DESIGN OF THE MEDIUM ENERGY BEAM TRANSPORT FROM HIGH-VOLTAGE TERMINAL

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Abstract

The RI beam factory at RIKEN Nishina Center needs high intensity of uranium ion beams. We have used so far the RFQ pre-injector upstream of the linac system, in which the extraction voltage of the ECR ion source is as low as 5.7 kV for the uranium beam. However, for much higher intensity beams from a newly developed superconducting ECR ion source, such a low voltage was expected to significantly increase their emittance due to the space charge effect. To reduce this effect, we prepared a new pre-injector line of 127 kV for uranium beams by placing the ion source on a high-voltage terminal. In this paper we present the design of the 127 kV medium energy beam transport, MEBT, and show the measured results through the line.

INTRODUCTION

As a part of RI beam factory (RIBF) project at RIKEN Nishina Center [1], we prepared a new pre-injector line, medium energy beam transport (MEBT) line, of 127 kV for uranium U^{35+} beams to produce intense uranium ion beams. A newly developed superconducting ECR ion source (ECRIS) [2, 3], which was originally developed for RIKEN's future injector, RILAC2, was set on a high-voltage Cockcroft terminal. The MEBT line is from the terminal to the entrance of the RIKEN linac (RILAC) (Fig. 1). This is only for temporary operation during from 2009 to 2010, and will be dissolved for RILAC2 construction. Some MEBT elements will be reused in the low energy beam transport of RILAC2. [4].

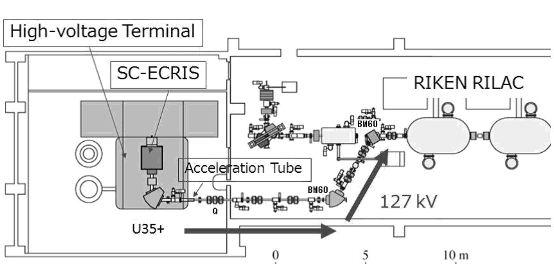

Figure 1: The MEBT line. The transverse lens elements between the acceleration tube and the RILAC entrance are two 60-degree bending magnets and thirteen quadrupoles.

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The U^{35+} beams were extracted from the ECRIS, which had 15 kV to 17 kV higher voltage than the Cockcroft terminal. Through an acceleration tube, the beams were transported from the terminal to the MEBT line. The voltage of the Cockcroft terminal was operated to make the beam energy in the MEBT line 127 kV. After passing the 13.6 m MEBT line, the 127 kV U^{35+} beams were directly injected into the RILAC at RIKEN without using a RFQ.

MEBT DESIGN

The MEBT optics elements are in following order: the acceleration tube, triplet quadrupoles (TQ), doublet quadrupoles (DQ), buncher, DQ, 60 degree bending dipole (BM), 2 DQs, -60 degree BM and DQ. The MEBT line was determined through the acceleration tube and its downstream simulation. We had to design the MEBT before testing the newly developed ECRIS. Therefore we needed to assume the beam properties in the low energy beam transport (LEBT) [5] on the Cockcroft terminal. We assumed that the U^{35+} beam had upright emittance of 150 pi mmm-rad and round beam of 10 mm to 20 mm diameter at the LEBT slit position 0.5 m upstream from the acceleration tube entrance. The beam situation deeply depends on the level of space charge compensation. The MEBT design was required to accept as many different beam conditions from the LEBT as possible.

The acceleration tube was originally designed for 100 kV acceleration, but it is durable to 120 kV acceleration. Actually, it was operated under 110 kV to 112 kV in 2009. To model the acceleration tube, we used KOBRA simulation code [6]. The diameter of the acceleration tube was chosen to avoid aberration, and was 100 mm. The longitudinal distance between 100 kV electrode and ground electrode is 260 mm. Through the simulation, we choose the acceleration tube geometry, where the beam emittance was to be properly reduced during acceleration along with the ion speed ratio (Figs. 2, 3). Around the acceleration tube we modeled that the U^{35+} beam had full space charge effect of 200 eμA.

TRANSPORT code [7] was used to design the MEBT from the acceleration tube exit to RILAC entrance. We set the similar emittance figures of the H-H' diagrams of above KOBRA simulation results at the accelerator tube exit as the initial conditions of the TRANSPORT simulation. The initial conditions corresponded round beams of 10 mm, 12 mm, 15mm, and 20 mm diameter at slit position in the LEBT, but had a common emittance size of 65.6

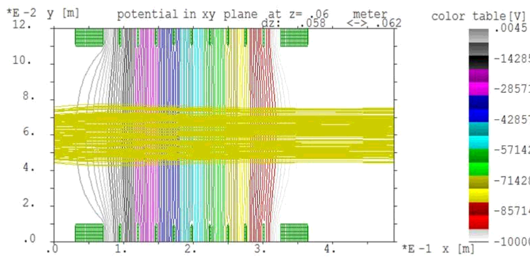

Figure 2: Potential distribution in the 100 kV acceleration tube.

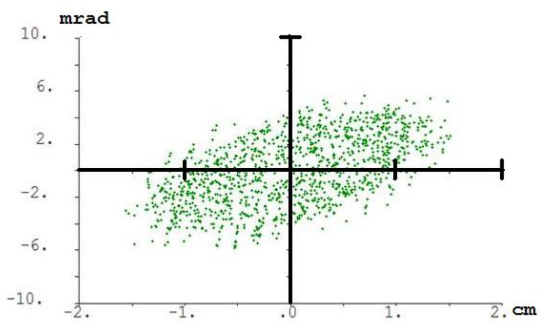

Figure 3: The h-h' diagrams of U^{35+} at the acceleration tube exit. Emittance at the accelerate tube entrance is 150 pi mmmrad.

pi mmmrad downstream of the acceleration tube (Table 1).

Table 1: MEBT assumed initial conditions at accelerator tube exit for diffrent beam diameter at LEBT slit.

At LEBT slit	At exit of the acceleration tube		
diameter	x_{max}	x'_{max}	r_{12}
	Emittance = 65.6 pi mmmrad		
10 mm	14.9 mm	5.27 mrad	0.553
12 mm	13.0 mm	5.46 mrad	0.384
15 mm	10.9 mm	6.06 mrad	0.0859
20 mm	9.13 mm	7.55 mrad	-0.304

The matching conditions at the connection flange surface of RILAC entrance were based on our old E014 data at RIKEN [8]: x_{max} = 7.13mm, x'_{max} = 14.2 mrad, r_{12} = -0.761, y_{max} = 12.5mm, y'_{max} = 5.30 mrad, r_{34} = -0.134, $\epsilon_x = \epsilon_y$ = 65.6 pi mmmrad.

The MEBT line was to have achromatic, beam diameter below 30 mm at buncher and also below 50 mm in the whole line, and durable to possible miss-alignment of quadrupoles or possible adjustment causing non-achromatic. From the TRANSPORT simulations, we needed to have Δp/p $\leq$ 0.03% at the acceleration tube exit. This restriction came from the longitudinal acceptance of the RILAC, and it determined the LEBT requirements. The MEBT was aligned to satisfy these conditions, variety of initial conditions, and space charge effect from 0 to 500 eμA (Figs. 4, 5).

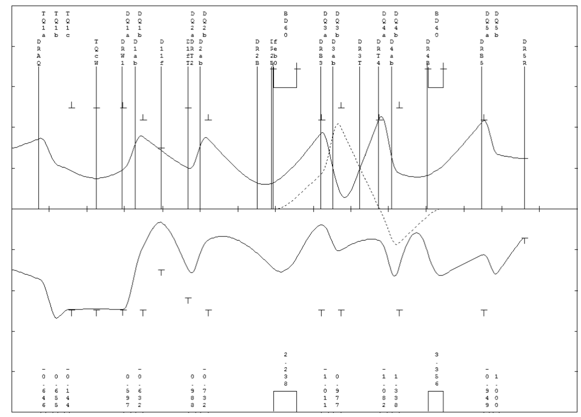

Figure 4: The MEBT beam profiles of 127 kV U^{35+} beams having 0 current space charge. Upper line is vertical profile, lowerd line is horizontal profile, and dashed line is R16. Transverse profile has cm unit, longitudinal unit is m, and R16 unit is cm/percent.

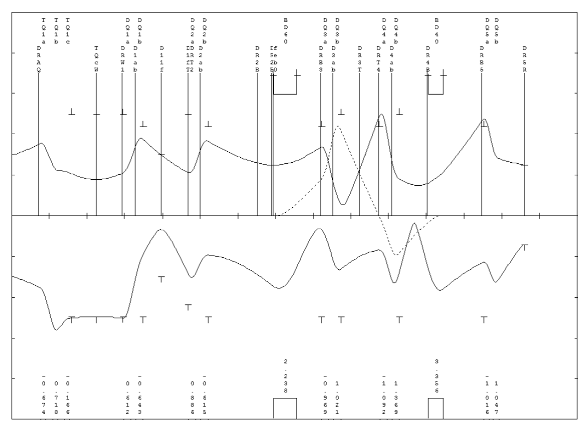

Figure 5: The MEBT beam profiles of 127 kV U^{35+} beams having 500 eμA space charge. Upper line is vertical profile, lowerd line is horizontal profile, and dashed line is R16. Transverse profile has cm unit, longitudinal unit is m, and R16 unit is cm/percent.

MEASUREMENT

Based on this design, the MEBT line was arranged, and it was ready in July 2009 [9]. The commissioning of the MEBT was performed from July to September 2009. $^{136}Xe^{20+}$ beams were used during the commissioning, which has the same mass over charge ratio as $^{238}U^{35+}$ beams. The operation of the MEBT with $^{238}U^{35+}$ beams was performed from November to December 2009. The measured currents in these operations are in Table 2. FC means a Faraday cup. FC_{H0} is downstream of the analyzing bending magnet in the LEBT, FC_{e014} is at the end of the MEBT, and FC_{e11} is downstream of the analyzing bending magnet right after the RILAC. The MEBT magnets were optimized not to maximize the FC_{e014} current but to improve the RILAC transmission.

Table 2: The measured currents at LEBT, MEBT and RILAC.

Date	Beam	FC_{H0}	FC_{e014}	FC_{e11}
2009/9/11	$^{136}Xe^{20+}$	24 eμA	17 eμA	8.4 eμA
2009/11/13	$^{238}U^{35+}$	10.3 eμA	8.0 eμA	N/A
2009/11/16	$^{238}U^{35+}$	10.0 eμA	6.2 eμA	2.7 eμA

For $^{238}U^{35+}$, the emittance that included the current over 1/3 of the peak current in MEBT might be $\epsilon_x \cong \epsilon_y \cong 30 \sim 40$ mm·mrad at 127 kV, which was estimated from the data of a profile monitor with tuning a quadrupole.

CONCLUSIONS

As a part of RIBF, the MEBT line was designed, constructed, and operated. It has shown the designed capability of beam transport. Through the line, intense uranium beam was transported from the new ECRIS, and the ECRIS was tested. This line is going to be dissolved this summer to prepare RILAC2 construction.

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