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DESIGN OF MACHINE PROTECTION SYSTEM FOR SXFEL-UF

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Abstract

Shanghai Soft X-ray Free-Electron Laser (SXFEL) facility is divided into two phases: the SXFEL test facility (SXFEL-TF) and the SXFEL user facility (SXFEL-UF). SXFEL-TF has met all the design specifications and has been available in beam operating state. SXFEL-UF is currently under commissioning and is planned to generate 3 nm FEL radiation using a 1.5 GeV electron LINAC. To protect the critical equipment rapidly and effectively from unexpected damage, a reliable safety interlocking system needs to be designed. Machine Protection System (MPS) is designed by Programmable Logic Controller (PLC) and Experimental Physics and Industrial Control System (EPICS) which is based on a master-slave architecture. In order to meet different commissioning and operation requirements, the management and switching functions of eight operation modes are introduced in the MPS system. There are two FEL lines in user facility named SXFEL beamline project (BSP) and undulator (UD) , and the corresponding design of MPS is completed. This paper focuses on the progress and challenges associated with the SXFEL-UF MPS.

INTRODUCTRION

Shanghai Soft X-ray Free-Electron Laser test facility(SXFEL-TF) has been successfully completed in 2020, and the beam energy of the test facility is 840 MeV. The SXFEL user facility (SXFEL-TF) is a critical development step toward the construction of a soft X-ray FEL user facility in China and has been currently undergoing commissioning at the Shanghai Synchrotron Radiation Facility (SSRF) campus[1]. The LINAC accelerator of SXFEL-UF is designed to increase the beam energy to 1.5GeV[2]. Not only the original undulator beam line has been upgrade in SXFEL-UF, but also a new undulator beam line adopts high-throughput working modes such as SASE has been new built.

The requested response time of Machine Protection System (MPS) is less than 20ms, so PLC is employed to execute the underlying logic. Experimental Physics and Industrial Control System (EPICS) is a set of software tools for building distributed control system to operate devices such as particle accelerators and large experiments[3]. The EPICS framework is adopted in the control system in SXFEL-UF and MPS. Due to the hardware structure and function division for test facility, modification and extension has been implemented for new demands of SXFEL-UF.

MPS COMPOMENT

System Structure

The structure of SXFEL machine protection system is shown in Figure 1. The operator interface (OPI) is connected to the input and output controller (IOC) through the local area network, and takes a approach of the EPICS CA protocol. IOC runs on Linux system, and MOXA DA-662 embedded computer is used as IOC server, equipped with 16 serial ports and 4 network ports. Embedded software and hardware technology is applied to complete the development of embedded EPICS IOC.

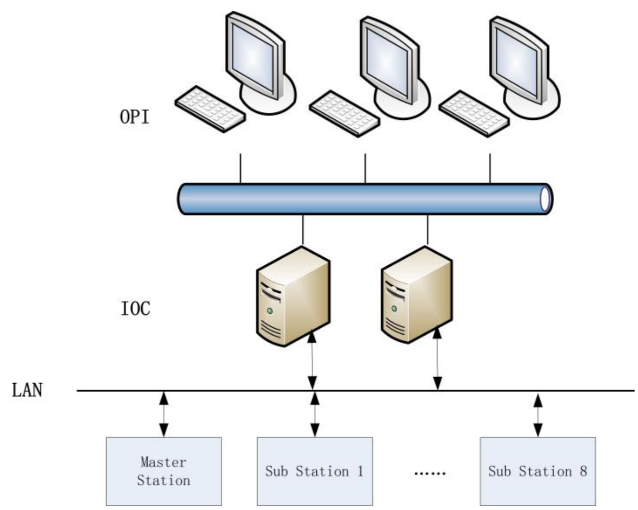

Figure 1: The scheme of SXFEL-UF MPS.

Signal Statistics

Almost all the systems should be assigned the interfaces with MPS, such as radio frequency system, vacuum system, power supply system, water cooling system, timing system and personal safety protection system (PPS) and so on. At present, the number of interlocking input/output signals is aboout 1000, the main equipment interlocking signals are listed in Table 1.

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Table 1: Summary of Main Interlock Signals

No.	device/signal	number
1	timimg control	17
2	vacuum warn and alarm	234
3	pump power supply	302
4	vacuum valve status and control	135
5	modulator status and control	51
6	PPS signal	12
7	cooling water status	78
8	RF switch signal	8
9	Leakage/pressure monitor signal	24

Function Realization

Omron CS1G-H series PLC are applied in MPS, and the CPU model is CPU43. There were 7 PLC stations used for master-slave architecture in SXFEL-TF, including one station for injector (IN), 3 stations for Linac (LA), 2 stations for undulator (UD) section, and one master station for comprehensive treatment. In SXFEL-UF MPS, 9 stations have been arranged for total interlock processing together, which the master station, injector station and 3 linac stations are reserved, but more signals and logic processing are increased. Transmission line (TL) are new added before undulator lines in user facility, so one station for TL and 3 UD stations used for both undulator lines have been restudied and implemented in our new design.

Master station is provided with the function to management and switching the operation mode, and more important function is can synthesize the selected mode and interlock input signals to make corresponding logical judgments and responses. One of the features is to logically integrate the global interlock signal and the output signal from each slave station and fan out to other slave stations. Another feature is to permit the global output signals, the exciting permit signals such as:

- Beam permit.
- Timing system permit signals.
- Driving laser shutter.
- PPS and shutter permit.
- Undulator line selection.
- Operation mode switching.

The local sub stations are connected with device signals such as vacuum, valves, water cooling, air pressure, and water leakage of the accelerator section where they are located. Every sub-station operates at different interlocking logic in accordance with different interlocking requirements to ensure the normal operation of the equipment in its own section. And sub-stations also send the beam permit signal and timing control output signal to master station through synthesis all the logic signals.

In addition, SXFEL has been arranged by a total of 17 modulators. According to the interlock signals of the section where the modulator is located and the command from the Master station, some of the sub-stations need to complete the judgment of the modulator interlock status and control the operation of the modulator

Another significant function of the local sub-station is to realize the local vacuum protection. When there is a vacuum leakage, the vacuum isolation is realized through valve control to avoid leakage and spreading. The vacuum alarm signal needs to be transmitted between the sub-stations, and the upstream station transmits the end vacuum status signal to the downstream sub-station as the vacuum protection input signal. The main signal interaction between each stations shown in figure 2.

OPERATION MODE DESIGN

In the early stage of beam debugging, RF conditioning and section commissioning of accelerator are required. In order to facilitate the operation and reduce the occurrence of misoperation, mode control and switching have been realized in MPS according to different accelerator operating conditions. The adjustment personnel can select a specific mode according to the specific conditions of debugging, and MPS can automatically match different interlock logic in different modes.

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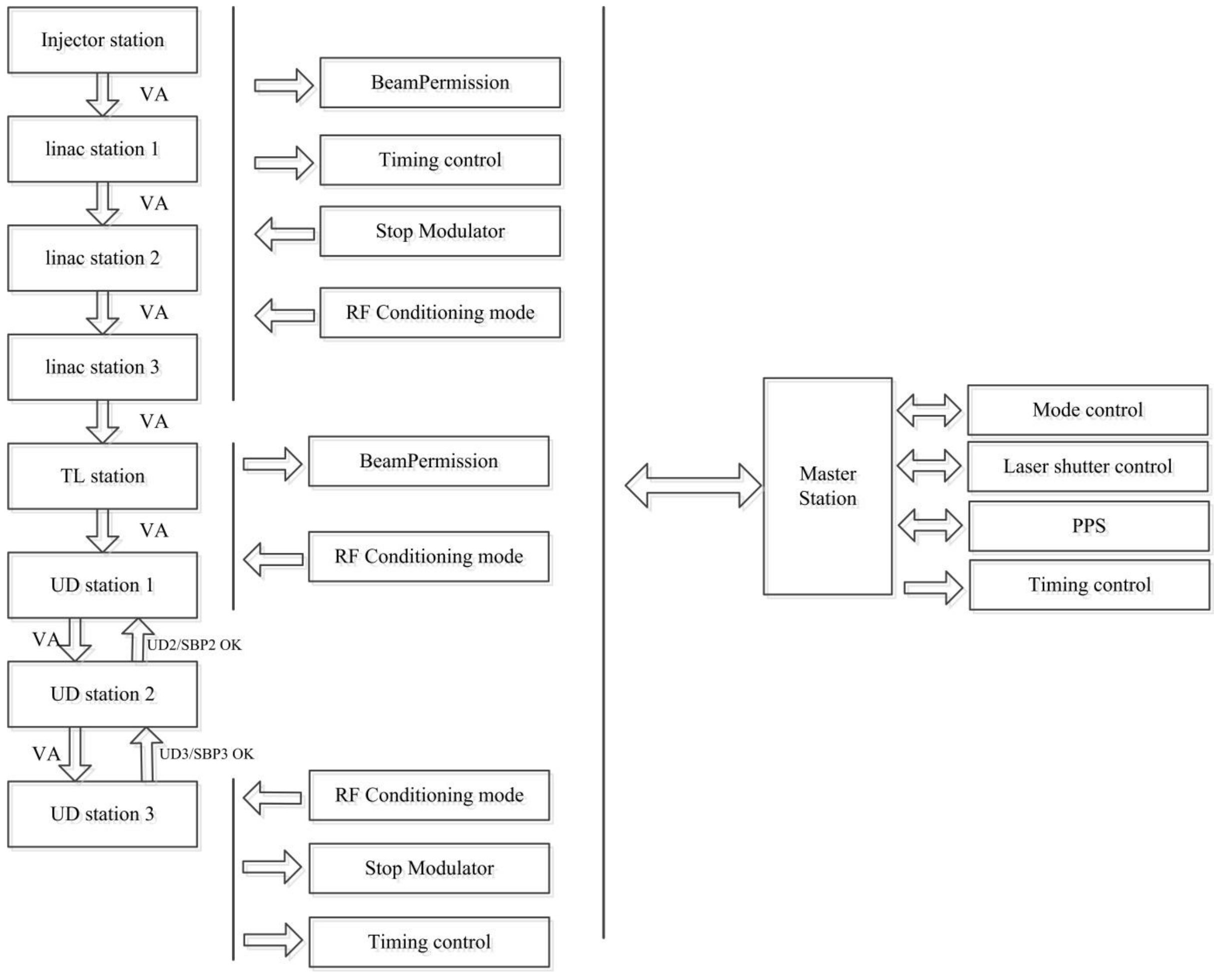

Figure 2: The structure of stations and signal interaction.

7 operation modes are realized in SXFEL-UF MPS, which continuing the original design in test facility. Two beamlines can be chosen flexibely, and the beamline selection is achieved individually.

- STOP mode. The driving laser shutter should be shut down, all timing trigger signals should be stop and all vacuum valves are closed.
- RF Conditioning mode. it is necessary to stop the timing control for the driving laser and close the laser shutter, and the timing trigger to all power sources should be maintain in the normal interlock state.
- Injector debug mode. In this mode, only debugging of the injector section is performed. So the interlock for injector section is normal, but signals from other sections such as linac or undulators are bypassed.
- Linac debug mode. It is necessary to establish a normal interlock from the injector section to the end of the main accelerator, and bypass the interlock input signals from the undulator section.
- Undulator debug mode. Establish normal interlock from the injector section to the end of the main accelerator, but the signal of the B iron at the end of UD should be bypassed.
- Running mode. MPS should operate normally in accordance with the predetermined interlock logic.
- Laser debug mode. All timing triggers should be stop except the trigger for laser system.

The operation mode control is realized by hardware, and the control of the mode panel and the specific logic switching are all achieved by the master station. The design of the mode control panel is shown in Figure 3. The operator needs the key to activate the mode selection function, and the key can be switched between "mode lock" and "mode selection". After entering the "mode selection", 7 modes can be cyclic selected by clicking the "selection button". After the selection is completed, the key should be turned to "mode lock" to complete the switching. The master station also sends effective information to each sub-station and device after the mode is locked, and then the entire system can perform the interlock logic under the new mode.

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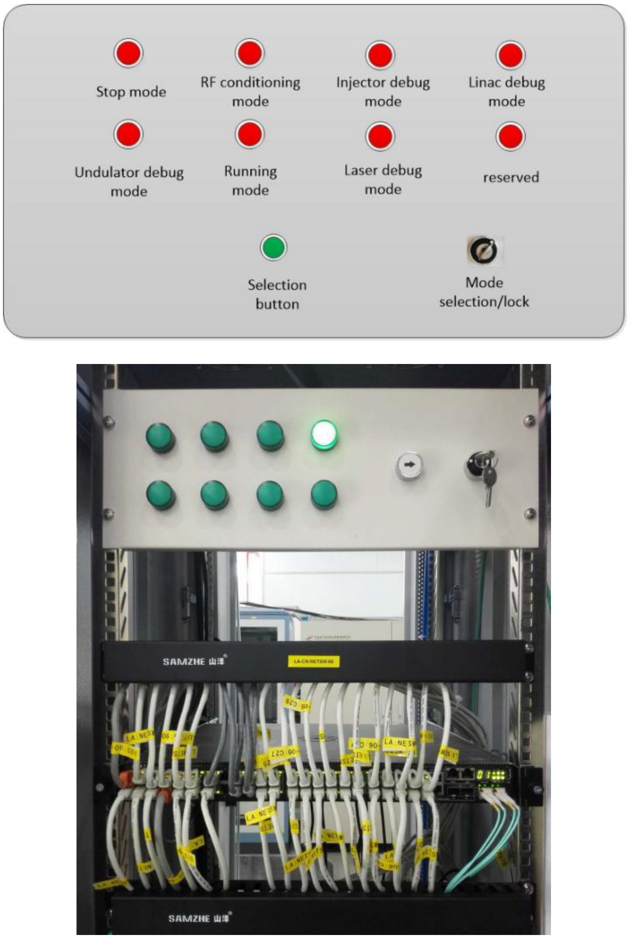

Figure 3: The design of control panel for mode selection.

ALERTING SIGNAL PROCESSING

Once the equipment involved in the interlock fails or the signal exceeds the set threshold, MPS will take protective measures according to the predetermined interlock logic and output the corresponding interlock protection signal. When the alerting signal returns to normal, the interlock output signal is restored or not at this time, which depends on whether the interlock signal is latched. Once the fault signal is latched the alarm signal must be confirmed by the operator before the interlocking state can be canceled, even if the input signal returns to normal, and it cannot be automatically reset.

The alerting signals should be latched and recorded when the failures occur at the normal running mode or debugging mode in SXFEL-UF MPS. But the state of each system can not meet the operating standard at RF conditioning mode, the latch function may cause frequent operation for reset by the operator. So the automatic reset method is adopted to eliminate the interlock output. The Master station will send a signal to all the sub-stations whether to work at the RF conditioning mode. According to this, each sub-station will determine whether the local signals needs to be latched. For each PLC station, every interlocking input signal corresponds to a latch signal and a reset signal. The processing flow of the SXFEL-UF MPS input signals is shown in Figure 4.

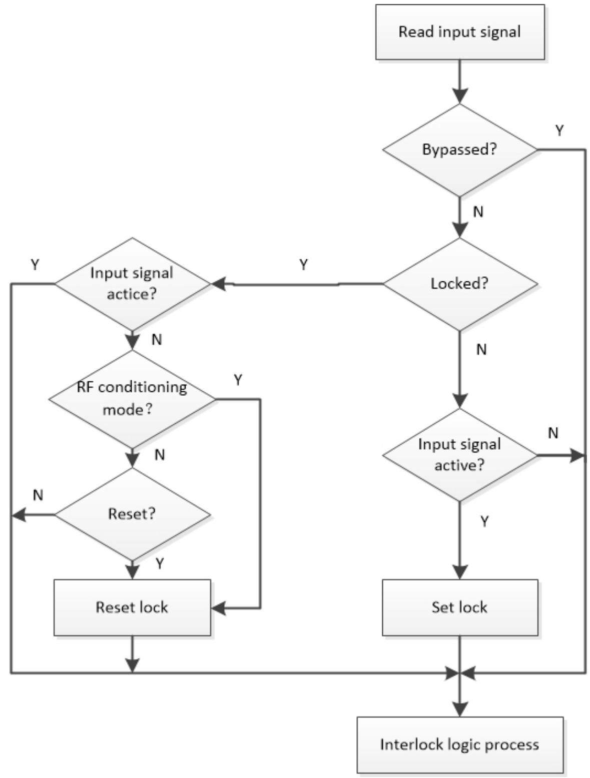

Figure 4: Flow chart of input signal process.

OPERATION GUI

SXFEL control system base on EPICS, and MPS remote control system uses MOXA DA-662 embedded sever built-in Monta Vista Linux system as EPICS IOC. The netDev IOC device driver developed by Japan KEK is used, which can realize the communication with OMRON CS1 series PLC through Ethernet module[4].

The operator interface (OPI) is developed by EDM, which is composed of the main interface of MPS and various sub-interfaces. 6 new sub interfaces for both undulator lines have been added, and the two lines selection and enable judgment have been finished and modified at main interface for SXFEL-UF. The global interface of SXFEL-UF MPS shown in Figure 5, and the interface of MPS for SXFEL injector is shown in Figure 6.

The current operating mode of the accelerator, the interlock status of each station, and overview information of MPS signals such as vacuum and water cooling are all displayed in main interface. At the interface of each accelerator section and undulator section, the specific information of the interlock input signals can be obtained at the sub interface divided by accelerator section. Also the corresponding control operations for reset, bypass and equipment control can also be performed.

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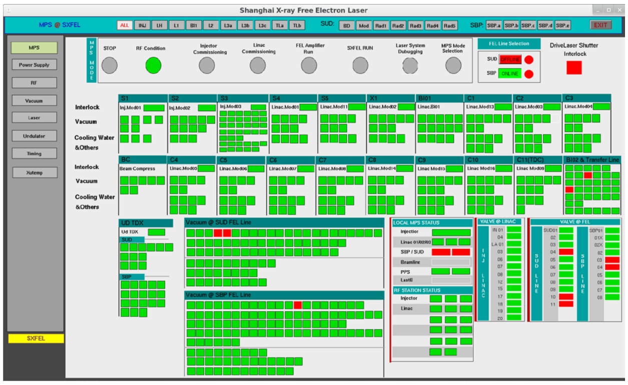

Figure 5: The global interface of SXFEL-UF MPS.

Figure 6: The interface of interlock system for SXFEL injector.

CONCLUSION

PLC is used to achieve the collection, calculation and interlocking protection of all interlocking signals at SXFEL-UF MPS. Based on the architecture of Master main station and local sub-station design, interlocking protection with operation mode switching and management functions is realized. The interlocking protection requirements of various systems such as vacuum, water cooling, high frequency, timing and personal safety have been available in our system. And distributed control system based on the standard model and EPICS have been build and realized for SXFEL-UF MPS system.

Through online testing, the response time of the system is less than 15 ms, which totally meets the physical requirements of 100 ms response time at the device repetition frequency of 10 Hz. The performance may also satisfy the demand of 20 ms response time .

After a long-term operation measurement, the SXFEL-UF MPS is stable and reliable, and the interlocking function is running normally, which effectively meets the requirements of debugging and operation at various stages.

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