UPGRADE OF VACUUM CONTROL SYSTEM FOR J-PARC MAIN RING

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Abstract

The vacuum control system in J-PARC Main Ring has been in operation for about 16 years. The ion pumps had been controlled by commercial EPICS-embedded PCs, microIOCs. However, the microIOC was discontinued, and no spare available since 2018. Therefore, we replaced the microIOCs with MOXA servers (serial-LAN server) and saba-taro micro-servers during 2023 and 2024. In addition, to have faster response time, we redesigned: a) the EPICS database configurations and b) the hardware cable connections. The upgraded system has been in operation without a problem since Jan. 2024.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator complex. It consists of three accelerators: a 400-MeV Linac (LI), a 3-GeV Rapid Cycling Synchrotron (RCS), and a 30-GeV slow cycling Main Ring Synchrotron (MR) [1, 2]. Since the initial beam in 2006, we have been dedicated to enhancing the beam power of J-PARC. Concerning MR, the original design power is 750-kW. By using new power-supply system for the main magnet in Jan. 2023, a high-power trail of MR (one shot) achieved 753-kW in Apr. 2023 [3]. In Jun. 2024, the beam power of 800-kW was achieved for stable beam delivery to the neutrino facility [4].

The vacuum control system of J-PARC MR has been in operation since 2008 and has been running stably without any big problem. Most of the ion pumps are controlled by a commercial industrial PC, microIOCs [5]. However, after 16 years of operation, the microIOC has been discontinued, and we no longer have any spare ones. Therefore, it is urgent to quickly develop a new system that can integrate with the existing high-level applications as before.

Firstly, this paper shows the application of microIOC in J-PARC MR in last 16 years and the difficulties of the renewal of the vacuum control system. Secondary, the new scheme of the system is introduced, including the implementation of the system. Finally, improvements to achieve faster responses in RS485 serial lines are also described in the paper.

MICROIOC AND OLD SCHEME

The microIOC is an embedded computer designed by Cosylab [6]. The devices can be connected through serial (RS485/RS232), GPIB or other ports, then be monitored and controlled by Experimental Physics and Industrial Control System (EPICS) via Ethernet. Figure 1 shows a microIOC used in J-PARC MR.

In J-PARC MR, we purchased 4 units in 2007, each has eight RS485 ports, costing about 340,000 yen per unit. Three of them were installed in three power-supply buildings (D1, D2, D3), one as a backup spare.

There are roughly 100 ion pumps in MR, and about 70 of them are controlled by microIOCs via RS485 serial line. Left of them have been controlled by PLC I/O modules, depending on cases. Figure 2 shows some of ion pumps controllers with RS485 port. The scheme of the vacuum control system is shown in the left of Fig. 3.

Figure 1: Photo of microIOC in J-PARC MR.

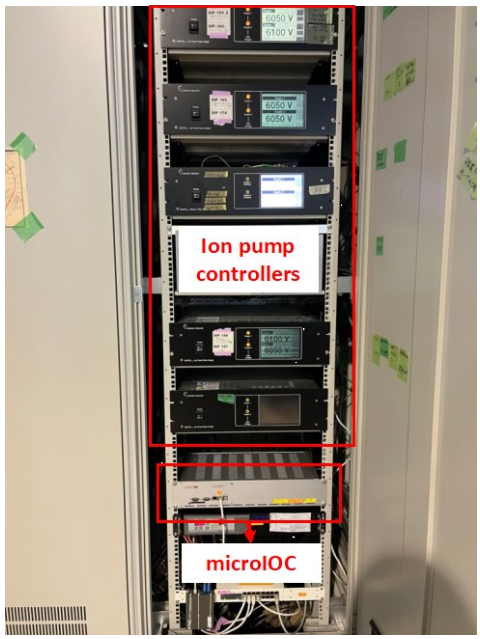

Figure 2: Photo of ion pump controllers controlled by microIOC in a rack at J-PARC MR D3.

However, the spare of microIOC was used to replace the broken one in Jun. 2018. Since then, we had no spare available. Therefore, we planned to replace the vacuum control system with new hardware.

Nevertheless, we faced the challenges shown below:

(1) Develop new hardware driver while keep using the current high-level applications. The original hardware driver for microIOC was based on a device support generator, GDL. It has been available since 1996 and

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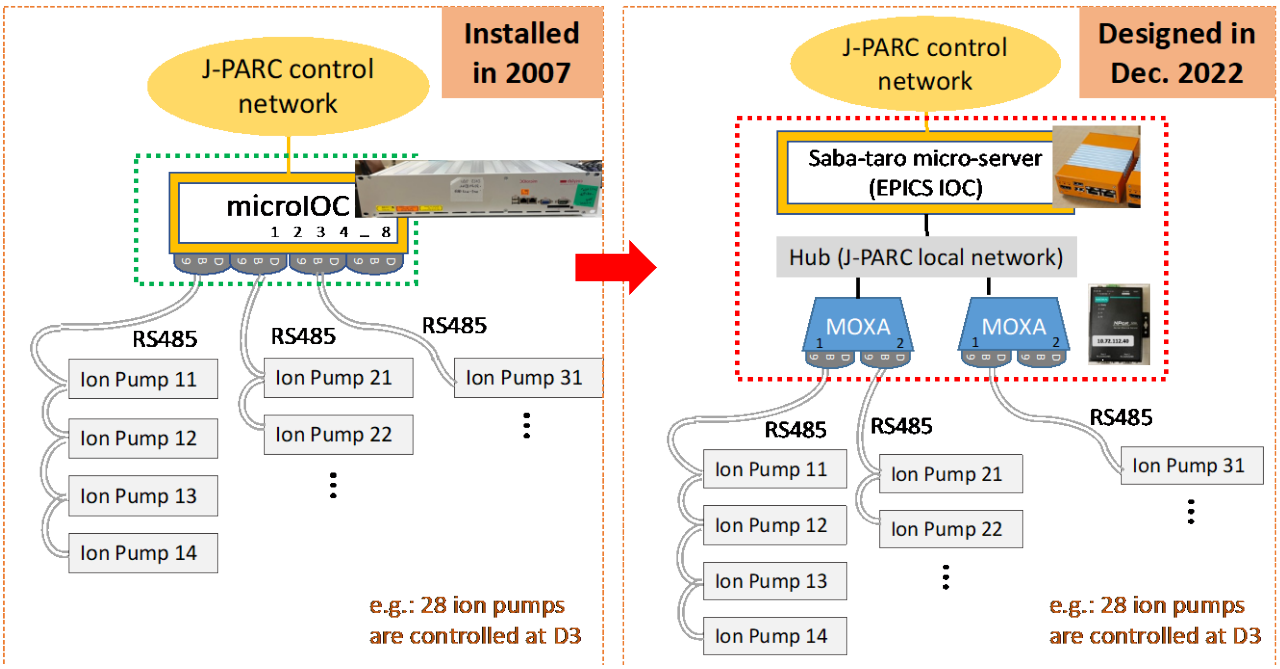

Figure 3: Old and new schemes of the vacuum control system in J-PARC MR.

is no longer maintained. We need to redevelop low-level code for new hardware.

(2) Do the renewal work only on a maintenance day. The schedules also need to be discussed with the vacuum group. The renewal work should not disturb J-PARC beam operation.

DESIGN OF NEW SCHEME

Hardware

In Dec. 2022, we designed a new scheme for vacuum control system to replace microIOCs. To develop a new system quickly, we decided to use standard products: a MOXA serial port server [7] and a saba-taro micro-server [8]. The new scheme is shown in the right of Fig. 3. A MOXA server realizes serial-to-Ethernet solutions, and is easily configured through terminal or website. It is widely used in accelerator field and is very cost-effective, costing approximately 45,000 yen. A saba-taro micro-server is a standard EPICS IOC (Input/Output controller) at the J-PARC MR. It has two Ethernet ports. The first port is connected to J-PARC control network to enable the monitoring and control of vacuum devices, and the second port is connected to MOXA servers through a network cable.

We would like to keep using the original RS485 chains for time being. We chose a MOXA server with two ports (NPort 5250A), each port can connect to one RS485 chain. Numbers of MOXA servers used in different power-supply buildings are case dependent, for example, two pieces at D3.

Software

Same as microIOC, Linux and EPICS IOC are running on each of the saba-taro micro-servers.

The new hardware driver is developed based on the EPICS module, StreamDevice, available since 2007 [9].

The high-level applications remain unchanged. Therefore, operators are allowed to observe and operate the ion pumps as they did before.

IMPLEMENTATION OF NEW SCHEME

In Jun. 2023, we first started a renewal work at the power-supply building, D3. Instead of a microIOC, two MOXA servers and a saba-taro micro-server were implemented. Figure 4 shows the photo at D3 after the renewal

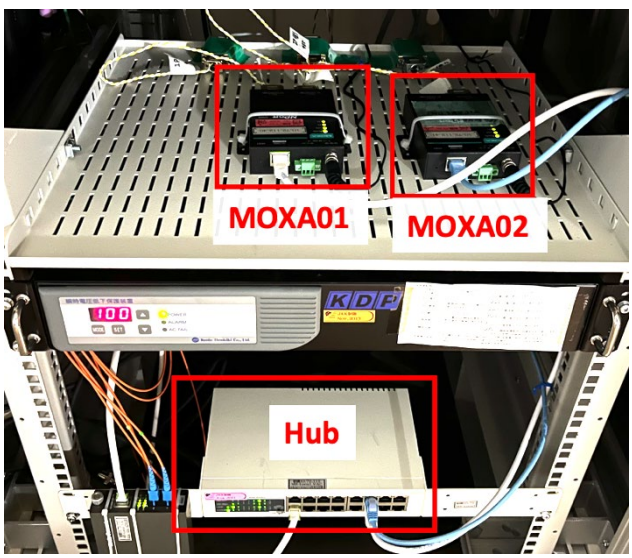

Figure 4: Photo of the MOXA servers after the renewal work at J-PARC MR D3 building. Saba-taro micro-server is not shown, since it is located in a distant local control room at D3.

work was completed. Three serial ports of two MOXA servers are used for controlling 28 ion pumps (see also the right of Fig. 3).

Figure 5 shows the archived vacuum data from the day of the microIOC replacement at D3 (14th Jun. 2023). The first half of the figure shows the data by previous system. Then, the replacement work took place between 1PM and 2PM. After that, the new system started. The second half of the figure shows that the new system perfectly took over the old system's job. It is worth noting that the data suspension due to the renewal work was only one hour.

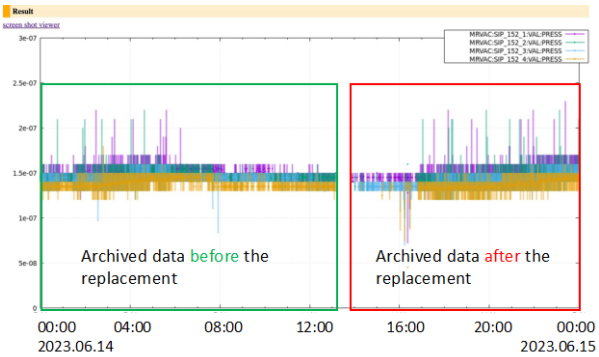

Figure 5: Archived vacuum data at D3 on 14th Jun. 2023.

After the new system at D3 has shown stable operation over six months, two microIOCs at D1 and at D2 were also replaced in Jan. 2024. Finally, all the microIOCs have been replaced with MOXA servers and saba-taro micro-servers. Figure 6 is the GUI to show all the ion pumps of J-PARC MR vacuum system. It was used with the old system, while the same GUI works well as before.

IMPROVEMENTS OF PERFORMANCE

In addition to replace the microIOCs with new hardware, we did two improvements to achieve faster response time: (a) redesign the EPICS configuration, and (b) redesign hardware cable connections.

Redesign EPICS Database Configuration

Figure 7 shows the loop how the EPICS database processes to get vacuum data. In the original configuration, there are six EPICS records in a regular loop, four of them (CUR, PRESS, UNIT, STAT) send requests to ion pumps and get replies through a RS485 serial line. One of the RS485 chains at D3 had 16 ion pumps. We measured the time interval of monitoring 16 ion pumps, and found that it took about 3 seconds.

However, during beam operations, the unit (UNIT) and the status (STAT) of ion pump are not frequently changed. We divided the regular loop into two loops: a regular loop and a slow loop (Fig. 8). In the new configuration, the UNIT and the STAT are in the slow loop.

After redesigned the EPICS database configuration, the response time for monitoring 16 ion pumps was improved from 3 seconds to 1.5 seconds.

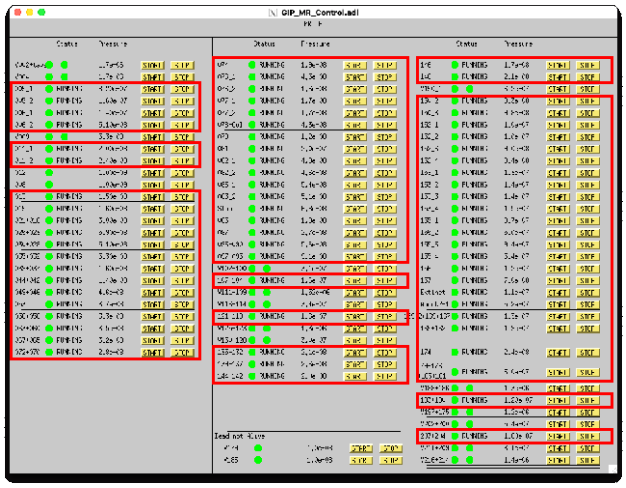

Figure 6: GUI of ion pumps of J-PARC MR. The highlighted parts with red boxes are the ion pumps monitored and controlled through new hardware.

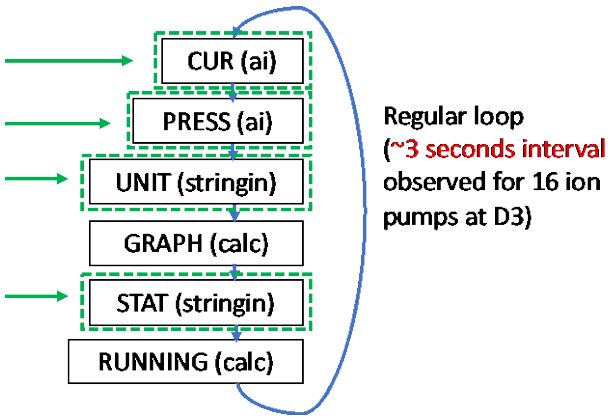

Figure 7: Loop of EPICS database in the original configuration.

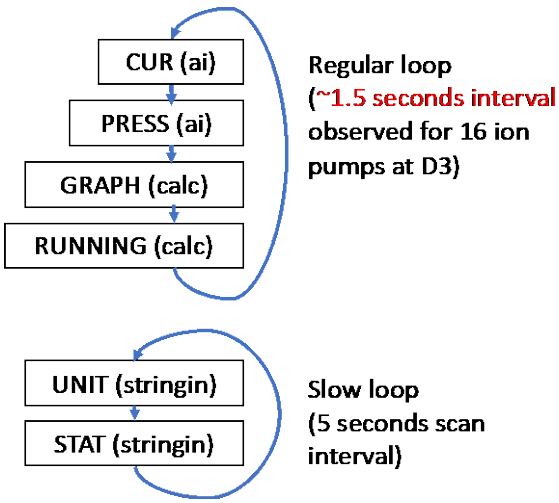

Figure 8: Divide the original regular loop into two loops.

Redesign Hardware Cable Connections

In the original RS485 chains, one chain often had many slaves, i.e., more than ten. We redesigned these chains by

splitting into two. This has greatly affected the response time. For example, the chain with 16 ion pumps at D3 was updated to have two chains (Fig. 9). After splitting the chain, the response time was reduced to 1 second.

Up to now (summer of 2024), all the RS485 chains at D3 and D2 have already been updated. The chains at D1 are scheduled in this summer shutdown.

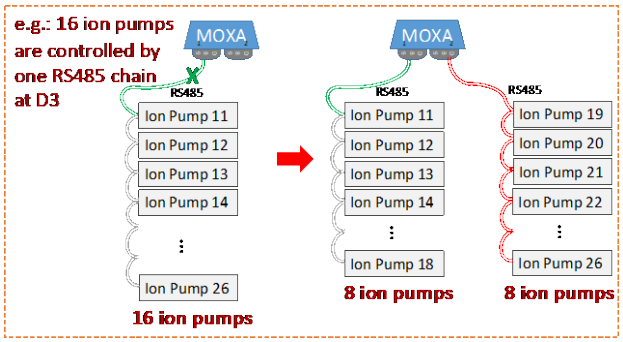

Figure 9: An example at D3: a chain with many (16) slaves and how it looks after splitting it into two.

CONCLUSION

The vacuum control system in J-PARC MR has been upgraded by replacing microIOCs with MOXA servers and saba-taro micro-servers. From the operator's perspective, the new system is identical to the old one, since we paid special attention to the new hardware and driver not to affect to the existing high-level applications.

To have faster response time, we also redesigned the EPICS database configuration and the hardware cable connections. These improvements have reduced the response time from 3 seconds to 1 second.

The upgrade is inevitable for the operation and maintenance of vacuum control system in J-PARC MR for the next 10 years.

ACKNOWLEDGEMENTS

We express our best thanks to J-PARC MR staff members and company (KIS) members for their encouragement and suggestions during system development.

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