UPGRADES OF TEMPERATURE MEASUREMENTS AND INTERLOCK SYSTEM FOR THE PRODUCTION TARGET AT J-PARC HADRON EXPERIMENTAL FACILITY

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Abstract

Hadron experimental facility is designed to handle intense slow-extraction proton beam (750kW-15μA) from Main Ring of Japan Proton Accelerator Research Complex (J-PARC). On May 23, 2013, due to malfunction of the slow-extraction system in Main Ring, the production target in Hadron experimental facility was locally damaged because of overheat by absorbing proton beam in extremely short period (5 milliseconds). After the accident we have improved the monitoring system of temperature of the target with 100 milliseconds sampling rate in order to detect damage to the production target as soon as possible. The monitoring system has been operated without failure after the accident. This manuscript reports the upgrades of the temperature measurements at the J-PARC Hadron experimental facility.

INTRODUCTION

The Hadron experimental facility [1] (HD-hall) at Japan Particle Accelerator Complex (J-PARC) shown in Figure 1 is designed to handle intense slow-extraction proton beam from Main Ring (MR). The period of beam extraction from the MR to the HD-hall is 2 seconds and the operation cycle is 6 seconds.
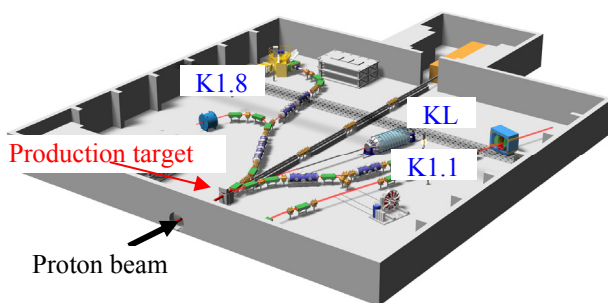

Figure 1: Illustration of the HD-hall.

On May 23th, 2013, 2×10^{13} proton beams were rapidly extracted to the HD-hall in 5 milliseconds due to malfunction of power supply of Extraction Quadrapole magnet in the MR. The production target [2] in the HD-hall was locally damaged because of rapid rise of temperature by beam deposit in extreme short period.

In order to detect the damage to the production target, the requirements of temperature measurement system are as follows.

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- Upgrade read-out system of the production target temperature.
  - Hundred milliseconds sampling
  - Synchronization with beam extraction
- Make trend graphs and the waveform spectra of the target temperature as a function of time to tell the operators the state of the production target.

THE PRODUCTION TARGET

The production target at the HD-hall is made of gold and a copper block with coolant stainless pipes. Gold is chosen for high density, high thermal conductivity and good chemical stability. The total size of a gold structure is $15^W \times 6^H \times 66^L$ [mm]. The gold structure was divided into 6 pieces to reduce thermal stress. The water coolant pipes, embedded in the copper block, were made of stainless steel to avoid erosion and corrosion. The gold structure, the copper block and the coolant pipes are bonded by a Hot Isostatic Pressing (HIP) process.

The production target is located in an airtight chamber filled with helium gas. The beam entry and exit are covered with beam windows. Twenty thermocouples were attached at the surface of the gold pieces (12), the copper structure (2), the water and helium gas pipes (4) and the edge of the beam windows (2). The production target is designed to be capable for up to 50-kW proton beams.

MEASUREMENT AND CONTROL DEVICE

Before the accident we had measured the temperatures of the production target with 1-second cycle with a Programmable Logic Controller (PLC). The PLC had consisted of one EPICS-CPU, which is an embedded EPICS IOC on Yokogawa's FA-M3 PLC platform [3], three temperature monitor and one output modules. However, the temperature-measurement cycle of 1 second was too slow to detect the rapid temperature rise of the production target. Therefore we have upgraded the measurement system of the target temperature. Measurements of temperature with 100 milliseconds sampling are controlled with the sequence-CPU. The sampled data are stored in the sequent memory of the sequence-CPU. Then, an EPICS-IOC, running on the adjoining CPU module, installed next to the sequence-CPU, can take data from the sequence CPU via shared memory. Finally, the operators can monitor waveform spectra of the temperature rise on the production target, via the EPICS waveform record.

In the sequence-CPU, the temperature data of the production target are continuously compared to the thresholds for each thermocouple. An interlock signal is issued when the temperature exceeds the threshold. The interlock signal is transferred to the accelerator and the next beam extraction is safely stopped.

The start and stop timing of the measurement is synchronized with the beam extraction cycle, using the gate signal synchronized to the accelerator operation. The system of the PLC is shown in Figure 2.
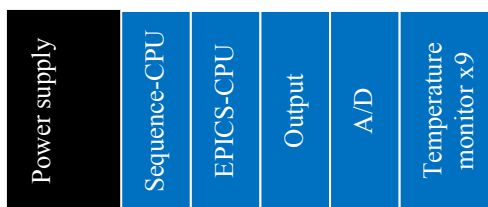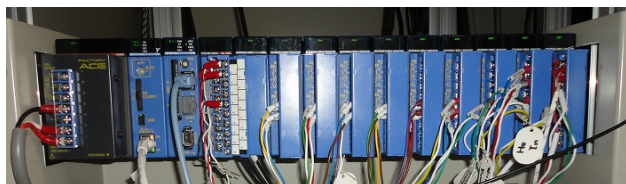

Figure 2: Photograph and illustration of the PLC.

METHOD TO MEASURE TEMPERATURES SYMCHRONIZED WITH BEAM EXTRACTION

We have developed the system of the temperatures synchronized with beam extraction to display the time structure of the target temperature. The way of the system is described in Figure 3 and as follows.

I   The gate signal synchronized with beam extraction (ON-Beam) is detected by the A/D module in the PLC.

II   When the leading edge of the gate signal is detected, the measurement starts with 100 milliseconds sampling rate, and ends after 5.8 seconds. The data are stored in the shared memory on the sequence-CPU.

III   After the completion of each temperature measurement, the sequence-CPU issues the signal to the adjoining CPU module for data-taking.

IV   The adjoining CPU starts to read temperature data via the shared memory, and store data into EPICS waveform records.

V   Finally, the system waits for the timing gate of the next beam extraction after the completion of the temperature measurement.

The EPICS sequencer [4] has been used in order to operate the system synchronized with the beam extraction.
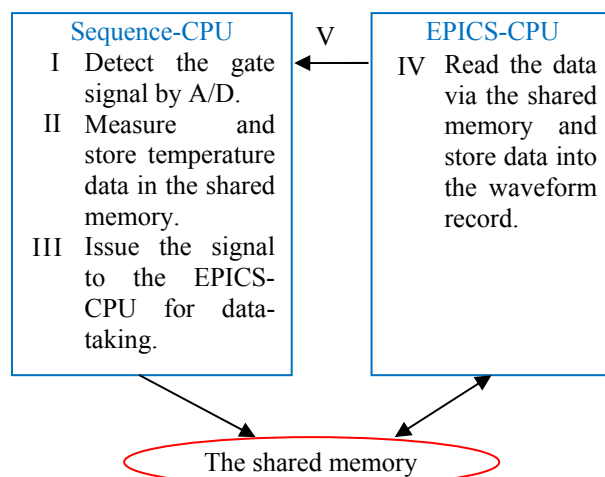

Figure 3: Diagram of how to measure the temperatures synchronized with beam extraction.

INTERLOCK AND ALARM SYSTEM

The interlock signals of the beam line components are used in the Machine Protection System [5] (MPS) in J-PARC. The MPS automatically stops beam operation when the MPS status is broken by the interlock signals from the accelerator and the beam line components. The EPICS Alarm Handler [6] has been introduced to notice the operators the warnings from the equipments. As for the production target, two-step thresholds ("Warning" and "Alert") for all temperature data are defined, using EPICS ALARM field (HIGH, HIHI, etc.).

The MPS signals from the target system are assigned to be "Alert".

DISPLAYS

Temperature data synchronized with beam extraction, trend graphs and MPS status are displayed in a control room for the operators. These displays are mentioned as follows.

Temperature Data Synchronized with Beam Extraction

A GUI program for the temperature data synchronized with beam extraction has been developed with wxPython [7]. WxPython is a GUI toolkit for the Python programming language. The operators can monitor the current data via this GUI program and inspect the past data if necessary. Figure 4 shows the typical waveform spectra of the target temperatures during the normal beam operation of 33kW. A smooth temperature rise during the beam extraction is measured from 0.6 to 2.6 seconds. The smooth decrease of temperature continues to 5.8 seconds from the beginning of the measurement. The maximum temperature of the gold pieces was 250.0 degree Celsius at the forth from the front piece. The temperature rises of the copper block and the coolant pipes were not more rapid than that of the gold pieces. The maximum temperatures and the averaged temperatures for last five

shots are displayed on the upper of this graph for beam commissioning.
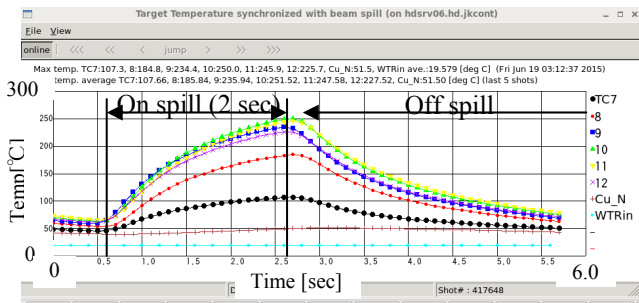

Figure 4: Display of temperature data synchronized with beam extraction during 33-kW beam operation. Its vertical axis is for the temperature [degree Celsius], and the horizontal axis is for the time [second].

Trend Graphs

The trend of temperature data are displayed by Strip Tool [8] as shown in Figure 5. The target temperature and the thresholds of "Warning" and "Alert" are shown in the same window. Figure 5 shows the typical beam operation continued to operate for 30 minutes without beam stop.
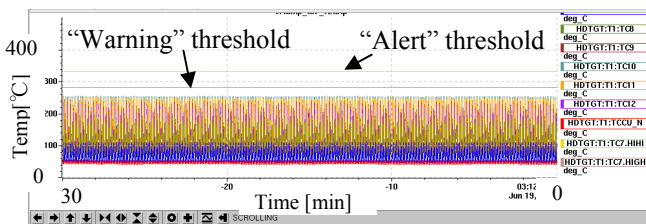

Figure 5: Display of trend graphs. The beam condition of this figure was the same as that of Figure 4. Its vertical axis is for the temperature [degree Celsius], and the horizontal axis is for the time [minute].

The Current Values and the Interlock Status

A GUI program for the current values, thresholds, and the interlock status of temperature has been developed with MEDM [9]. Figure 6 illustrates a top view of the production target. The operator can recognize the current values and the interlock status at a glance.
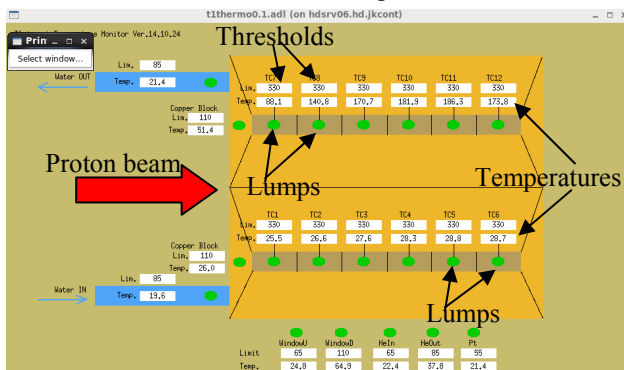

Figure 6: Display of interlock status.

SUMMARY

- The measurement and interlock system of the target temperature has been developed with the PLC. The temperature data and the interlock signals are handled and controlled with the sequence-CPU module. The EPICS-CPU module can handle the data from the sequence-CPU via the shared memory. The waveform records of temperature as a function of time can be referred on the EPICS-CPU.
- The measuring system operates to synchronize with the beam extraction. The operator can monitor the waveform spectra as a function of time in every beam extraction.
- The trend graphs, the current data of temperature, and the interlock status are shown visually for the operator.
- The two-step alarm system has been introduced for the operators, using ALH.
- The upgraded system has been successfully and stably operated with up to 33-kW proton beams.

ACKNOWLEDGMENT

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