BEAM LOSS AND RESIDUAL DOSE AT 100 KW USER OPERATION IN THE J-PARC ACCELERATOR

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Abstract

The accelerator facilities in J-PARC have been commissioned since January 2007. According to the progress of beam commissioning and construction of accelerators and experimental facilities, operational beam power becomes larger. The RCS produces 120 kW beam to MLF and the MR provides 50 kW beam to Neutrino target. In such high intensity operation, Linac ACS section, RCS injection and arc section, and MR collimator section become slightly higher residual dose area. We try to improve these losses before it is too late.

INTRODUCTION

The Japan Proton Accelerator Research Complex (JPARC) project is a joint project of Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK). The accelerator complex consists of a linac (an acceleration energy is 181 MeV so far and it will upgrade to 400 MeV by installing Annular Coupled Structure linac (ACS) in 2013), a 3 GeV Rapid-Cycling Synchrotron (RCS), and a 50 GeV synchrotron Main Ring (MR) [1]. The beam commissioning of accelerator facilities started in January 2007. Construction of J-PARC facilities and beam commissioning were continued, now acceleration beams are provided to a materials and life science experimental facility (MLF) for the neutron experiments, a hadron experimental hall, and a neutrino target which produces a neutrino beam to Kamiokande. In this paper, we present the histories of operational beam power and residual dose distributions after operation of these three accelerators.

LINAC

The J-PARC linac commissioning started in January 2007. The beam power of linac was increased with the advance of commissioning and construction of other facilities. Figure 1 shows the history of linac output power and residual dose rate since January 2007.

Residual dose values were chosen at some representative points. During the beam commissioning period from January 2007 to November 2008, we only used low repetition beam for commissioning and there were no significant residual dose. But when we started high duty user operation at a repetition rate of 25 Hz, more than 200 μSv/h dose rate was observed at the first bending magnet of the Linac – 3GeV RCS Beam Transport (L3BT) line (Blue plot in Fig. 1). We found that the residual dose on the inside (a H- beam direction) of the magnet was smaller than that on the outside (a proton beam direction) of the magnet. From the distribution of residual dose on the magnet, we considered that the source of this dose distribution was caused by the loss of proton beam. This proton beam was generated by the scattering of H- beam and the residual gas in the transport line between the ion source and Radio Frequency Quadru-

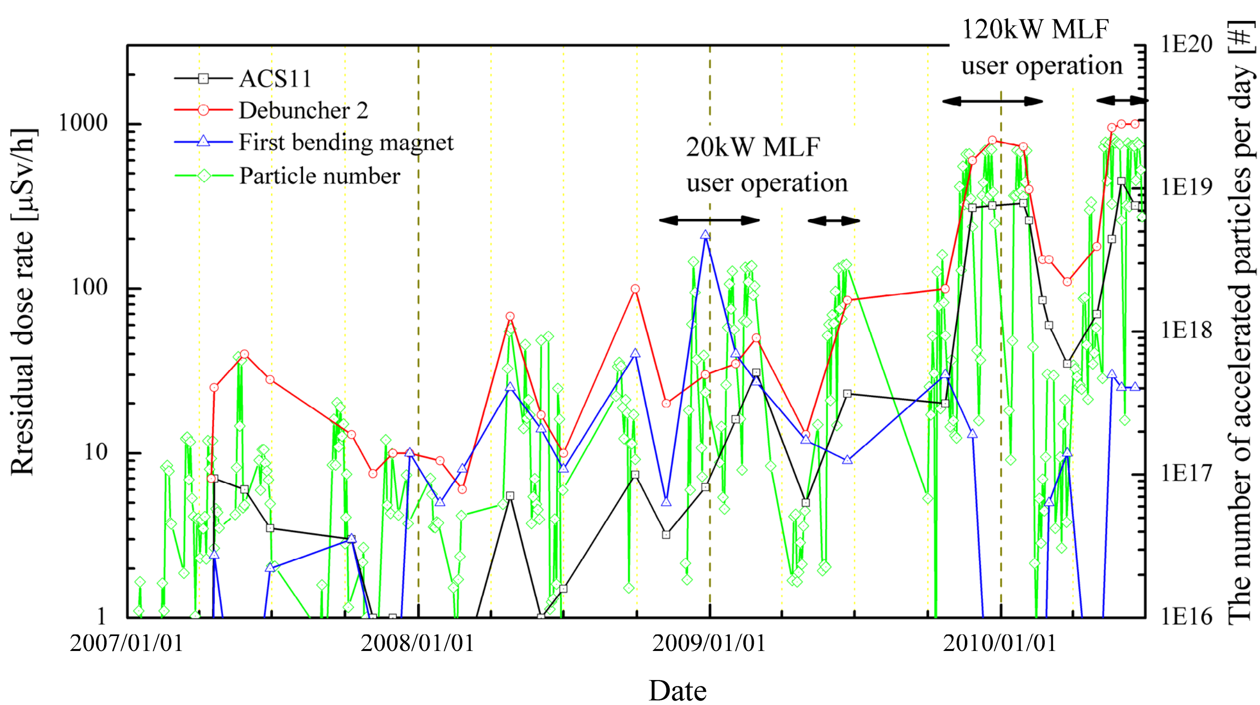

Figure 1:History of the linac operation and residual dose.

pole linac (RFQ), and accelerated by the RF of inverse phase. Finally the proton beam was bent to the opposite direction of H- beam and lost. In order to remove this proton beam, we made a chicane orbit in the transport line between the RFQ and Drift Tube Linac (DTL) by using steering magnets. As a result, the loss at the L3BT first bending magnet was reduced and the residual dose becomes less than 100 μSv/h even if the beam power was increased [2][3].

After taking that step, there were no significant losses at the 20 kW user operation. But when we started 120kW user operation, we observed that the significant losses were distributed around the future ACS section (Black and red plots in Fig. 1). Previous beam study indicated that the pressure rise caused the stripping and loss [3]. However, SNS member discussed a possibility of intra-beam stripping [4]. We investigated the dependence of the loss monitors on the peak current. The dependence of the Beam Loss Monitor (BLM) near the debuncher 2 on the peak current is shown in Fig. 2 and pressure in the beam duct near the debuncher 2 is in Fig. 3. Figure 3 shows that the pressure barely changed during this experiment. On the one hand, if the loss was due to the stripping by the residual gas, it linearly depends on the peak current. On the other hand, if the loss was due to the intra-beam stripping, it depends on the square of the peak current.

It seems that the BLM signal depends on the square of the peak current in Fig. 2. This result indicates that there is a possibility of the intra-beam stripping as source of the beam loss. We will investigate more detail of loss mechanism at the future operation.

RCS

The RCS have been commissioned since October 2007 [5][6]. The RCS ring is designed to accelerate a proton beam up to 3GeV and supplies it to the MR and the neutron production target in the MLF. Beam supply for MLF and MR commissioning begun in May 2008, and user operation for MLF users started in December 2008. RCS commissioning was continued, and as a result, Operational beam power was increased to 120kW since November 2009. Figure 4 shows the history of RCS output power and residual dose rate since October 2007.

In the RCS, the first significant loss was observed at the branch of H0 dump line (Black plot in Fig. 4). And after the beginning of the user operation, the additional loss was observed at the Beam Position Monitor (BPM) put at the downstream of the H0 dump branch (Red plot in Fig. 4). From the following beam study, we were certain that these losses were caused by the scattering of the injection and circulating beam at the charge exchange injection foil. Figure 5 shows the BLM signal dependence on the number of the foil hit at the H0 dump branch. It is shown that there is a strong correlation between the BLM response and the number of the foil hit. When we used the painting injection, the number of the foil hit was reduced and BLM signal became smaller. Our detailed beam study confirmed that it is proportional to the number of the foil

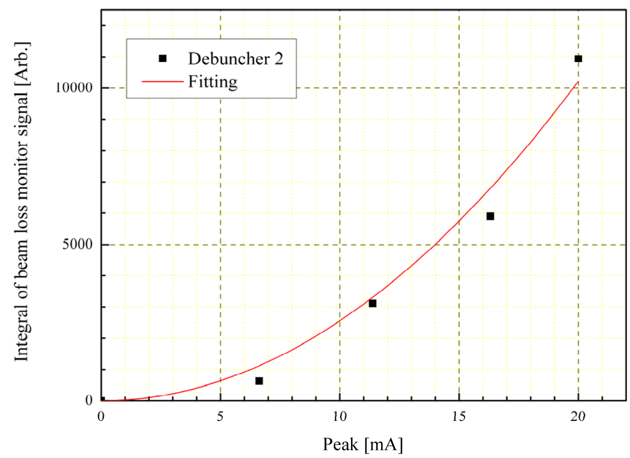

Figure 2: BLM signal of ACS section.

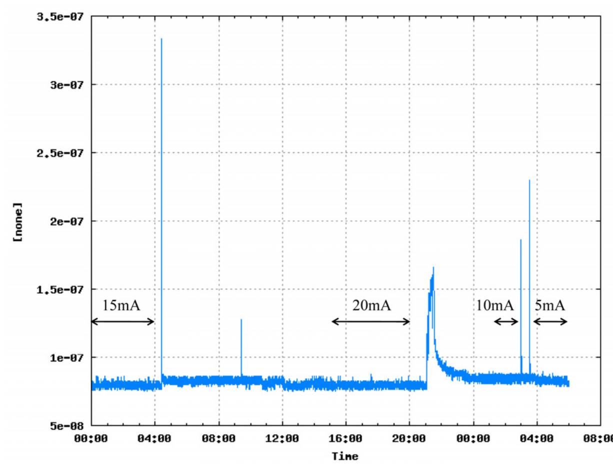

Figure 3: Pressure of ACS section during the peak current study.

hit [7][8]. Thus, now we use the painting injection and we adjusted the foil position in order to minimize the number of the foil hit.

In addition, another loss was observed between the injection septum magnet 1 and 2 at 120kW operation. The residual dose could be observed only at the opposite direction of the injection (H-) beam orbit of the vacuum chamber (Magenta plot in Fig. 4). Therefore, we consider that the beam loss was probably caused by the charge exchanged particles which was similar to the linac case. We also investigated loss dependence on the peak current and its result is shown in Fig. 6. In the linac case, the BLM signal depends on the square of the peak current. However, Fig. 6 indicates that the loss at the injection septum depends linearly on the peak current. This result was quite different from the linac case. The source of this loss may differ from the linac loss of ACS section.

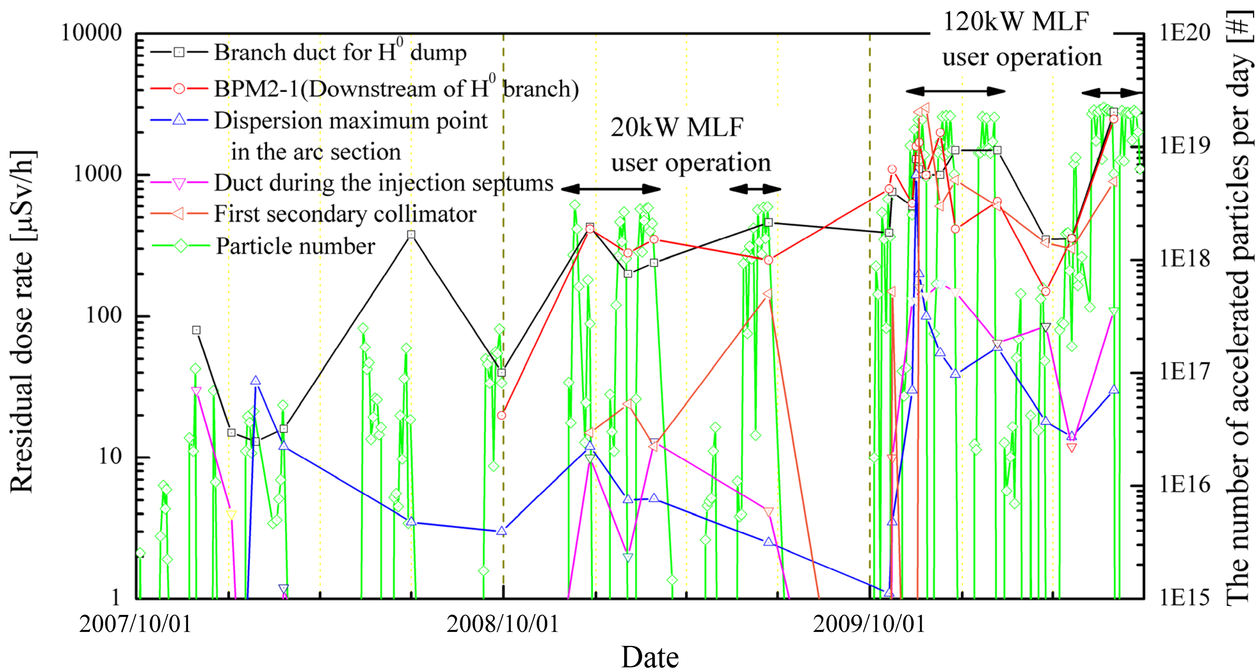

Figure 4: History of the RCS operation and residual dose.

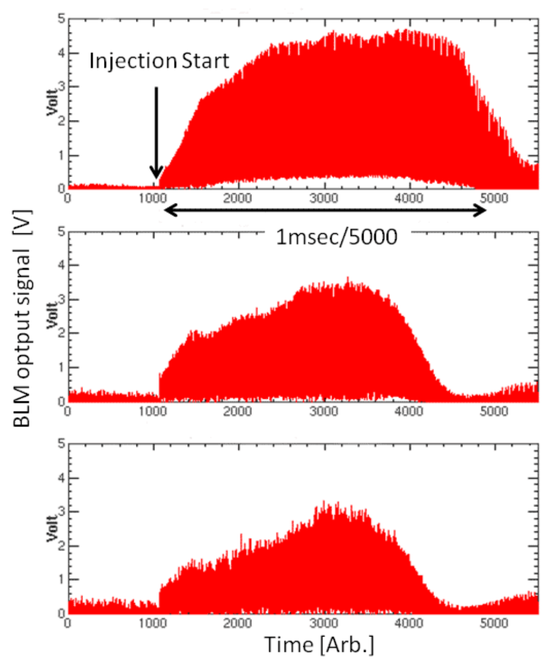

Figure 5: BLM signal at the H0 dump branch. Upper figure shows the BLM signal without painting. Middle figure shows the BLM signal with 100πmm-mrad painting. Lower figure shows the BLM signal with 150πmm-mrad painting.

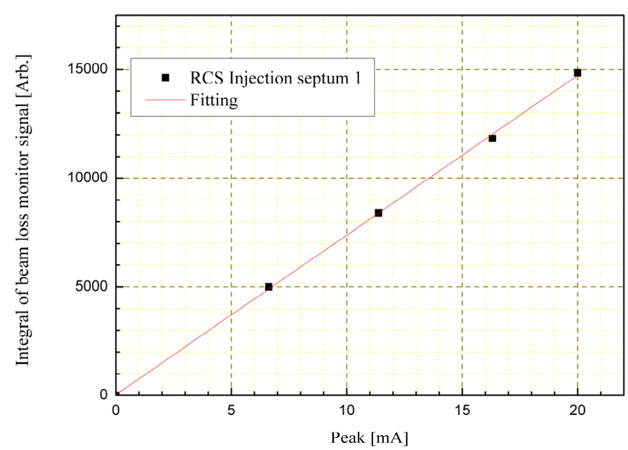

Figure 6: BLM signal between RCS injection septums.

The missing-bend cells in the arc section also have been activated to less than 100 μSv/h (blue plot in Fig. 4). These losses were caused at the middle of the acceleration period and sensitive for the tune variations and the longitudinal painting pattern. We think that the tune shift due to the chromatic effect brought about these losses. On the one hand, since we have only DC power supply for the sextupole magnet system, the chromaticity was corrected only at the injection period. On the other hand, our RF system makes large longitudinal acceptance and some particles (that belong to the longitudinal tail) have larger (or smaller) momentum than the synchronized particles. Thus the particle, that had large longitudinal amplitude, would cross the resonance and it was lost at the missing-bend cells (the missing-bend cells have large dispersion function value and there are the narrowest acceptance point except the collimator). In order to take measures for the losses at arc sections, we installed an AC sextupole magnet power supply system to achieve a full chromatic correction during acceleration. We will check its effect in the next beam commissioning period.

The current transformer indicated that the survival rate is about 99% at 120kW operation. Most losses were localized on the collimator and there was no high activated area except above mentioned point. we were able to access all of the accelerator tunnel [9].

MR

The beginning of the MR commissioning was May 2008. The MR has two extraction lines. One is the slow extraction line to deliver proton beam to the hadron experimental hall. The other is the fast extraction line to deliver the beam to the neutrino target for the T2K (Tokai-to-Kamioka) experiment. In January 2009, we succeeded slow extraction for hadron beam line. And neutrino beam line commissioning started in April 2009. The regular T2K experiment started in January 2010 to take physics data. So far, the maximum intensity of 70 kW has been delivered to the Neutrino target [10]. Figure 7 shows the history of MR output power and the residual dose rate since May 2008.

In the early stage of MR commissioning, there are no significant residual dose. But after starting user operation for T2K experiment, the residual dose rate became higher as MR beam power progressed. Especially the collimator section (Red and Blue plots in Fig. 7) and the branch duct of injection abort dump (Magenta plot in Fig. 7), that is a downstream of the collimators, had higher dose rate. In order to establish higher beam operation, we took two measures during the summer shutdown in 2010. The first one is to install an additional shielding in the collimator of the RCS to MR beam transport line. Since its capacity became larger, it enabled to remove more beam halo before MR injection. The second one is to replace the branch duct of injection abort dump with a wider one according to the suspension of injection dump. These two measures, and the further beam studies will also achieve higher output. Moreover, an additional shielding for MR ring collimator is also planned.

CONCLUSION

J-PARC accelerators have been favourably commissioned. So far the RCS produces 120kW beam to MLF and the MR provides 50kW beam to Neutrino target. From the experience of these high intensity operation, we should improve the following issues.

Linac:
・Widely distributed loss along the ACS section.

RCS:
・Loss at the downstream of the injection point caused by the foil scattering.
・Loss at the dispersion maximum points in the arc section due to insufficient chromatic correction.
・Loss during the injection septums.

MR:
・Loss at the collimator section.

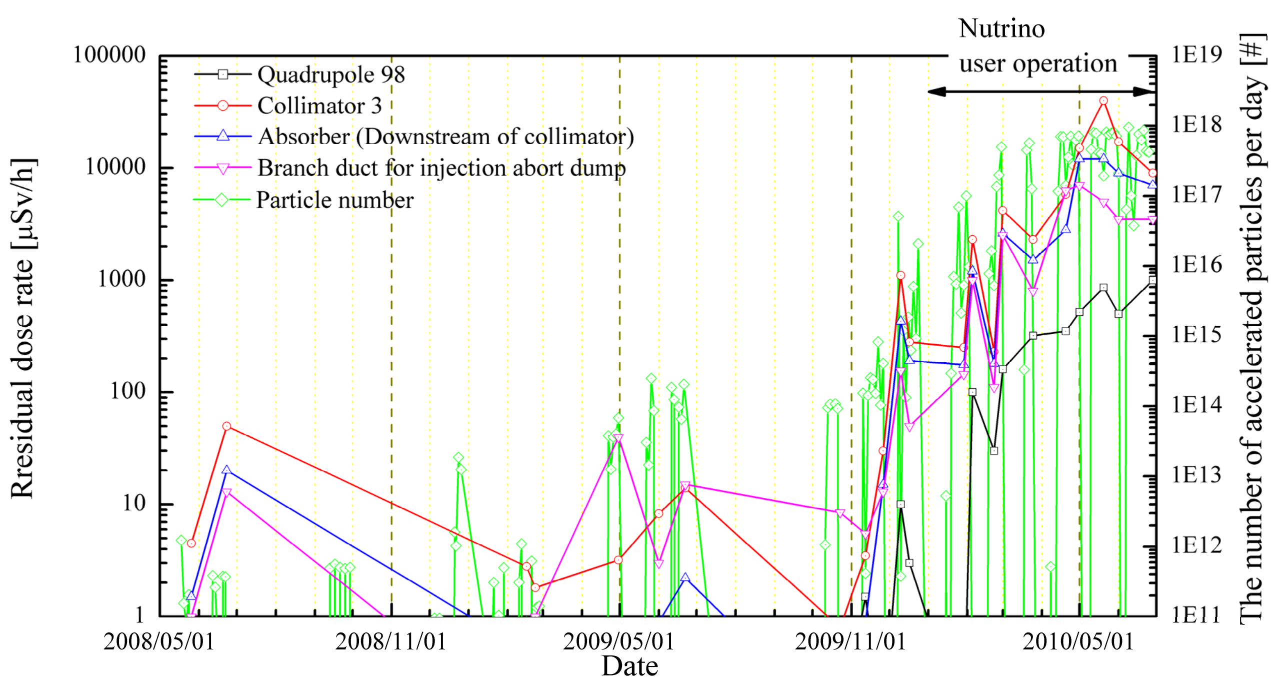

Figure 7: History of the MR operation and residual dose.

Among these issues, we took measures for the loss at the RCS arc and the MR collimator section by installing an AC sextupole magnet power supply system for RCS, the additional shielding of the collimator at the RCS to MR beam transport line and branch duct with wider aperture for MR. We also plan to install new collimator at the downstream of the RCS injection foil and additional shielding of MR ring collimator to reduce their residual dose. As for the losses at Linac ACS section and RCS injection septum, further investigation is needed to improve these situations.

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