LONGITUDINAL BEAM ACCEPTANCE OF J-PARC DRIFT TUBE LINAC

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Abstract

Since we have no tool to measure the longitudinal beam profile at the J-PARC linac, we have tuned operational parameters for the matching of both longitudinal and transverse directions only from the measurement of the transverse beam profile by wire scanners at matching sections. Therefore it is very useful for us if the beam profile on the longitudinal phase space can be measured. It motivated us to measure the longitudinal acceptance of the DTL. In the measurement, we introduced a "tank level scan" to measure the shrinkage of the acceptance in addition to the conventional phase scan. The measurement scheme and experimental results are presented in this paper.

INTRODUCTION

The J-PARC is comprised of three accelerators: a 181 MeV linac, a 3 GeV rapid cycling synchrotron (RCS) and a 30 GeV main ring (MR). The 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 (Separate-type DTL) [1].

In addition, there is a beam transport section so called MEBT1 between RFQ and DTL. The main role of this section is to realize the transverse and longitudinal beam matching to DTL. For this purpose, eight quadrupole magnets and two bunchers are placed in the section. Their operational parameters are determined as minimizing the transverse emittance at the DTL exit, which is measured by four wire scanners [2]. In other words, now we have tuned the operational parameters only from the results of the transverse profile measurement. Therefore if we can measure the longitudinal profile, it is very helpful for us to conduct the matching. We could modify the tuning scheme as introducing the longitudinal profile measurements to decide the operational parameters. Since the DTL section locates nearby MEBT1, It is very useful if we can observe the longitudinal beam profile by a conventional phase scan of the DTL cavities. It motivated us to measure the longitudinal acceptance at the first cavity of the DTL section.

Blue points in Fig. 1 show the DTL longitudinal acceptance. The acceptance is calculated by IMPACT simulation. Particles launched from the DTL entrance with various phase and energy with respect to the design value, and then see whether each of them reaches to the location about 130 m downstream of the SDTL section. This location is equivalent with the location of the slow current transformer (SCT), which we used in the

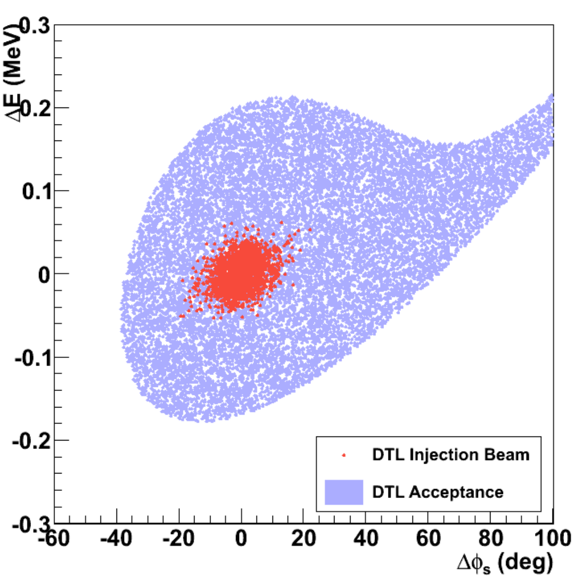

Figure 1: Longitudinal acceptance at the DTL entrance (blue points). Design beam distribution at the DTL entrance (red points) is also shown for comparison.

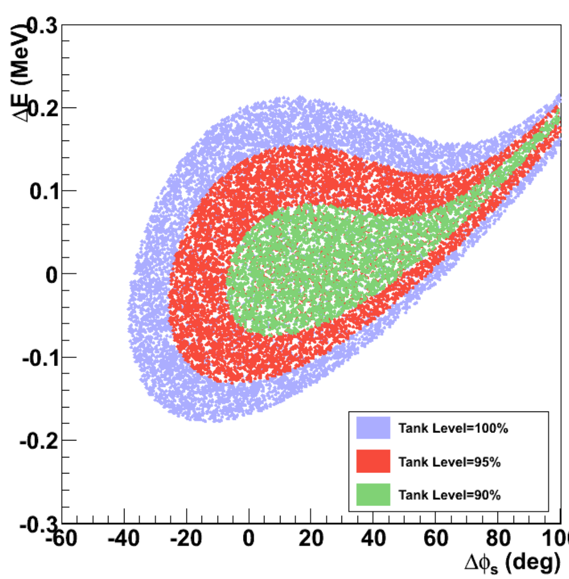

Figure 2: The longitudinal acceptance at the DTL entrance with the tank level of the 1st DTL cavity scaled to 100 % (blue points), 95 % (red points) and 90 % (green points) of the design value, respectively.

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experiment discussed below. In this paper, the DTL acceptance is defined as follows. If a particle reaches to the SCT, we assume that the particle was in the acceptance at the DTL entrance. Therefore, a blue point in Fig. 1 is the longitudinal phase space coordinate at the DTL entrance for a particle which survives until the location of the SCT. The horizontal axis in Fig. 1 is the beam injection phase to DTL with respect to design of -30 deg ($\Delta\phi_s$), and the vertical axis is the beam energy with respect to design energy of 3 MeV (ΔE). The acceptance is distributed for -40 to 60 deg on the $\Delta\phi_s$ axis and -0.18 to 0.2 MeV on ΔE axis, respectively. For the comparison, design beam distribution is also shown as red points. It looks that the acceptance has a sufficient margin to the beam profile. Since the acceptance edge at the negative $\Delta\phi_s$ side is almost vertical to the $\Delta\phi_s$ axis, we could get the beam profile on the $\Delta\phi_s$ direction by slice the beam at the acceptance edge. Therefore we performed the measurement by changing the beam injection phase to the 1st DTL cavity. We call this measurement as “phase scan” in this proceedings.

Figure 2 shows the simulated acceptance with lower tank level for the 1st DTL cavity. In this figure, the tank level is lowered with 5 % step. The simulation indicates the acceptance shrinks on ΔE direction as well as $\Delta\phi_s$

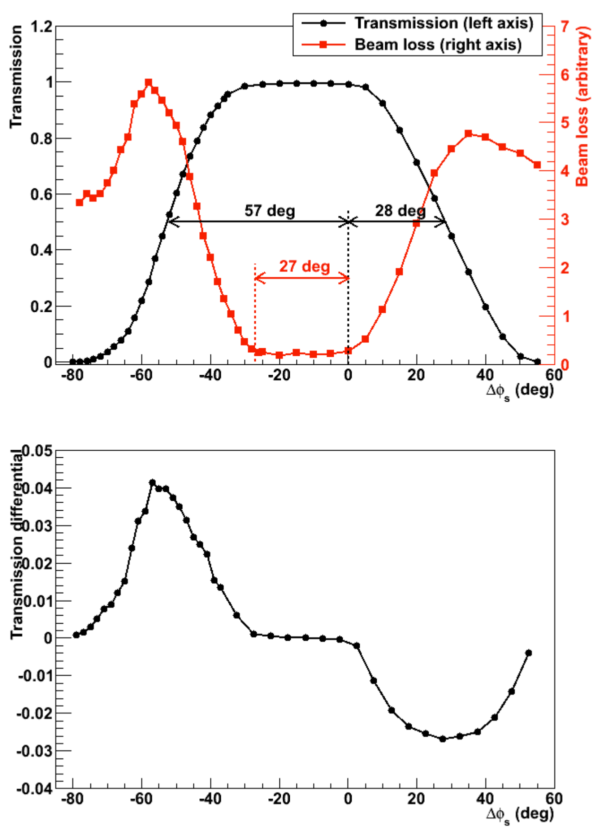

Figure 3: (Top) Experimental result of phase scan. The black line with filled circles is the transmission result (left axis), and red line is the sum of all BLM signals between DTL to SDTL sections. (Bottom) The differential of the transmission of the top figure.

direction as tank level becomes low. Therefore if phase scan with reducing the DTL1 tank level is performed, we could get the information in ΔE direction. We call this measurement as “tank level scan” in this proceedings.

MEASUREMENT

In this section, we show the experimental results. The measurements were performed at the beam current of 15 mA. 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 SCT, which is used to measure the beam current at its location. When a 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 DTL section to the middle of the beam transport line where is about 130 m downstream of the SDTL section.

The other monitor is beam loss monitor (BLM). BLM is supposed to be more sensitive than SCT to a slight beam loss. Therefore it can detect when only the halo reaches the edge of acceptance in a scan. Since the particles out of the acceptance are lost between the middle of DTL to the end of SDTL sections, we summed up all BLM signals in these sections.

Phase Scan Result

For the phase scan, the injection phase to DTL is shifted by changing the driven phase of RFQ and two bunchers in MEBT1 by the same absolute value. Top of Fig. 3 shows the experimental result of the phase scan. We took a data in the range of $\Delta\phi_s$ from -80 deg to 55 deg, where the transmission is not zero. The black line with filled circles is the beam transmission. Assuming the beam core centre is on the acceptance edge when the transmission is decline to 50 %, the acceptance on the $\Delta\phi_s$ axis is -57 deg to 28 deg. This observation has a significant discrepancy from the simulation shown in Fig. 1, where the acceptance is from -40 deg to 60 deg. Therefore the measured width is 15 deg wider than the simulation one and actual centre shifts to negative side by 34.5 deg.

If we assume a sharp edge for the acceptance, the slope of the black curve in the top of Fig. 3 corresponds to the beam density at the phase. Therefore, we can obtain a longitudinal profile projected onto a certain axis in the longitudinal phase plane by differentiating the black curve with respect to the phase. The situation is equivalent to the transverse profile measurement by beam collimation with a one-side movable jaw. The projection axis should be perpendicular to the jaw edge or the acceptance boundary. Then, the shape of the acceptance shown in Fig. 1 indicates that the projection axis for the negative side of the black curve is close to the phase axis. Meanwhile, that for the positive side would be the one with some mixing between the phase and energy.

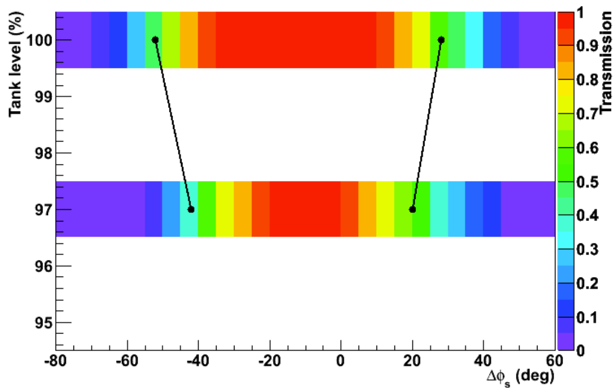

Figure 4: The transmission data of the tank level scan. We measured the transmission at the tank level of 100 % and 97 %. The black lines with filled circle shows the acceptance edge of each tank level.

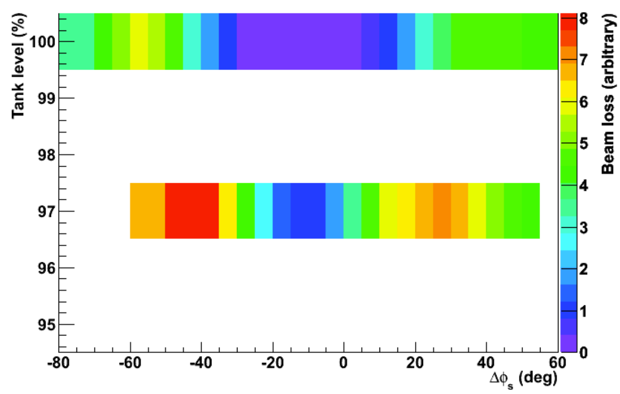

Figure 5: The BLM data of the tank level scan. The beam loss becomes larger as warm colors.

The bottom of Fig. 3 shows the differential curve with respect to the phase. We assume that the peak in the negative side approximately corresponds to the distribution in the phase direction. Then, the peak in the positive side includes the information for the energy profile also. By fitting the peak in the negative side with a Gaussian curve, we have found that the beam has an RMS (Root Mean Squared) phase width of 9.9 deg. We have also found that the beam extends from -80 deg to -30 deg in the phase direction. The peak position is about -55 deg and it is close to the location of the acceptance edge. This result supports the assumption that the beam core centre is on the acceptance edge when the transmission is 50 %.

The BLM result is shown as the red line with filled squares in the top of Fig. 3. The distribution has a flat bottom from -27 deg to 0 deg with the 100 % transmission. It means no beam loss occurs in the flat bottom, but there is no margin of the acceptance in the positive side. 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 30 deg in the left side of the beam core and 28 deg in the right side, thus the beam including halo is distributed in the range of 58 deg on $\Delta\phi_s$ direction.

Tank Level Scan Result

Next the tank level scan results are shown. We performed the scan at the two tank levels: 100 % (design) and 97 %. Figure 4 shows the result of the transmission. Colors indicate the transmission of each tank level and $\Delta\phi_s$. Black circles 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 is decreased, and reduction rate is about 8 deg/% which is twice faster than the simulation. It is really seen in Fig. 4 that the phase acceptance is sufficiently wide to cover the halo with the tank level of 97 %. However, the BLM signal shown in Fig. 5 indicates that we have certain beam loss with any $\Delta\phi_s$ with this tank level. Although the beam loss may come from the shrinkage of the acceptance on the ΔE direction, we need further study to make it clear.

SUMMARY

To obtain the beam characteristics in the longitudinal phase plane at the DTL entrance, we have performed a beam acceptance measurement with phase scan method. In the measurement, we have succeeded in experimentally demonstrating that we can obtain the longitudinal phase distribution in an approximated way. The measured phase profile is wider than expected, and we have also found a significant shift in the phase direction. This discrepancy between the observation and the expectation is open for the future and more detailed comparison between the particle simulation and the experiment.

The phase scan measurement has also provided us with some information for the energy distribution as a beam profile projected onto an axis with some mixing between the phase and the energy. We have also tried to obtain information for the energy distribution in another way by introducing a tank level scan method. Although the attempt is still in a preliminary stage, it has already shown some signs of discrepancy between the particle simulation and the experiment. Actually, the measured acceptance for DTL has been significantly wider with the operating tank level, but it shrinks more rapidly as we decrease the tank level. We believe that it is worthwhile pursuing to deepen our understanding of beam characteristics and to improve the tuning scheme for MEBT1.

REFERENCES

[1] Y. Yamazaki eds., "Technical design report of J-PARC", KEK Report 2002-13, JAERI-Tech 2003-44.

[2] H. Sako et. al., "Transverse Beam Matching and Orbit Corrections at J-PARC Linac", Proceedings of LINAC08, Victoria, BC, Canada.