MACHINE STABILITY ANALYSIS BY PULSE-BASED DATA ARCHIVER OF THE J-PARC RCS

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Abstract

The J-PARC RCS runs with a repetition rate of 25 Hz. The beam intensities from current monitor data and beam loss monitors (BLM) data are archived for all pulses and are analyzed to study machine stability. It was found that after replacing ion source, the beam intensity seems to be more stable than before. In addition, beam position monitors (BPM) data are regularly recorded. In this paper we report a few examples of the data recorded by BLM or BPM in the case of magnet power supplies feedback problem or vacuum problem, respectively. In case of the bending magnet problem, not all BLMs show increasing signal, some BLMs' signal were decreasing. In case of the vacuum pump trouble, within a few seconds, the beam losses were quickly increasing. It is described these incidents with various data.

INTRODUCTION

The Japan Proton Accelerator Research Complex (JPARC) has three accelerators and three experimental facilities. The Linac upgrade was upgraded in two stages, namely energy upgrade and intensity upgrade [1]. The energy upgrade from 181 to 400 MeV was performed in the end of 2013 by adding annular-ring coupled structure (ACS) cavities [2]. The intensity upgrade, involving increasing the peak beam current from 30 to 50 mA, was realized by replacing the front-end part of the Linac during the summer shutdown of 2014. The front-end part comprises an RF driven ion source [3] and a 50 mA RFQ [4].

The second accelerator is a Rapid-Cycling Synchrotron (RCS). The RCS injection system, bump magnets power supplies, was also upgraded to adapt the system to higher Linac energy. RF harmonics of the RCS is $h = 2$, and there are two bunches inside the ring. The proton is accelerated up to 3 GeV and is extracted with a 25 Hz repetition rate. The RCS delivers an intensive primary proton beam to the Materials and Life Science Experimental Facility (MLF) and serves as a booster for the Main Ring (MR) proton synchrotron with a period of 2.48 s or 6 s. Four consecutive batches (eight bunches in total) are delivered in every MR cycle. The MR has two beam-extraction modes, fast and slow extraction mode. The first one is for neutrino experiment (NU), and the second one is for hadron experimental facility (HD). By the end of June 2015, nominal beam power of the MR was 330 kW for NU and 33 kW for HD. These are correspond to 4.4×10^{13} protons per pulse (ppp) and 1.010^{13} ppp for NU and HD, respectively, at the RCS intensity.

The designed output beam power of the RCS is 1 MW, and the corresponding beam intensity is 8.3×10^{13} ppp. Even though it was only pulsed mode, the RCS achieved

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the design intensity in the beginning of 2015 [5]. It was a successful demonstration, but it revealed several issues pertaining to continuous 1 MW operation. The beam power of the routine user operation has been increased step-by-step. It commenced from 300 kW in fall 2014, increased to 400 kW in March, and reached 500 kW in the spring 2015. Development to achieve 1 MW user operation is underway. In addition, it is required to provide high availability and stable operation. A data-archiving system might be useful for analyzing accelerator stability and investigating the cause of any interruption in accelerator operation. Using these pieces of information, one can improve accelerator stability. In this paper, various examples are presented.

DATA ARCHIVING SYSTEM

The RCS has a threefold symmetric lattice with a circumference of 348 m. The RCS has three straight and three arc sections in the ring. The RCS houses various types of beam instruments [6], and a few important monitor data are continuously recorded and archived. These instruments include 54 beam position monitors (BPM) [7], intensity monitors DCCT and SCT, and beam loss monitors (BLM). The circulating beam current from the raw DCCT data is divided by the revolution frequency to obtain intensity, and the raw BLM signal is integrated in signal processing units. Most of BLMs are proportional chamber type (PBLM), and ninety PBLMs are distributed all over the ring.

The archive system employs reflective memory to read all 25 Hz, 20 ms-long pulses [8]. Although time resolution is limited, these data, BLM and DCCT, are recorded thrice every pulse with a 10 ms interval. BPM data is recorded every 1 ms. Although the system can store all data, 50 consecutive pulses are recorded every minute as archived data.

The Machine Protection System (MPS) is an interlock, triggered by any machine failure or large beam loss detected by BLM. If it is due to a machine failure on the beam, some amount of beam loss is expected. An MPS event triggered by BLM only is an indication of hidden problems.

INTENSITY STABILITY

It is mentioned already that the ion source was replaced in the intensity upgrade stage. The old ion source was of the LaB_6 filament type without cesium. The new one is a cesium feed RF-driven ion source. Figure 1 shows an example of a one-day intensity plot of the new source. The beam destinations were both NU and MLF. Only a few interruptions were observed over the course of a day, and they were caused by MPS. The new ion source seems to be more stable than the old one.
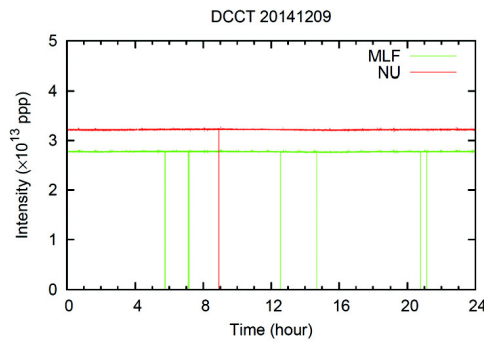
Figure 1: Stable DCCT intensity plot for one day. Data of NU and MLF mode are plotted separately.
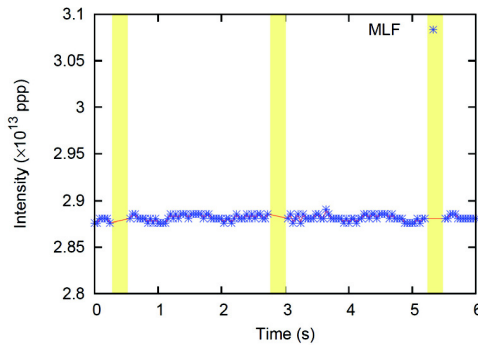

Figure 2: Stable intensity from the Linac to RCS. Only the MLF beam is operated, and the NU beam is not operated. Seven empty pulses are employed at intervals of 2.48 s. There is no fluctuation even just after each interval, which is unlike the case when using the old front-end system. The yellow hatched region represents the time gap for seven pulses.
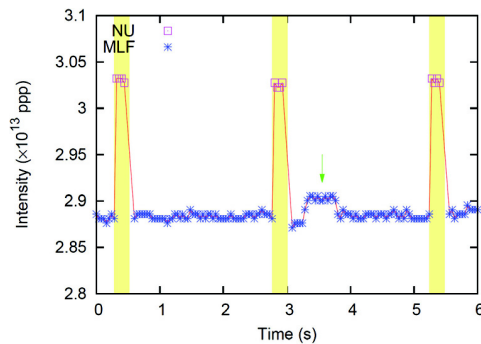

Figure 3: Similar to Fig. 2, but with NU beam under operation. Occasionally small fluctuations are seen after NU pulses (green arrow). The yellow hatched region corresponds to the NU pulses and three empty pulses.

In case of the old source, a few empty or very-lowintensity pulses were present. Moreover, slight variations (~2% higher) were observed right after the pulse gap[1] [9]. Upon re-

placement with the new ion source, these phenomena seemed to disappear (Fig. 2). Only slight fluctuation is seen as in Fig. 3, in the NU mode.
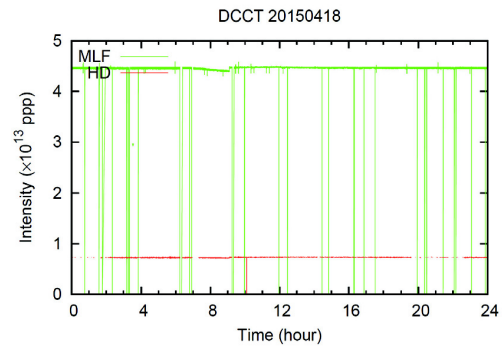

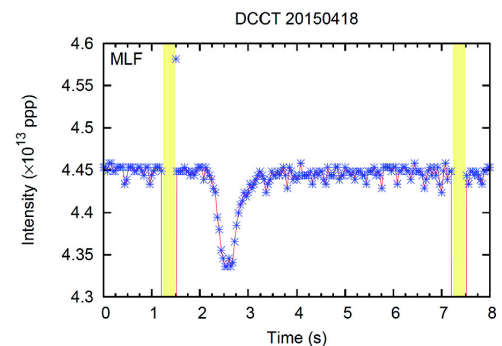Figure 4: DCCT plot of full day. MLF beam power is 500 kW, and the MR is in the HD mode.

Figure 5: DCCT plot of 8 s duration around 4:09. Two gaps represent time of HD beam, and a small fluctuation was observed (2 % drop). The yellow hatched region corresponds to the HD pulses and three empty pulses.

Figure 4 shows another DCCT plot after the MLF beam power reached 500 kW in the HD mode. Contrary to Fig. 1, on that day, the ion source was unstable. It was found that the ion source plasma disappeared for some seconds and intensity fell immediately without recovery. We had to increase the hydrogen low rate to the ion source to stabilize it. There is no interlock for such event on the accelerator side. However, the neutron target system should stabilize their temperature, and the target system prohibits sudden changes in intensity within a few seconds. Irregular small fluctuations were detected as well, as shown in Fig. 5.

PBLM PATTERN AND TREND

In this section, a few examples of the PBLM pattern and the trends in the PBLM signal are described.

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[1] This gap is due to the switching of the beam destination to the MLF and the MR. Four consecutive pulses are delivered to the MR. Because of residual field of pulse bending magnet in the beam transport line, three more empty pulses follow. If the beam for the MR stops for any reason,

seven consecutive pulses are empty from the MLF viewpoint. Recently, a compensation scheme of the pulse bending magnet residual field is taken care, three empty pulses will be filled with MLF pulses.
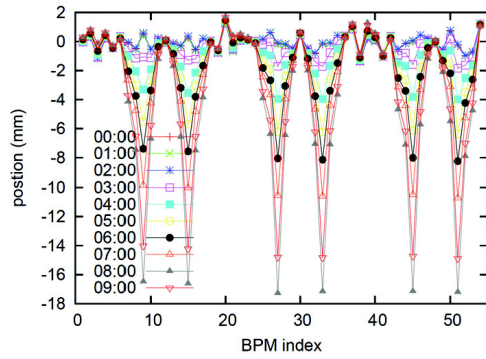
Figure 6: Horizontal COD excursion during BM feedback of. The excursion seems to start around 3:00 and evolves within several hours.

Main Magnet Feedback Error 1: BM

The RCS main bending magnet (BM) and quadrupole magnets (QM) power supplies have a feedback system to stabilize. The system uses recorded waveforms of output current, analyzes them, and provides feedback to the power supplies through a network. In one instance, this feedback loop was cut of owing to network trouble. There was no direct warning, although the power supply was drifted. It was only noticed when a beam orbit excursion occurred as a result.

Given that the RCS has six dispersion peaks in three arc sections, mismatch signature between bending field and particle momentum appears on these peaks. Figure 6 shows horizontal closed-orbit distortion (COD) excursion during the problem. In the beginning, COD was only about $1 \sim 2\,\text{mm}$, but it developed to almost 16 mm at the peak after several hours. Because the dispersion peak is $\eta \sim 5\,\text{m}$, it corresponds to field mismatch of 3×10^{-3}.

The RCS was operated in NU and the MLF modes. The PBLM patterns of the NU and MLF modes are shown in Fig. 7, and their time evolutions are shown in Fig. 8. The trend in the PBLM signal is shown in Fig. 9. The PBLM19 (C05-01) signal gradually decreased, especially in the case of the NU-beam. In contrast, the PBLM47 (C16-01) signal increased. As stated above, in some BLM cases the loss decreased, whereas in other cases, it increased. However, their absolute signal sizes were different, which was not very apparent. There was no MPS interlock trigger by the BLMs, which is one of the reasons why it took some time to realize the problem.

Main Magnet Feedback Error 2: QM

The same network problem occurred a few days later. One of a quadrupole magnet family power supply (QFL) was affected. At this time, a noticeable number of BLM MPS events were detected. Figures 10 and 11 present the PBLM pattern and the signal trends of PBLM19 and PBLM47, respectively. The trends clearly indicate the increase in beam loss. There are many red-colored interruptions in the trend graph, which means that many MPS events occurred in the NU mode.
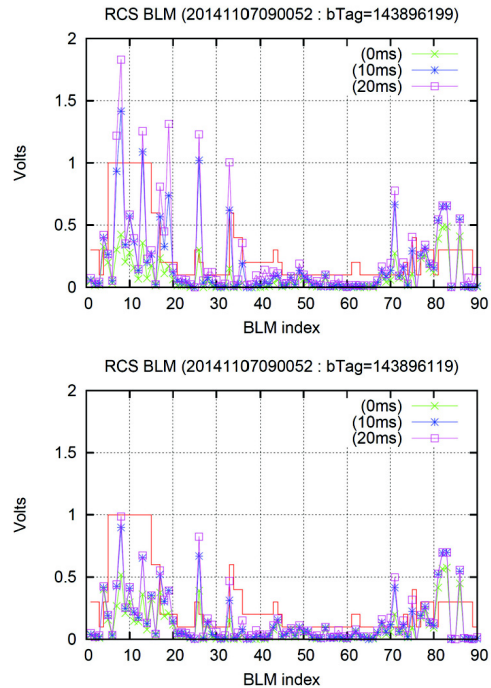

Figure 7: PBLM pattern data of NU (upper) and MLF (lower) modes. The horizontal axis represents the BLM index, and the vertical axis represents the magnitude of the BLM signal.
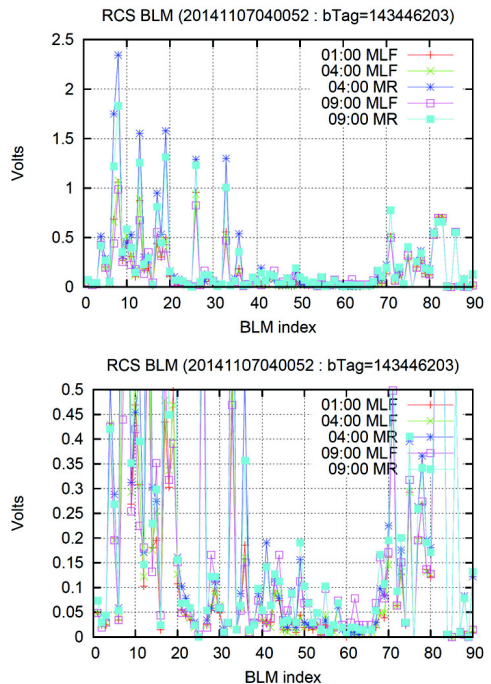

Figure 8: Evolution of PBLM pattern data during BM feedback problem. Vertical scale is zoomed in lower figure.

Vacuum Pump Failure

After the beam power for the MLF was increased from 300 to 400 kW, three turbo molecular pumps (TMP) around the RCS injection area failed within two weeks. The PBLM loss pattern and the short-term PBLM08 (C03-02) trend
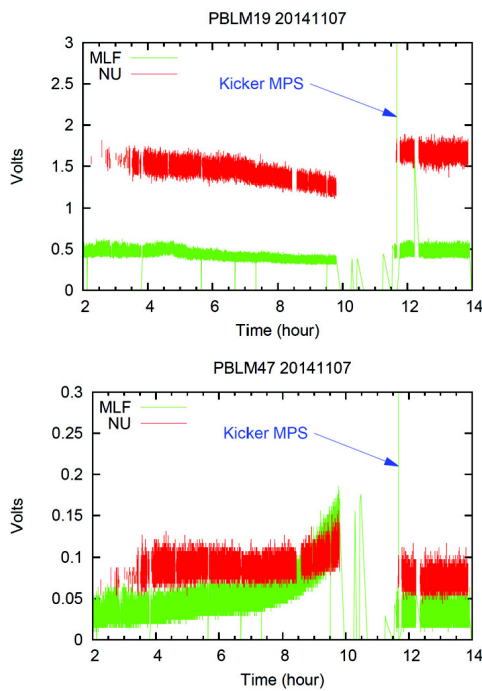
Figure 9: PBLM19 (upper) and PBLM47 (lower) signal trends are shown within 12 hours. The large beam loss at time at 11:40 was ascribed to an external cause, namely an MPS event due to the misfiring of the RCS extraction kicker magnet. The problem was solved at that time, and the loss signal is back to its previous level.

Figure 10: PBLM pattern in the NU mode. Before the trouble (upper) and the last moment of the problem (lower).

of the events are shown in Fig. 12. Vacuum level MPS (exceeding 10^{-3} Pa) stopped the beam. Neither the TMP

itself nor PBLM was related to MPS. Certainly, the signal of the NU mode was higher than that of the MLF mode. The PBLM08 signal grew quickly within a few seconds.
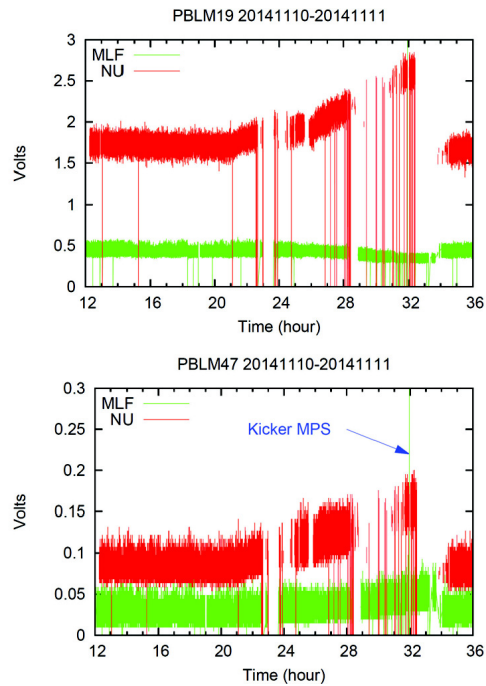

Figure 11: PBLM19 (upper) and PBLM47 (lower) data during QFL trouble. Beam loss started to increase at around 22:00. A large beam loss at time around 32 h ascribed to an external cause, which is the misfiring of the RCS extraction kicker magnet. The problem was fixed after 34 h (second day 10:00).
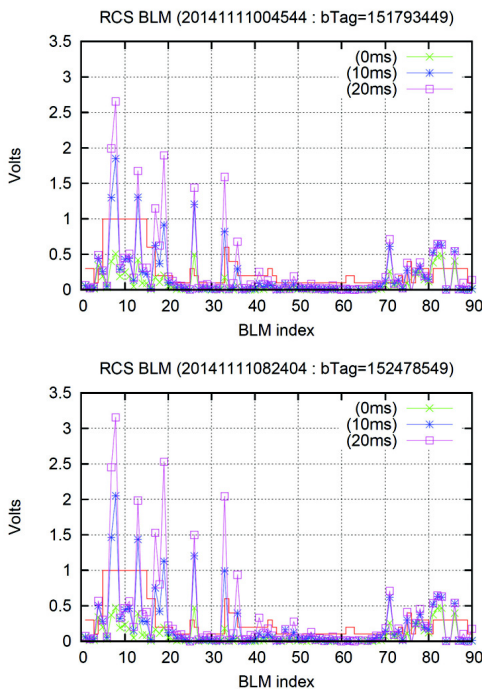
BLM Trend

Figure 13 shows the DCCT and PBLM19 trend plots of the day on which beam power to the MLF increased from 400 to 500 kW. The BLM19 signal clearly increased. In this period, the MR was operated in the HD mode. Thus, the beam intensity is lower than that in the NU mode and the beam loss is smaller as well.

SUMMARY

In this study, we describe how beam intensity became more stable after the introduction of the new ion source. However, small and random fluctuations were observed occasionally, especially, when the MR was running along with the HD operation. PBLM patterns and PBLM trend data are also displayed for various incidents. In most of cases, the PBLM signal is below the MPS threshold, but it contains some useful information. These evidences are elaborated owing to the data-archiving system, which can distinguish whether each pulse is in the MR or the MLF mode and record all 25 Hz pulses without dead time. The system can be improved and used to establish even more stable accelerator operation in the future. A new scheme to synchronize various events recorded by different instruments or digitizers
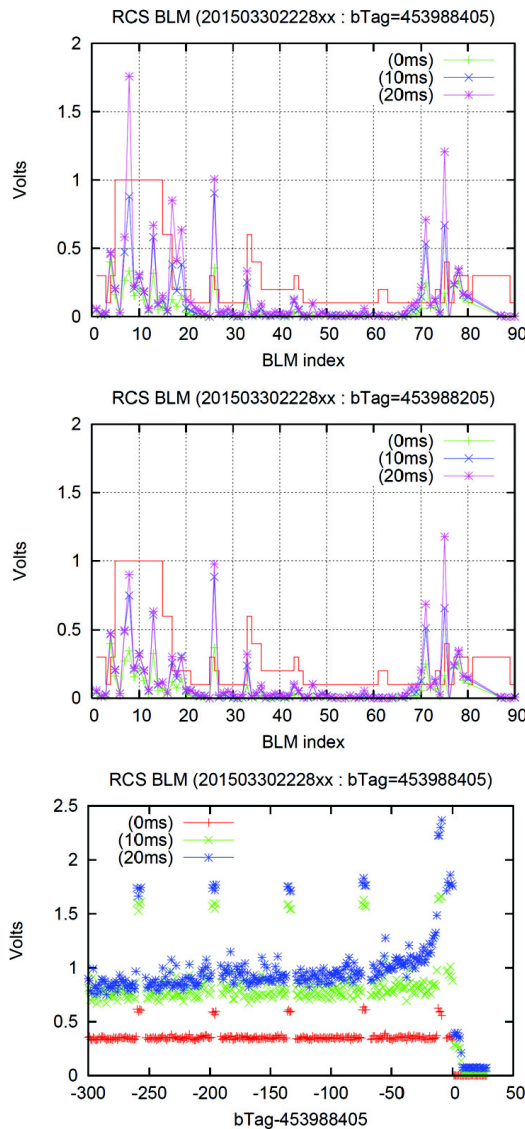
Figure 12: PBLM pattern data in MLF mode and short trend of PBLM08 signal (14 s in full range) in the event of TMP failure.

is also planned. The scheme might generate more useful information owing to the better time resolution on offer.

Figure 13: DCCT plot from 400 kW to 500 kW (upper) and PBLM19 trend at the same time scale (lower).

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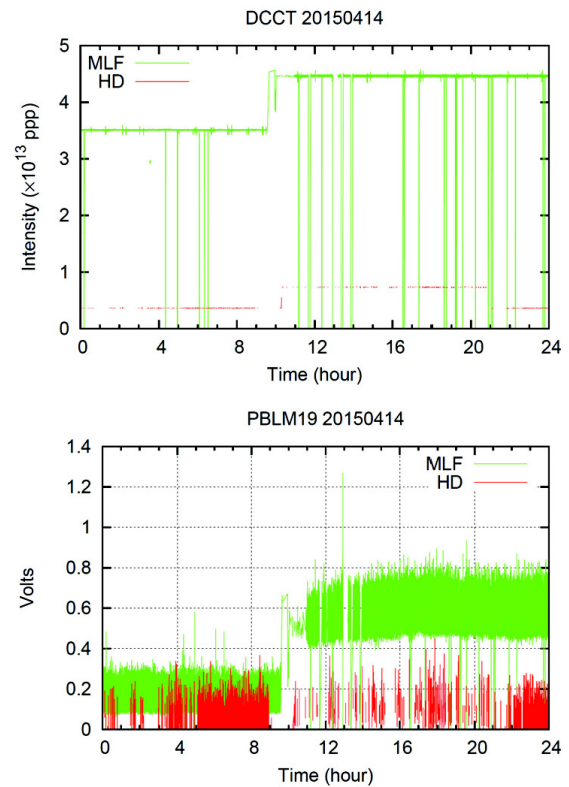
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