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Space Charge Dominated Beam Transport and Matching Section between Ion Source and Linac

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The low energy (50 keV) beam transport line from the ion source to the RFQ whose beam intensity had been limited at ~1 mA by space charge repulsion has been redesigned to attain the beam current up to ~20 mA. The main modification is to utilize the smooth focusing with rather large beam size, replacing some hardware with wider beam aperture. Perfect matching in transverse phase space is also pursued with the use of permanent solenoidal fields, which is expected to improve the beam transmission through the RFQ linac.

KEY WORDS: Space Charge Repulsion / Phase Space Matching / Axial Symmetry / Twiss Parameter

1. Introduction

The low energy beam transport line from the ion source to the entrance of the RFQ has been operated since 1991 at the ion linear accelerator of Institute for Chemical Research, Kyoto University[1)]. In the existing system, the transverse phase space matching is incomplete and beam transmission through the RFQ is limited below 74%. Further, the system utilizes such an ion optics as be focused into a very small beam size in order to cope with the small gap (35 mm) of the Mixing Magnet, which increases the space charge repulsion and, therefore, results in beam blow up. From the reasons above mentioned, the beam line has an upper limit of transmittable beam current of ~1 mA[2)]. In order to improve this situation, upgrading of the transport line is started assuming the design current of 20 mA for the time being. At this intensity, beam behavior affected by a non-linear effect due to space charge force is expected to become apparent in the linear accelerator. In the present paper, design of the ion optics for this upgrading is presented together with the hardware modifications.

2. Beam Optics

From the design of the RFQ, Twiss parameters at the entrance of the RFQ are required to have the values as listed up in Table 1. As the starting values of these parameters at the position of the Einzel lens shown in Fig. 1, we used the ones also given in Table 1 assuming

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the parallel beam both in horizontal and vertical directions.

The four vanes of the RFQ are tilted by 45° for easiness of attaching the evacuation port to the cavity and transverse focusing by the RF electric field is decomposed into x and y directions shown in Fig. 2. On the other hand, existence of the Mixing Magnet defines the horizontal plane as the orbital plane. In order to avoid the mixing between betatron oscillations in horizontal and vertical directions, it is needed to make a round (i.e. axially symmetric) beam

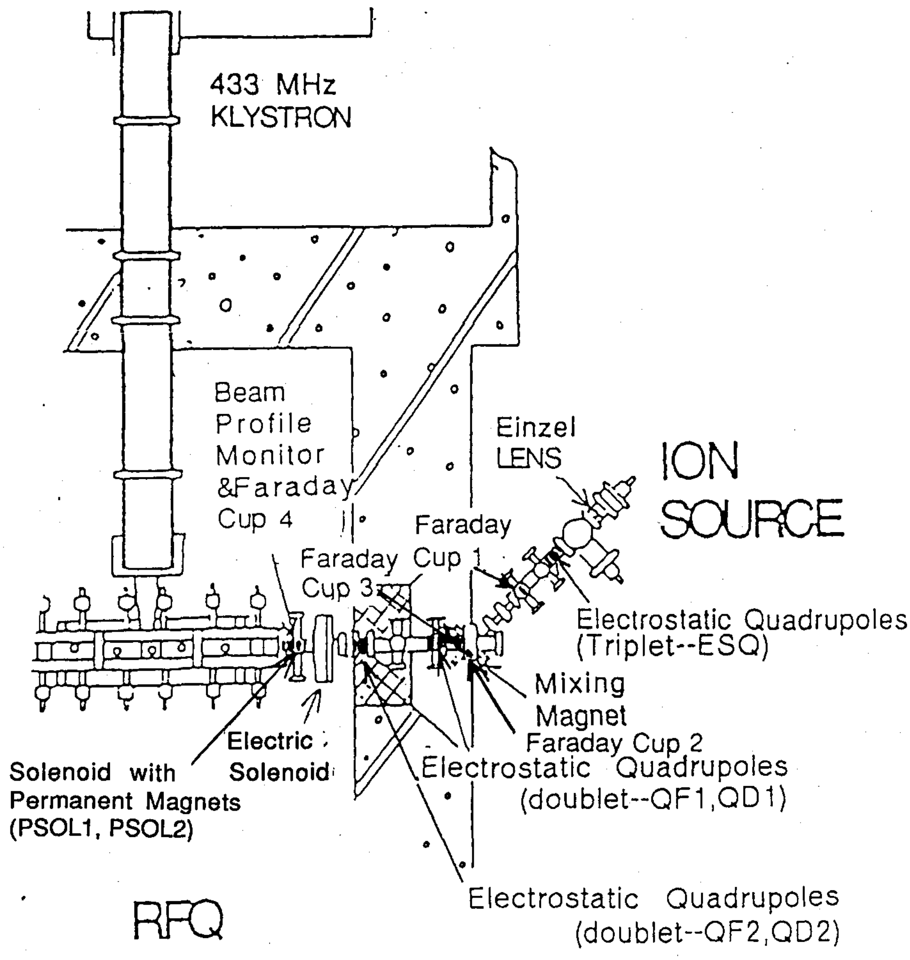


Fig. 1. Layout of the Low Energy Beam Transport System. Transverse Phase Space matching is made between the center of the Einzel lens and the entrance of the RFQ.

Table 1. Twiss Parameters at the starting and end points of the transport line

Starting Point (Center of Einzel)		End Point (Entrance of RFQ)	
Beta-function	Alpha	Beta-function	Alpha
3.1 m	0	0.057 m	2.508

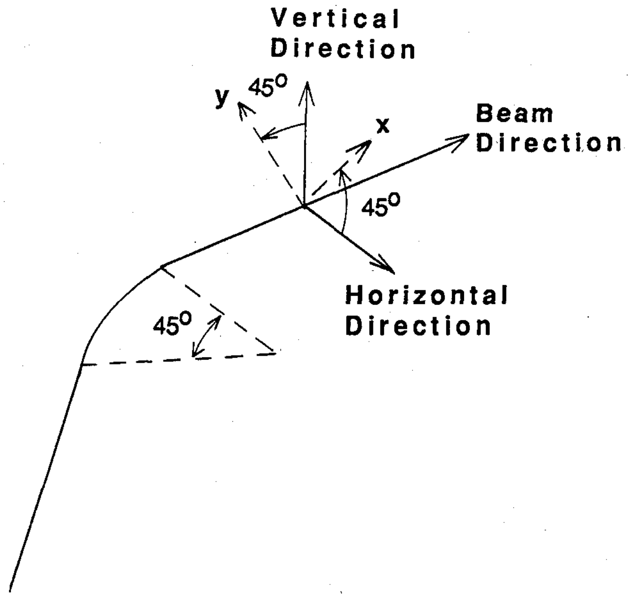


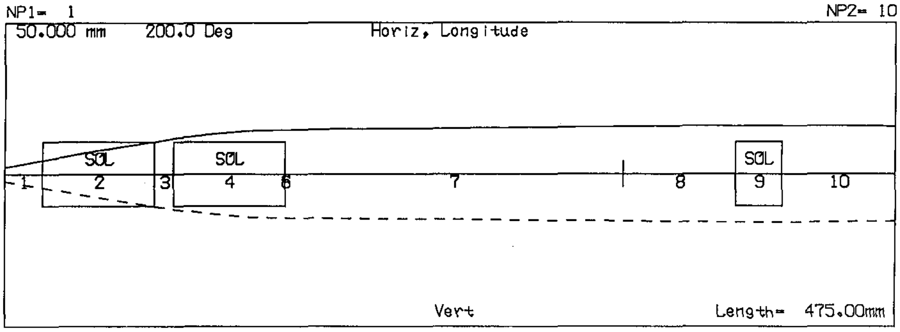
Fig. 2. Definition of x and y directions with respect to horizontal and vertical directions. If the horizontal and vertical directions are 45 degrees rotated counter clockwise around the beam direction viewing from the unstream, they will coincide with x and y directions respectively.

downstream from the electric solenoid to the entrance of the RFQ utilizing only axially symmetric optical elements in this region. For this purpose, the transverse phase space acceptance is traced back to the entrance of the electric solenoid as shown in Fig. 3 (a) for zero beam current with use of the computer code TRACE-3D[3], where the strengths of the solenoidal fields made by permanent magnets, PSOL1 and PSOL2 (both 60 mm in length), are assumed to be 4600 G and 6600 G, respectively.

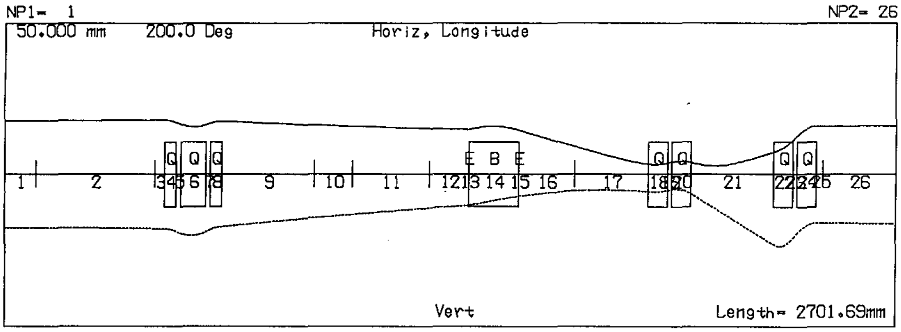
In order to make matching throughout the entire beam transport line, transverse matching is pursued with two doublets of the electrostatic quadrupoles (4 parameters). As it is difficult to install focusing element just upstream the Mixing Magnet, edge focusing of 23° in vertical direction is adopted. In Fig. 3 (b), the transverse phase space matching between the positions of the Einzel lens and the electric solenoid for zero beam current is shown. Combining these two parts in real beam direction, the entire beam transport line is composed and matching condition for this section is searched for various beam intensities below 20 mA and such an ion optics is searched, as is not changed so largely and beam blow up does not occur for these beam currents. The beam envelope of the entire "Low Energy Beam Transport" is shown in Fig. 3 (c) for the beam current of 20 mA as a typical example.

3. Improvement of the Hard-Ware

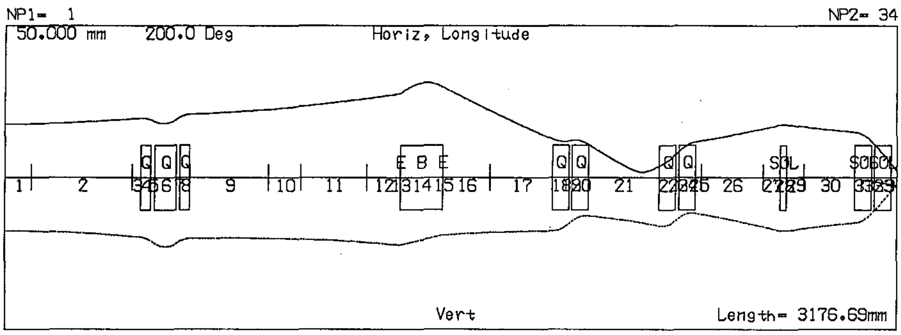
So as to realize the ion optics described in the previous section, the aperture of the ion-



(a)



(b)



(c)

Fig. 3. Beam envelopes at (a) the axially symmetric final stage, (b) other region than (a) and (c) the entire Low Energy Transport line. (a) and (b) are calculated at the designing stage and beam current of 0 mA is assumed to make the design process easy. (c) is calculated after the composition of the ion optics is fixed and beam current of 20 mA is assumed.

optical elements are checked and the Mixing Magnet is decided to be replaced by the one with wider gap size (60 mm). The power supply for the magnet is not to be changed and the new magnet is required to be excited to the necessary magnetic field (1.67 kG and 2.37 kG are required to bend H^+ and $H_2{}^+$ as large as 45°, respectively) with the old power supply (20 A, 15 V). The magnet is required to be excited up to the level which can deflect $H_2{}^+$ (molecular hydrogen) as large as 45° so as to observe abundance of H^+ relative to $H_2{}^+$.

The newly fabricated Mixing Magnet is shown in Photo 1. The main specifications of the magnet are given in Table 2. The excitation characteristics of the magnet is shown in Fig. 4 and the field distributions along the central line at the entrance and the exit of the magnet are shown in Fig. 5(a) and Fig. 5(b), respectively.

4. Present Status and Summary

The low energy transport line with transverse phase space matching which can deliver the beam with the intensity of 20 mA is newly designed based on the existing ion optics in

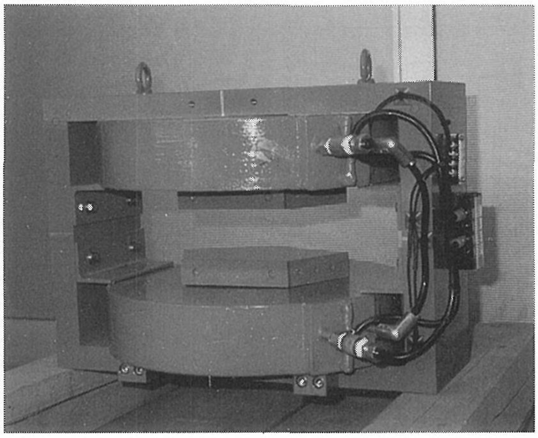


Photo. 1. An overall view of the newly fabricated mixing magnet with wider gap (60 mm).

Table 2. Main Specifications of the New Mixing Magnet

Magnet Gap	60 mm
Maximum Excitation Current	20 A
Maximum Field	2.7 kG
Coil Impedance	0.65 Ω
Deflection Angle	45°
Radius of Curvature	0.193 m
Flow Rate of Cooling Water	4 l/min.
Weight	192 kg

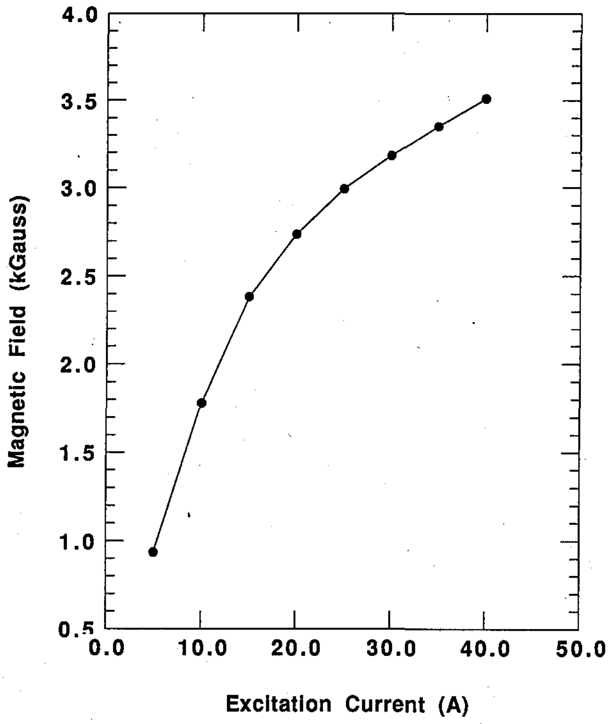


Fig. 4. Excitation characteristics of the newly fabricated Mixing Magnet with wider gap of 60 mm.

most part. The main change for the new line is replacement of the Mixing Magnet and its chamber to enlarge the beam aperture and addition of solenoidal fields made by permanent magnets to realize transverse matching with the acceptance of the RFQ.

The mixing magnet has been just fabricated and is found that it can safely excite the needed field with the existing power supply. The new vacuum chamber is to be fabricated based on the new magnet to accommodate the beam of larger size as shown in Fig. 3.

Among the solenoids made by permanent magnets, the one to be used just before the entrance of the RFQ (PSOL2) has already been fabricated and is reported elsewhere[4]. Another one (PSOL1) is to be fabricated from now on based on the experience of the first fabrication and the ion optics described here.

Before the completion of the new high current beam transport line, another a few months will be needed.

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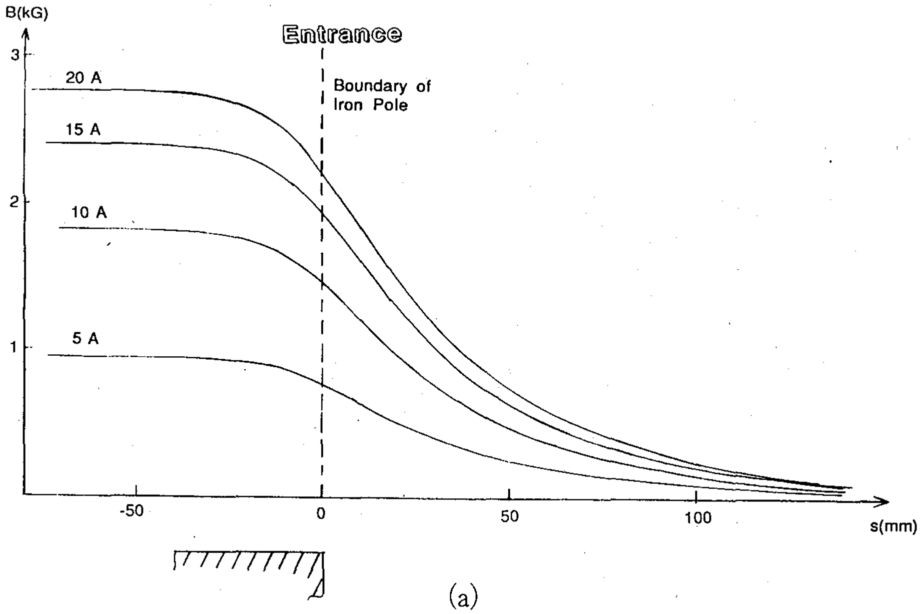
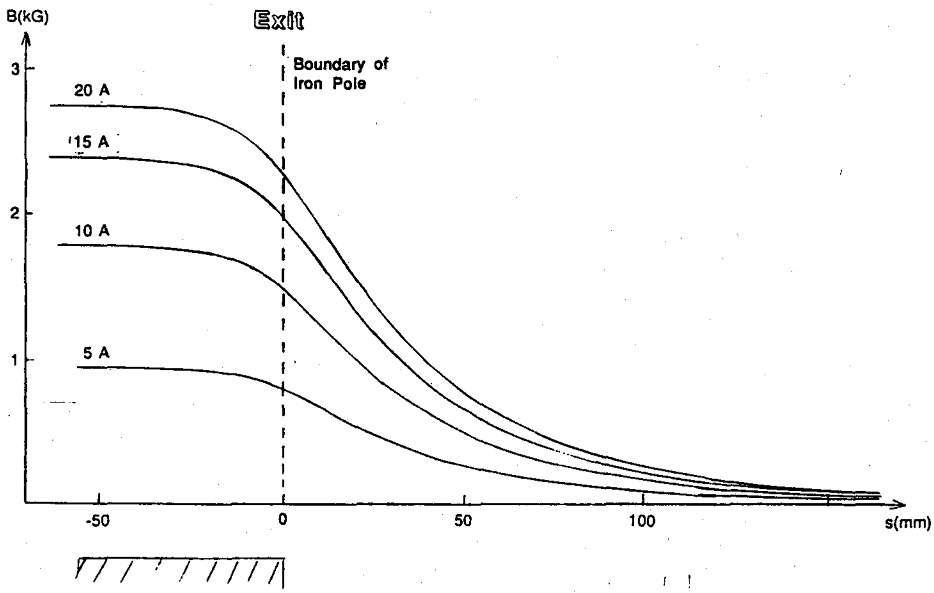


(a)



(b)

Fig. 5. Fringing field distribution of the new Mixing Magnet at the entrance (a) and the exit (b).

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