Update status of the J-PARC 3NBT control system

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ABSTRACT

At J-PARC, a 3 GeV proton beam with power of 1 MW can be delivered to the Japan spallation neutron source through a beam transport line called 3NBT. At high power accelerator facilities, even a small abnormal event can be of importance; therefore, a beam control system is crucial. To identify small anomalies, a system for rapid data analysis is required. Here, we developed a control and data analysis system based on the Experimental Physics and Industrial Control System and Control System Studio. At the Japan spallation neutron source, pitting damage on the mercury target vessel is an important issue. Because pitting damage is proportional to the beam current density, a beam transport system using nonlinear beam optics has been developed. To efficiently perform beam tuning, a beam control system based on the Strategic Accelerator Design code has been developed. With several beam pulses and by using the screen’s operational panel, the required magnet field can be calculated and automatically set. Data sharing between the experts and authorized personnel is important when an anomaly occurs. We have also developed an automated e-mail system to announce the abnormal event, which reduces the response time. Thus, we can reduce both beam tuning and system downtimes employing these systems.

KEYWORDS
J-PARC, 3GeV beam transport facility, EPICS, SAD, CSS

1. INTRODUCTION

J-PARC is a proton accelerator complex facility comprising the 400 MeV LINAC, 3 GeV Rapid Cycling Synchrotron (RCS), and 50 GeV synchrotron (Main Ring: MR). The 3 GeV beam transport facility (3NBT) is a beam transport line from the RCS to the Material and Life Science Facility (MLF) in J-PARC [1]. The 3NBT is 314 m long and transports a 3 GeV proton beam of 1 MW power. In such a high-power beam facility, even a small error can result in a large incident. Therefore, efficient monitoring and timely action are vital. Moreover, system automation is important for stable operation.

Recently, the following upgrades were made to the control system in the 3NBT.
- Upgrade of the control system for the water cooling system
- Installation of the beamline gas monitoring system
- Automation of the e-mail alert system
- Upgrade of the operator interphase with the Strategic Accelerator Design (SAD)/Experimental Physics and Industrial Control System (EPICS).
2.1. Control System for Water Cooling System

At 3NBT, InTouch, a commercial Human–Machine Interface (HMI) software, was used for the water cooling system. InTouch can communicate with the Programmable Logic Controller (PLC) of the water cooling system. However, InTouch works only on Windows and has to be maintained for each Windows system. (The system worked on Windows XP.) Moreover, InTouch does not support EPICS [2], the main platform of the J-PARC control system.

When upgrading the controls of the water cooling system, we considered two possibilities. One is upgrading the InTouch system, and the other is replacing it with the Control System Studio (CSS), a HMI software of the EPICS. Table I shows a comparison between InTouch and CSS.

Both InTouch and CSS have several functions as the HMI of the water cooling system. However, InTouch does not support the EPICS channel access protocol and cannot share data with other systems such as magnet power supply, vacuum system, and beam monitors. The license fee for InTouch is estimated to be over 5 million yen for the system update, and the number of clients is limited by the license. In the previous system, trend data were saved on the server PC as text files and data could be accessed only by the server.
Table I. Comparison of Control System HMI

<table>
<thead>
<tr>
<th></th>
<th>Previous</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HMI Software</strong></td>
<td>InTouch</td>
<td>CSS</td>
</tr>
<tr>
<td><strong>OS</strong></td>
<td>Windows</td>
<td>Windows, Linux, Mac</td>
</tr>
<tr>
<td><strong>Monitoring Item</strong></td>
<td>Water only</td>
<td>All data on EPICS</td>
</tr>
<tr>
<td><strong>Available terminal number</strong></td>
<td>One (License required)</td>
<td>Many (License free)</td>
</tr>
<tr>
<td><strong>EPICS I/O</strong></td>
<td>Not supported</td>
<td>Supported</td>
</tr>
<tr>
<td><strong>Trend graph</strong></td>
<td>One at a time Limit 8 lines</td>
<td>Multiple graphs available</td>
</tr>
<tr>
<td><strong>Data Base</strong></td>
<td>Csv text file MySQL (optional)</td>
<td>Postgre SQL</td>
</tr>
</tbody>
</table>

The CSS is developed as a HMI software of the EPICS and is license free. The CSS works in Windows as well as in Macintosh and Linux, meaning that we can monitor/control the new system from anywhere in J-PARC. The CSS is free from operation system failures. The CSS cannot access the PLC by itself but needs the EPICS to connect to the PLC device driver. The CSS supports PostgreSQL as a data archive server; hence, we can access data from any client terminal. With the CSS, we can show many graphs at once (Fig 2), and the operator can freely change the graph arrangement. Thus, the CSS has many advantages as the HMI software for the user.

Figure 2. Example of the new water cooling system.
2.2 Gas Monitoring System of the Proton Beam Line

In the previous system, we monitored the pressure of the proton beam line, wherein we observed unexpected increases in pressure. In addition, we had issues with the vacuum pump and cracks in the chain cramp of the vacuum line. There was also the potential risk of water leakage from a proton beam window and the release of gases from the muon target. In the 3NBT beam line, the muon production target is around 280 m from the RCS. The muon target is made from graphite, and it rotates due to heat removal and dispersion. During beam operation, if the target rotation accidentally stops, the temperature of the target will quickly increase, leading to target damage. To quickly identify and analyze such damage, a quadrupole mass spectrometer (Q-MASS) was installed in the proton beam line. Figure 3 shows results of the Q-MASS measurement during beam operation, throughout which various elements are detected. Some amounts of spallation products are released just after beam irradiation, but others would be kept within the target. Hence, this damage to the target would be detected by the Q-MASS. Other issues such as vacuum or water leaks from the proton beam window would be also detected by the Q-MASS.

Figure 3. Trends of gas production measured by Q-MASS.

In the first operation stage of the Q-MASS, its operation frequently terminated due to radiation damage. Because the MLF receives high power proton beam, large amounts of high-energy gamma rays and neutrons are present in the beamline tunnel. Then, we introduced a radiation shield of lead and polyethylene around the Q-MASS. Consequently, we realized stable operation of the Q-MASS.

2.3 Automated E-mail alert System

At 3NBT, the vacuum and water cooling systems operate throughout the day. The operation of these systems are continuous during the maintenance period, but at nights and holidays, the system was left unattended. Therefore, the detection of issues was sometimes delayed during certain periods. Hence, we developed an automated e-mail alert system on the 3NBT control system. Figure 4 shows the data flow of the system and sample e-mails. Because the J-PARC control system is separated from outside of the system by a firewall, sending e-mails directly...
from the monitor system is not possible. However, through the firewall proxy, we can send operation data to the outside server. Then, the data are analyzed and when some issues are detected, the alert system notifies the staff through e-mail or cell phone. By securing the data, we maintain control over the security of the control system.

Using this e-mail system, we found a water leakage on Jan 2, 2015, along with other issues within a short duration, and the system helped reduce the facility’s downtime.

![Data flow of the E-mail alarm system](image)

**Figure 4. Data flow of the e-mail system (left) and example of an e-mail (right)**

### 2.4 Beam Tuning Tool with SAD Code

At 3NBT, we used a command-based beam tuning tool. This tool took a long time to analyze and required a skilled operator. Then, we introduced a graphical system (Fig. 5) using SAD [3-7]. SAD was developed as an accelerator control tool in High Energy Accelerator Research Organization (KEK). The new system reads the beam monitor data and magnet current data and automatically analyzes the beam orbit. SAD calculates the next set of values of the magnetic field from the monitor data and set parameters.

### 2.5 Automated beam orbit correction

Upstream of the 3NBT is used for the beam path to the MR. Four proton beam pulses are scheduled for the MR in every cycle (Fig. 6). The duration of an MR cycle is 2.48 s for the neutrino facility and 5.48 s for the hadron facility. There is a pulse bending magnet for the MR in the 3NBT and initial four pulses (K1–K4) kicked to the MR. The kick angle calculated by the residual field is shown in Fig 7. K5–K6 pulses have large residual fields; therefore, they were not used. However, these two pulses contributed to the loss of the beam power for the MLF. We introduced a pulse correction coil for canceling the residual field and gained full beam operation, including those for K5 and K6.

Other issues include the bending magnet for the MR, which is located near the 3NBT beam line, and the solenoid magnet around the muon production target for high-efficiency muon extraction. Figure 8 shows the top view of the muon target. These magnets affect the beam orbit of the 3NBT and these magnetic fields are switched according to their own convenience. Thus, we added an automatic collection system for these magnets. The system monitors the currents of these magnets and automatically changes the magnetic field of the steering magnet on the 3NBT.
beam line. Figure 9 shows the deviation of the beam orbit by the solenoid magnet around the muon target. The left panel shows the orbit deviation of the solenoid field and the right one shows that after the correction.

Using the pulse correction coil and automated correction system, the beam orbit of the 3NBT becomes stable within 2 mm.

Figure 5. Screen of the beam tuning tool with SAD.

Figure 6. Pulse train from 3GeV RCS. Initial four pulses (K1–K4) kicked to MR.
3 Summary

CSS is applied as an operator interface for the water cooling system in 3NBT. With the e-mail notation system, we reduced the facility’s downtime. The SAD system installed improved the beam tuning system.
REFERENCES