CONTROL OF THE J-PARC SLOW EXTRACTION LINE BASED ON EMBEDDED EPICS

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Abstract

The J-PARC Main Ring supplies high energy proton beams to the Hadron Experiment Facility through the slow extraction line. It comprises of a series of septa, staring from a pair of electrostatic septa (ESS) followed by magnetic septa, and some of those septa are movable by using stepping motors to adjust their positions for a better optics. In order to control the power supplies of the septa and the stepping motors, an EPICS-based control was implemented by using a new type of Input / Output Controller (IOC), which runs Linux on a CPU module of FA-M3 Programmable Logic Controller (PLC). The CPU functions with normal I/O modules of FA-M3 on the PLC-bus. The most remarkable feature of the control system is that we replaced ladder programs with EPICS sequencer programs for the efficiency of the software development and ease of maintenance. The new type of IOCs have been working without any serious troubles during the beam commissioning period, from Run#21(Jan.2009) through Run#22(Feb.2009). This paper describes the details of the new IOC and its experiences in J-PARC operation including long term stability.

INTRODUCTION

The J-PARC Main Ring is a high power proton synchrotron that boost the beam energy up to 30GeV, possibly 50GeV, to achieve 1MW beam power for high energy experiments [1]. The beam is supplied to the Hadron Experiment Facility through the slow extraction line. The beam is extracted through electrostatic septa (ESS), low field magnetic septa (MS1), middle field magnetic septa (MS2) and high field magnetic septa (MS3) installed along the beam line [2]. (see Fig. 1) The first three septa are movable by using stepping motors to adjust their positions for a better optics aliment.

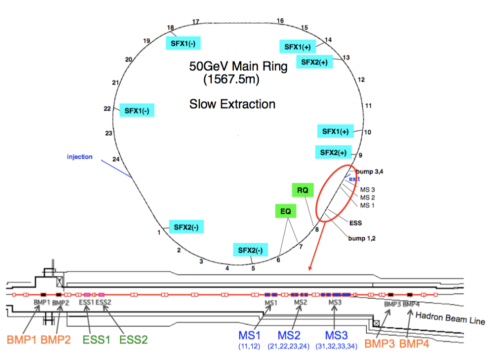

Figure 1: Layout of J-PARC slow extraction line.

In the EPICS-based J-PARC Control System, the standard method to control those devices is to use PLCs as the front-end controller. The IOCs are used just to set parameters to them and monitor the status over the network. However, this method requires programming on both PLCs and IOCs to make the software development costly. In addition, the EPICS device and driver support to make them communicate each other becomes complicated one. In order to solve the problems, a new type of IOC has been developed based on a CPU module of FA-M3 PLC. The CPU can function as a general purpose controller with I/O modules of FA-M3 on PLC-bus. (see Fig. 2) Since the CPU runs Linux as its operations system, it takes no special effort to run IOC core program on the CPU. This embedded EPICS approach allows us to make the PLC itself an IOC to simplify the system. By using the IOC, the ladder programs running on the sequence CPU can be replaced with EPICS sequencer programs, which are easier to develop and maintain [3][4][5].

Figure 2: A new type of IOC (F3RP61).

POWER SUPPLY CONTROL

On account of a limited budget, recycled power supplies were used for all the septa except ESS. Table 1 shows the recycled power supplies used in the slow extraction line. Though the power supplies originally have PLCs as their dedicated controller, they do not have Ethernet module to interface with IOCs since they are old models. Instead, they have analog and digital I/O modules to accept commands and parameters for the remote control. In order to control them, we have installed the new type of IOCs with I/O modules to connect themselves with the PLCs by using metal cables. (see Fig. 3).

Table 1: The Power Supplies used in the Slow Extraction Line

Power supply for magnetic septa	Produced time
Low field	about 10 years ago
Middle field	about 20 years ago
High field (front-side)	about 10 years ago
High field (rear-side)	about 20 years ago

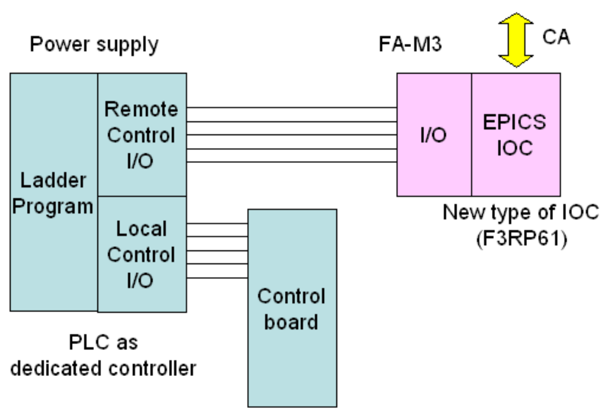

Figure 3: Control of existing power supply.

In this system, the existing PLCs handles minimum logic to turn on/off the power supply and to set/read the output current. The IOCs take care of: 1) ramping up/down the output current to the value specified by the operator, 2) clearing the set values when the power supply is interlocked due to internal faults or external conditions. The following code shows, for illustration, a part of an EPICS sequencer program to ramp up the current.

```
ss current_set {
  state target_check {

    when (current < target && run == TRUE) {
    } state current_up

    when (current == target && run == TRUE) {
     run = FALSE;
     pvPut(run);
    } state target_check
  }

  state current_up {
    when(delay(current_interval)) {
       if (run == TRUE) {
          current = current + step;
          if (current >= target) {
             current = target;
             output = current;
          } else {
             output = current;
          }
          pvPut(output);
       }
    } state target_check
  }
}
```

As the above example shows, due to the notion of state set and the "when" clause to wait an event, the readability of EPICS sequencer program is good enough to allow us to develop and modify the program it quickly on demand.

Fig. 4 shows the control panel for the power supply of the low field septum. (see Fig. 4).

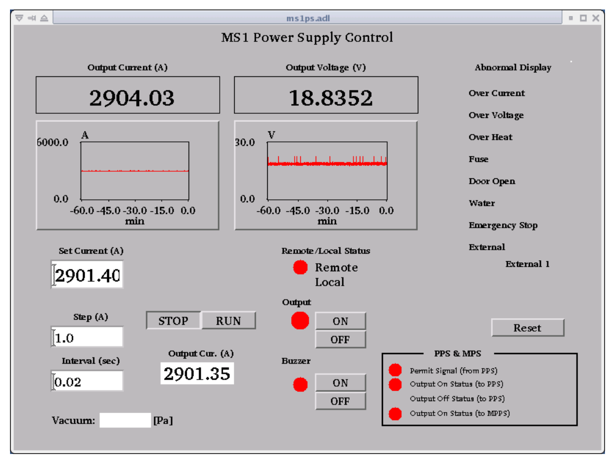

Figure 4: Control panel for power supply of septum.

STEPPING MOTOR CONTROL

In total, there are seventeen stepping motor units to control the positioning in the slow extraction line, as shown in Table 2.

Table 2: Using Stepping Motors in the Slow Extraction Line

Target	Axes
ESS1,2 (electrode/yoke and up/downstream)	8
Low field magnetic septa (up/downstream)	2
Middle field magnetic septa (up/downstream)	2
Screen monitors	5

The driver unit of the stepping motors are controled by using a positioning module of FA-M3, which sends a train of pulses to the driver unit to specify the distance of the motion along the axes. The positioning of the septa itself does not require special logic because it is basically executed independently for each of the axes by the operator. On the other hand, a sequence logic was required to be implemented by using an EPICS sequencer program in order to make the positioning module work in accordance with the specification of the module. Only one template sequencer program was used to control all of the axes to make the program simple and easier to maintain.

INTERLOCK STATUS MONITOR

In the interlock system, for high reliability, ordinary PLC's CPUs were adapted to implement the logic to protect devices and humans. The F3RP61-based IOC, which works with the sequence CPU on the same PLC-bus, is used just to monitor the interlock status. Using the IOC for this purpose has the following advantages. In the first place, the IOC can poll the PLC much faster since the transfer rate on the PLC-bus can be handled of times higher than that of message-based transactions over the Ethernet. For this reason, it is not necessary to transfer all the data at once by using waveform type record. Just reading the data by using mbbiDirect type record suffices. It makes the application software simpler and easier to maintain. Next, we can reduce the traffic on the network owing to the event driven communication of Channel Access (CA) between the IOC and OPI. Though it does not matter in the J-PARC control system where the PLC network layer is isolated from the IOC network layer, more generic control systems can benefit from the feature.

Two IOCs have been used in the slow extraction interlock system. One is for Intermediate Distribution Frame (IDF), which handles interlock signals, i.e., temperature and cooling water flow, from the magnets in the tunnel. The other is Personal Protection System (PPS) to stop the power supply to protect the human from radiation and/or high voltage. (see Fig. 5)

Figure 5: Monitor panel of status for PPS.

OPERATIONAL EXPERIENCES

In total, eight of the new IOCs were fully installed in Nov.2009 for the magnet power supply control, stepping monitor control, and interlock status monitor. They have been tested for a couple of months to confirm the stability of the software. The commissioning of the slow extraction line started in Jan.2009. Since them, the IOCs had been used for the real operation of the slow extraction line without any serious problems throughout the beam commissioning period, from Run#21(Jan.2009) through Run22(Feb.2009).

NEW POWER SUPPLY CONTROL

The next commissioning of the slow extraction line is scheduled in Fall.2009. In this operation, a new extraction quadrupole (EQ) magnets and ripple magnet(RQ) was installed in the main ring to use spill feedback system. A new power supply has been designed and constructed for the EQ and RQ magnets. The sequence logic was implemented by using a ladder program on a ordinary PLC's CPU of an FA-M3 PLC by the supplier. In order to interface the PLC with EPICS-based control system, an F3RP61 as an IOC was installed in the PLC to work with the sequence CPU side by side. The IOC set the current into the PLC and monitors the status of the power supply though the PLC memory. It make the system simpler compared to having external IOC communicating with the PLC over the network.

CONCLUTION

A new type of IOC based on F3RP61 has been adopted to control the power supplies of the septa, the stepping motors for the positioning of the septa and the screen monitors and the interlock status monitor. By replacing ladder programs with EPICS sequencer programs, the efficiency of the software development has been considerably increased and the maintenance of them made easy. The IOC can be used to monitor the interlock status to reduce unnecessary transactions over the network. In total, eight of the new IOCs have been used in the system and they have worked without any serious troubles during the beam commissioning period, from Run#21(Jan.2009) through Run#22(Feb.2009).

REFERENCES

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