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# THE SOFTWARE-BASED MACHINE PROTECTION SYSTEM USING EPICS IN J-PARC MR

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*Abstract*

In J-PARC, a dedicated MPS (Machine Protection System) stops accelerator beam operation automatically when an interlock signal comes. The MPS accepts interlock signals of accelerator components by hard-wires. Recently, a software-based MPS, called "Soft-MPS", was introduced, which uses EPICS PVs without wiring. A PLC controller running Linux was configured to watch at EPICS PVs over network. After logical calculations, it outputs an interlock signal to arise a MPS event. From the first Soft-MPS setup in 2018 spring, nine Soft-MPS setups are currently used.

## INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator facility in Japan. It has been operated collaboratively by Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK). It consists of three accelerators: a linear accelerator (LINAC), a Rapid Cycling Synchrotron (RCS), and a Main Ring (MR). MR started beam operation in 2008 [1].

A MPS (Machine Protection System) is a mechanism to stop accelerator operations automatically. In general, a MPS accepts various faulty signals from accelerator components: interlock signals of power-supplies, over-threshold alarm from beam-loss monitors, and so on. In J-PARC MR, we have a dedicated MPS [2]. When a faulty signal is detected during beam-delivery operation, the MPS starts a procedure to extract beams to the abort dump immediately (order of 10 microseconds). The MPS is essential to avoid damages caused by high-intensity proton beams.

As default, all signals come into the MPS are hard-wired. Recently we have introduced software-based MPS (Soft-MPS), with which input signals are given by an EPICS-based control system (i.e. software). This report provides implementation and operation details of our Soft-MPS.

## DEVELOPMENT OF SOFT-MPS

### *Why We Need Soft-MPS ?*

There are 2 reasons of using Soft-MPS. (1) To install interlock signals quickly. A Soft-MPS can implement a new interlock signal easily, because of no cabling. This type of Soft-MPS should be switched to standard-MPS using hard-wire later. (2) To use non-hardware parameters. For example, machine operation modes, beam bunch information, etc. Such signals are difficult to be given by hard-wire cables.

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### *Overview*

In J-PARC, we have been using an EPICS-based control system for the accelerator equipment [3] [4]. In J-PARC MR, a PLC controller (a CPU module running Linux with I/O modules of Yokogawa FA-M3 series [5]) are widely used as an EPICS input/output controller (IOC) [6] . A Soft-MPS setup is also an EPICS IOC, which consists of a CPU module and a Digital-Output module.

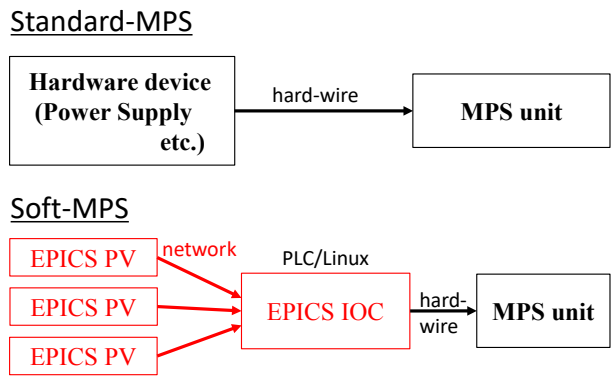


Figure 1: Standard-MPS vs. Soft-MPS.

Differences between standard-MPS and Soft-MPS are shown in Fig. 1. A standard-MPS has a hard-wire cable from a hardware device to a MPS unit. While a Soft-MPS uses EPICS process variables (PVs), which correspond to device interlock signals. Using remote PV parameters over network, an IOC would generate an output interlock signal to a MPS unit. Figure 2 shows photos: a PLC-type IOC for Soft-MPS and a MPS unit. Two are connected by a hard-wire cable. These are installed in the D1 building.

Typical process flows in an IOC are shown in Fig. 3. Four different setups of Soft-MPS are implemented in one IOC. Each of setups watches at remote PVs, located in distant buildings (D2, D3 and CCR). Logical outputs from setups are summarized, and finally a real output signal (a blue "DO") would be generated.

### *Reliability Mechanism*

A Soft-MPS watches at PVs via a network. In general, signal-inputs over network are less reliable than using hard-wire. To improve reliability, Soft-MPS has two mechanisms: (a) detection of PV communication loss, and (b) latch and hold alert status of each input.

**PV Communication Loss** When a PV, which is located at a remote IOC, becomes unavailable to communicate,

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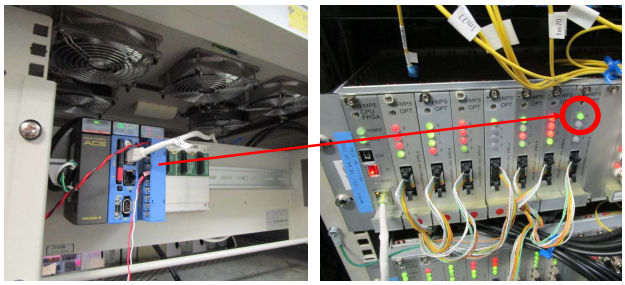

Figure 2: Photos of an EPICS IOC and a MPS unit.

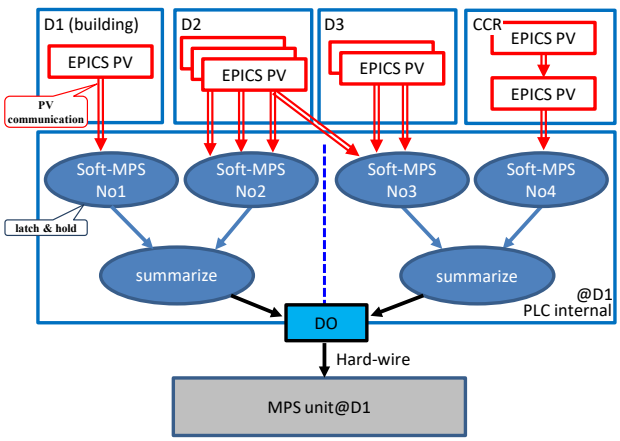


Figure 3: Process flows in a PLC-type IOC.

"Severity field" of the PV turns to an alert status "INIVALID". Each of Soft-MPS setups in Fig. 3 watches at this. When a PV communication loss is detected, a Soft-MPS arises an interlock event.

**Latch and Hold** Sometimes we have a momentary alert: a PV shows an alert status, but it comes back to normal status immediately. Each of Soft-MPS setups in Fig. 3 has a latch-and-hold mechanism for all of the input signals.

## OPERATION OF SOFT-MPS

Following the first Soft-MPS setup in 2018 spring, nine Soft-MPS setups are currently used in May, 2019. Three types of Soft-MPS were implemented: linear motion guides, a Multi Ribbon Profile Monitor in the injection area (INJ-MRPM), and coil voltage of the magnet B15D in the 3-50 beam-transport line (3-50BT B15D).

### *Linear Motion Guides*

In order to measure beam profiles in J-PARC MR, we have introduced several linear motion guides.

- 3D scatterer [8]
- Multi Ribbon Profile Monitor in Slow-Extraction area (SX-MRPM) [9]
- Extinction monitor [10]

The linear motion guides above are used only for beam tuning studies. After a study finished, they should be removed from beam lines. However, they have no interlock outputs. As a temporary measure, a Soft-MPS setup was implemented using PVs of linear motion guides.

In beam-delivery operations, the Soft-MPS setup generates an alert output, when one of the linear motion guides is still in the beam line. Figure 4 is a screenshot of overall MPS status in MR, and the implemented Soft-MPS for linear motion guides are shown in the blue square.

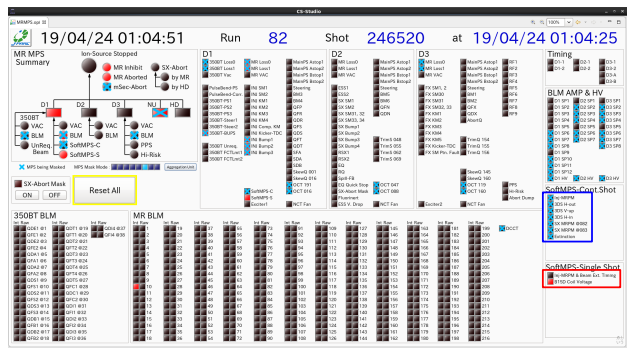


Figure 4: Soft-MPS implementations in a MPS status screen.

### *INJ-MRPM*

The Multi Ribbon Profile Monitor in Injection area (INJ-MRPM) is also a linear motion guide [11], but its alert condition is different from others. When beam intensity is low, the INJ-MRPM is not damaged during small number of beam turns. Thus, the condition of Soft-MPS for INJ-MRPM is:

- (low-intensity beam) Limited fill-pattern of beam bunches, limited number of protons per bunch
- (small number of turns) Beam extraction must be before 100 turns or less

The condition above is difficult to implement by hard-wire only. However, it is easy when a Soft-MPS setup uses parameter PVs. The implemented Soft-MPS is shown in the red square in Fig. 4.

### *Coil Voltage of 3-50BT B15D*

The B15D is a bending magnet in the 3-50BT beam-transport line. On March 15th, 2019, the magnetic field of B15D became unstable, and the beam operation stopped. We suspected an interlayer short circuit of the magnet coil [12].Thus, new Soft-MPS setup for B15D was implemented to supervise interlayer voltages, as shown in the red square in Fig. 4. MR beam operation restarted on April 1st. On April 24th, the Soft-MPS detected irregular behaviors of coil voltages, and the beam operation stopped again. We decided to suspend MR beam operation [12].

Figure 5 shows the cooling water temperatures and coil interlayer voltages on April 24th. The normal range of the coil interlayer voltage is from 13.35V to 13.80V, however, the ch2 and ch3 voltages are alarming in red.

The Soft-MPS scheme is effective for quick implementation of MPS. In the case of B15D, the Soft-MPS setup was implemented in a few days. It contributed to quick restart of beam operation on April 1st. In addition, after April 1st, the

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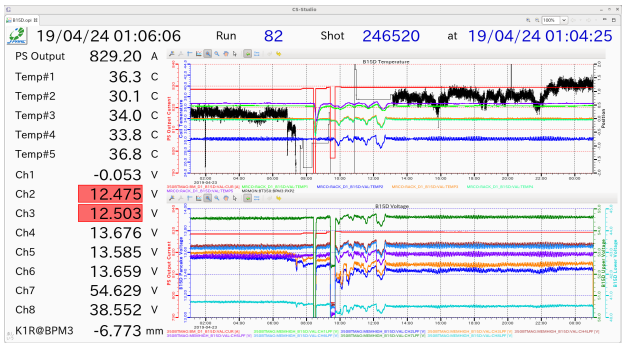


Figure 5: 1-day trends of coil voltages and water temperatures of B15D.

Soft-MPS setup was inevitable for careful beam operation with a suspicious B15D magnet.

## CONCLUSION

The Soft-MPS setups were implemented and operated in J-PARC MR. The Soft-MPS uses EPICS PVs as input signals, summarizes them, and outputs an interlock signal to a MPS unit using hard-wire cabling. The advantages of Soft-MPS are quick implementation and use of non-hardware parameters. The number of Soft-MPS setups is currently nine, but we expect more in the future.

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