MEASUREMENT AND SIMULATION IN J-PARC LINAC

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Abstract

In J-PARC linac, significant transverse emittance growth and halo formation are observed with the design peak current of 30 mA. In the previous study, the most probable cause of the beam quality deterioration was identified as the longitudinal mismatch at MEBT with a help of particle simulations. Based on this finding, we have performed a retuning of MEBT buncher amplitudes experimentally, and have succeeded in mitigating the emittance growth and halo development. It demonstrates that a particle simulation is helpful in identifying the mechanism behind the experimentally observed beam quality deterioration in a high-intensity proton linac, and setting the direction for the practical tuning for it.

INTRODUCTION

J-PARC linac 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) [1]. While its design peak current is 30 mA, it started its user operation in December 2008 with the reduced peak current of 5 mA. We have been increasing its beam power since then, and it is currently operating with the peak current of 15 mA [2].

As reported in the previous workshop of this series [3], we experienced a significant emittance growth in DTL followed by halo development in SDTL in a demonstration operation with the design peak current of 30 mA. Distinctive features of this phenomenon are as follows;

- Absence of halo development in DTL in spite of the significant emittance growth in this section
- Absence of emittance growth in SDTL despite the significant halo development in this section

This phenomenon is assumed to be space-charge-driven, because it has not been observed with the lower peak current of 5 mA.

In the previous study [3], we have concluded from an extensive particle simulation that the emittance growth and halo development are likely to be caused by a longitudinal mismatch at MEBT (Medium Energy Beam Transport) between RFQ and DTL. The simulation has shown that a longitudinal mismatch leads to a transverse mismatch oscillation due to space-charge coupling, and then drives a halo development. This mechanism explains why the halo development is delayed until the beam reaches SDTL. However, we could not perform an experiment to retune the longitudinal matching at that time because the peak current was limited to 5 mA due to a sparking problem in RFQ [4]. As RFQ is recovering and the peak current has been increased to 15 mA, we have tried to mitigate the emittance growth and halo development experimentally by retuning the buncher cavities in MEBT. We have observed the qualitatively same beam quality deterioration with the peak current of 15 mA, although the degrees of emittance growth and halo development are naturally more modest than those observed with 30 mA.

In this paper, we present experimental results in the tuning performed base on the findings in a particle simulation described in the reference [3].

ORIGINAL MATCHING AT MEBT

The layout of MEBT is shown in Fig. 1 schematically. We have two buncher cavities in MEBT to perform a longitudinal matching between RFQ and DTL. Originally, the amplitude and phase of bunchers were set with a amplitude-phase scan tuning with monitoring the output beam energy. The beam energy was measured with TOF (Time Of Flight) methods using two downstream FCT's (Fast Current Transformers). An FCT detects the beam phase, and we use two FCT's just after the buncher under tuning for the TOF measurement. The present monitor layout in MEBT is found in the reference [5].

As the buncher cavity has only an RF gap, the resulting phase scan curve is a simple sinusoidal curve. Then, it is easy to find its effective gap voltage and synchronous phase from the measurement. The synchronous phases are set to -90 degree, and the amplitudes are set to the design values determined from Trace3D calculation [6]. In the Trace3D calculation, we assume twiss parameters obtained with PARMTEQM simulation at the exit of RFQ [7].

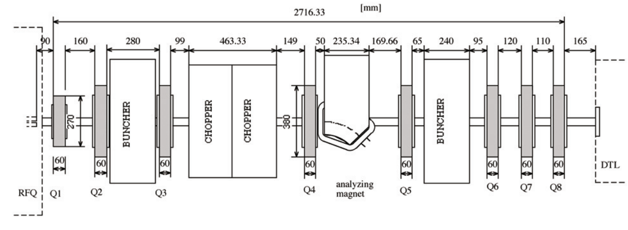

Figure 1: The schematic layout of MEBT.

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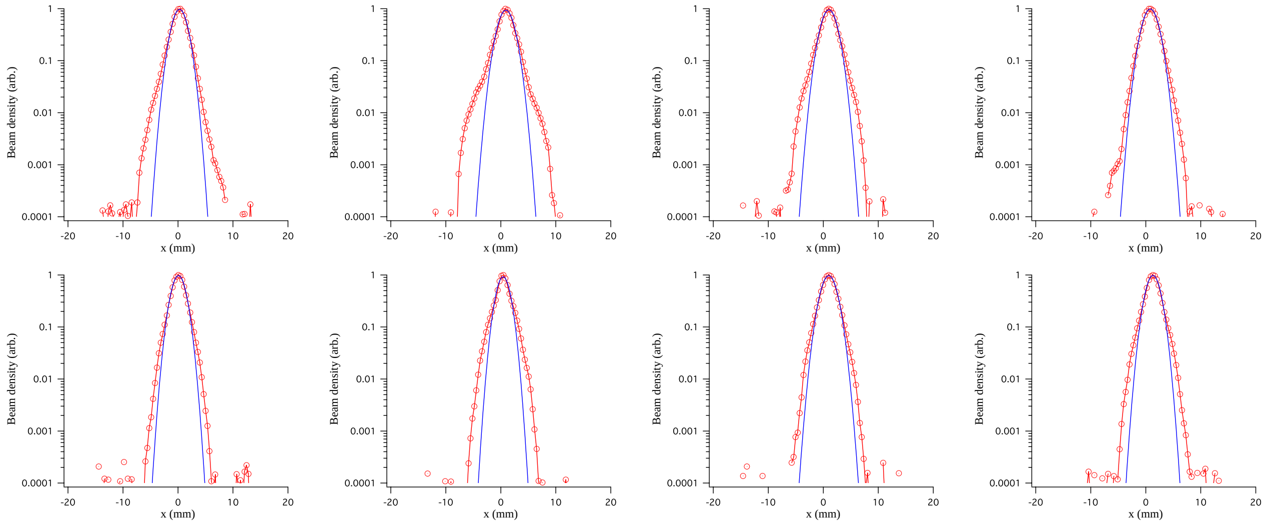

Figure 2: The horizontal beam profile measured at the exit of SDTL before (upper raw) and after (lower raw) the buncher tuning. There are four wire scanner profile monitors periodically placed after SDTL, and each column corresponds to the measurement result obtained with each monitor. Red circle: measurement, blue line: Gaussian fit. The same notation is adopted in Fig. 3.

EMITTANCE GROWTH AND HALO DEVELOPMENT

As reported in reference [3], we observed a significant emittance growth in DTL with the design peak current of 30 mA. The measured emittance at the exit of DTL is 0.42 πmm·mrad in horizontal and 0.36 πmm·mrad in vertical. On the other hand, the measured emittance at the exit of RFQ is around 0.22 πmm·mrad. There is no significant emittance growth after the DTL exit. This tendency has not been seen with the lower peak current of 5 mA. The emittance values shown in this paper are all normalized RMS (Root Mean Squared).

The measured beam profile also shows interesting features as mentioned above. The transverse beam profile is measured with four profile monitors of the wire scanner type at the exit of DTL, and each wire scanner is 7 $\beta\lambda$ apart with β and λ being the particle velocity scaled by the speed of light and the RF wave length. Contrary to our expectations, the measured beam profile at the DTL exit lacks obvious beam halo in spite of the significant emittance growth in DTL. The observed beam profile is virtually Gaussian. As the phase advance between neighboring two wire scanners is about 60 degree in this region, the halo is supposed to be detected by some of these wire scanners if it has been generated.

Meanwhile, the halo-like structure is clearly seen at the SDTL exit where we also have periodically placed four wire scanners. It should be stressed here that the halo is developed in the SDTL section despite the absence of significant emittance growth in this region.

As reported in [3], an extensive simulation study reveals that the onset of halo generation has a certain sensitivity to the kind of mismatch assumed in the simulation. Actually, the onset is delayed in some cases with certain types of longitudinal mismatch. Assuming a certain longitudinal mismatch at the DTL entrance, the measured behavior can be qualitatively reproduced in the simulation.

In the particle simulations, we have adopted IMPACT code [8] with 95,322 macro-particles. We have employed $32 \times 32 \times 64$ meshes for the Poisson solver and the integration step of $\beta\lambda/10$ in the particle simulations. While the adopted parameters are modest, we suppose that they are sufficient to investigate the RMS emittance growth and qualitative characteristics of halo development.

RETUNING OF LONGITUDINAL MATCHING AT MEBT

Based on the finding described in the previous section (and in reference [3] in more detail), we have performed a longitudinal matching at the DTL entrance varying the buncher amplitudes with a trial-and-error method. The tuning has been performed with the peak current of 15 mA, which is the present nominal peak current for the user operation. In the tuning, the amplitudes of two bunchers are changed by 10 to 20 % to minimize the emittance at the exit of DTL. Specifically, the first buncher amplitude is increased by 20 % from the original setting and the second buncher amplitude is decreased by 10 % in the tuning. After the tuning, the horizontal emittance at the DTL exit has been reduced from 0.266 πmm·mrad to 0.232 πmm·mrad. The vertical emittance has also been reduced from 0.231 πmm·mrad to 0.207 πmm·mrad. At the same time, the halo development in the SDTL section has clearly been mitigated as shown in Figs. 2 and 3.

As seen in Figs. 2 and 3, slight halo still exists after the buncher tuning. While we might be able to mitigate it fur-

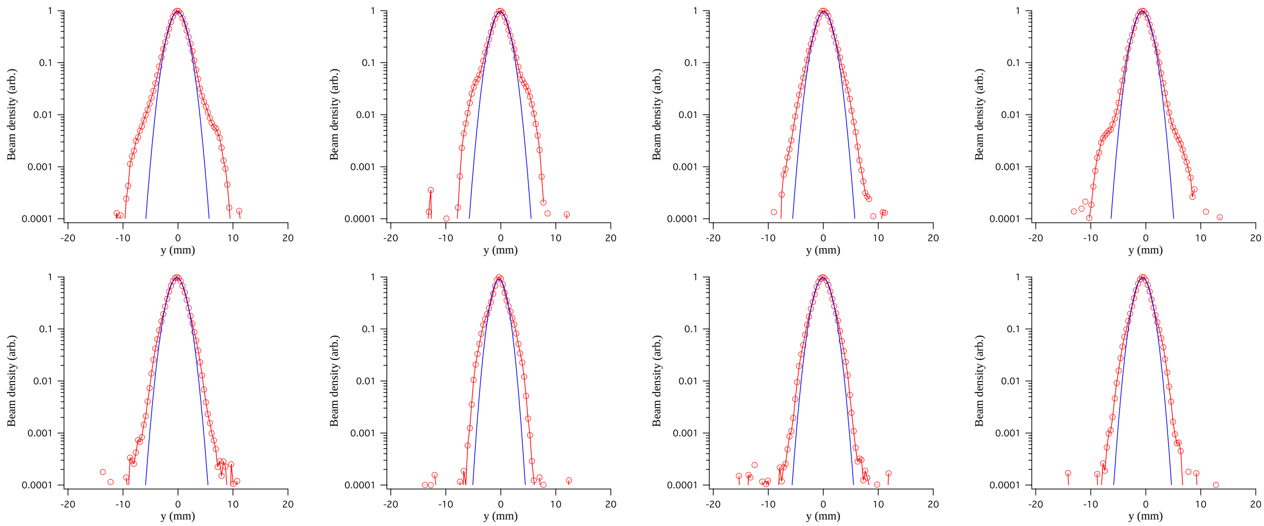

Figure 3: The vertical beam profile measured at the exit of SDTL before (upper raw) and after (lower raw) the buncher tuning.

ther with more detailed buncher tuning, we haven't tried it yet in a through manner. An experiment suggests that it may be caused by transverse mismatch [9], but we need to study further on this in more elaborated way. Then, it may be adequate to conclude at this point that the cause of the residual halo is still open for future studies.

We have also conducted a particle simulation with the peak current of 15 mA to find the effect of the assumed buncher amplitude error on the emittance growth in DTL [9]. The comparison of the emittance growth between simulation and experiment has been discussed in the reference [9] for the cases with and without buncher tuning. Simulations shows smaller emittance growth than the experiment, but the agreement seems reasonable.

It should also be noted that we don't have good understanding on the reason why the original tuning had a significant error for the buncher amplitudes.

SUMMARY

The dominant cause of the emittance growth in DTL and the following halo development in SDTL has been identified to be longitudinal mismatch at the DTL entrance with an extensive particle simulations. Then, both of the emittance growth and the halo development have been successfully mitigated with a trial-and-error tuning of the buncher amplitudes. This experiment indicates that the particle simulations are capable of helping to identify the cause of experimentally observed beam quality deterioration and serving as a practical tool to set the direction of the beam tuning for a high-intensity hadron linac.

This measurement also indicates that there existed a significant error in the original longitudinal matching at the DTL entrance. The original matching was performed in a rather standard way with a phase and amplitude scan method with TOF measurement with two beam phase monitors. In the measurement, the optimum amplitudes of two bunchers are determined with Trace3D calculation assuming the twiss parameters obtained with a PARMTEQM simulation for RFQ. It is important to pursue the reason why we had a significant tuning error in the original tuning for the future improvement of the tuning procedure.

REFERENCES

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

[2] T. Koseki, "High intensity aspects of the J-PARC facility", in these proceedings.

[3] M. Ikegami, H. Sako, T. Morishita, Y. Kondo, "Measurement and simulation in J-PARC linac", ABDW-HB'08, Nashville, August 2008, p. 231 (2008).

[4] K. Hasegawa, "Status of the J-PARC linac" , to be published in Procs. of LINAC'10.

[5] S. Sato et. al.,"Upgrade of beam diagnostics in LEBT and MEBT of J-PARC linac", LINAC'06, Knoxville, August 2006, p. 268.

[6] K. R. Crandall, D. P. Rusthoi, TRACE-3D Documentation, Los Alamos National Laboratory Report LA-UR-97-886, 1997.

[7] Y. Kondo et. al., "Particle distribution at the exit of the J-PARC RFQ", LINAC'04, Lübeck, August 2004, p. 78.

[8] J. Qiang, R. D. Ryne, S. Habib, V. Decyk, J. Comput. Phys., 163 (2000), p. 434.

[9] H. Sako, , "Reduction of transverse emittance growth in J-PARC DTL" , to be published in Procs. of LINAC'10.