

LONGITUDINAL BUNCH SIZE MEASUREMENTS WITH AN RF DEFLECTOR AT J-PARC LINAC

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Abstract

We have measured the longitudinal bunch size of beams from the radio-frequency quadrupole linac (RFQ) at the Japan Proton Accelerator Research Complex (J-PARC). The radio-frequency deflector (RFD) is installed in the medium-energy beam transport section (MEBT1) between the RFQ and the drift-tube linac (DTL). The RFD, which is usually used to produce a macro pulse configuration for the 3-GeV rapid-cycling synchrotron, is utilized to produce a different deflecting angle depending on the bunch arrival phase. Transverse beam profiles were measured after the RFD with and without deflection to extract the longitudinal bunch size. The Courant-Snyder parameters in the longitudinal direction were estimated by measurements for different strength of the upstream buncher. These measurements are one of the important steps to understand the longitudinal beam properties at a high beam current.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) linac consists of the 50-keV negative hydrogen (H^-) ion source (IS), the 3-MeV radio-frequency quadrupole linac (RFQ), the 50-MeV drift-tube linac (DTL), the 191-MeV separated-type DTL (SDTL), and the 400-MeV annular-ring coupled structure (ACS). The medium-energy beam transport section (MEBT1) is installed between the RFQ and the DTL. The radio-frequency deflector (RFD) combined with the scraper system is used to produce a macro pulse configuration for the 3-GeV rapid-cycling synchrotron (RCS).

The J-PARC linac provides beams with the peak current of 40 mA, which will be upgraded to 50 mA for the 1-MW operation at RCS. Further, a higher beam current is being investigated for the second target station project. For operation with such a high beam current, it is important to understand the longitudinal beam properties, especially in MEBT1.

We previously proposed longitudinal measurements by utilizing the RFD as a kind of bunch rotator. This scheme was originally proposed in [1], and some simulation studies were reported in [2]. In addition, a longitudinal halo component in RCS was measured with this scheme [3]. The present paper reports measurements of the longitudinal bunch size after the experimental setup and simulation studies are described.

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SETUP

MEBT1 is a 3-m-long transport line, as shown in Fig. 1. MEBT1 has two main functions. One is the matching of the beam to the DTL. For this purpose, eight quadrupole magnets (Q1 to Q8) and two buncher cavities are used. The other is the production of a macro pulse configuration in accordance with the radio-frequency of the RCS. The RFD and the scraper located 0.72 m downstream from the RFD serve this function; unwanted bunches are horizontally deflected by the RFD and then dumped to the scraper. The RFD consists of two radio-frequency gaps operated in a TE_{11} -like mode. The operation frequency is 324 MHz which is same as those of the RFQ and the DTL. The distance between the gaps corresponds to $3\beta\lambda$, where β is the particle velocity normalized to the speed of light and λ is a radio-frequency wavelength. Because the two radio-frequency gaps are independently operated with a semiconductor amplifier, the synchronous phase and the radio-frequency voltage are tuned separately.

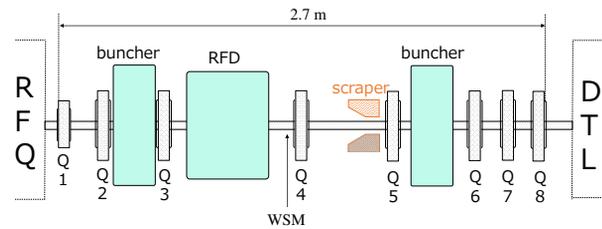


Figure 1: Schematic of MEBT1.

In the nominal operation of the J-PARC linac, the synchronous phase is chosen at the crest of the radio-frequency field in the RFD, as shown in the top figure of Fig. 2. In order to measure the longitudinal bunch size, the synchronous phase is set at the zero-crossing point, as shown in the bottom figure of Fig. 2. Whereas the centroid of the beam is not shifted, the particles are away from the centroid in accordance with the relative phase difference ($\Delta\phi$):

$$\langle (x \pm k(\Delta\phi - \delta))^2 \rangle = \langle x^2 \rangle \pm 2k \langle x \Delta\phi \rangle + k^2 \langle \Delta\phi^2 \rangle + k^2 \delta^2, \quad (1)$$

where x is the horizontal position, k represents the deflecting angle, and δ is the phase offset to the zero-crossing. In Eq. (1), the positive (negative) sign is selected when the deflecting angle is increasing (decreasing). Then, the longitudinal bunch size can be extracted by combining two measurements with the increasing and decreasing timing:

$$\langle \Delta\phi^2 \rangle = [\langle (x + k(\Delta\phi - \delta))^2 \rangle / 2 + \langle (x - k(\Delta\phi - \delta))^2 \rangle / 2 - \langle x^2 \rangle] / k^2 + \delta^2. \quad (2)$$

The horizontal beam profiles are measured by a wire scanner monitor (WSM) [4] located between the RFD and the Q4.

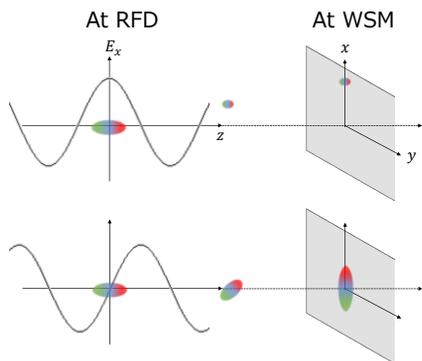


Figure 2: Schematic RFD setting for the nominal operation (top) and longitudinal measurement (bottom).

SIMULATION

We have performed beam dynamics simulations using the three-dimensional particle-in-cell code, IMPACT [5]. In the simulations, particles are launched at the MEBT1 entrance and tracked to the WSM location. The output beam from the RFQ was estimated by PARMTEQM [6] and used as the initial beam distributions in these simulations. The magnetic field for each quadrupole magnet was implemented from the design and measurement. The electromagnetic fields inside the RFD were calculated using ANSYS HFSS [7] and implemented in the simulation.

The simulations for the RFD were verified by beam measurements with the nominal setting. The horizontal beam profiles in the WSM were measured with several RFD voltages as shown in Fig. 3. The peak positions in the profiles are consistent with the simulations. The differences in the profile width between the measurements and the simulations are considered to have resulted from a misunderstanding of beam properties in the transverse direction. The effect of the different transverse beam properties was estimated by the simulations, and it is less than 0.5° .

The accuracy of the longitudinal bunch size measurement was investigated with simulations. Virtual measurements were performed for several peak currents and buncher radio-frequency voltages. The bunch width ($\Delta\phi^2$) was calculated using Eq. (2) and compared to the true value. Figure 4 shows the results. The differences between the calculations and the true values are due to the space charge effects between the RFD and WSM (the space charge effects are not included in Eq. (2)). The difference is less than 0.5° when the peak current is below 40 mA.

RESULT

Longitudinal measurements were conducted for the peak current of 44 mA. The measurements were performed using both the gaps in the RFD. Before the measurements, the phase of the RFD relative to the beam was measured so that the phase offset δ in Eq. (2) vanishes.

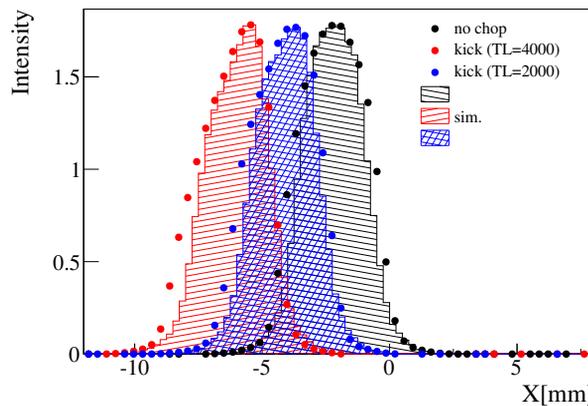


Figure 3: Beam profiles in the horizontal direction. The black, the red, and the blue dots show the measurements by the WSM for several field strengths of the RFD. The black, the red, and the blue histograms show the simulations.

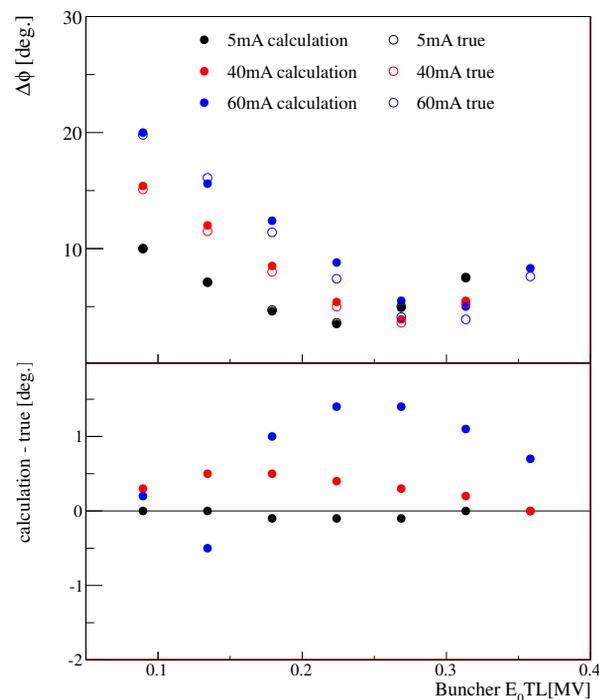


Figure 4: Results of virtual measurements using the simulations. (Top) the calculated longitudinal width, and (bottom) the differences between the calculations and the true values.

Figure 5 shows the longitudinal bunch size calculated for several buncher radio-frequency voltages. The Courant-Snyder parameters of the simulations were fitted with the SIMPLEX algorithm [8]. The simulation results with the fitted beam parameters are shown by the smooth curves in Fig. 5. The fitted longitudinal emittance is $0.13 \text{ deg}\cdot\text{MeV}$, which is consistent with the PARMTEQM simulations within a few ten percent. Systematic uncertainty of the

estimation of the longitudinal emittance and the detailed comparison with the simulation are being investigated.

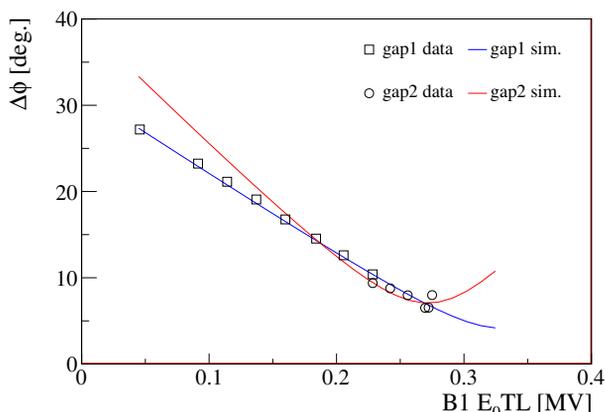


Figure 5: Result of measurement of the longitudinal bunch size using the first gap of the RFD (square) and second gap (circle). The blue and the red lines show the simulations after fitting the measurements for the first gap and the second gap, respectively.

SUMMARY

We have measured the longitudinal properties of beams from the J-PARC RFQ by using the RFD. The simulation

technique using the particle-in-cell code, IMPACT, has been developed for the measurements. There are good agreements between the measurements and the simulations after fitting the Courant-Snyder parameters of the input beam in the simulations. This study is one of important steps to understand the longitudinal beam properties at a high beam current.

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