UPGRADE OF THE BEAM MONITOR SYSTEM FOR HADRON EXPERIMENTAL FACILITY AT J-PARC

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Abstract

Hadron experimental facility at Japan Proton Accelerator Research Complex (J-PARC) has been improved toward safety operation of high intensity beams. The monitor system of the slow-extraction beam line also has been upgraded to detect abnormal beam extraction. The rate monitor which measured the number of second particles from the production target with the rate of 1 kHz was prepared to detect short pulse extraction. The beam profile monitor was upgraded to read out the data at several times during a beam spill to detect a beam with the narrow width even for a short time. The beam loss monitor was upgraded to monitor beam loss with the rate of ~10 kHz to detect unexpected large loss immediately.

INTRODUCTION

Hadron experimental facility at Japan Proton Accelerator Research Complex (J-PARC) is designed to provide high intensity beams for particle and nuclear physics [1]. A 30-GeV proton beam show-extracted from main ring is injected to a production target (T1) at the hadron experimental facility. The acceleration cycle for the slow-extraction is 6 sec and the spill length is 1.5~2.0 sec.

Figure 1 shows an overview of the hadron experimental facility. In the beam switching yard, there are 33 beam line magnets in 250 m tunnel. In the HD-hall, the proton beams are injected to the production target (T1) and produce secondary particles. The proton beams are transported to the beam dump and absorbed safely. Several kinds of beam monitors are installed in the slow-extraction beam line. The beam monitors involving this paper are shown at Fig. 1.

On May 2013, a proton beam was instantaneously extracted to hadron facility in 5 msec. The short pulse beam molt the production target. After the accident, the beam operation was stopped at the hadron experimental facility. For the recovery of the hadron experimental facility, we upgraded the slow-extraction beam line in many aspects to sustain the abnormal beam extraction. The beam monitor system of the slow-extraction beam line was also upgraded to detect the abnormal beam extraction. The monitor system was developed based on EPICS [2]. The interlock system of the beam line was also improved based on the upgraded monitor system to protect the machines of the accelerator and the beam line.

The rate monitor was upgraded to measure the number of second particles from the production target with the rate of 1 kHz for the detection of short pulse extraction. The readout system of the beam profile monitor was improved to detect a beam with the narrow width even for a short time. The main purpose of the rate monitor and the beam profile monitor is to detect the abnormal beam extraction which may damage the production target. The readout system of the beam loss monitor was improved to detect unexpected large loss immediately. The operation of the slow-extraction beam line was restarted on Apr 2015 successfully.

RATE MONITOR

The rate monitor measures the number of second particles from the production target by using plastic scintillation counters. The rate monitor is installed outside the shielding enclosure of the beam line. The rate monitor was upgraded to read out the particle count with the rate of 1 kHz. Since the number of the second particles is sensitive to the beam intensity, the rate monitor is used to monitor the time structure of the beam intensity. The signals from the scintillators are converted to short pulses with the width of ~60 nsec by a NIM discriminator. The number of the second particles is measured by counting the pulses with a VME module with a FPGA board (GNV-251). The EPICS Input/Output Controller (IOC) runs on Linux on a VME CPU modules (VME-7807).

Figure 2 shows the online monitor display of the rate monitor. The number of the particles per 1 msec is plotted as a function of time. The upper panel shows the example plot in the case of the normal beam extraction. The lower panel shows the predicted plot in the case of the short pulse extraction. In the case of the short pulse extraction, the measured count will increase instantaneously, while the integrated number of the measured count will decrease due to the dead time of the read out system.

The important roles of the rate monitor are the detection of the short pulse extraction and the generation of signals for the interlock system. The upper threshold is set for the number of the particles per 1 msec (instantaneous count). In addition, the upper and lower thresholds are set for the number of the particles per 3 sec (integrated count). In the GNV-251 module, the integrated count is compared with the thresholds for every spill and the instantaneous count is compared with the threshold for every 1 msec. When the particle count crosses the thresholds, the GNV-251 module generates the interlock signal immediately and then the interlock system stops the next beam extraction [3, 4]. The control system of the rate monitor was also developed based on EPICS. The timing of the read out and the threshold values are controlled via EPICS records.

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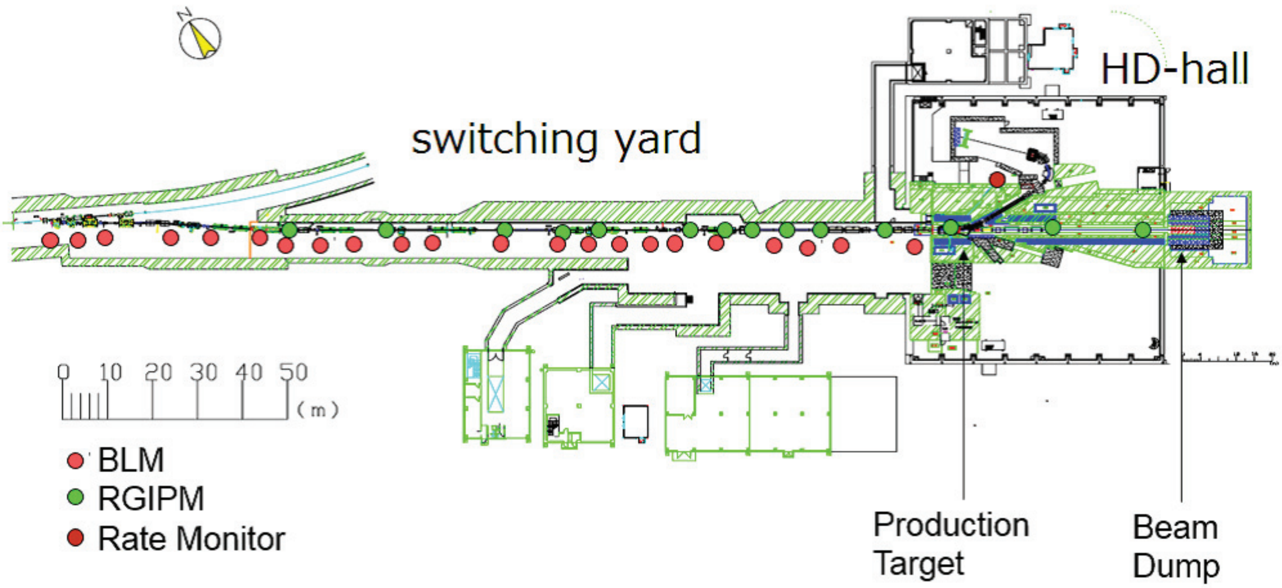

Figure 1: An overview of the Hadron Experimental Facility. Beam monitors involving this paper are shown.

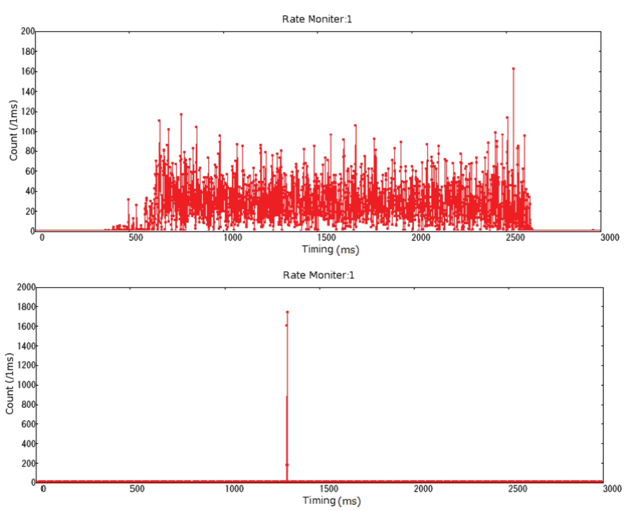

Figure 2: The online monitor display of the rate monitor. The number of the particles per 1 msec is plotted as a function of time. The upper panel shows the example plot in the case of the normal beam extraction. The lower panel shows the predicted plot in the case of the short pulse extraction.

Figure 3 shows the summary results of the rate monitor at the 33kW beam power operation. Left panel shows the result of the maximum value of the instantaneous count per a beam spill. Right panel shows the result of the integrated count. The upper and lower thresholds are also shown at Fig. 3. The integrated count was rather stable. However, the average of the integrated count was different before and after the machine maintenance. It made a double peak structure at Fig. 3. The fluctuation of each peak of the integrated count is less than 1%. The upper threshold value for the instantaneous count is 375. The upper and lower threshold values are 64000 and 37500, respectively. The performance of the interlock system related with the rate monitor was also confirmed.

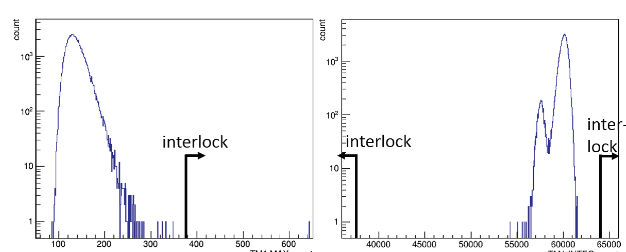

Figure 3: The results of the rate monitor at the 33kW beam power operation. Left panel shows the result of the maximum value of the instantaneous count per a beam spill. Right panel shows the result of the integrated count. The upper and lower thresholds are also shown.

BEAM PROFILE MONITOR

The beam profile in the slow-extraction beam line is measured with Residual Gas Ionization Profile Monitor (RGIPM) [5, 6]. 14 RGIPMs are located on the slow-extraction beam line as shown at Fig. 1. The signals of the RGIPMs are integrated up to about 2 sec by using a VME slow integrator (GNV-370N). The integrated signals are recorded with a VME A/D board (Advme-2607) after every beam extraction. The EPICS IOC runs on Linux on a VME CPU modules (VME-7807).

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The RGIPM located at the front of the production target (T1 RGIPM) was upgraded to read out eight times per a beam spill. The read out timing of the T1 RGIPM is controlled by the GNV-251 module via EPICS records. Figure 4 shows the online monitor display of the T1 RGIPM in the case of the normal beam extraction. The upper left panel shows the pedestal data measured in the interval of every beam extraction. The other panels show the measured beam profiles after the subtraction of the pedestal. The red lines and the blue lines represent beam profiles for horizontal and vertical direction, respectively. The number at each panel represents the order of the read out. The position and width of the beam profile do not change dramatically depending on the order of the read out in the case of the normal beam extraction.

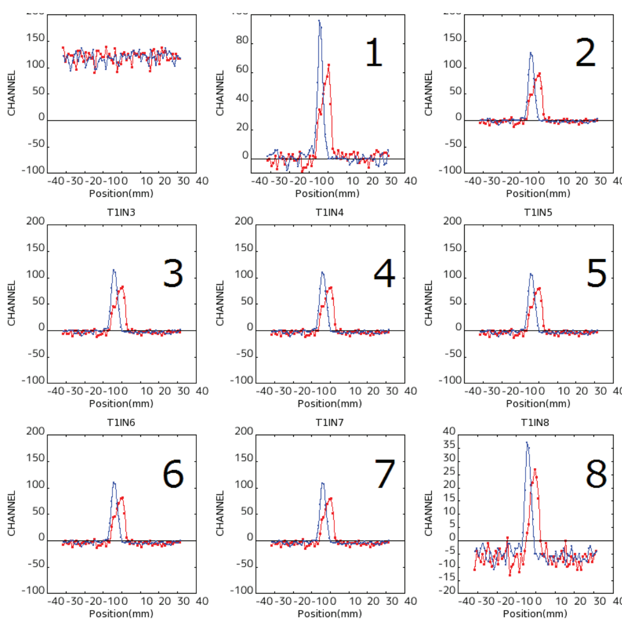

Figure 4: The online monitor display of the T1 RGIPM. The upper left panel shows the pedestal data measured in the interval of every beam extraction. The other panels show the measured beam profile after the subtraction of the pedestal. The red lines and the blue line represent beam profiles for horizontal and vertical direction, respectively. The number at each panel represents the order of the read out.

The improvement of the read out system of the T1 RGIPM aims at the detection of the abnormal beam extraction a with narrow width even for a short time. The lower threshold is set for the beam width at the T1 RGIPM in every time window. The threshold values are also controlled via EPICS records. When the beam width becomes below the threshold in any time window, the signals for the interlock system are generated to stop the next beam extraction.

Figure 5 shows the summary results of the beam widths at time window 4 at the 33kW beam power operation. Left panel shows the result of the beam width for horizontal direction and right panel shows the result of the beam width for vertical direction, respectively. The lower thresholds are also shown at Fig. 5. The typical beam widths at the T1 RGIPM were 2.6 mm and 1.8 mm for horizontal and vertical direction, respectively. The beam widths were rater stable. The fluctuation of the beam width was within 0.2 mm. The lower thresholds were ∼1.9 mm and ∼1.2 mm for horizontal and vertical direction, respectively. The performance of the interlock system related with the beam profile monitor was also confirmed.

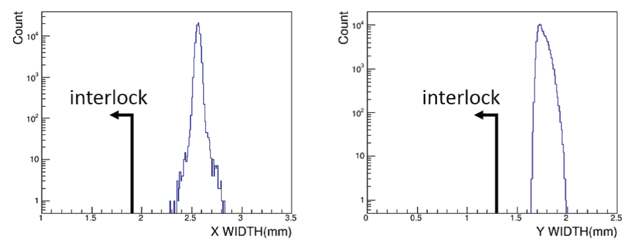

Figure 5: The summary results of the beam widths at time window 4 at the 33kW beam power operation. Left panel shows the result of the beam width for horizontal direction and right panel shows the result of the beam width for vertical direction, respectively. The lower thresholds are also shown.

BEAM LOSS MONITOR

Beam loss at the slow-extraction beam line is measured by using air ionization chamber (BLM). 22 pairs of BLMs are located beside the beam line as shown at Fig. 1 to monitor unexpected large beam loss.

The signals of BLMs are integrated up to about 2 sec by the GNV-370N module in the same way as the RGIPMs. FA-M3 Programmable Logic Controller (PLC) was introduced to read out the integrated signals of the BLMs to detect the accidental large loss immediately. Figure 6 shows a picture of the PLCs of the BLM read out system. A PLC sequencer CPU (F3SP71-4S), PLC A/D modules (F3HA12-1R) and a PLC output module (F3YC08N) are used to read out the integrated signals and to generate signals for the interlock system. The EPICS IOC runs on Linux on a PLC CPU module (F3RP61-2L) [7].

The PLC A/D modules digitize the integrated signals with the rate of 200 kHz. The ADC values of the integrated signals are compared with the thresholds every time the PLC sequencer CPU scans. The scanning rate of the PLC is ∼10 kHz. When the ADC values excess the thresholds, the F3YC08N module generates the interlock signals immediately. The ADC values are recorded as EPICS records for every 200 msec during the beam extraction for online-monitoring. Figure 7 shows the online monitor display of the BLM. Each panel shows the measured beam loss at each time window after the subtraction of the pedestal. The number at each panel represents the order of the read out. The measured beam loss is plotted as a function of the located position of the corresponding BLM. Blue bar represents one

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of the pair BLM and red bar represents the other of the pair, respectively. The upper thresholds are set for the measured beam loss. The interlock system of the BLMs also worked well.

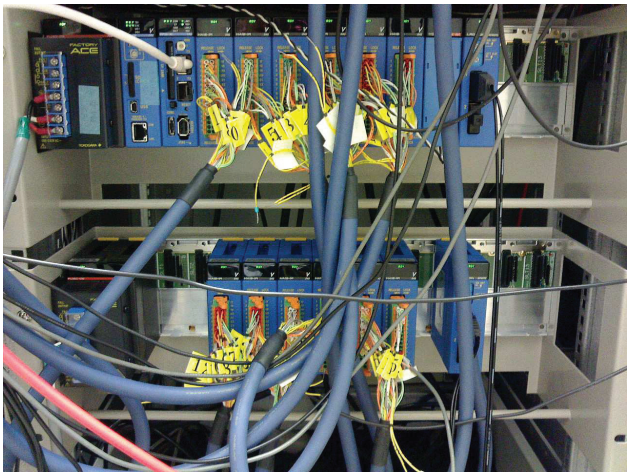

Figure 6: A picture of the PLCs of the BLM read out system.

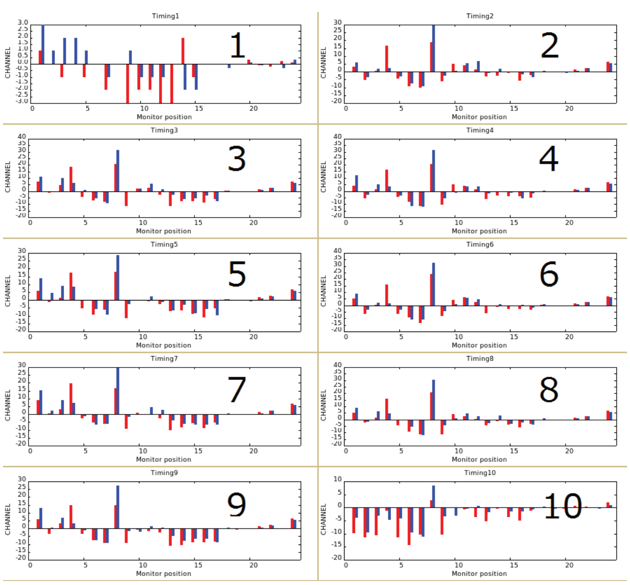

Figure 7: The online monitor display of the BLMs. The number at each panel represents the order of the read out. Blue bar represents one of the pair BLM and red bar represents the other of the pair, respectively. The measured beam loss are plotted as a function of the located position of the corresponding BLM.

SUMMARY AND OUTLOOK

The rate monitor, the RGIPMs and the BLMs have been improved to detect the abnormal beam extraction and investigate the status of equipment of the beam line. These monitors also generate the signals for the interlock systems to protect machines at the beam line when the abnormal beam injection is detected. The slow-extraction beam line was recovered on Apr 2015. The operation of the beam line was successfully done for ∼2 months with the upgrade monitor and interlock system.

A new interlock system (Sx Abort) will be introduced from Oct 2015 so that the abnormal beam could be aborted even during the beam extraction. The Sx Abort system will be powerful method to protect the machines at the beam line. The 33 kW beam power has been achieved on June 2015, which corresponds ∼1.5 times higher than one on May 2013. The beam power is planed to be increased further gradually. The beam monitor system and the interlock system of the beam line have been improved toward safety operation of the higher power beam.

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