BEAM LOSS MONITORING AND MITIGATION AT J-PARC DTL

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Abstract

In the J-PARC linac, we have observed significant residual radiation at the first tank of a 50 MeV drift tube linac (DTL). The residual radiation has been localized at a certain drift tube. It has motivated us to measure the beam loss at the DTL. Instead of a gas-proportional counter which is normally used as a beam loss monitor in J-PARC linac, we employed a scintillation counter for the detection of the beam loss. In this paper, we present the results of beam loss measurement and beam loss mitigation tuning by using the scintillation counter.

INTRODUCTION

The mitigation of the residual radiation is the key issue for an accelerator to retain the ease of hands-on maintenance. J-PARC is a high intensity proton accelerator facility designed for a MW-class beam. The present beam power for an user operation is 300 kW at the extraction of 3 GeV Rapid Cycling Synchrotron and the beam power is still on the way to the achievement of the design. The beam power of the injector linac is 18 kW at present and the power finally reaches seven times of the present. Therefore, it is no exaggeration to say that the beam loss mitigation is most important issue for the linac.

In the injector linac, a 50 keV negative hydrogen (H^-) beam is extracted from an ion source (IS), then the beam is accelerated up to 181 MeV by a 3 MeV Radio Frequency Quadrupole (RFQ), a 50 MeV Drift Tube Linac (DTL) and a 181 MeV Separate-type DTL (SDTL) [1]. A medium energy beam transport (MEBT) is placed in between RFQ and DTL. MEBT is 3 meter long and the transverse and longitudinal beam profiles are optimized for DTL injection by eight quadrupole magnets (QMs) and two buncher cavities. In addition, horizontal and vertical steering magnets (STMHs, STMVs) are installed in each QMs for a beam orbit correction. DTL is a typical Alvalez structure linac with RF frequency of 324 MHz. It consists of three tanks and length is about 27 meter in total.

After significant restoration effort from the great east Japan earthquake, the J-PARC accelerator resumed its operation in December 2011. Then, the user operation was started in January 2012 with the linac beam power of 7.2 kW. In March 2012, the beam power was extended to 13.3 kW, which is same power as just before the earthquake. In the early period after the resumption of the user operation, we observed the significant residual radiation in DTL. The residual radiation is localized to the two places; near the 25th drift tube (DT #25) and DT #55 of the first tank of DTL. Since we have not alined the DTL cavities after the earthquake, these residual radiations is considered to come from the distortion of the DTL elements due to the earthquake vibration. The beam energy of these points are low and the absorbed material seldom radioactivate. In addition, the DTs are covered by a 25 mm iron vacuum chamber and the chamber interrupts the most of radiations. Therefore we suppose substantial beam is lost around the points. For the detection of beam loss, we employ a scintillation counter. Several scintillation counters are installed around high residual radiation points, and we have successfully observed the beam loss signals [2]. We also find that the beam loss rate depends on the beam injection orbit to DTL. Therefore, we measure the dependence of the beam loss on the DTL injection orbit and successfully optimized the orbit.

In this paper, we discuss the mitigation tuning of residual radiation with the measurement of beam loss by scintillation counters.

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RESIDUAL RADIATION AT DTL BEFORE THE TUNING

We have performed a residual radiation survey in the accelerator tunnel periodically. Here we review the history of residual radiation of DT #25 and #55 from December 2011 to November 2012 in Tab. 1. The listed radiations are measured on the vacuum chamber surface. Then the measurement are performed about five hour after beam shutdown.

The first appearance of the significant residual radiation

Table 1: History of the residual radiation at DT #25 and #55 in DTL1 from Dec. 2011 to Nov. 2012. The unit is μSv/h. The residual radiation has been measured on contact to the vacuum chamber five hours after beam shutdown.

(μSv/h)	**Dec. 27 2011**	**Feb. 23 2012**	**Mar. 15 2012**	**May 25 2012**
DT #25	0.26	0.18	3.18	5.85
DT #55	1.52	7.20	26.3	33.5

(μSv/h)	**July 7 2012**	**Oct. 31 2012**	**Nov. 19 2012**
DT #25	5.61	2.10	1.80
DT #55	33.9	11.4	10.3

is in February 2012, one month after the resumption of the user operation with beam power of 7.2 kW. The residual radiation is at about 6.0 meter downstream from the DTL entrance. It is near the DT #55 and the beam energy is about 13.4 MeV. While whole residual radiation level in the DTL section is below 1 μSv/h before the earthquake, we observe 7.2 μSv/h on contact. Then, another high radiation point is found in the next maintenance interval which is just after resuming 13.3 kW operation. In the first survey after the extension, the residual radiation at DT #55 increases drastically. It is about four times as high as the previous measurement in 7.2 kW operation and it becomes close to 30 μSv/h. Moreover, we find another high residual radiation point around DT #25, where the residual radiation is about 3 μSv/h. It is about 2.3 meter downstream from the DTL entrance, where the beam energy is about 6.9 MeV. Afterwards, the residual radiation in both points deteriorates again and they keep the similar level until the summer shutdown.

BEAM LOSS MEASUREMENT

In this section, we introduce the beam loss measurement at the DTL1. The beam loss monitors are installed in the summer shutdown. Then the measurement with beam is perfumed at the beginning of October, in the startup commissioning of the linac after the summer shutdown.

Measurement Setup

We employed a scintillation counter for beam loss detection, instead of gas-proportional counter which is generally used as a beam loss monitor in J-PARC linac. The gas-proportional counter is sensitive to X-rays, and it could be hard for the gas-proportional counter to detect the beam loss because X-rays emitted inside the DTL cavities could be obstructive for the detection. Therefore we measured the beam loss by scintillation counter which is less sensitive to X-rays than proportional one. The scintillation counter is comprised from a plastic scintillator and a photomultiplier tube (PMT). The plastic scintillator is BC-408, manufactured by Saint-Gobain Crystals, with size of 200 $\times$ 10 $\times$ 10 mm^3. The PMT, H3164-10 manufactured by Hamamatsu Photonics, is fixed to the tip of the plastic scintillator.We placed four plastic counters for the measurement. The counters are attached to left and right side on the vacuum chamber at DT #25 and #55 on the beam line height.

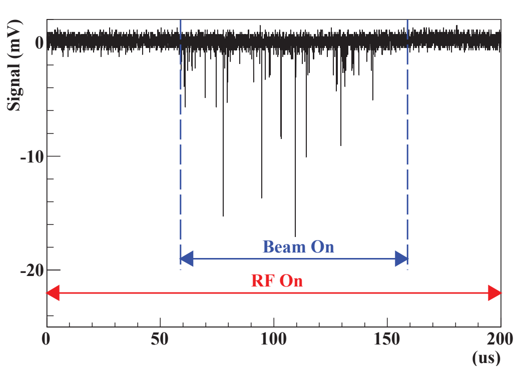

Figure 1: A typical waveform of the scintillation counter placed at DT #25 in DTL1. A beam pulse width is 100 μsec and a beam starts at 56 μsec.

Table 2: Settings for last two STMs (07, 08) in MEBT. The BL product for them is set to the value listed in the row "Initial" before the measurement. The beam loss is measured for the range listed in the row "Scan", and finally we set the BL to those in the row "Final".

($\times 10^{-3}$ Tm)		Horizontal #07	Horizontal #08	Vertical #07	Vertical #08
Initial		−1.5	−2.0	−0.4	0.5
Scan	Max	−0.8	−1.0	1.0	1.0
	Min	−2.0	−2.0	−1.0	−1.0
	Interval	0.2	0.25	0.4	0.4
Final		−1.8	−1.0	−1.0	1.0

Data Acquisition

The PMT signals are recorded by a digital oscilloscope. Using a oscilloscope with four input channels, we record the signal of all scintillation counters simultaneously. The beam pulse width is 100 μsec without a beam chopping, and we set the time scale of the waveform to 200 μsec with a sampling interval of 20 nsec to record the signal of an entire beam pulse. A typical waveform at DT #25 is shown in Fig. 1. In this figure, a beam pulse arrives at DTL1 at 56 μsec and it ends at 156 μsec. We can clearly observe beam loss signals, although the scintillation counters are placed outside of a vacuum chamber which is made from 25 mm thickness iron wall. The waveform of the scintillation counters at DT #55 is similar, but signal height is about twice due to different beam energy. It should be noted that the RF is applied for entire waveform in Fig. 1, i.e. X-rays are emitted from DTL cavities for the waveform. However we cannot observe the signals in off-beam region. It means the contamination from the X-rays is negligibly small in this measurement.

We measure dependence of the beam loss on the DTL injection orbit (position and angle). The injection orbit is corrected by last two steering magnets (07 and 08) in MEBT. The setting of these STMs before the measurement are listed at the row "Initial" in Tab. 2. We change the BL of these magnets in the range listed at the row "Scan" in Tab. 2. In each setting, the waveform is recorded five times to reduce the statistical fluctuation.

TUNING

In order to compare the beam loss in each steering setting, we count the number of signals the height of which exceeds a threshold. Since the threshold should be higher than the baseline, we evaluate the signal fluctuation in off-

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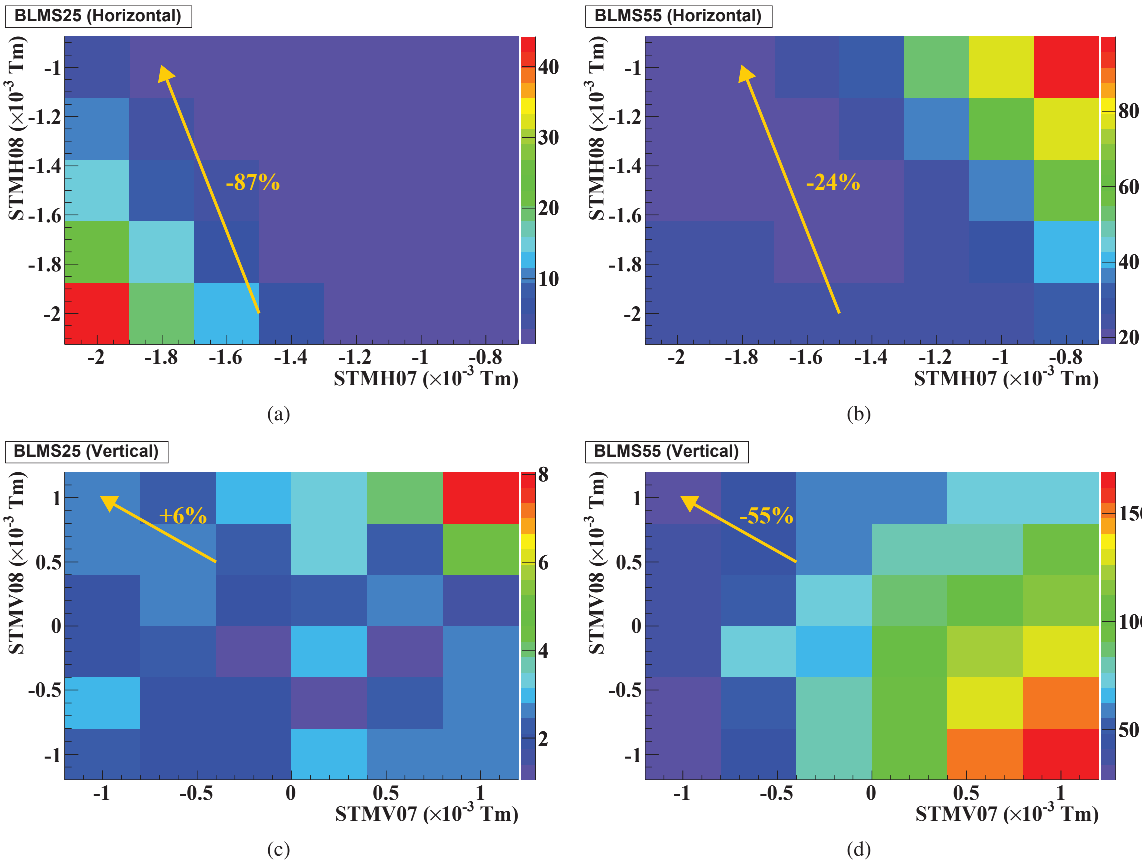

Figure 2: Results of the beam loss measurement. In each figure, horizontal axis shows the BL of STM07 and vertical one is that of STM08. Color of each cell shows the number of signals; beam loss increases from a cold to warm color. The arrows in the figures shows the variation of the STM settings by the measurement. (a) (b) beam loss at DT #25 and #55 by horizontal orbit scan. (c) (d) beam loss at DT #25 and #55 by vertical orbit scan.

beam region; from 0 to 56 μsec in Fig. 1. While the on-beam signal height distribution has a tail to negative voltage side, the off-beam distribution is almost symmetric with respect to the mean. Therefore we set the threshold to five times of root-mean-square (RMS) of the off-beam signal height from its mean.

The beam loss measurement with various STM settings are summarized in Fig. 2. The horizontal results are shown in Fig. 2(a) for DT #25 and Fig. 2(b) for DT #55. The color in each cell shows the amplitude of the beam loss; the beam loss increases as the color becomes warm. The arrow in the figures indicates the change of settings. Here we denote that a horizontal STM as STMH and that of vertical as STMV. We change the STMH07 (08) setting from -1.5 (-2.0) to -1.8 (-1.0) $\times 10^{-3}$ Tm. The beam losses at DT #25 and #55 reduce by 87 % and 24 %, respectively. The vertical measurements are shown in Fig. 2(c) for DT #25 and Fig. 2(d) for DT #55. We change the STMV07 (08) setting from -1.5 (-2.0) to -1.8 (-1.0) $\times 10^{-3}$ Tm. Although the beam loss at DT #25 slightly increases by 6 %, that of DT #55 reduces by 55 %. The residual radiation after the tuning is listed in the Tab. 1. The radiation level on October 31 becomes about 1/3 in both places, and we can see the decline of the residual radiation on November 19. Consequently, we successfully mitigate the beam loss of these places.

SUMMARY

We can detect the beam loss in DTL by scintillation counters even though the beam energy is below 20 MeV behind iron wall of 25 mm thickness. By adjusting the DTL injection orbit to the minimum beam loss setting, the beam loss successfully becomes less than half. Moreover, the residual radiation shows a tendency to decline. Since we confirm that the scintillation counter is a powerful tool for the beam loss detection in low energy region, we consider the introduction of the scintillation counter as beam loss monitor.

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