DOI: 10.15669/pnst.4.264

Progress in Nuclear Science and Technology
Volume 4 (2014) pp. 264-267

ARTICLE

Operation status of interlock system of Materials and Life Science Experimental Facility (MLF) in J-PARC

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The Materials and Life Science Experimental Facility (MLF) in J-PARC is a facility which generates neutron and muon beams by injecting highly intense pulsed proton beams into targets and supplies them to user experimental instruments. In the MLF, an interlock system (MLF-IL) is running to keep safety operations of the facility in various situations such as beam irradiations and target maintenances. Since the first proton beam injection in 2008, the MLF-IL has been operated stably without any serious troubles in spite of the device upgrades in the target systems and the increase of user instruments. This paper describes the design concept, the operation and the modification of the MLF-IL.

Keywords: target station; interlock systems; MLF; J-PARC; MPS; PPS; TPS

1. Introduction

The Materials and Life Science Experimental Facility (MLF) at the Japan Proton Accelerator Research Complex (J-PARC) generates pulsed muon and neutron beams by injecting highly intense proton beams supplied from accelerators through the 3-GeV proton beam transport line (3NBT) into graphite and mercury targets. Then it supplies muon and neutron beams to many user instruments placed in two experimental halls of the MLF. For supplying the secondary beams safely and efficiently, a general control system (MLF-GCS) that consists of an integral control system, an interlock system, a common server, networks and a timing distribution system is operated in the MLF [1]. The MLF-GCS is the advanced and independent system that controls the target stations including a mercury target, neutron moderators with supercritical hydrogen, and cooling systems for radioactive waters and gases. Especially, the interlock system of the MLF (MLF-IL) has important roles to keep safe and stable operations of the facility in various situations such as beam irradiation, maintenance of the target stations, device upgrades of the targets and emergency. The MLF-IL has been designed to administer many instruments and high radiation areas safely, work closely with the interlock systems of accelerators and other facilities through the Central Control Room (CCR) of the J-PARC, stop beam injections if necessary, and keep all over the MLF safe in emergencies. It also plays key roles in order to improve the user beam availability of the whole J-PARC by minimizing beam stop frequencies, periods and areas.

Since the first proton beam injection in May 2008, the MLF-IL has been operated stably without any serious troubles. On the other hand, its modification based on experience of beam operations and maintenances is in progress now. This report describes the design concept, structure, the operation and the modification of the MLF-IL.

2. Outline of MLF interlock systems

2.1. Structure and function

Figure 1 represents a structure of the MLF-IL in the MLF-GCS. It consists of three kinds of subsystems named MPS (Machine Protection System), TPS (Target Protection System) and PPS (Personnel Protection System). Each subsystem has a veto to stop the proton beam injection for protecting personnel and machines in the MLF. The structure in Figure 1 is composed of the MPS part combining with the integral control system and the PPS part. Both the parts consist of Personal Computers (PC) and Programmable Logic Controllers (PLC) such as an Administrative Control PCs (ACP), General Control Panels (GCP), PPS Management Panels (PPS-MP) and Local Control Panels (LCPs) connected through duplicate optical networks for PLC links, named NET-H and FA-link, and duplicate metal cables. Operations of each part are executed individually by the ACP and a PPS operating PCs in the MLF Control Room (MLF-CR) of the MLF. The operation data of

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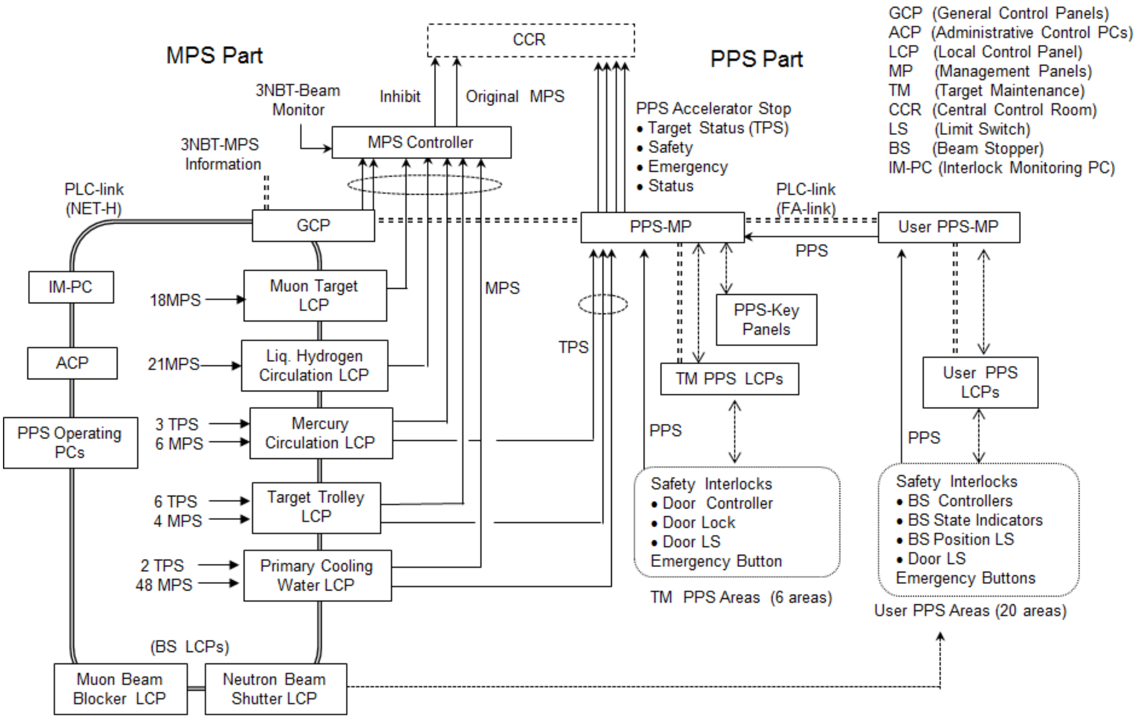

Figure 1. Structure of MLF interlock system (MLF-IL) in the MLF-GCS.

them are exchanged each other through the GCP and the PPS-MP.

The MPS is a system for preventing trouble in important machines due to unusual irradiations by prohibiting proton beam injections. In Figure 1, integral controls all over the MLF are executed by controlling more than 35 LCPs by the GCP through the NET-H. In addition, 5 LCPs which have sensors detecting MPS events are connected to a MPS controller through metal cables. The MPS controller consisting of several exclusive modules, were developed by the J-PARC control group for protecting accelerators from thermal shock caused by the proton beam. If the MPS sensors detect unusual events, the MPS signals are collected in each LCP and transmitted to the MPS controller. The GCP also transmits a few MPS signals relating to operation status of the whole MLF.

The MPS controller transmits two kinds of beam stop signals named “Inhibit” and “Original MPS” to the CCR. It transmits the “Inhibit” signal at first after receiving the MPS signals. Then proton beam injections into the MLF are stopped by changing distribution patterns, which are generated by a scheduled timing system of the J-PARC, of proton beam pulses from the accelerators to each facility. If the beam pulses are detected by beam monitors of the 3NBT during emission of “Inhibit” signal, the “Original MPS” signal transmits to the CCR. Then a radio frequency power to a linear accelerator (LINAC) is terminated and beam shutters between the ion-source and RFQ (a type of LINAC) are closed. The function of the “Inhibit” signal was added in December 2011 for minimizing the beam stops by MPS. It is very useful to improve the user beam availability of the J-PARC.

The PPS is a system for preventing exposure of personnel to high-radiation by administering entrance into high radiation areas named PPS areas. In the MLF, there are two kinds of PPS areas relating to the target maintenance and user instruments, named TM and user PPS areas. In 6 TM PPS areas, PPS devices such as door controllers, electric door locks and door Limit Switches (LS) are controlled by the PPS-MP through the FA-link and metal cables. In 20 user PPS areas, user PPS devices such as Beam Stopper (BS) controllers for operating neutron shutters or muon blockers are administered by user PPS-MP and four user PPS-LCPs. The PPS also terminates the proton beam to protect personnel from high-radiation during proton beam injections. The exclusive PLC in the PPS-MP transmits four kinds of signals, named “Target Status”, “Safety”, “Emergency” and “Status”, to the CCR for permitting or prohibiting proton beam injections. Since the beam stop by the PPS is required higher reliability than the MPS, not only the beam shutter close but also the ion-source termination, is included in this procedure.

The TPS is a system for preventing troubles related to the mercury target from expanding to become serious if the beam stop operation executed by the MPS ends in failure. Since the beam stop by the TPS is required to have the same reliability as the PPS, the TPS signals are transmitted to the CCR as the “Target Status” after collecting in the PPS-MP. Then the beam is terminated by utilizing the beam stop procedure of the PPS. In Figure 1, 3 LCPs for target trolley, mercury circulation and primary water circulation systems, transmit TPS signals. Detail information on the MPS, the TPS and the PPS is collected and monitored on an Interlock Monitoring PC (IM-PC) in a lump. In addition, this PC also deals with the information on the MPS of the 3NBT which influences directly the beam operation of MLF. These useful functions with the IM-PC were added in 2010 for comprehending the status of beam stop signals as quickly and accurately as possible based on experience of the beam operations.

2.2. Startup procedures of the MLF

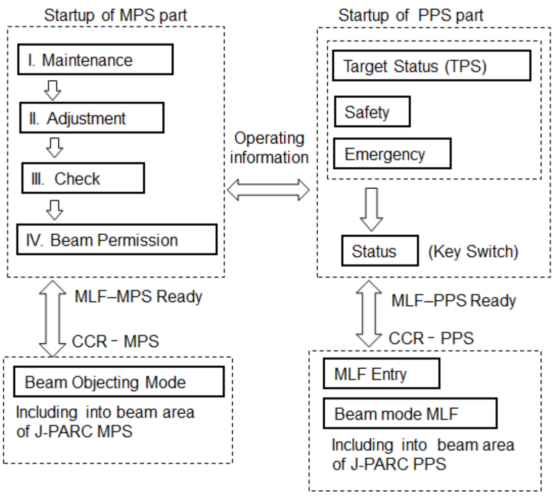

Figure 2. Startup procedures with the MLF-IL.

The MLF-IL has essential roles for integrating startup and shutdown procedures throughout the MLF. **Figure 2** represents the startup procedure by the MLF-IL. The MPS combining with the integral control system administers almost all instruments in the MLF under four operational states of "Maintenance", "Adjustment", "Check" and "Beam Permission". The ACP executes the MLF status transitions from "Maintenance" to "Beam Permission" step by step with button switches and also monitors the MPS sensors relating to the transitions. "Maintenance" is the state for exchanging or repairing devices of the targets, moderators, etc. "Adjustment" is for startup, shutdown and adjustment of the instruments. "Check" is for ensuring that all the instruments are ready for proton beam injections. After transiting to "Beam Permission" state, the MPS of MLF signifies to be ready for beam injection to the CCR by resetting the final MPS signal emitted from the GCP directly. Then the CCR includes the MLF in a beam operation area defined by the MPS of J-PARC.

On the other hand, the PPS requires that "Target Status", "Safety" and "Emergency" interlock signals become ready independently for proton beam injections. "Target Status" is the signal for the TPS events such as mercury leakage, "Safety" is the signal for ensuring safety of entrance into the PPS areas, and "Emergency" is the signal for emergency buttons which are placed around PPS areas for terminating proton beam injections manually. After ensuring that these signals are ready, the PPS of MLF signifies to be ready for the beam injection by turning on the "Status" key in the PPS key panel. Then the CCR prohibits entering the TM areas by the "MLF-Entry" signal and includes the MLF in the beam permission areas defined by the PPS of J-PARC and finally commences the beam injection.

2.3. Administration of the PPS areas

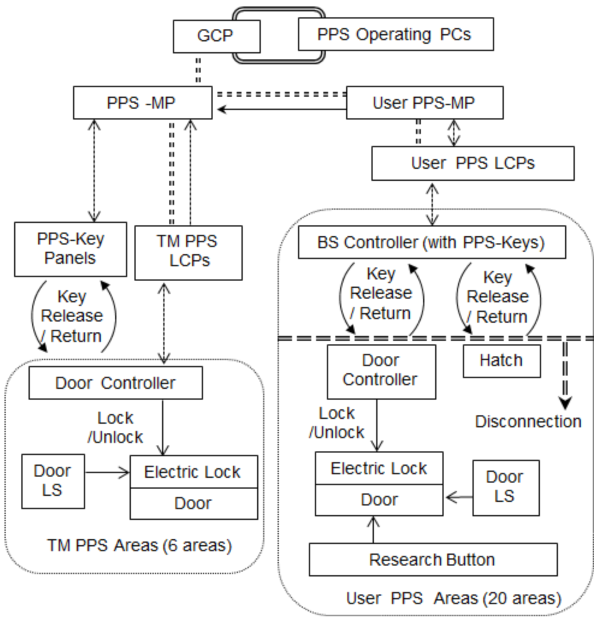

Figure 3. Structure and procedure for accessing to PPS areas.

The PPS of MLF administers the various PPS areas over the TM PPS areas and the user PPS areas from the MLF-CR. It is also required to ensure not only safety beam operations but also flexible modification and expansion of the user PPS areas under increasing user instruments year by year. In these complicate situations, the PPS of MLF was designed to administer entrance into the PPS areas simply based on safety keys and minimal interlock functions.

Figure 3 represents the structure and the procedure for accessing to the PPS areas. In the TM areas, personnel pull off the key from the PPS key panel, put it into the door controller, unlock the door, and enter into the PPS area. All enabling signals of the PPS devices for the TM area are controlled with the PPS operating PCs. In addition to the keys for the TM areas, the PPS key panel also deals with several keys having special functions such as "Status" key and "Shield Block" keys which ensure to restore shield blocks removed from target stations during maintenance periods. In the user PPS areas, users pull off the key from the BS controller, put it into the door controller, unlock the door, and enter into the area [2]. After checking that all users exit from the PPS area as sounding the research button, they lock the door, pull off the key from the door controller, and return it into the BS controller. The keys in the BS controller are also utilized for locking hatches which are set on the user PPS areas for installing experimental samples and devices. The beam stopper can be opened by using a button switch on the BS controller after all keys are returned into the controller. The statuses of the user PPS devices can be monitored in the MLF-CR, and if necessary, beam stopper operations by users are inhibited.

In "Safety" design of the user PPS areas, almost all user PPS devices such as the door controller, door lock, and research button were disconnected from the user PPS-MP and PPS LCPs except for the BS controller and door limit switches which ensure indispensable safety functions. In addition, main programs for operation functions with the BS controllers were concentrated into the PLCs in user PPS LCPs. These structures became to enable fabrication of the small size BS controller, easy connection of user PPS devices, and flexible and individual design of each user PPS area.

2.4. Safety design in emergency

The MLF-IL is designed in consideration of safety for various emergencies based on failsafe concept. In Figure 1, main components such as the GCP and the PPS-MP, optical networks and metal cables are duplicated, and if the devices or cable relating to proton beam injections fail or disconnect, the beam stop signals are transmitted to the CCR. In the loss of external power supplies, the control function of the MLF-GCS are kept by Uninterruptible Power Sources (UPS) and back-up generators, almost all instruments relating to the target stations are shut down automatically according to their interlock sequences in emergencies, and more than 7000 operation data continue to be stored in a common Data Base (DB) server every 5 seconds. If the power supplies for PPS devices around the PPS areas are lost, entrance into the area is prohibited by locking the door mechanically though exit from the area enables always. In addition to the DB server, a storage function for the data of PPS devices every one second has been worked in the PPS operating PCs since 2009 for comprehending the PPS status quickly and actually. This function was very useful for analyzing behaviors of the PPS devices at the Great East Japan Earthquake (GEJE) [3].

On the day of the GEJE, the beam operation of the MLF was stopped in the morning, and the target stations were kept ready for restart of the beam operation from the evening. In the MLF, strong quakes were detected by the sensors of liquid levels and pressures in many circulation systems after about 90 seconds and the external power supplies were lost after about 150 seconds. The control function of the MLF-GCS was kept active by the back-up generators until manual shutdown. Just after the power loss, the beam stop signals on "Target Status" were emitted by shutdown of the mercury and primary water circulation systems. All the doors of the TM areas were locked mechanically. On the other hand, many doors of the user PPS areas were unlocked in lifting the neutron shutters by motors at the shutter close positions. In initial design on "Safety", the beam stop signals were emitted even if the limit switches detecting the shutter close positions were cut off only a few seconds under unlocking the doors of the user PPS areas. For the reliable operations of the PPS, however, it was not relevant because needless beam stop signals were transmitted frequently by vibrations of the shutters during earthquakes. Accordingly the PPS function was modified in January 2010 so as not to emit the beam stop signal if the cutoff states of the limit switches do not continue more than 5 seconds, and it worked well at the GEJE.

3. Conclusion

This paper explained the design concept, the structure and the functions of the MLF-IL which consists of the MPS, the PPS and the TPS. It also reported on the roles of the MLF-IL for integrating the startup procedure of the MLF, administering entrance into the PPS areas, and ensuring safety in emergency. Since the first proton beam injection, the MLF-IL has been operated safely and stably without any serious troubles in spite of the device upgrades of the target systems for ramping up the proton beam power and the increase of user instruments year by year. It also behaved as planned based on its safety design in an emergency at the GEJE. These results substantiate the validity of the MLF-IL which was designed how to ensure safety of the machines and personnel under various and complicate situations in the MLF.

Acknowledgements

The authors are grateful to Dr. Y. Ikeda, Dr. M. Arai, Mr. T. Kato, the members of Neutron Source Section and the staffs of J-PARC Center for their useful help and suggestions.

References

[1] K. Sakai, M. Ooi, T. Kai, H. Kinoshita, S. Kawasaki, A. Watanabe, M. Kaminaga and M. Futakawa, Construction status of the General Control System of the Materials and Life Science Experimental Facility (MLF) of J-PARC, *Nucl. Instr. Meth.* A 600 (2009), pp.75-77.

[2] T. Kai, K. Sakai, T. Nakatani, H. Takada, K. Oikawa, K. Shimomura, W. Higemoto, H. Kinoshita, M. Ooi and M. Kaminaga , Users' beam interlock system at the materials and life science experimental facility of J-PARC, *Nucl. Instr. Meth.* A 600 (2009), pp.176-178.

[3] K. Sakai, S. Sakamoto, H. Kinoshita, M. Seki, K. Haga, H. Kogawa, T. Wakui, T. Naoe, Y. Kasugai, H. Tatsumoto, T. Aso, S. Hasegawa, F. Maekawa, K. Oikawa, M. Ooi, A. Watanabe, M. Teshigawara, S. Meigo, K. Ikezaki, A. Akutsu, M. Harada, H. Takada and M. Futakawa, *Influence of Great East Japan Earthquake on Neutron Source Station in J-PARC*, JAEA-Technology 2011-039, Japan Atomic Energy Agency, (2012). [in Japanese]