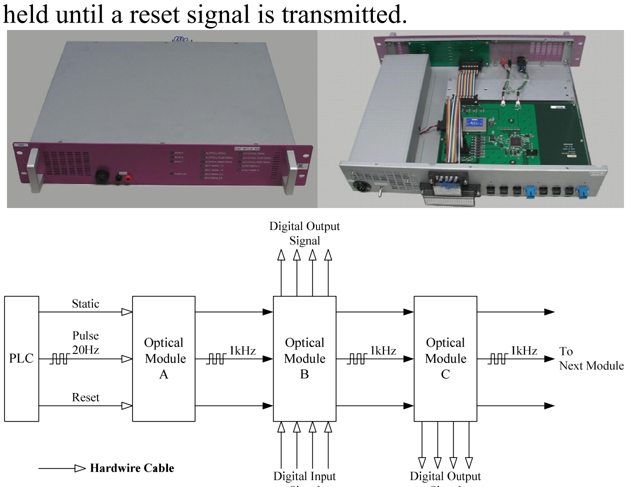

Figure 3: Relation between modules.

The permission signals outputted from each interlock system are transmitted to the controlled equipment via the optical modules. The optical module and the BIS play an important role in achieving high-speed transmission. These are designed such that the scan time of the PLC utilized in this system is 2 ms and the transmission speed of the optical module is 5 ms. Figure 4 shows the design of the high-speed transmission system.

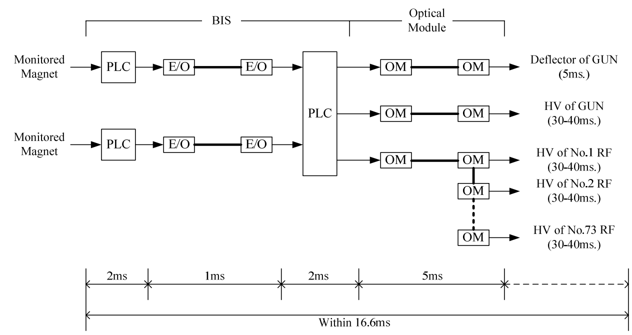

Figure 4: Design of high-speed transmission system.

Data Collection Module

ASIS information is recorded in the host computer system. The ASIS and the host computer system are connected through an FL-net. Since the ASIS must be protected from unauthorized access from the network, this module is separated from the computer network.

The data collection module is implemented on a PLC; it collects information from CIS, EIS, and BIS through an independent FL-net. The collected information is transmitted to the host computer system. The PLC of the module is installed in the safety office. While this module is a part of the ASIS, it does not influence the logic and hardware of the ASIS even if it breaks down.

CONCLUSION

The accelerator safety interlock system (ASIS) for the XFEL at SPring-8 has been established with the objective of protecting personnel from radiation hazards. As a safety system, it should be reliable, stable, and easy to maintain. Further, it should be capable of high-speed transmission and should be independent. We developed an ASIS consisting of three interlock systems; we also developed the optical module and the data collection module.

The hardware of the CIS and the EIS was already produced as the end of September, 2009. The optical module prototype was developed and was successfully tested in a noise environment. The ASIS is planned to be operational in October, 2010.