Beam Dynamics Design in the Low Energy Beam Transport of the Heavy Ion Linac

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Introduction

A conceptual design for a heavy ion linear accelerator is in progress. The first accelerator in the linac is a normal conducting RFQ(radio frequency quadrupole). Three charge states of the uranium beam will be accelerated in the RFQ from 10 keV/u to 300 keV/u [1]. The heavy ion beams extracted from an ion source are delivered to the RFQ through an LEBT(low energy beam transport) system. The LEBT have two main functions. One is the beam selection in order to select and deliver beams with three charge states only. The other is matching the beams into RFQ. This work is related to the beam dynamics design of the LEBT especially for uranium beams .

2. Beam Dynamics in the LEBT

The LEBT consists of three parts as shown in Fig. 1. The first is the matching section of the heavy ion beams extracted from an ion source to the beam selection system. It consists of four electrostatic quadrupoles. The second part is the beam selection system which includes two 90° degree bending magnets and two electrostatic triplets. The aperture for beam selection is located at the center between two bending magnets. The third part is for matching beams into RFQ. This part also consists of four electrostatic quadrupoles.

The beam energy depends on the charge state of the uranium beam when it is extracted from ion source. Because the simultaneous accelerator of three charge states is considered in the RFQ, we studied the beam transmission with the charge states of +32, +33, and +34 where the design state is +33. The kinetic energy and the beam emnittance for +33 state are 10 keV/u and 0.1 π mm-mrad in the normalized rms unit.

We note that the kinetic energy is proportional to the charge state and the momentum in low energy is proportional to the square root of the kinetic energy. Because the magnetic rigidity is given by the momentum divided by charge, it is inversely proportional to square root of charge. This dependence can be used to select the specific charge states in the beam selecting section.

Because the focal length in an electrostatic quadrupole magnet is proportional to the kinetic energy over charge in low energy limit, it becomes independent of the charge states. That is why we use the electrostatic quadrupoles in two matching sections and triplets.

2.1 Beam Selecting Section

First of all, we studied the achromatic condition in the beam selecting section. The achromatic section should reduce the emittance growth and the beams with different charge states are combined into a single phase space ellipse after the second bending. Because this section is symmetric, the achromatic condition can be obtained by $D'=0$ at the center of this section where D is the dispersion function and prime describes d/dz.

The next step is finding the beam condition that the horizontal beam size becomes as small as possible at the aperture for beam selection. We used asymmetric input beams in the entrance region of the first bending magnets in order to achieve this purposes.

The result is given in Fig. 2. It was calculated by TRANSPORT code [2]. In this simulation we assumed that aperture radius of the quadrupoles is 70 mm. The resulting vane-tip voltage is 5.51 kV. It corresponds to the magnetic field gradient of 1.62 T/m if we used the electromagnetic quadrupole.

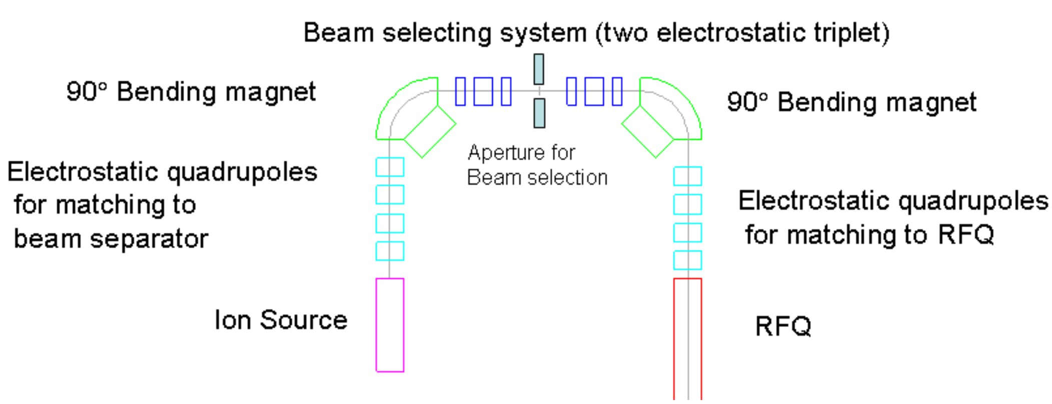


Fig. 1. Layout of the heavy ion LEBT: It consists of two matching sections and a beam selecting system.

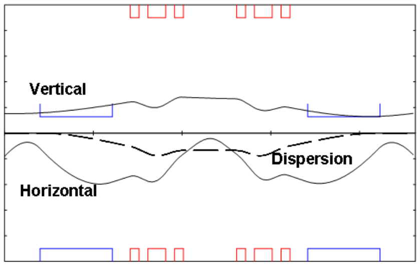


Fig. 2. TRANSPORT result in the beam selecting section: Dispersion function(dotted lint) and beam envelop function both in horizontal and vertical directions.

2.2 LEBT

From the input and output beam information of the beam selecting section, we can obtain the matching condition in the two matching sections. The required vane tip voltage are summarize in Table I. The TRANSPORT simulation result in LEBT is given in Fig. 3 which also shows the numbering system of eight electrostatic magnets for Table I. The aperture radius of the electrostatic quadruoles is 70 mm in this simulation.

Table I: Specification of electrostatic quadrupoles for beam matching.

Electrostatic Quadrupole	Vane Tip Voltage (kV)
ESQ1	2.82
ESQ2	-7.92
ESQ3	9.54
ESQ4	-2.75
ESQ5	3.36
ESQ6	-7.00
ESQ7	10.32
ESQ8	-12.52

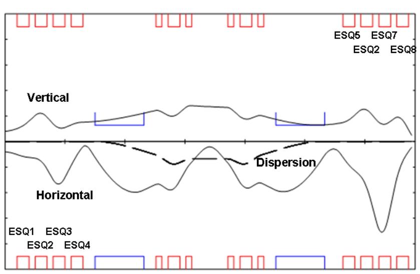
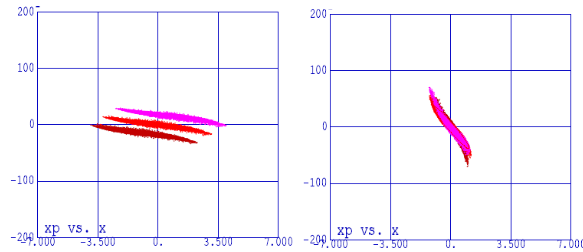


Fig. 3. TRANSPORT result in the heavy ion LEBT: Dispersion function(dotted lint) and beam envelop function both in horizontal and vertical directions.

2.3 Particle Simulation Result

In order to determine the aperture size for beam selection, we performed particle simulations by using TStep code [3]. Because three different charge states can be included simultaneously in the code, we used two sets of charge states: +32, +33, +34 in the first set and +31, +33, +35 in the second set. The number of macro particles is 30,000 and the beam current is 8 pμA for $^{238}U^{+33}$. The particle distributions of the first set in x-x' space are given in Fig 4(a) after the first bending magnet and in Fig 4(b) after the second bending magnet. Fig 5. shows the particle distribution of both set before and after the aperture for beam selection. We used a 40×140 mm^2 rectangular aperture. It is good enough to clearly select the first set of three charge states.



(a) (b)

Fig. 4. Particle distribution of the first set (a) after the first bending magnet and (b) after second bending magnet.

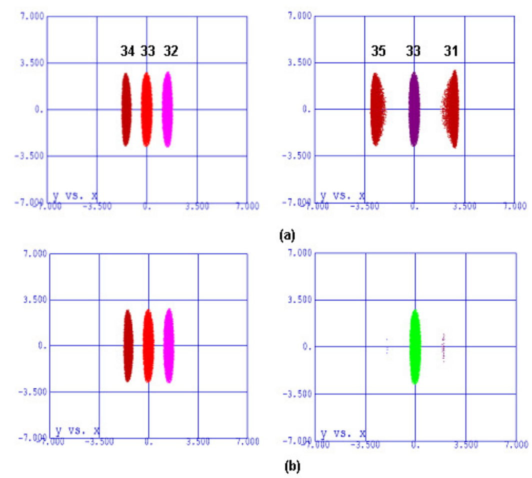


Fig. 4. Particle distribution (a) before and (b)after the beam selecting aperture: first set in left and second set in right.

3. Conclusions

We studied the beam dynamics in the heavy ion LEBT. The beam matching conditions through achromatic beam selection system are obtained. We also studied beam selection by using a rectangular aperture.

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