BEAM COMMISSIONING OF THE J-PARC LINAC MEDIUM ENERGY BEAM TRANSPORT AT KEK

M. Ikegami, T. Kato, Z. Igarashi, S. Yamaguchi, A. Ueno, K. Ikegami, M. Okada
C. Kubota, K. Yoshino, K. Nigorikawa, E. Kadokura, M. Kawamura, Y. Fukui
N. Kamikubota, F. Naito, H. Tanaka, S. Noguchi, S. Fukuda, E. Takasaki,
J. Chiba, S. Anami, S. Arai, H. Kobayashi, KEK, Tsukuba, Ibaraki, Japan
Y. Kondo, T. Kobayashi, T. Ito, K. Hasegawa, H. Yoshikawa,
J. Kishiro, Y. Yamazaki, JAERI, Tokai, Ibaraki, Japan
S. Wang, S. Fu, IHEP, Beijing, China
R. Ryne, J. Qiang, LBNL, Berkley, CA, USA

Abstract

The construction of the initial part of the J-PARC linac has been started at KEK for beam tests before moving to the JAERI Tokai campus, where J-PARC facility is finally to be constructed. The RFQ and MEBT (Medium Energy Beam Transport) has already been installed at KEK, and the beam test has been performed successfully. In this paper, the experimental results of the beam tests are presented together with simulation results with a 3D PIC (Particle-In-Cell) code.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) accelerator consists of a 400-MeV linac, a 3-GeV RCS (Rapid Cycling Synchrotron), and a 50-GeV synchrotron [1, 2]. The linac is comprised of a 50-keV negative hydrogen ion source, a 3-MeV RFQ, a 50-MeV DTL, a 190-MeV SDTL (Separate-type DTL), and a 400-MeV ACS (Annular Coupled Structure linac). The construction of the initial part of the J-PARC linac has been started at KEK to develop and establish the linac system before moving to the JAERI Tokai campus, where the J-PARC facility is finally to be constructed. The 324-MHz RFQ and the MEBT (Medium Energy Beam Transport) has already been installed at KEK, and the beam test has been performed successfully from April to July 2002, and January to February 2003. Between these two series of experiments, slight modification of the LEBT (Low Energy Beam Transport) was performed to install a pre-chopper cavity. These beam tests aim to verify the performance of key components of the MEBT. The MEBT has two main roles, namely, to perform transverse and longitudinal matching to the succeeding 324-MHz DTL, and to chop beams with the same frequency with the RCS injection cycle in order to minimize the beam loss at the injection. The schematic layout of the MEBT is shown in Fig.1(a). The MEBT includes eight quadrupole magnets (Q1 to Q8) for transverse matching, two 324-MHz buncher cavities for longitudinal matching, two rf deflection cavities (RFD's) and a scraper for beam chopping, and various beam diagnostic instrumentation for beam diagnosis. We also have five two-plane steering magnets for beam steering. Although various developments have been performed in the experiments, we focus on the emittance measurement results and its comparison with particle simulations in this paper. As for the rf chopper performance which is another key issue on the beam test, we present experimental results in a separate paper [3].

EXPERIMENTAL SETUP

In the beam test, a TBD (Temporal Beam Diagnostic system) is placed at the exit of the MEBT, which will be removed when installing the DTL. The TBD includes a transverse emittance monitor and a Faraday cup. The emittance monitor is double-slit type, and its first slit is located 534 mm downstream from the exit of the MEBT. The slit width and slit interval of the emittance monitor are 0.1 mm and 205 mm, respectively.

In the actual operation, the beam should be strongly focused at the exit of the MEBT to satisfy the matching condition to the DTL. However, the strengths of the last two quadrupoles are weakened in the experiment to enable the emittance measurement at the downstream beam diagnostic system. Figure 1 (b) shows a beam profile for a typical quadrupole setting which satisfies the matching condition to the DTL, and Fig.1 (c) shows a typical beam profile for the experiment, in which only the last two quadrupoles are weakened. In Fig.1 (c), the downstream end of the plot corresponds to the first slit position of the emittance monitor in the TBD. The quadrupole and buncher setting in Fig.1 (c) corresponds to those in Measurement I in the next section.

The transmission ratio through the MEBT is measured with three CT's (Current Transformers), which are located after Q1 (CT1), at the exit of the RFD cavities (CT2), and after Q7 (CT3). We also have three FCT's (Fast Current Transformers), eight BPM's (Beam Position Monitors), and four WS's (Wire Scanners) for beam tuning. Each WS has horizontal, vertical and oblique (45 deg) carbon wires with the diameter of 7μm. As for the detailed layout and specifications for beam monitors, refer to the reference [2].

We use a LaB_6 filament for the ion source in the experiments. The peak current reaches 33 mA at the exit of the

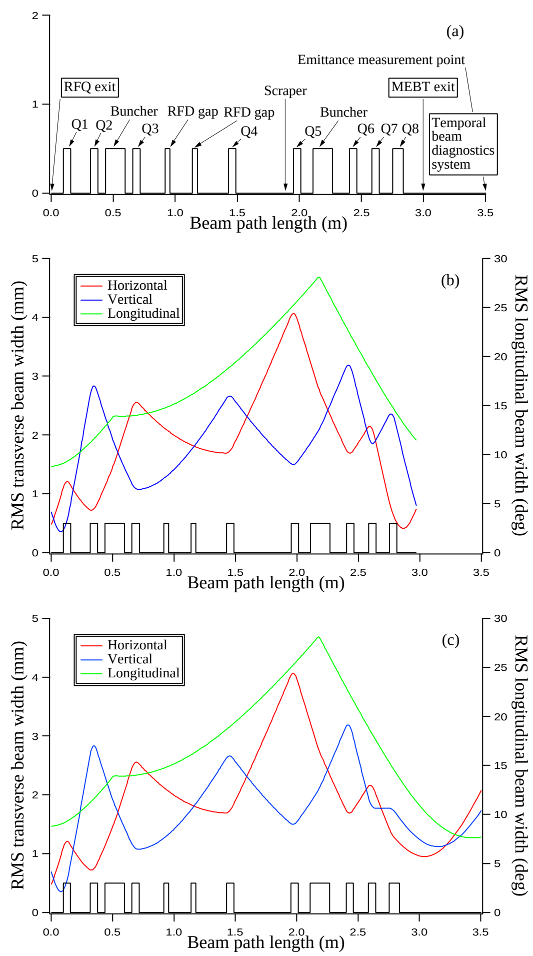

Figure 1: MEBT layout and typical beam profile along the MEBT. (a) Schematic layout of the MEBT. (b) Beam profile along the MEBT for a matched case. (c) A typical beam profile along the MEBT in the experiment.

ion source, and 29 mA at the exit of the RFQ without using cesium seed, which nearly satisfies the design output beam current for the RFQ of 30 mA. We also use a lower beam current of 5 mA for specific beam studies. The duty factor has also been changed from 0.025 % to 0.25 % depending on the purpose of the experiment. We have changed the repetition rate from 5 Hz to 25 Hz, and the pulse width form 50 μsec to 100 μsec. The design duty factor for the first phase of the project is 1.25 % with the repetition rate of 25 Hz and the pulse width of 500 μsec. In the emittance measurement we describe in the next section, we usually use the repetition rate of 12.5 Hz or 25 Hz in order to shorten the measurement time, which is typically about 15 min for one plane.

EXPERIMENTAL RESULTS

The measured normalized rms emittances are summarized in Table 1. Measurement I and II in Table 1 show the emittance at the exit of the MEBT measured with the TBD. Measurement I was obtained in the beam test of January to February 2003, and measurement II was obtained in that of April to July 2002. Measurement III shows the emittance at the exit of the RFQ, which was measured setting up the same TBD after the RFQ before installing the MEBT. As the development of the ion source has been underway in parallel with the beam test, the maximum available beam current was limited to 10 mA when Measurement III was performed. The peak current listed in Table 1 is measured with CT1. Although a certain amount of emittance growth has been observed in increasing the beam current, the obtained normalized rms emittance, which is 0.21 to 0.25 πmm·mrad, is tolerable according to LINSAC end-to-end simulations[2]. LINSAC is a 3D particle-particle code developed at KEK[4].

Table 1: Measured normalized rms emittance

Measurement	**I**	**II**	**III**
Location	MEBT	MEBT	RFQ
Peak curr. (mA)	28.7	24.6	10.0
Hor. (πmm·mrad)	0.252	0.227	0.173
Ver. (πmm·mrad)	0.214	0.220	0.194

Table 2 shows the measured peak current in Measurement I and II. The transmission ratio, which is defined as the ratio of CT3's readout to CT1's, reaches 99.3 % in Measurement I without using steering magnets. In Measurement II, the transmission ratio is limited to 96.3 % while we use the first steering magnet, which is built in Q1, to improve the transmission ratio. Table 2 indicates that slight modification of the LEBT have some effect on the transmission ratio through the MEBT.

Table 2: Transmission ratio of the MEBT

Measurement	**CT1**	**CT2**	**CT3**
I	28.7 mA	28.5 mA	28.5 mA
II	24.6 mA	23.9 mA	23.7 mA

Figure 2 shows the phase-space distribution obtained in Measurement I. In Fig.2, x and y denote the horizontal and the vertical positions, and s is the path length of the design particle. Measured phase-space density is represented by 100k dots (particles) in Fig.2.

Because the emittance monitor in the TBD will be removed when installing the DTL, WS's play an important role in actual beam tuning. Figure 3 shows a typical beam profile measured with WS3, which is located 81 mm upstream from Q4. In the measurement, quadrupole setting is the same with Measurement I, while the bunchers are turned off. The pulse width is shortened to 50μsec to reduce the heat load of the carbon wire. The measurement was done with the repetition rate of 5 Hz.

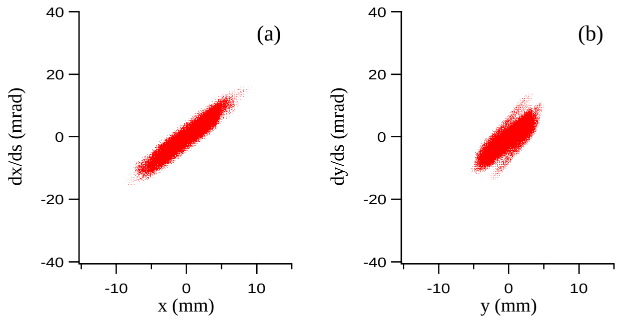

Figure 2: Phase-space distribution measured with the emittance monitor in Measurement I. (a) Horizontal phase-plane. (b) Vertical phase-plane.

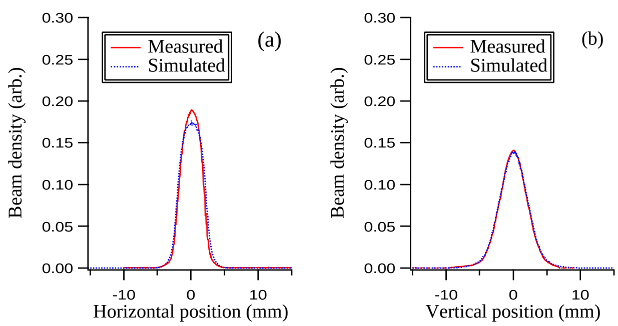

Figure 3: Beam profile measured with WS3 located before Q4. The quadrupole setting is the same with Measurement I, while the bunchers are turned off. (a) Horizontal beam profile. (b) Vertical beam profile. The beam profile obtained in an IMPACT simulation is also shown.

COMPARISON WITH SIMULATION

As a preliminary test on the agreement between experiments and simulations, we have performed 3D PIC (Particle-In-Cell) simulations with IMPACT[5] assuming a 6D Gaussian distribution at the exit of the RFQ. In the simulations, we assume transverse Twiss parameters at the exit of the RFQ which was obtained with Measurement III, and the initial transverse emittances are adjusted to reproduce measured ones at the TBD after the MEBT. We also assume initial longitudinal parameters obtained with PARMTEQm[6] simulations for the RFQ. Figure 4 shows obtained phase-space distribution at the emittance monitor after the TBD, in which we consider the same lattice setting and beam conditions with Measurement I. In the simulation, 1M simulation particles and $64 \times 64 \times 64$ meshes are employed, and the integration step width is set to $\beta\lambda/10$. The assumed initial normalized rms emittances are 0.234 πmm·mrad, 0.193 πmm·mrad, and 0.0822 πMeV·deg in the horizontal, vertical, and longitudinal directions, respectively. In Fig.4, 100k particles out of 1M particles are displayed. Comparing Fig.4 with Fig.2, it is seen that the qualitative agreement between the simulation and the experiment is reasonable, while the shape of the tail portion

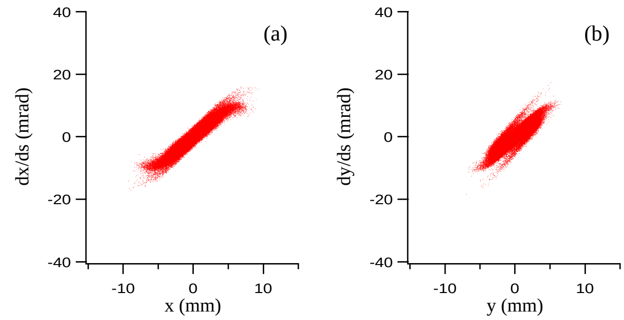

Figure 4: Phase-space distribution at the emittance monitor obtained with an IMPACT simulation for Measurement I. (a) Horizontal phase-plane. (b) Vertical phase-plane.

is slightly different. In Fig.3, we show the beam profile obtained in a similar IMPACT simulation. While the simulated rms beam width is slightly wider in the horizontal direction, the agreement in the vertical direction is excellent. These agreements indicate that the tail portion is already developed to some extent at the exit of the RFQ. Efforts to obtain more realistic initial distribution at the exit of the RFQ is now underway, with which the agreement between experiments and simulations is expected to be improved.

SUMMARY

The beam tests of the RFQ and the MEBT for the J-PARC have been successfully performed at KEK. The peak current of 29 mA is achieved at the exit of the RFQ without using cesium seed. The measured normalized rms emittances are 0.252 πmm·mrad and 0.214 πmm·mrad in the horizontal and the vertical directions, which is tolerable according to LINSAC end-to-end simulations. Preliminary simulation studies are performed with a 3D PIC code, IMPACT, and the agreement between experimental and simulation results is found reasonable.

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