

LONGITUDINAL BEAM PROFILE MEASUREMENT AT J-PARC SEPARATED DRIFT TUBE LINAC

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Abstract

In J-PARC linac, we have been experiencing beam losses at the beam transport line after the linac exit. There has been an argument that the longitudinal loss could be a cause of the beam loss, which motivated us to conduct an experimental investigation on the margin between the longitudinal acceptance of the linac and the actual beam distribution. In the experiment, we have introduced a "tank level scan" to measure the margin in the energy direction in addition to the conventional phase scan which has been employed to measure the margin for the phase direction. The measurement scheme and experimental results are presented in this paper.

INTRODUCTION

J-PARC linac consists of a 50 keV negative hydrogen (H^-) ion source, a 3 MeV RFQ (Radio Frequency Quadrupole linac), a 50 MeV DTL (Drift Tube Linac), and a 181 MeV SDTL (Separated DTL) [1]. The beam power of J-PARC linac for user operation has been gradually increased and reached 13.3 kW just before the Tohoku Region Pacific Coast Earthquake in March 2011. In the user operation, we have been experiencing beam losses widely distributed in the straight section after the SDTL exit [2]. The residual activation reaches several hundred $\mu Sv/h$ on contact to the beam duct several hours after the beam shutdown. Although the residual radiation level is still in a tolerable range, it is important to identify the loss mechanism and take reasonable countermeasures because we are intending to realize tenfold beam power by energy and intensity upgrades of the linac. An experiment to increase the vacuum pressure in the SDTL section indicated that the beam loss is caused by H^0 generated in the scattering of H^- with the residual gas [3]. Observed insensitivity of the beam loss to the beam orbit also supports the theory. However, there has been an argument that the beam loss could be caused by longitudinal beam losses due to particles slipt out of the acceptance of SDTL. It motivated us to conduct an experiment to measure the margin between the acceptance and the actual beam distribution in the longitudinal phase plane.

Blue points in Fig. 1 show the SDTL longitudinal acceptance. The horizontal axis is the beam injection phase to the SDTL entrance with respect to design of -27 deg

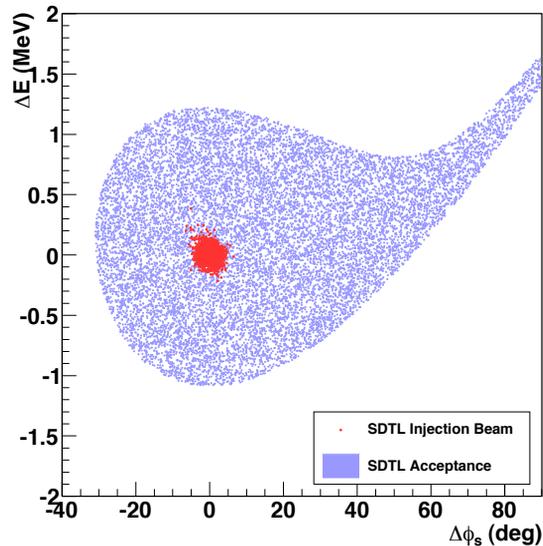


Figure 1: Longitudinal acceptance at the SDTL entrance (blue points). Design beam distribution at the SDTL entrance (red points) is also shown for comparison.

($\Delta\phi_s$), and the vertical axis is the beam energy with respect to design energy of 50 MeV (ΔE). The acceptance is distributed for -30 to 60 deg on the $\Delta\phi_s$ axis and -1.1 to 1.2 MeV on the ΔE axis, respectively. For comparison, design beam distribution is also shown as red points. The acceptance looks enough tolerance to the beam distribution even if the emittance becomes several times worse than the design. Although, beam halo could be distributed more broad, which may cause the beam loss at the downstream of the SDTL part.

The SNS already investigated the beam loss coming from the SCL longitudinal acceptance [4] by measuring the longitudinal acceptance. They performed an acceptance scan in which they produce various phase and energy beam at the 2nd cavity. To control the injection phase, they shifted the driven phase of the 2nd and more downstream cavities by the same amount. Meanwhile, they changed the synchronous phase of the 1st cavity to control the injection energy to the 2nd cavity. In the J-PARC SDTL section, there are 30 cavities and each of two cavities is driven by one klystron. If we adopt the same scheme with SNS, the first two SDTL cavities would be used for the injection

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tion energy control. As the acceptance at the 3rd cavity is similar to the 1st one, we need additional energy gain of 1.2 MeV to cover the entire acceptance. However, the first two SDTL cavities can provide the additional energy gain of only 0.6 MeV. Therefore, it is not sufficient to scan over the entire acceptance. This limitation necessitated us to devise another method to measure the acceptance margin in the energy direction.

We measured the acceptance margin by combining two kinds of measurements. One is a measurement of beam loss by changing the beam injection phase to SDTL to check the tolerance including the beam halo. Since this measurement is conventional phase scan, we call this measurement as "phase scan" in this proceeding. Figure 2 shows the simulated acceptance with lower tank level for the all cavities. In this figure, the tank level is lowered with 5 % step. The result indicates that the acceptance especially for the ΔE direction shrinks as the tank level is low. Therefore if phase scan with reducing the all tank levels is performed, we can know the acceptance tolerance on the ΔE direction also. We call this measurement as "tank level scan" in this proceedings.

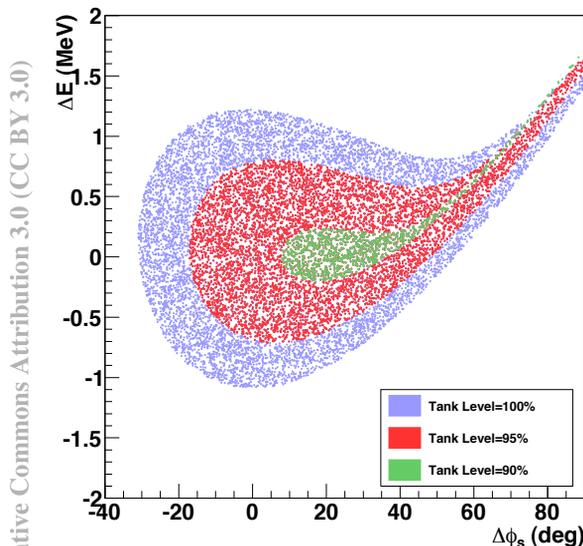


Figure 2: The longitudinal acceptance at the SDTL entrance with the tank level of all SDTL cavities scaled to 100% (blue points), 95% (red points) and 90% (green points) of the design value.

MEASUREMENT

In this section, we introduce experimental results. The acceptance can be measured by scanning the tank parameters monitoring the beam loss or beam survival downstream. Two kinds of monitors were used for the measurement. One is slow current transformers (SCT) which are used to measure the beam current at their location. When a

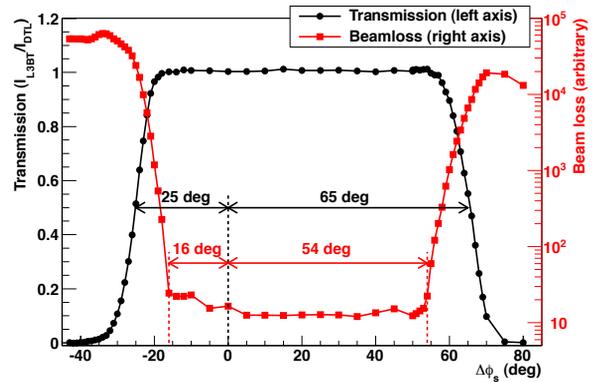


Figure 3: The result of phase scan. The black line with filled circles is the transmission result (left axis), and red line is the BLM result (right axis).

beam core reaches the acceptance edge, we can detect it as a decline in the transmission efficiency. Therefore we can estimate the location of the acceptance edge by SCT data. We measured the beam transmission between the upstream of the SDTL section to the middle of the beam transport line where is about 130 m downstream of the SDTL section. Another monitor is beam loss monitors (BLM). BLM is supposed to be more sensitive than SCT to a slight beam loss. Therefore, it can detect it when only the halo reaches the edge of acceptance in a scan.

Phase Scan Result

For the phase scan, the injection phase is shifted by changing the driven phase of all 30 cavities by the same absolute value. Figure. 3 shows the result of the phase scan. We took a data in the range of $\Delta\phi_s$ from -45 deg to 80 deg, where the transmission is not zero. The black line with filled circles is the beam transmission. Assuming the beam core center is on the acceptance edge when the transmission is declined to 50 %, the acceptance on the $\Delta\phi_s$ axis is estimated to be from -25 deg to 65 deg. On the other hand, the simulation shown in Fig. 1 indicates that the acceptance on the axis is -30 deg to 55 deg. Therefore the actual acceptance is wider by 5 deg and its center is shifted to positive direction by about 7 deg compared with the simulation. The BLM result is the red line with filled square in Fig. 3. The distribution has a flat bottom from -16 to 54 deg with the 100 % transmission. It means no beam loss occurs in the flat bottom. The BLM signal drastically increases as the phase setting goes outside the flat bottom, and saturates at the phase with negligible transmission. From the results of SCT and BLM measurements, we can obtain the width of beam halo because the distance of the acceptance edge and the BLM flat bottom edge is equivalent to the halo width. Therefore, we can conclude that the halo width is 9 deg in the left side of the beam core and 11 deg in the right side, respectively.

Tank Level Scan Result

Next the tank level scan results are shown. We performed the scan at the six tank levels: 100 % (design), 95 %, 93 %, 90 %, 89 % and 88 %. Figure 4 shows the result of the transmission. Colors indicate the transmission of each tank level and $\Delta\phi_s$. Black square points show the $\Delta\phi_s$ at 50 % transmission in each tank level, i.e. they indicate the acceptance edges. The acceptance reduces as tank level become low, and reduction ratio is about 4 deg/% in the tank level of higher than 93% and the ratio increases as decline of the tank level. It is readily seen in Fig. 2 that sufficient phase acceptance to cover the beam halo exists even with the tank level of 90 %. Nevertheless, the BLM signal shown in Fig. 3 indicates that we have certain beam loss with any $\Delta\phi_s$ with the tank level. From these observation, we can conclude that the longitudinal halo has started to split out of the acceptance in the energy direction first in shrinking the acceptance by lowering the tank level. As we mentioned above, the shrinkage of the acceptance on the ΔE direction is faster than that of $\Delta\phi_s$ direction. Therefore the loss mainly comes from the beam halo on the ΔE direction.

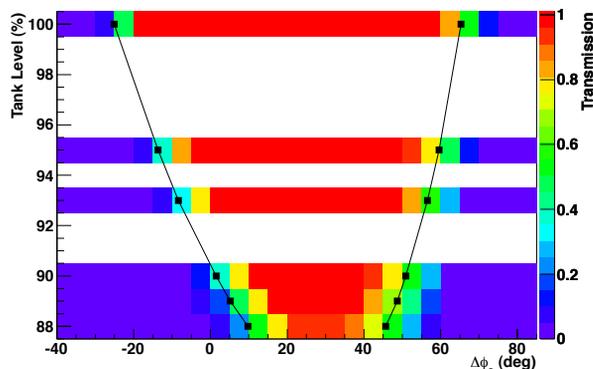


Figure 4: The transmission data of the tank level scan. We measured the transmission at tank level of 100 %, 95 %, 93 %, 90 %, 89 % and 88 %. The black lines with filled square show the acceptance edges in the each tank level.

We should note that the acceptance widths of the measurement and simulation have large discrepancy especially in the low tank level region. Table 1 shows the comparison of the acceptance width of simulation and measurement. Although the ratio of the acceptance is almost constant in the tank level of higher than 95 %, it becomes smaller and smaller in the tank level of lower than 93 %. We are now investigating why this discrepancy was made by simulation.

SUMMARY

As an effort to identify the mechanism for the beam loss observed in the beam transport line after the SDTL exit, we have experimentally investigated the margin between the longitudinal acceptance of SDTL and the actual beam

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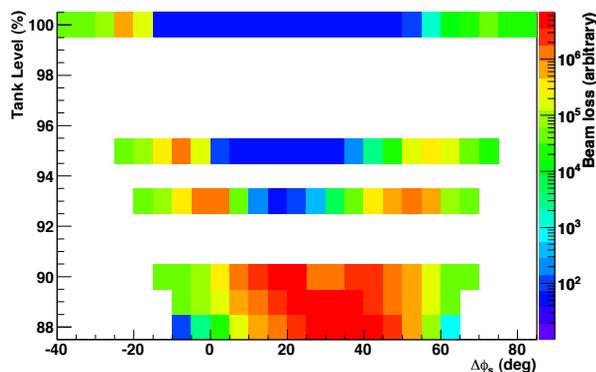


Figure 5: The BLM data of the tank level scan. The beam loss becomes larger as warm colors.

Table 1: The acceptance comparison. In the table "Sim." means the simulation and "Meas." means the measurement, respectively

Tank Level	Acceptance Width (deg)		Ratio W_s/W_m
	Sim. (W_s)	Meas. (W_m)	
100 %	85	90	0.94
95 %	70	74	0.95
93 %	58	65	0.89
90 %	32	50	0.64
89 %	14	55	0.25
88 %	0	36	0

distribution. In the experiment, we have devised and introduced a tank level scan method to find the margin in the energy direction. Combining it with the conventional phase scan method, the longitudinal acceptance of SDTL has been studied with SCT and BLM. The measurement has confirmed that we have sufficient margin both in the phase and energy directions with the nominal tank parameters. It let us to conclude that the measurement can provide us with valuable information on the width of longitudinal halo. Detailed comparison between the observation and particle simulation is now underway to further deepen our understanding on the longitudinal beam characteristics and the validity of the accelerator model.

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