SUPPRESSION OF BEAM LOSS AT THE BENDING MAGNET OF THE FIRST ARC IN THE J-PARC LINAC

H. Sako*, Japan Atomic Energy Agency, Tokai, Naka-gun, Ibaraki, Japan
M. Ikegami, High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan.

Abstract

The highest beam loss in the J-PARC linac was observed at the first bending magnet in L3BT in the opposite side to H$^-$ deflection. A loss source candidate is H$^+$ ionized in LEBT. An H$^+$ peak was measured with a wire scanner monitor at MEBT1 by splitting H$^+$ and H$^-$ with steering magnets. H$^+$ is separated from H$^-$ beam with a horizontal steering magnet and a bending magnet at MEBT1 then H$^+$ is stopped by the scraper originally for beam chopping. The loss and radiations were reduced significantly while good chopping performance is kept.

INTRODUCTION

On 26 Dec. 2008, after Run 20 with 4.5 days of 0.27 kW operation at linac (4.5 kW at RCS 3GeV), the highest residual radiations of 210, 100, and 10 μSv/h in the linac were measured around the first bend magnet (BM01) at L3BT (at the green, yellow, and cyan points in Fig. 1). Before that the points have never been measured. On Jan. 2 additional beam loss monitors (BLMs), BLMP21B and BLMP21C were installed in the H- beam deflection side and the opposite side of BM01, respectively as in Fig. 1. The red curve of Fig. 2 shows beam loss distributions in the linac in Jan 2009. The beam loss has a peak at BLMP21, BLMP21B, and BLMP21C.

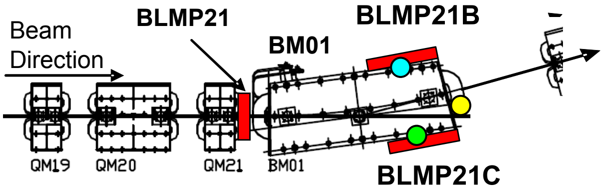

Figure 1: Beam loss monitors at BM01 (red), and 3 radiation measurement points (cyan, green, and yellow).

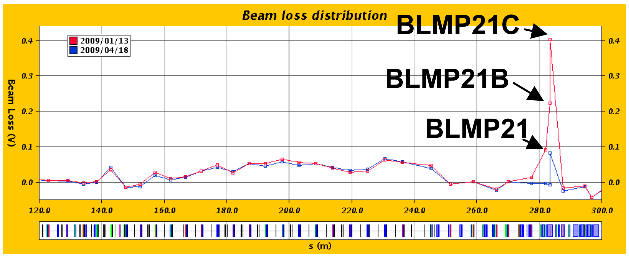

Figure 2: Beam loss distributions in the linac on 13 Jan. 2009 (red) and on 18 Apr. 2009 (blue).

MEASUREMENTS OF H$^+$

The highest loss in the opposite side of the H$^-$ deflection in BM01 suggests that the beam loss is caused by positive charge particles which have similar momenta to the H$^-$ beam, namely 181 MeV in kinetic energy. Thus, the loss source may be H$^+$s produced by ionization of two electrons in residual gas. Only two H$^+$ source candidate locations exist in the linac. One is LEBT, between the ion source (IS) and RFQ. Since the beam current from IS is DC, ionized H$^+$s are bunched in RFQ around the RF phase shifted by 180 degrees with respect to the H$^-$ acceleration phase and accelerated from 50 keV to 3 MeV as H$^-$. At downstream cavities of DTLs and SDTLs, H$^+$s produced by bunched H$^-$s ionized with residual gas are not accelerated but lost locally, while at the 180-degree shifted phase, the H$^+$ bunch is accelerated up to the linac full energy and will be lost in BM01. The other possible H$^+$ source is after the last SDTL up to BM01, where there is no acceleration cavity and H$^+$s ionized in the H$^-$ bunch can reach BM01. The highest gas pressure in the linac of 8.82x10^{-4} Pa is at LEBT with 0.6 m length with the gas thickness (pressure times length) of 6.49x10^{-4} Pa m. The gas thickness from the last SDTL to before BM01 is 3.676x10^{-5} Pa m. The ratio of H$^+$/H$^-$ is estimated to be only 4.6x10^{-6} using cross sections and formulae in Ref. [1] due to 4-order smaller H$^-$ to H^0 and H^0 to H$^+$ cross sections at 181 MeV than those at 50 keV. Therefore we performed an H$^+$ measurement in MEBT1.

The bottom plot shows model calculations of horizontal beam widths for H$^-$ and H$^+$ in MEBT1. The H$^-$ curve is based on the fit to wire scanner measurements. For H$^+$ calculations, the initial Twiss parameters and emittance at the entrance of MEBT1 are taken as the same values as those of H-, because there are almost same at the exit of RFQ in PERMTEQ calculations [2]. As shown in the bottom plot of Fig. 3, the beam widths of both H$^+$ and H$^-$ are small (1.27 mm and 0.26 mm respectively) at WSM07. Therefore we chose WSM07 for H$^+$ measurement. We set in 3 horizontal steering magnets, STMH05, STMH06 and STMH07 magnetic field integral of +0.00030, +0.00330, and -0.00140 (Tm) to separate H$^+$ and H$^-$. The model calculations of the H$^+$ and H$^-$ orbits are shown in the top plot of Fig. 3. The calculated positions of H$^+$ and H$^-$ are -3.79 mm and +3.79 mm, respectively.

Fig. 4 shows measured horizontal beam profiles at WSM07 with the magnetic field in the 3 steering magnets for H$^+$-H$^-$ separation (blue) and without the magnetic field (red). A clear negative satellite peak was observed with in the left side of the main H$^-$ peak. The measured peak position separation between H$^+$ and H$^-$ peaks was 7.0 mm which is consistent with the calculation (7.6 mm). H$^+$

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*hiroyki.sako@j-parc.jp

should show indeed opposite sign signal to that of H^-, because H^+ can only kick out electrons from the graphite wire, whereas main component of H^- is electron deposit into the wire [1]. H^0 produced in LEBT cannot be accelerated by RFQ and do not reach to MEBT1. Even if a small number of H^0s exist, they induce the same sign signal as H^- and the peak position should be between H^- and H^+ peaks, which are hidden by the H^- peak.

The measured H^+/H^- ratio is 1.861×10^{-3}. The ratio calculated from Ref. [1] using the gas thickness of LEBT of 5.340×10^{-4} Pa m is 1.033×10^{-3}. They have a factor 2 difference, which may be because the pressure is measured at the pump head. The probability of H^- depositing electrons on the graphite wire of 7 μm thickness (average thickness of 5.50 μm) is estimated to be 99.1 % using Ref. [1]. The probability of H^+ ionizing carbon in the wire is estimated to be 92 % using data in Ref. [4] (H^+ on CH_4 collisions at 6 MeV). The measured ratio is not corrected for these probabilities.

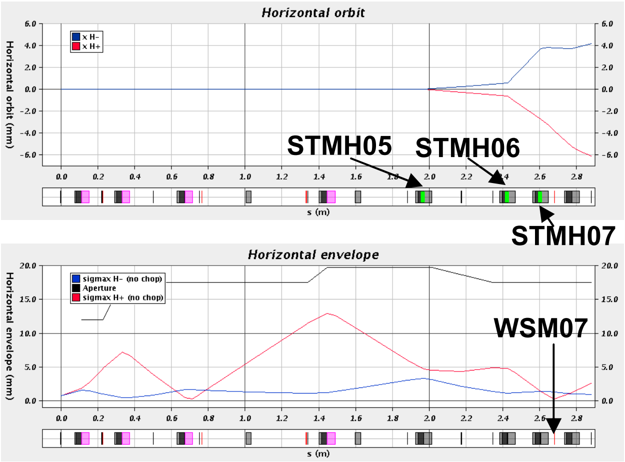

Figure 3: The top plot shows horizontal orbits of H^- (blue) and H^+ (red) in MEBT1. The bottom plot shows the horizontal beam widths of H^- (blue) and H^+ (red).

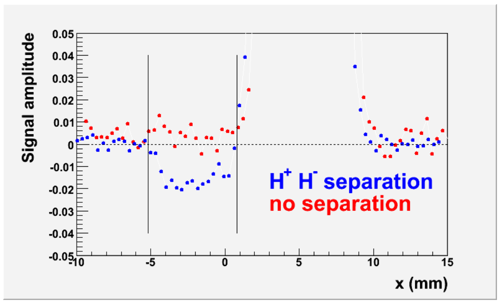

Figure 4: Beam profiles at WSM07 in MEBT1 with H^+ - H^- separation (blue) and without separation (red). The two vertical lines show the cut applied for H^+ signal.

BEAM LOSS SUPRESSION

H^+s produced in LEBT may be a main source of the beam loss at BM01. They should be stopped at the position as upstream as possible to suppress beam loss. There is a graphite scraper in MEBT1 which stops H^- beam kicked by the RF chopper in the horizontal positive direction. Therefore the scraper is positioned in the horizontal positive side as in Fig. 5. Note that H^+, which is bunched in 180-degree shifted RF phase with respect to H^-, is kicked also in the horizontal positive direction. The kick angle by the chopper is estimated to be 22.66 mrad using the kicked and not kicked H^- beam positions with the beam position monitor (BPMs) just after the chopper.

If H^+s and H^-s are separated with horizontal dipole magnets before the scraper, with H^+s deflected in the positive direction, the scraper may be used to stop only H^+s but let H^-s bypass. We used a horizontal steering magnet (STMH04) and a bend magnet (MEBD1:BM01) between the chopper and the scraper to separate H^+s and H^-s. The bend magnet is originally to lead the beam to a beam branch for emittance measurements and for H^+-H^- separation the power supply is replaced by that for a steering magnet for better current precision. Since the aperture of the Buncher 2 just after the scraper is narrow (35 mm diameter), the H^- orbit must be kicked back at STMH05. The designed field configuration of H^+-H^- separation is -0.00072, +0.00100, +0.00072 in the field integral (T m). The model calculations of the H^+ and H^- orbits with and without the chopper electric field, and magnetic field of the steering and bend magnets are shown in Fig. 5. The vertical thick blue line shows the scraper position in operation, which stops H^+ and H^- beams with the chopper kick and H^+ without the chopper, but let H^- pass. Filled square show H^- orbit positions measured by the BPMs, which agree with the model.

In this configuration, we have measured beam loss with the BLMs with varying the scraper position. The raw beam loss signal includes a saturation effect which has been investigated with varying chopping ratio [5]. The raw beam loss voltage (v_r) can be corrected to;

$$v_c = -3.6768e-05 + 2.7439v_r + 2.7439v_r^2 + 484.43v_r^3 - 5328.4v_r^4 + 37059v_r^5 - 95128v_r^6 + 97762v_r^7$$

The corrected loss with this formula is plotted in Fig. 6. Note that the definition of the direction of the scraper position axis is opposite to that of the orbit position.

As inserting the scraper (to the positive scraper direction and the negative orbit direction), beam loss is reduced.

The ratio of BLMP21 and BLMP21B to BLMP21C are 0.025 and 0.20, and almost same for different scraper positions. Note also that without the H^+-H^- separation fields, the corrected beam loss for BLMP21, BLMP21B, and BLMP21C are 0.883, 8.44 and 46.0 at the previous scraper position setting of 32.5 mm. About a factor of 3-4 is already reduced without moving the scraper position, due to the large H^+ orbit deviation of +10mm where a significant fraction of H^+ may be stopped by the beam duct (see Fig. 5).

The final position of the scraper is set to 35.5 mm, where the loss reduction factor is 24, 30, and 31 for BLMP21, BLMP21B and BLMP21C. The chopping performance was confirmed to be unchanged.

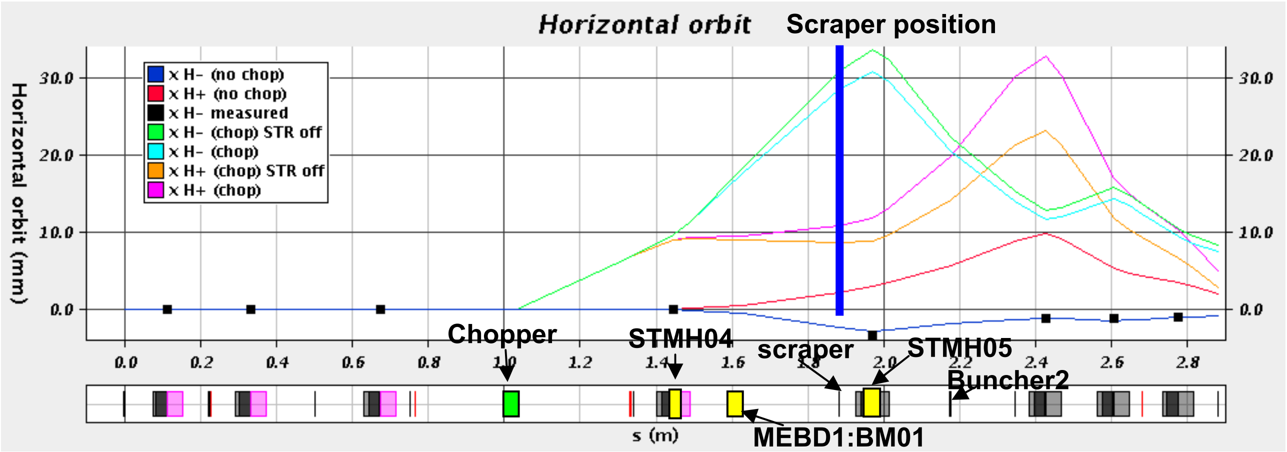

Figure 5: Horizontal orbits of H$^-$ (blue) and H$^+$ (red) with H$^+$ separation without chopping, orbits of H$^-$ (green) and H$^+$ (orange) without H$^+$ separation with chopping, and orbits of H$^-$ (cyan) and H$^+$ (pink) with H$^+$ separation with chopping.

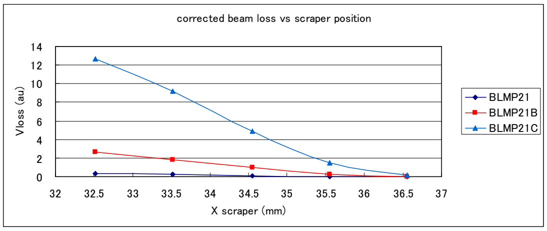

Figure 6: Beam loss as a function of the scraper position.

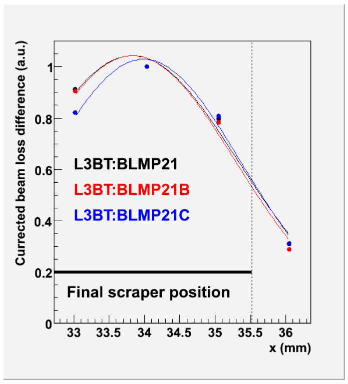

Figure 7: Corrected beam loss difference as a function of the scraper position.

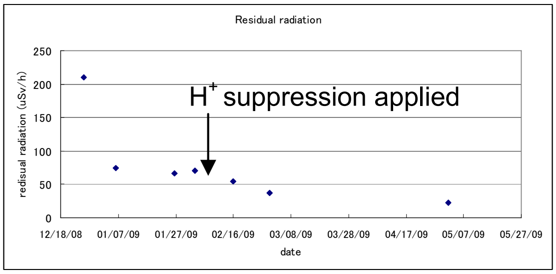

Figure 8: Residual radiations at the green point in Fig. 1 around BLMP21C as a function of measured dates.

To investigate the beam loss source, we take difference of adjacent points in Fig. 6 and the horizontal value is taken as the average of the two points as shown in Fig. 7. Each plot of the 3 BLMs is normalized to 1 at the scraper position of 34 mm. The distributions should reflect the shape of the loss sources. They are very similar, both in the center positions and in the widths. By fitting to Gaussian, the center positions are 33.83, 33.83, and 33.99 mm and the widths (σ) are 1.49, 1.45, and 1.39 mm, for BLMP21, BLMP21B, and BLMP21C, respectively. Note that the rms width of H$^+$ was 1.436 mm and consistent with these loss distributions, which suggests the main loss source around BM01 is H$^+$s produced in LEBT.

RADIATION MEASUREMENTS

Fig. 8 shows radiation measured at BLMP21C as a function of the measured date. Only the first point is after 4.5 kW operation, and the rest is after 20 kW operation. Since 8 Feb. 2009, the H$^+$ suppression has been applied, when radiations have been reduced. Detailed analysis including integrated beam power and the interval from the last beam operation to the measurement are underway.

CONCLUSIONS

The beam loss and radiations at the first bend magnet were reduced significantly using H$^+$-H$^-$ separation using dipole magnets, and suppression of H$^+$ in MEBT1 by the scraper. The observed loss and direct H$^+$ measurements suggest the loss source is mainly H$^+$s produced in LEBT.

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