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Progress of the General Control System for the Materials and Life Science Experimental Facility in J-PARC

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Abstract. For safe and stable beam operation, the general control system (GCS) of the Materials and Life Science Experimental Facility (MLF) comprises several subsystems, such as an integral control, interlock, server, network, and timing distribution systems. Since the first beam injection in 2008, GCS has operated stably without any serious troubles, even with annual upgrades to the target devices for ramping up beam power and annual incremental upgrades of the user systems. In recent years, however, it has been significantly improved with regard to sustainable long-term operation and maintenance. The monitor and operation system of GCS has been upgraded by changing its framework software to improve its potential flexibility for maintenance. The interlock system was also modified in accordance with a re-examination of the Japan Proton Accelerator Research Complex (J-PARC) risk management system. This study reports the recent progress of GCS.

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 the muon and neutron beams to many user instruments placed in two experimental halls of MLF [1]. For safely and efficiently supplying muon and neutron beams, a general control system (GCS) operates within MLF. GCS comprises several integrated subsystems, such as a controller for the muon and neutron targets, interlock systems for safe operations, and shared servers for administering operational data [2, 3, 4]. It is an independent system that controls the target stations, including a mercury target and neutron moderators with supercritical hydrogen. Although GCS is an independent system, it works closely with the control systems of the accelerators and other facilities in J-PARC.

After the construction of most of GCS subsystems was completed, commissioning for operation and control of the entire MLF proceeded stepwise in June, 2007. During a short period before the first beam injection, the trial operations, performance tests, and improvements of GCS subsystems were executed under restricted conditions. Since the first proton beam injection in May, 2008, GCS has been operated safely and stably without any serious troubles. In recent years, however, it has been significantly improved with regard to sustainable long-term operation and maintenance. This study provides an overview of the recent progress of GCS for MLF in J-PARC.

2. Overview of GCS in MLF

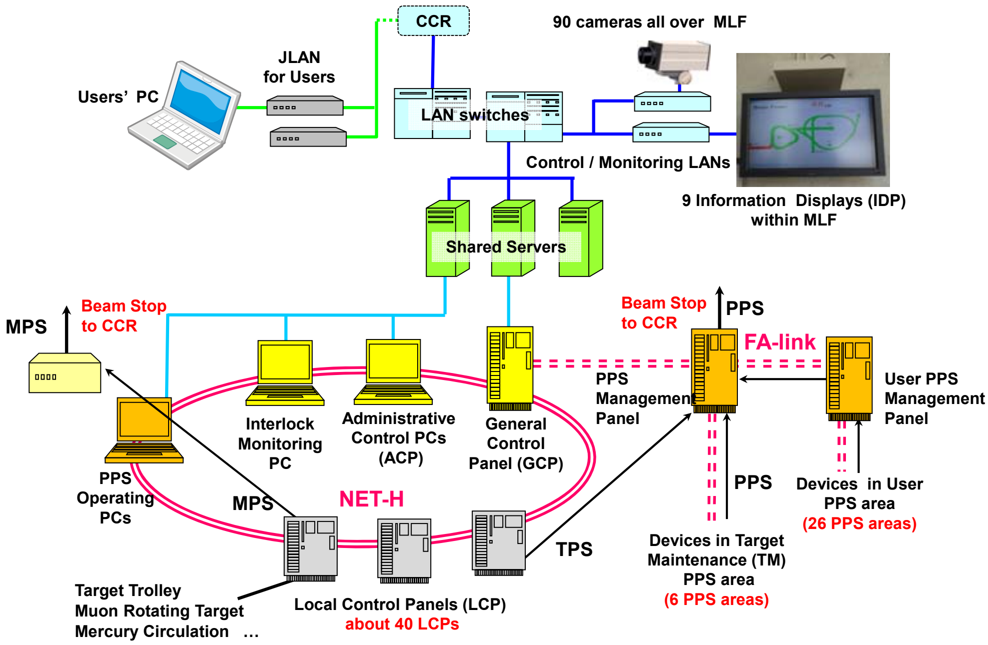

Figure 1. Outline of GCS within MLF in J-PARC.

Fig. 1 shows an outline of GCS within MLF. It comprises several subsystems, such as integral control and interlock systems, shared servers, network systems, and a timing distribution system [2, 5]. GCS administers three kinds of interlock systems related to beam stop, called the machine, target, and personnel protection systems (MPS, TPS, and PPS). The integral control and interlock systems comprise personal computers (PCs) and programmable logic controllers (PLCs), such as administrative control PCs (ACP), the general control panel (GCP), PPS management panel (PPS-MP), and local control panels (LCPs). These systems are connected through duplicate optical networks for PLC linking, called the NET-H and FA-link, and duplicate metal cables. They operate the instruments in the entire MLF, such as the target trolley, muon rotating target, and mercury circulation systems, by the ACP and GCP through the NET-H and approximately 40 LCPs. Moreover, they safely administer many instruments and high radiation areas, work closely with the interlock systems of the accelerators and other facilities through the Central Control Room (CCR) of J-PARC, stop beam injections if necessary, and maintain safety in MLF in emergencies. The shared servers comprise server PCs for purposes such as web distribution (WD), data storage (DS), and monitoring cameras. They acquire, arrange, store, display, and distribute over 7000 operational data items. Operations for GCS are executed by a monitor and operation (MO) system comprising an ACP, PPS operating PC (PPS-PC), interlock monitoring PC (IM-PC), DS server, WD server, and others, in a MLF control room (MLF-CR) located on the third floor of MLF.

Network systems of GCS comprise a control LAN (C-LAN) and monitoring LAN (M-LAN). The C-LAN is a duplicate Ethernet system for controlling the accelerator and facilities within J-PARC administered through CCR. M-LAN is used to control approximately 90 monitoring cameras in MLF using a camera server. In addition, J-PARC has a network system for general users (JLAN). C-LAN is connected to JLAN extending from CCR and goes through a firewall. The WD server distributes operational information, such as operational status, beam power, and beam trend, to users through nine information displays (IDPs) connected to C-LAN, and users' PCs connected to JLAN in the form of a Web browser.

3. Recent progress of GCS in MLF

After the construction of most of GCS subsystems was completed, commissioning for operation and control of the entire MLF proceeded stepwise in June, 2007. Fig. 2 shows the time series of commissioning on operation and control of the MLF. Since the first beam injection in 2008, GCS has been operated as expected without any serious troubles, even with annual upgrades to the target systems for ramping up the proton beam power and annual incremental upgrades to the user apparatus. It also worked in accordance with its safety design when the Great East Japan Earthquake (GEJE) occurred in March, 2011 [5, 6]. In recent years, however, it has been significantly improved with regard to sustainable long-term operation and maintenance. The MO system of GCS has been upgraded by changing its framework software to improve its potential flexibility in its maintenance [7, 8]. Moreover, the risk management system for J-PARC was re-examined because of an incident that caused radioactive material leakage at J-PARC Hadron Experimental Facility in May 2013, where an “Alert” status for examining signs of an abnormal situation was added between the “Normal” and “Emergency” statuses. Consequently, the interlock systems of GCS were also improved.

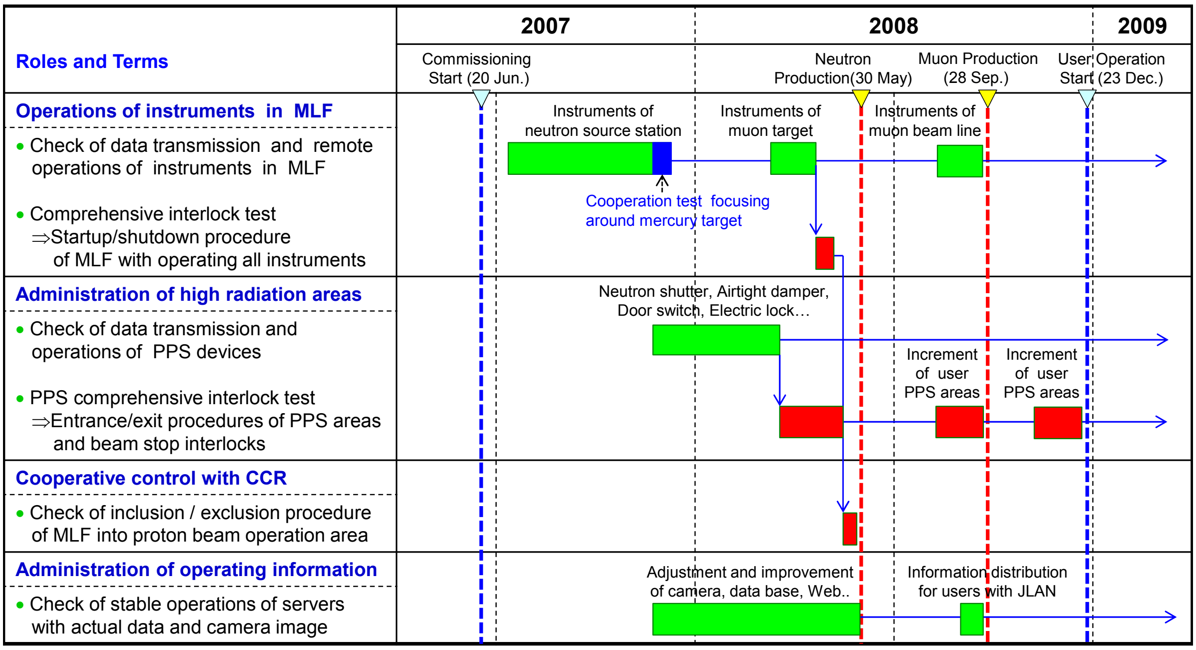

Figure 2. Time series of commissioning on operation and control of the whole MLF.

3.1. Interlock system

Fig. 3 represents the structure of the interlock systems within GCS as of November, 2014. The interlock systems, comprising MPS, TPS, and PPS, play an important role in ensuring the safety of personnel and machines [5]. MPS is a system for preventing trouble in important machines due to unusual irradiations by prohibiting proton beam injections. In Fig. 3, seven LCPs, which have sensors for detecting MPS events, are connected to an MPS controller through metal cables. If MPS sensors detect unusual events, MPS signals are collected in each LCP and transmitted to the MPS controller. The MPS controller transmits two kinds of beam-stop signals, called “MLF Inhibit” and “MLF MPS” to CCR. It transmits “MLF Inhibit” signal at first after receiving MPS signals. Then, proton beam injections into MLF are stopped by changing the distribution patterns (which are generated by a scheduled timing system of J-PARC) of the proton beam pulses from the accelerators to each facility. If the beam pulse is detected during transmission of the “MLF Inhibit” signal, the “MLF MPS” signal for terminating the accelerator operation is transmitted to CCR. Then, the radio-frequency power to the linear accelerator (LINAC) is terminated and beam shutters between the ion-source and RFQ (a type of LINAC) are closed.

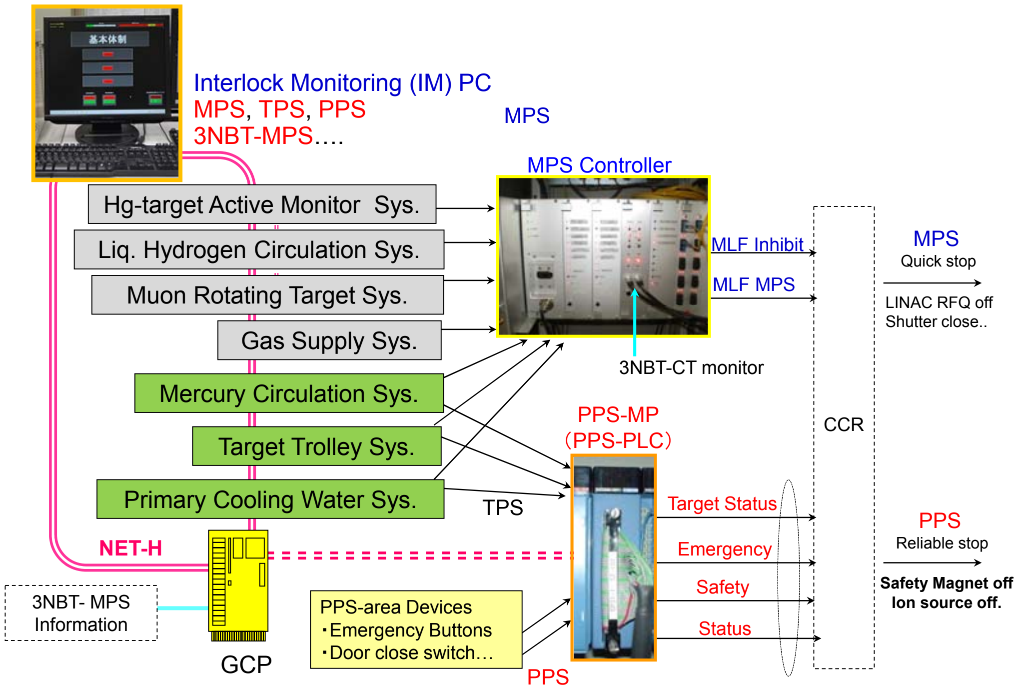

Figure 3. Structure of the interlock systems within GCS.

PPS is a system for preventing exposure of personnel to high radiation. In MLF, there are two kinds of PPS areas, called the target maintenance (TM) and user PPS areas in Fig. 1. In six TM PPS areas, PPS devices, such as door controllers, electric door locks, and door limit switches (LS), are controlled by PPS-MP. In 20 neutron and 6 muon 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. PPS also terminates the proton beam to protect personnel from high radiation during proton beam injections. The exclusive PLC in PPS-MP transmits four kinds of signals, called “Target Status,” “Safety,” “Emergency,” and “Status,” to CCR for permitting or prohibiting proton beam injections. Since the beam stop by PPS requires higher reliability than MPS, not only the beam shutter close but also the ion-source termination are included in this procedure.

TPS is a system for preventing problems related to the mercury target from becoming serious when the beam stop operation executed by MPS fails. Since the beam stop by TPS is required to have the same reliability as PPS, TPS signals are transmitted to CCR as the “Target Status” after collecting in PPS-MP. Then, the beam is terminated by executing the PPS beam stop procedure. In Fig. 3, three LCPs for the target trolley, mercury circulation, and primary water circulation systems transmit TPS signals.

IM-PC collects and monitors detailed information about the 128 MPS, 10 TPS, and PPS items through the PLC links in a lump. It deals with the information about the MPS of the 3NBT, which directly influences the beam operation of MLF, and displays the status related to the risk management system. If MPS or TPS events related to mercury leakage are detected, IM-PC and IDPs display the “Alert” status, and the MPS controller transmits “MLF MPS” for terminating accelerator operation independently of the “MLF Inhibit” transmission.

3.2. Upgrade of monitor and operation systems

In Fig. 1, the current MO system, which comprises ACP, PPS-PC, servers, and other components, was designed on the basis of the iFIX- Supervisory Control and Data Acquisition (SCADA) and iHistorian software systems for framework and data storage. Furthermore, it has functioned as expected. However, the downside was its costly maintenance because of its poor flexibility on the operating system (OS) and software versions. To improve the maintenance flexibility of GCS, we planned a significant upgrade of the MO system [7, 8]. According to the plan, we considered the schematic of the upgraded MO system in 2012, on the basis of the condition of the current functions, so as to control all LCPs, and acquire, store, and distribute operational data in a suitable data format. Fig. 4 outlines the schematic of the upgraded MO system. In Fig. 4, the following components of the MO system were adopted: experimental physics and industrial control system (EPICS) as framework software, an OPC server as a data input/output module, control system studio (CSS) as a user interface window, postgre SQL for the DS server, and web OPI for the WD server. Furthermore, we manufactured the prototypes of the upgraded MO system and evaluated its actual performance with true data, such as data transmission speed from the PLCs, control functions from the user interface windows, storage capability of the DS, and long-term reliability. After confirming that it works properly, as designed, we built two full-scale upgraded MO systems in 2013. One is the MO system, which controls the devices for the target stations by using more than 130 operation screens and acquires operational data for about 7000 items every second. The other system administers PPS devices using seven screens and acquires data for about 1400 items. They have been operated in parallel with the current systems during beam operation and maintenance for over half a year, and have been debugged, unlike the current systems, which were replaced in 2014.

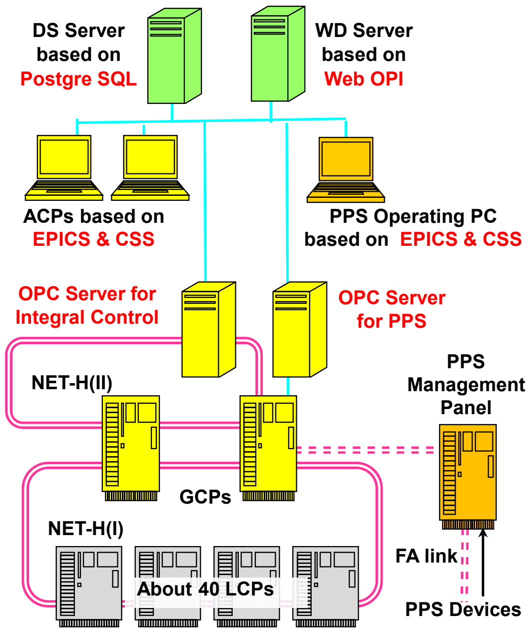

Figure 4. Structure of the upgraded MO systems.

3.3. Safety design in emergency

GCS is designed with regard to safety for various emergencies on the basis of the failsafe concept [5]. In Fig. 1, the main components, such as GCP and 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 CCR. In a loss of external power supplies, the control functions of GCS are maintained by uninterruptible power sources (UPSs) and back-up generators; almost all instruments relating to the target stations are automatically shut down according to their interlock sequences in emergencies and operational data continue to be stored in the DS server every 5 s. If the power supplies for PPS devices around PPS areas are lost, entrance into the area is prohibited by mechanically locking the door (although exit from the area is always enabled). In addition, the storage function for the data of PPS devices every second has been designed for quickly comprehending the actual PPS status.

On the day of the GEJE, the beam operation of MLF was stopped in the morning and the target stations were on standby for the restart of the beam operation in the evening [6]. In MLF, strong quakes were detected by the liquid-level and pressure sensors in many circulation systems after about

90 s, and the external power supplies were lost after about 150 s. The control function of GCS was kept active by the back-up generators until manual shutdown for about 3 h. Immediately after the power loss, the beam stop signals on "Target Status" were transmitted by the shutdown of the mercury and primary water circulation systems. All doors of TM areas were mechanically locked. These results substantiated the validity of its safety design for emergency accidents [5, 6].

4. Summary

This study explained the outline of GCS for MLF and provided an overview of its recent progress with a focus on the MO system, interlock systems, and safety design in an emergency. The MO system of GCS was upgraded by changing its framework software to improve its potential flexibility for maintenance. The interlock systems were modified based on a re-examination of the J-PARC risk management system. With regard to sustainable long-term operation and maintenance, exchange and upgrade of various instruments in GCS such as client PCs, servers, PLCs, batteries, and the monitoring camera system should be executed carefully at an appropriate time while maintaining its safe and stable operation. In fact, the power supplies and batteries within the control panels and PLCs have been exchanged stepwise since 2013, a full-scale upgrade of the network systems of GCS was started in 2014, and the monitoring camera system will be materially upgraded in a few years.

Acknowledgments

The authors are grateful to the members of the Neutron Source Section and the staff of J-PARC Center for their useful help and suggestions.

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