DEPENDENCE OF BEAM LOSS ON VACUUM PRESSURE LEVEL IN J-PARC LINAC

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Abstract

In J-PARC linac, a 181-MeV negative hydrogen beam is supported to a succeeding 3-GeV synchrotron with normal operation power at 100-300 kW. During operation, a beam loss in the straight section of the beam transport line immediately after the linac exit is found. The residual radiation level reaches 0.3 mSv/h on the surface of the vacuum chamber several hours after the beam shutdown with the linac beam power of 12 kW. We suppose that the residual gas scattering of negative hydrogen ions generates neutral hydrogen atoms and they give rise to the beam loss by hitting the vacuum chamber wall. To confirm this speculation, the vacuum pressure level in the linac had been changed in order to find the dependence of the beam loss on it. After data analysis, we found the relationship between beam loss amplitude, which was attained from beam loss signal, and vacuum pressure was linear. In this paper, we present the experimental result and some analyses in this study.

INTRODUCTION

J-PARC linac nowadays mainly consists of a 50-keV negative hydrogen ion source, a 3-MeV RFQ (Radio Frequency Quadrupole linac), a 50-MeV DTL (Drift Tube Linac), and a 181-MeV SDTL (Separate-type DTL). We plan to upgrade the linac energy to 400 MeV by adding ACS (Annular Coupled Structure linac) in the straight section after the SDTL exit [1].

The beam power of J-PARC linac for user operation has been gradually increased and reached 13.3 kW just before the earthquake in March 2011. The mitigation of beam loss is a main issue in the J-PARC linac because it is indenting to have tenfold increase of the beam power by the energy and intensity upgrade.

In the user operation of J-PARC linac, we have been experiencing a beam loss widely distributed in the future ACS section as shown in Figure 1. A preliminary experiment was conducted to see the response of the beam loss level to the vacuum pressure level intentionally increasing the vacuum pressure level by turning off some of the vacuum pumps. The result for this experiment indicated that the mechanism for the beam loss is the H0 component generated by residual gas scattering of H- beam. We extend the study in this paper to further confirm the conclusion.

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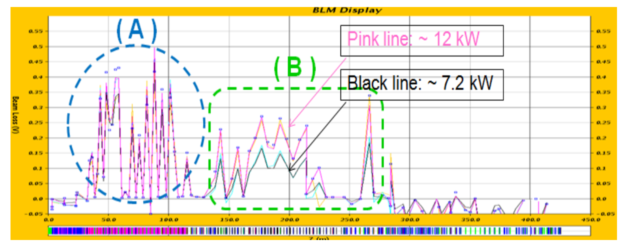

Figure 1: Beam loss of J-PARC linac in normal operation. Beam loss in section A mainly caused by X-ray leaked from DTL and SDTL tanks. Pink: 12 kW beam power from linac & 200 kW from the RCS; Black: 7.2 kW from linac & 120 kW from the RCS.

BEAM LOSS REDUCTION BY VACCUM IMPROVEMENT

We have added several NEG pumps (Non-evaporable Getter Pump) in the downstream part of SDTL and the upstream to middle part of the future ACS section. More specifically, we have added four NEG pumps in the SDTL section after the 26th, 27th, 28th, and 29th tanks and four NEG pumps in the future ACS section at the addresses of ACS07, 11, 13, and 15 shown in Figure 2.

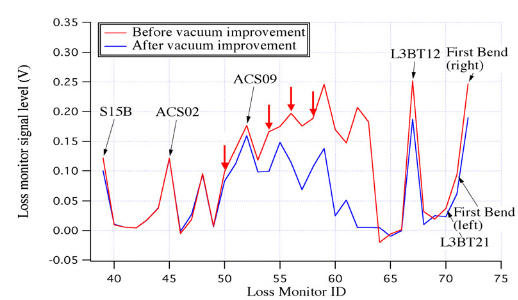

Figure 2: Beam loss profile in the beam transport line after the SDTL exit before and after the vacuum improvement. The red arrows show the locations of NEG pumps in the future ACS section.

Figure 2 also shows the beam loss signal before and after the vacuum improvement. In this figure, it is readily seen that the beam loss is significantly reduced in the middle to downstream part of the future ACS section.

Then, it has led us to the next step where we demonstrate reduction of the beam loss by improving the vacuum pressure in the SDTL section and the future ACS section with additional vacuum pumps.

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EXPERIMENT OF RESIDUAL GAS STUDY IN SDTL 8-15 SECTION

Experiment Conditions and Method

An online experiment had been done to find the relationship between beam loss in the future ACS section and residual gas in last part of SDTL section. The depiction is shown in Figure 3. Firstly we turned off the ion pumps in SDTL 8-15 section in order to increase the vacuum pressure in SDTL 8-15 section. Then the measured data was record as a curve due to the time for ion pump vacuum meter and BLM.

Here the online beam condition is that FRQ tank level 95 %, no-chopped beam with frequency 1.0 Hz, pulse length 100 microseconds, energy 181 MeV at the end of linac. we surveyed for beam with peak current both 15 mA case and 20 mA case.

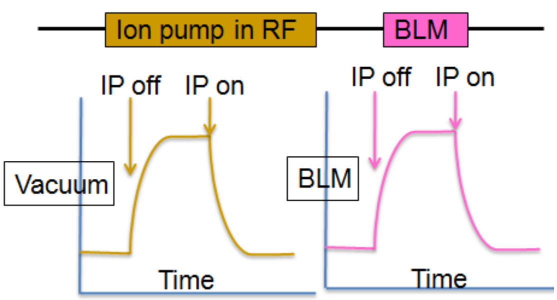

Figure 3: Simply depiction of online experiment study of beam loss due to vacuum pressure control by ion pump.

Experiment Results

After data taking, we made the relation between those two data curves from Vacuum meter and BLM. Here firstly we should also need to transfer data from Beam Loss Monitor signal to 'so called' corrected beam loss amplitude [2], which is supposed to be linear to the number of lost particles. The corrected beam loss (v_c) amplitude is obtained by fitting the raw BLM signal (v_r) with the following seventh-order polynomial as shown in equation (1).

$$v_c = -3.68 \cdot 10^{-5} + 2.74\mathrm{v_r} + 2.74\mathrm{v_r^2} + 484\mathrm{v_r^3} \\ -5330\mathrm{v_r^4} + 37100\mathrm{v_r^5} - 95100\mathrm{v_r^6} + 97800\mathrm{v_r^7} \qquad (1)$$

Then we compared the data from vacuum meter at ion pumps and BLM as shown in Figure 4. A linear relationship between the corrected beam loss (v_c) and vacuum pressure change, in the time which is between turning off and turning on the ion pump, had been found as shown in Figure 4 also.

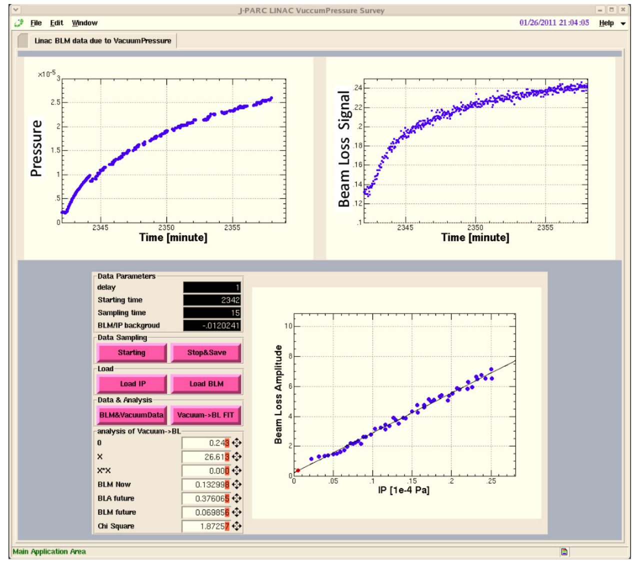

Figure 4: The relation between those two data curves from vacuum meter and BLM.

ANALYSES OF EXPERIMENT RESULT OF RESIDUAL GAS STUDY

Physics Reactions Between Residual Gas and Beam as Well as Main Reason to Cause Beam Loss

Physics reactions between residual gas and negative hydrogen ion beam mainly includes electron stripping, ionization energy loss, nuclear elastic scattering, nuclear absorb, and multiple scattering [3]. Due to the beam energy 181 MeV, and vacuum pressure caused by residual gas about 10^{-6} Pa, the main reason to cause beam loss is electron stripping, while others can be ignored.

Why the Relationship Between Vacuum Pressure and Beam Loss Amplitude is Linear?

From figure 4, we can see the A linear relationship between the corrected beam loss (v_c) and vacuum pressure. The reason can be explained as follow:

Here we think ion numbers in unit transverse plant before and after a layer of residual gas are I and I'. Then I and I' can has

$$I - I' = -dI = N_s \sigma I \qquad (2)$$

Where N_s the number of nuclear of residual gas, σ the cross-section of charge transfer of hydrogen ion and atom.

$$N_s = L_{SDTL} \frac{dP}{1.0125\times10^5 Pa} \cdot \frac{6.022\times10^{23}}{22.4L} \cdot 10^{-2} = k \cdot d \qquad (3)$$

Where P is the vacuum pressure of residual gas

$$\frac{dI}{I} = -k\sigma \cdot dp$$

$$I = I_0 e^{-k\sigma P}$$

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$$I_{H^0} = I_0 - I = I_0(1-e^{-k\sigma P}) \approx k\sigma I_0 \cdot P \tag{4}$$

If the Vacuum pressure is low enough, such as 10^{-5} Pa, we can have equation (4), which means linear relationship between the corrected beam loss (v_c) and vacuum pressure.

Surmising of Beam Loss with Low Vacuum Pressure of 5×10^{-7} Pa

By such linear relationship, we also surmised the beam loss in the future ACS section for lower vacuum pressure 5×10^{-7} Pa according to data from current 3×10^{-6} Pa case and two case with higher vacuum pressure in the experiment of 2×10^{-5} Pa and 1×10^{-5} Pa, which were shown in Figure 5. We can see a large improvement between the violent dashed line of 5×10^{-7} Pa case and cyan blue solid line of current 3×10^{-6} Pa case. Beam loss would reduce 44.2 % for 15 mA case and 47.9 % for 20 mA case.

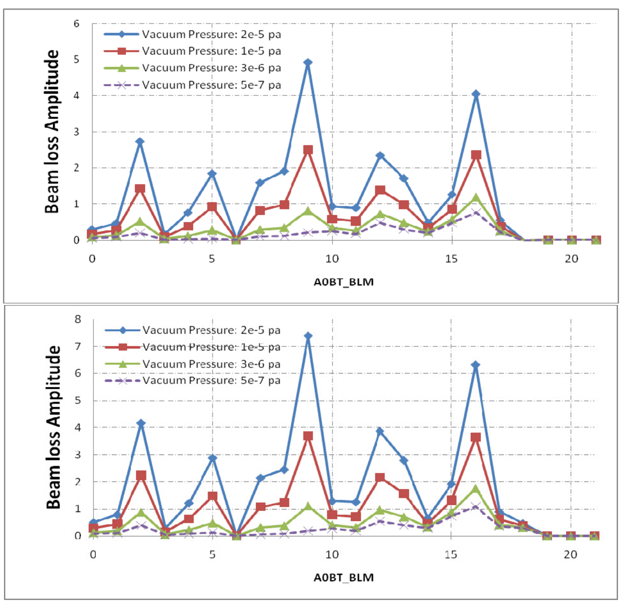

Figure 5: Surmising of beam loss with low vacuum pressure of 5×10-7 Pa (Up: 15 mA; Down: 20 mA)

Simulation and Another Method to Reduce Beam Loss by a Collimation System in MEBT2

For simply explanation of electron striping by residual gas, a beam simulation for 15 mA case has been performed. Here residual gas component of H_2O: 40%, H_2: 30%, CO_2: 20%, N_2: 10% is considered. Cross-section data of charge transfer of hydrogen ion and atom was chosen from the reference [4]. CODE IMPACT was used. Some beam distributions in transverse space were shown in Figure 6. Those results were corresponding to the beam loss in the user operation.

Here another method of installing collimation system in MEBT2 was also studied preliminary. The beam distribution and particle loss can be seen in Figure 6 and 7.

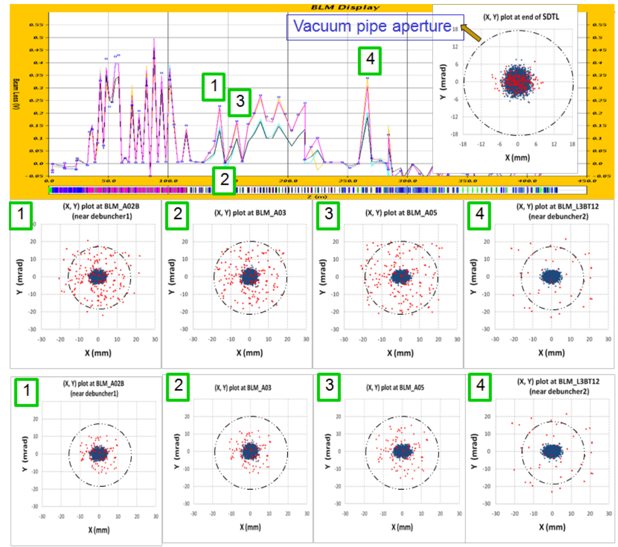

Figure 6: a beam simulation results with residual gas. Beam distributions for 5 place: the end of SDTL, and 4 positions at 4 BLM in future ACS section (blue: H^- ion; red: H^0, Up: normal; Down: with MEBT2 collimation)

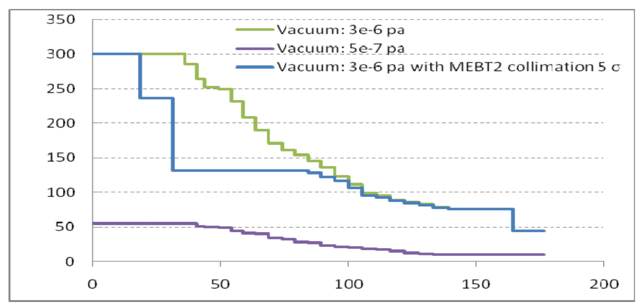

Figure 7: Particle losses in simulations according to different vacuum pressure and case with transverse collimation in MEBT2 section.

SUMMARY

An online experiment had been done to find the relationship between beam loss in the future ACS section and residual gas in last part of SDTL section. A linear relationship had been found and also explained. Two methods can reduce those beam loss. One is to reduce vacuum pressure to 5×10^{-7} Pa, with the other a new collimation in MEBT2 also useful.

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