BEAM DYNAMICS STUDIES ON LOW AND MEDIUM ENERGY BEAM TRANSPORT WITH INTENSE H⁻ IONS FOR J-PARC LINAC

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Abstract

Japan Proton Accelerator Research Complex (J-PARC) linac was intensity-upgraded up to pulse current of 50 mA of H^- beam by replacing the ion source and the Radio Frequency Quadrupole(RFQ). We measured beam properties at the end of low energy beam transport (LEBT) line test stand under several conditions to investigate the transverse halo and space charge effects of an intense H^- ions. The LEBT is composed of two solenoid magnets. Furthermore, space charge neutralization effects in the residual gas were considered into account to describe the behavior of the beam phase space evolution. LEBT transmission efficiency, beam losses were estimated and optimization for beam matching into acceptance of the RFQ is studied. Two-solenoid based LEBT section is connected to the RFQ which is followed by a medium energy beam transport (MEBT) line. In this paper, we discuss the outcomes of beam emittance measurements and the results from beam dynamics simulations throughout LEBT and the RFQ acceleration.

INTRODUCTION

To support the beam commissioning of the J-PARC [1] linac for future operation with 50 mA (50 keV) H^- ion beam current, emittance measurements using tha LEBT line test stand were carried out. For refined beam dynamics simulation initial parameters such as an effective current (defined by space charge neutralization degree), beam distribution from measurement are essential. Low-energy ions normally emerge from the extractor as diverging beams and therefore require refocusing to successfully inject into the acceptance-limited accelerator component, such as an RFQ. The J-PARC linac LEBT line based on two-solenoid system is used to match the beam into RFQ with minimum beam loss and acceptable emittance. In order to understand the beam behavior during the transport beam transmission efficiency associated with solenoids' setting and beam losses due to the transverse halo were investigated. Using the measured beam data, beam tracking simulations through RFQ which is followed by MEBT line are performed.

BEAM EMITTANCE MEASUREMENTS

A cesiated RF-driven multicusp H^- source [2] delivers over 60 mA beam current with a flattop pulse length of 700 μs to LEBT at the test stand. Sketch of the LEBT test stand is shown in Fig. 1. The test stand composed of the H^- ion source, electric and magnetic fields to transport the beam. An orifice divides the LEBT into two consecutive quasi-isolated areas at different pressures which corresponded to 3.8×10^{-4} Pa and 1.8×10^{-5} Pa in these particular experiments.

Due to large amount of H_2 gas load coming from the ion source, chemical composition of the residual gas in LEBT line is mainly H_2 molecules. The pressure 1.8×10^{-5} Pa after the orifice is maintained to protect the RFQ cavities from unwanted charges. The end of LEBT line test stand was equipped with diagnostic chamber containing movable horizontal and vertical emittance monitors and Faraday cups(FC). As shown in Fig. 2 the beam current extracted from the ion source is measured by the FC.

In Fig. 3, time-resolved measurements at linac operation pressure 3.8×10^{-4} Pa and 1.8×10^{-5} Pa are shown in hor-

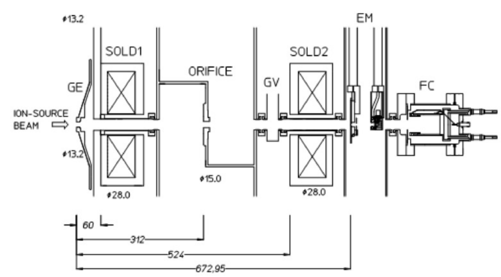

Figure 1: Sketch of the LEBT test stand.

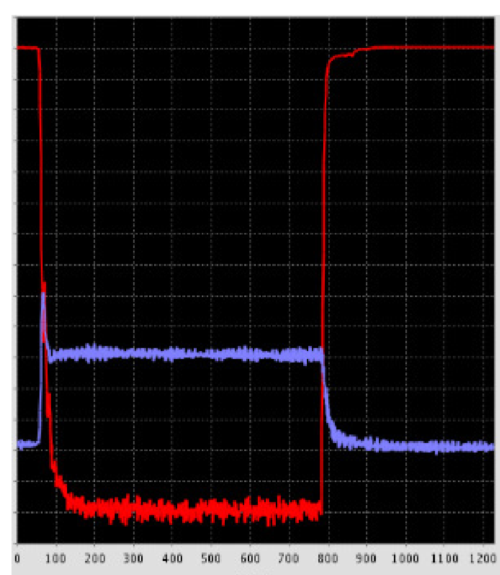

Figure 2: Waveform of the beam current(red curve, 4 mA/div). The time scale of the horizontal axis is 100 μs/div.

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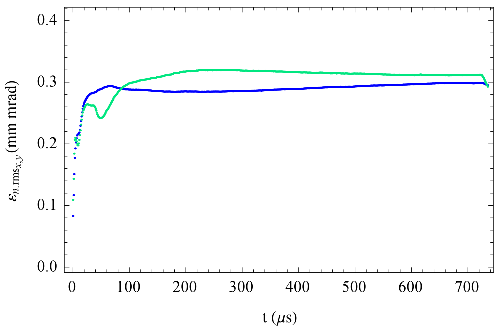

Figure 3: The horizontal(blue) and the vertical(green) normalized $\varepsilon_{n.rms}$ beam emittances as a function of time during the pulse.

izontal (blue) and vertical (green) plane. The flux densities of two solenoid magnets are found to be 0.618 T and 0.638 T for beam focusing. The ion source and LEBT line designed to deliver 60 mA H$^-$ beam with the energy of 50 keV and normalized beam emittance of 0.32 π mm·mrad at the entrance of the RFQ. Despite of transverse tails in measurements $\varepsilon_{n.rms}$ normalized transverse rms emittance values are within the RFQ acceptance. The following beam parameters are measured at the end of LEBT line: $\varepsilon_{n.rms_x}$=0.288 mm·mrad, $\varepsilon_{n.rms_x}$=0.317 mm·mrad, normalized β_x=0.239, α_x=1.93, β_y=0.287, α_y=1.9. The horizontal twiss α parameter as a function of time during the pulse is shown in Fig. 4.

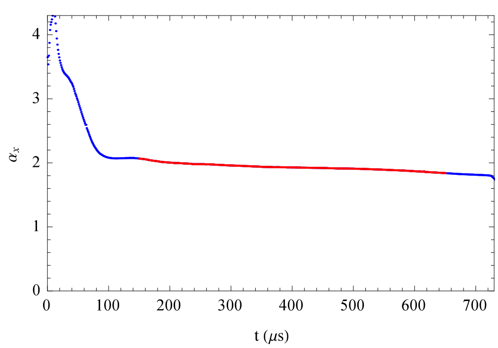

Figure 4: The horizontal twiss α parameter as a function of time during the pulse.

Twiss α is a relevant parameter to describe the beam phase space evolution by time. Characteristic time for charge neutralization is defined as the time which takes to obtain full charge neutralization of the beam. It is required to establish the phase space to a steady state and is inversely proportional to the residual gas pressure. Measurements show that, the variation of beam phase space becomes stable after t >100 μs where the space charge neutralization process gradually reaches to a steady state. Under the conditions as in the J-PARC linac operation, stable part of the beam phase space is highlighted in red color(Fig. 4). In this state beam can be matched into the acceptance of next accelerating structure(RFQ) for the entire pulse duration of 500 μs. If beam phase space is varying by time it complicates the matching of pulsed beams. Twiss parameter in the vertical plane is identical to the horizontal case and therefore the same explanation is true. Stable part of the beam pulse confirmed to be applicable for the beam matching and acceleration.

BEAM MATCHING INTO THE RFQ ACCEPTANCE

J-PARC linac intensity-upgrade up to pulse current of 50 mA of H$^-$ beam was realized by replacing the ion source and the RFQ [3]. Beam tracking and matching into the RFQ acceptance simulations has been carried out using General Particle Tracer (GPT) [4] code. The 3D field maps of solenoid magnets were employed and emittance measurements were used for input beam distributions. Matching the measured transverse beam phase space with 63 mA (50keV) H$^-$ beam current in the LEBT into the RFQ acceptance and particle tracking in the RFQ field results show total 18% beam losses due to transverse beam halo. The RFQ accelerates H$^-$ ions from 50 keV to 3 MeV where MEBT line transports the beam into a 432 MHz drift-tube-linac(DTL). Beam parameters at the RFQ exit can be used as the initial parameters for MEBT lattice.

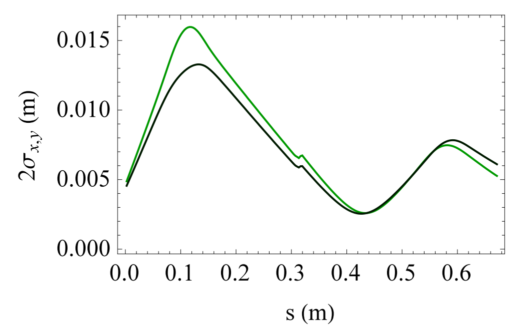

Figure 5: Beam tracking simulation results in the LEBT line leading to the RFQ. The total length of the LEBT is 629 mm. The horizontal(black) and the vertical(green) $2\sigma_{x,y}$ beam envelopes.

TRANSVERSE BEAM HALO

The influence of the solenoid focusing on the ion beam emittance were investigated while keeping the beam transmittance in LEBT constant. The goal is to find magnetic field values applied by the two solenoids of the LEBT. Beam transmittance in the LEBT depends on the setting of solenoid magnets. To improve the transverse halo, beam emittance measurements has been made as a function of time for different magnetic flux densities of the solenoids. The distance between two solenoids is 259 mm. Some of the data which were obtained from the experiments are compared in Fig. 6.

Beam ε_{rms} emittance in the horizontal and the vertical degrees of freedom are calculated from measurements. Phase space ellipses are shown as dashed lines and their values are equal to 4×ε_{rms} containing 86% of the total number

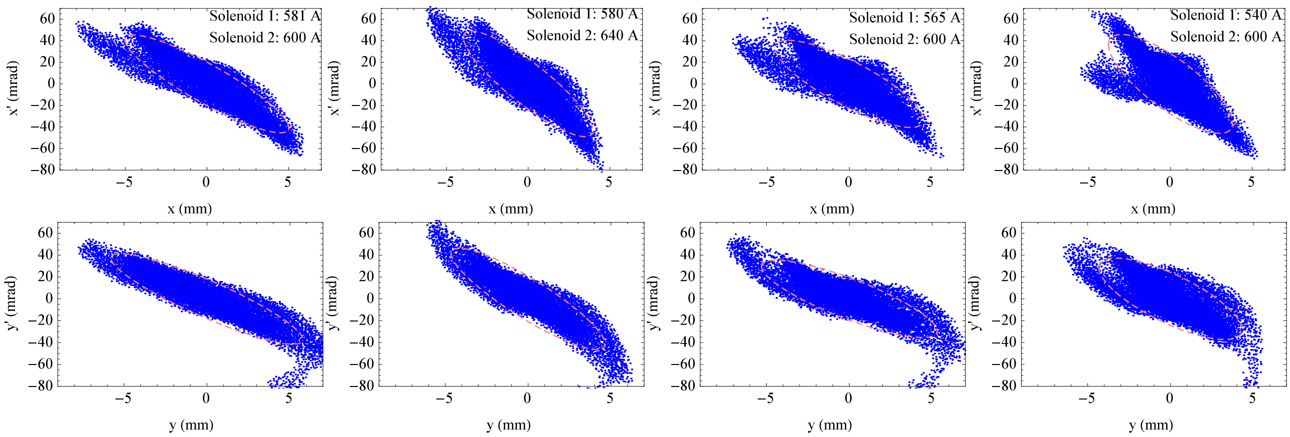

Figure 6: Phase space measurements (horizontal and vertical) for different magnetic flux densities of the solenoids. To investigate the solenoid magnet settings, the beam current transmission in the LEBT was kept constant. However, at the setting of (540 A, 600 A) transmission was dropped for 17%.

of particles. The results show the dense beam core having the same orientation and transverse halo to be created at the ion source extraction.

CONCLUSION AND OUTLOOK

Beam dynamics studies of the H^- ions at J-PARC LEBT line test stand using the time-resolved slit-grid emittance monitors has been performed. It is confirmed that, when charge neutralization process reaches to steady state the beam phase space and emittance remain constant for all measurements. Outcome of this study will bring clarity to MEBT. Once beam parameters are accurate MEBT lattice can be re-constructed for 50 mA DTL matching.

REFERENCES

[1] J-PARC website:`http://j-parc.jp/index-e.html`

[2] H. Oguri et. al., Rev. Sci. Instrum. **87**, 02B138 (2016).

[3] Y. Kondo et. al., Phys. Rev. ST Accel. and Beams **15**, 080101 (2012).

[4] General Particle Tracer, Pulsar Physics, `http://www.pulsar.nl/gpt/`.

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