RESIDUAL GAS PRESSURE DEPENDENCE OF BEAM LOSS

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Abstract

Residual gas in beam line essentially affects the beam loss and residual radiation on the accelerator. J-PARC linac is usually operated under 10^{-6} to 10^{-5} Pa in SDTL (Separate-type Drift Tube Linac) and A0BT (future ACS: Annular Coupled Structure linac) sections. In this situation, no serious beam loss was observed during the beam operation. In future development of J-PARC linac, because the peak beam energy and output will be increased, it is getting more serious problem. Before the development, it is important to understand a cause of beam loss and relation between beam loss and residual gas pressure. We measured beam loss at the normal and worse vacuum condition in both SDTL and A0BT sections. The result indicates that the beam loss depends on the residual gas pressure and position where the beam loss occurs is about 20 to 30 meter downstream. This suggests the optimum position for installation of vacuum system to minimize the beam loss. In this paper, we describe the experimental result and its discussions. In addition, the cause of the beam loss is considered to be a stripping from negative hydrogen ions to neutral hydrogen atoms.

SIGNIFICANT BEAM LOSS IN LINAC

The user operation of J-PARC linac was started in December 2008 with the limited beam power of 270 W from the linac. Since then, we have experienced some operational issues including those caused by uncontrolled beam losses. Mechanisms and cures for some of them have been identified in the beam studies, and we have succeeded in mitigating them. Presently, we are operating with the linac beam power of 7.2 kW. Examples of the beam loss and their cures in the history of the J-PARC linac beam commissioning are introduced.

Components of Linac and Beam Loss Measurement System

There are several matching sections (MEBT, SDTL, ACS, L3BT, Scraper Section and Injection) to tune in J-PARC linac. Some commissioning tools including Wire Scanner Monitors (WSM) and Beam Loss Monitors (BLM) are distributed in whole sections.

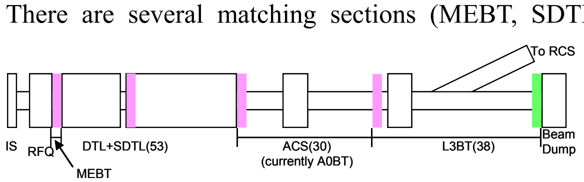

Figure 1: Layout of J-PARC linac and location of WSM. Pink boxes are the matching sections and green box is a place where the WSM with beam size monitor is installed. Brackets are the numbers of BLM in each section.

Beam Loss Monitor: Ar-CO_2 Gas Proportional Counter

A gas proportional beam loss monitor is employed as a BLM, because it is easy to make and maintain, and it has an advantage by composing with only a passive components, that is a practically key issue for the detector under the radiation surroundings (in Fig. 2)[1].

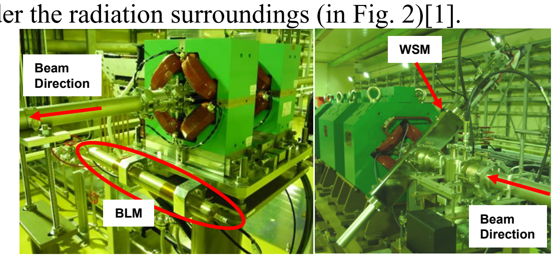

Figure 2: Installation of the BLM and WSM are shown. BLMs are installed behind the quadrupole magnet (left). WSMs are installed at the upstream of the matching section (right).

Wire Scanner Monitor with Beam Size Monitor

A system of WSM has a measurement head, a bias supplier, a stepping motor unit and an electrical circuit. A measurement head is installed with 45^0 against the horizontal and vertical axis (Figure 3). Tungsten wire with 30μm is employed excepting the MEBT section. WSMs installed in the beam dump and L3BT section, carbon plates with 2.0 mm thickness are installed as a beam size monitor (BSM). Because of wide detecting surface of BSM, it is considered to be more sensitive for small signals than 30μm tungsten wire [2].

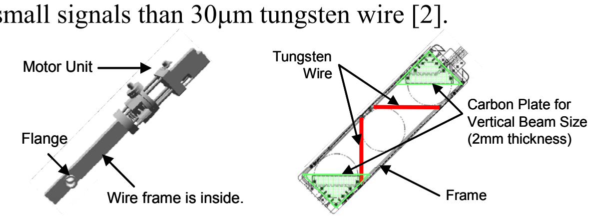

Figure 3: WSM and its frame are shown. Wire frame (right) is connected to a shaft controlled by motor unit and it is installed in a vacuum chamber (left).

Beam Loss Due to Residual Gas

We have confirmed that the proton removal affects the beam loss in this region. The remarkable insensitivity of the beam loss suggests that the beam loss is caused by the H^0 component generated with the electron stripping in the

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residual gas scattering. This supposition is supported with the experiment where the dependence of the beam loss to the vacuum pressure is measured with turning off some of the IP's (Ion Pumps). The beam loss is clearly increased by turning off IP's in some part of the SDTL section and the future ACS section.

Figure 4 shows a result in the experiment where the dependence of the BLM raw signals to the IP setting in the SDTL section is measured. Similar results are obtained for the IP setting in the future ACS section. We are installing some additional vacuum pumps during this summer shutdown to further study the cause of the beam loss [3].

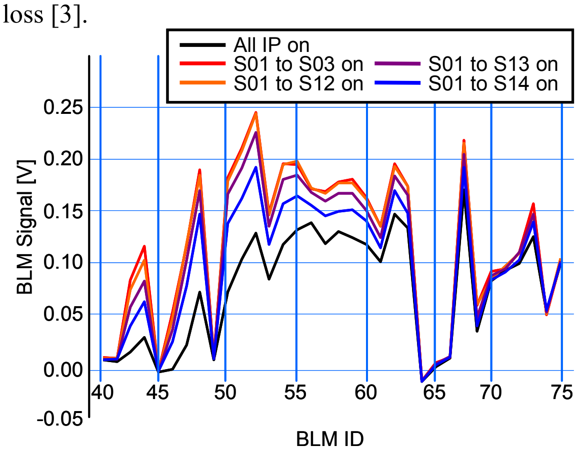

Figure 4: BLM raw signals with different IP settings. With all IP's on (black), IP's from SDTL04 to SDTL15 off (red), IP's from SDTL13 to SDTL15 off (orange), IP's from SDTL14 to SDTL 15 off (purple), and IP of SDTL15 off (blue). BLM #40 corresponds to the one at the SDTL end, and BLM #44 to #60 corrensspond to those in the future ACS section.

Beam Loss at Bend Magnet

Highest residual radiation was measured at the point B on the surface of bending magnet, because the point B is the opposite position to designed orbit for bended beam (shown in Fig. 5 and Table 1). All beam loss data around the bend magnet indicated that there remained proton (H^+) particles and they were bended opposite side by magnets as the negative hydrogen ions (H^-).

It is thought that H^+ particles are generated at the frontend and a beam transport. We are discussing the H^+ removal using scraper in MEBT subsection. Currently this is very effective to decrease the beam loss at bend magnet. After some operations have been experienced, residual radiation at the opposite side against the beam orbit remarkably decreased [4-5].

Table 1: Residual Radiation on the Bend Magnet

Unit [μSv/h]

Measurement point	A	B	C	D	E
After Run 19	75	210	100	10	13
Before Run20	33	75	55	4	8
After Run 20	50	67	80	6	12
After Run 21	47	70	60	4.5	6.5

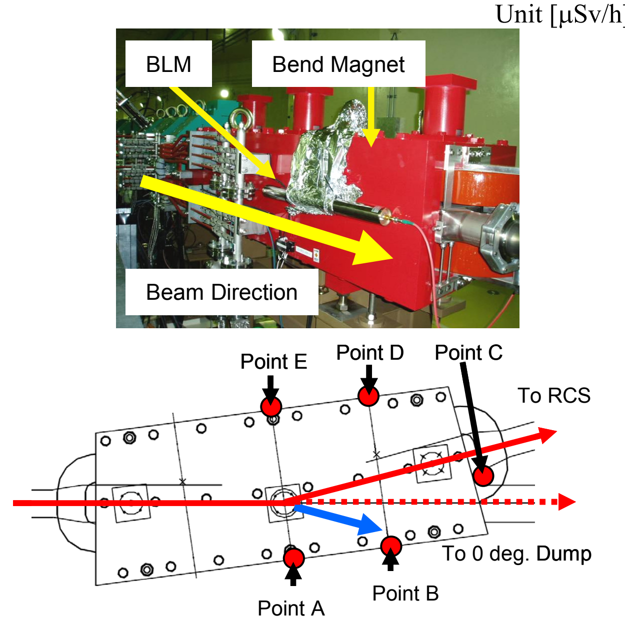

Figure 5: Measurement for residual radiation around the first bending magnet in L3BT section. BLMs are installed at the both sides of the bending magnet (top-left). Points A to E are the measurement point for residual radiation (top-right). Main beam orbit is along with the red line, orbit of the remained proton (H^+) is blue line.

Neutral Hydrogen Measurement

While the beam is bended at first bending magnet, main negative hydrogen ions are bended. But remained H^+ particles are bended another direction due to opposite electrical charge. On the other hand, neutral hydrogen (H^0) particles which are generated by the electron stripping of H^- ions due to residual gas scattering [6] are directory transported to the 0 deg. Beam dump.

We tried to measure the H^0 particles using the WSM and BSM installed just in front of the 0 deg. beam dump (Figure 1). When an H^0 particle passes through the wire or carbon plate, an electron stripped from H^0 particle plays a role in the signal for the WSM or BSM. Although the dynamic range of the WSM employed in J-PARC linac reaches over 10^4 [2], but WSM cannot measure H^0 particles due to quite small. However, the carbon plate in BSM is more sensitive than a wire due to the larger interactional cross section between H^0 particles and carbon plate. Then, we employ the BSM for H^0 particle measurement.

Signals from H^0 particles are successfully measured using BSM. Figure 6 indicates the half profiles of the H^0 particles, because the carbon plate can be inserted only in the center due to the restriction of the mechanical construction. When this measurement is conducted, the carbon plate is inserted step by step. Signals are averaged using 5 beam shots in each step and the carbon plate is inserted 0.5 mm step from outside of the beam center. Because these signals are integrated values, signal heights are gradually increased. But large fluctuations sometimes appear due to quite small signals. But totally, we can obtain the profiles similar to the Gaussian profiles.

Figure 6 shows the H^0 profiles with a chopped and no-chopped beam. No-chopped beam has a 500μs pulse width and a peak beam current is 15mA. Because the width of the intermediate beam pulse of the chopped beam is 650 ns, this beam duty is almost half compared with the no-chopped beam. Signal of the no-chopped beam is almost twice as high as that of chopped beam and this result agrees with such relation of a beam duty. Because these signals cannot be obtained by WSM but by BSM, because the dynamic range of the WSM reaches over 10^4, the number of the H^0 particles is estimated less than 1/10,000 of that of the H^- particles.

Based on this measurement, detail analysis will be conducted to explain an exact profile of H^0 particles and the population of the particles.

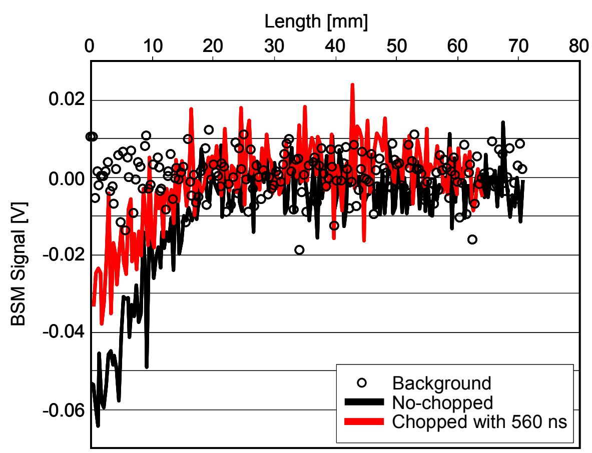

Figure 6: Signal from H^0 particles taken by carbon plate. Circle dots are signals taken under no beam operation. Signal from H^0 particles with no-chopped beam is indicated with black line. Signal from H^0 particles with chopped beam with about half duty of no-chopped beam is indicated with red line.

Summary

At the commencement of high-duty-factor operation for users in December 2008, we recognized the following three issues for the J-PARC linac beam commissioning, namely, considerable residual radiation localized at the first bending magnet after the linac, weaker but more widely distributed residual radiation in the future ACS section. The cause of the beam loss at the first bending magnet has been identified to be protons (H^+) captured at RFQ, and the beam loss has been successfully mitigated by introducing a chicane orbit at the beam transport line between RFQ and DTL [5].

As for the beam loss at the future ACS section, the experiments indicate that the beam loss is caused by H^0 component generated with the electron stripping of negative hydrogen ions due to residual gas scattering [6]. We are installing some additional vacuum pumps during this summer shutdown to further study the cause of the beam loss. It is important to fully understand the mechanism for this beam loss in order to seek higher beam power.

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