IMPROVEMENT OF THE LOW ENERGY BEAM TRANSPORT SYSTEM AT THE ICR 7 MeV PROTON LINAC

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Abstract

The 50 keV proton beam from the ion source is guided to the entrance of the RFQ through the low energy beam transport (LEBT) line. Because of the low energy, the beam current had been limited at ~1 mA by the space charge repulsion so far. In order to increase the beam current up to the order of 20 mA, the ion optics has been redesigned to utilize smoother focusing with rather large beam size. For the purpose, the Mixing Magnet with wider gap (60 mm) has been newly fabricated and related vacuum system has been replaced by the one with a wider aperture. In the present paper, the design of the new LEBT line is described together with the hardware development. The recent beam test is also reported.

Introduction

The ICR 7 MeV proton linac consists of an RFQ and a DTL [1]. For the future plan of the simultaneous acceleration of both H^+ and H^-, our LEBT has the feature that it has 45° bending magnet called Mixing Magnet and it is relatively long (Fig.1 shows the layout of the LEBT and beam monitors). Because in the old LEBT, the H^+ beam was strongly radially focused at the Mixing Magnet, the beam current was limited to ~1 mA by the space charge repulsion [2]. To improve this situation, the new beam line which has the wider aperture so as to avoid the space charge repulsion was designed [2] using computer code TRACE-3D [3]. The new Mixing Magnet with a wider gap and the edge focusing angle, which was designed including the effect of the fringing field was fabricated and installed into the LEBT line. The compact strong permanent magnet symmetric (PMS) lenses are under fabrication [4]. The beam test to transport the H^+ beam from the ion source to the entrance of the RFQ has been performed.

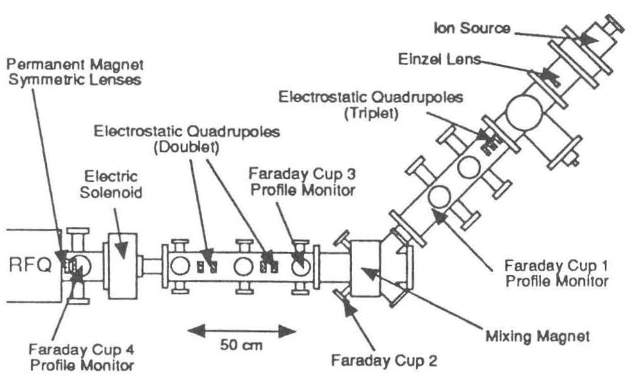

Fig. 1: The layout of the LEBT

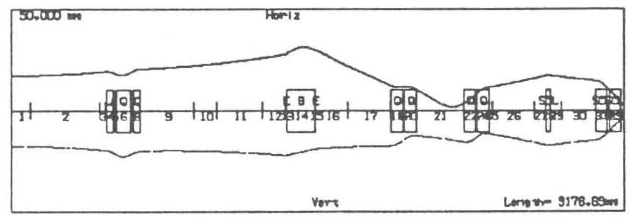

Fig. 2: Beam envelopes calculated by TRACE-3D at a current of 20 mA.

Modification of Ion Optics

In the old LEBT, the upper limit of the beam current at the Faraday cup 4 (see Fig.1) was ~1 mA. When the current extracted from the ion source was increased, the transported current was rather decreased because of the strong space charge repulsion. Most of all, the horizontal beam size was very small at the exit of the old Mixing Magnet by its radial focusing action. To avoid this situation, the new Mixing Magnet which had a wider gap (60 mm) and the edge angle of 23° was designed and fabricated.

The matching to the RFQ was not good (transmission was less than 74 % and for higher current ~50 %), because the strength of the final focusing before the entrance of the RFQ was not enough. So the permanent magnet symmetric lens has been designed and its fabrication is started.

New ion optics with the transverse phase matching has been designed by use of computer code TRACE-3D. The ion optics consists of an Einzel lens, a triplet of electrostatic quadrupoles, a bending magnet (Mixing Magnet), two doublets of quadrupoles, an electric solenoid and two axially symmetry permanent magnet lenses. Fig.2 shows the result of the calculation for the matched beam current of 20 mA. In this ion optics, the beam current of 20 mA is expected to be able to be transported without the emittance growth.

Mixing Magnet

Geometry

The shape of the iron pole of the new Mixing Magnet is shown in Fig.3. It has a wider gap (60 mm) than the old magnet (35 mm) and the edge angle of 23° for the vertical focusing. It also has removable shims illustrated in Fig.3 indicated as Entrance and Exit blocks. The role of these shims is to adjust the effective length of the Mixing Magnet appropriately. Thus we can correct the deviation of the beam orbit caused from the effect of the fringing field and the edge angle can be modified if necessary.

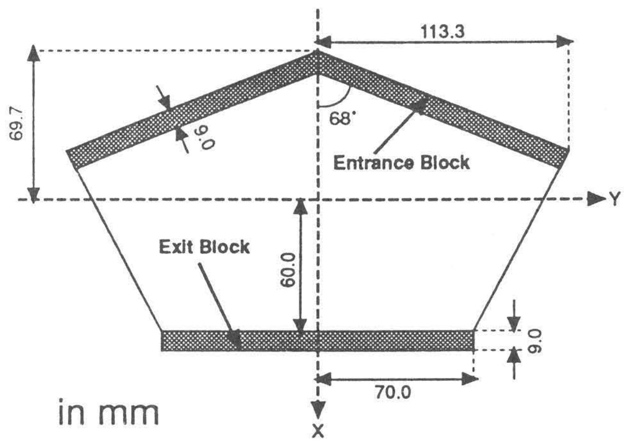

Fig. 3: The shape of the iron pole of the new Mixing Magnet.

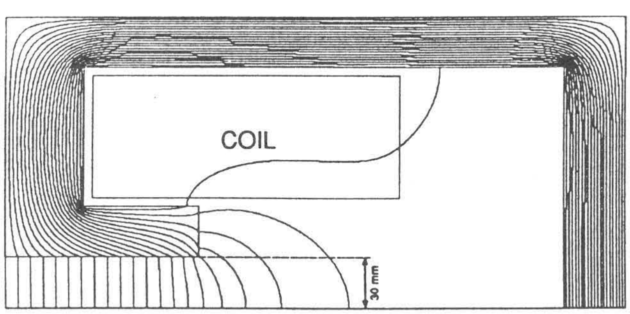

Fig. 4: The 2-dimensional field calculation by POISSON.

Design

First, we estimated the shape of the fringing field by computer code POISSON [5] in two-dimension (See Fig.4). We used the field value on the median plane and assumed that the strength of the field is proportional to magnet's current.

Then we determined the length of the shims (entrance and exit blocks) by calculating the H^+ orbit by the computer simulation. This simulation was done as follows.

The equation of motion for the charged particle in the magnetic field is written,

$$m_0\gamma\frac{d^2\vec{x}}{dt^2} = q\vec{v}\times\vec{B}. \quad (1)$$

This coordinate system is fixed to the laboratory system (see Fig.3).

To consider the orbit on the median plane, the equation reduces to four differential equations.

$$\begin{cases} \dot{x} = v_x \\ \dot{y} = v_y \\ m_0\gamma\dot{v_x} = qv_yB_z \\ m_0\gamma\dot{v_y} = -qv_xB_z \end{cases} \quad (2)$$

Then, we solved equations (2) by 4th order Runge–Kutta method. Assuming that the shape of the fringing field depends on neither the length of the shims nor the magnetic field strength, we calculated the length of shims to satisfy that at the exit of the magnet, the deflecting angle is 45° and the difference of the y-position between the ideal orbit and the calculated one should be small.

Finally, we got the relation between the length of the entrance and that of the exit block (see Fig.5). For easy fabrication, the length of the entrance and the exit blocks were determined 9.0 mm and 9.0 mm, respectively. The relation in Fig.5 can be satisfied if we install the magnet into the LEBT line shifting 2 mm downstream (in X direction in Fig.3). Shifting 2 mm is equivalent to changing the length of the entrance and the exit blocks to 7.1 mm and 11.0 mm, respectively (indicated 'shifted' in Fig.5).

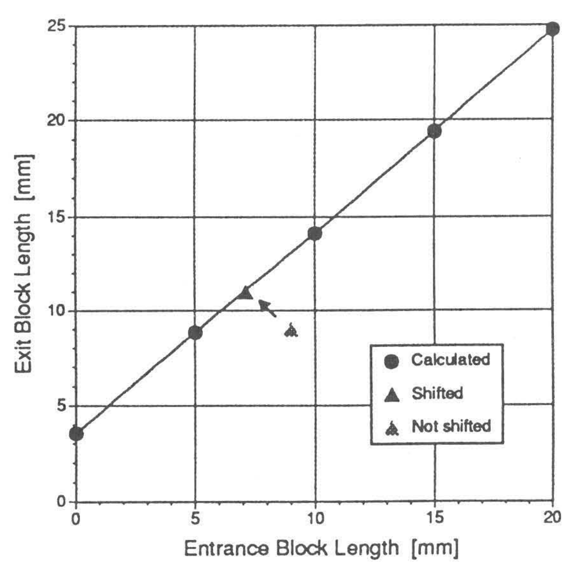

Fig. 5: The relation between the length of the entrance block and that of the exit block.

Field Measurement

After the Mixing Magnet was fabricated, the field measurement was done. Fig.6 shows the measurement system. We used slide tables whose strokes are 60 cm and 30 cm in the directions parallel and perpendicular to the rod, respectively. The slide tables are driven by stepping motors. By the lifter, we moved the Hall probe vertically which is fixed at the head of the rod. We mapped the field in 52 cm × 25 cm area with 1 cm steps. The measurement was done automatically by the computer and it took about an hour to map over the whole area.

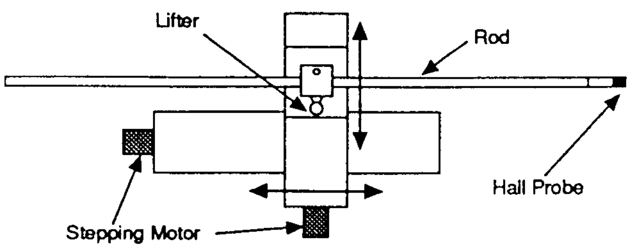

Fig. 6: The schematic view of the field measurement system.

Check of Design

Interpolating the magnetic field using the measured data of 1 cm × 1 cm mesh, the particle orbit was calculated in a similar way when we designed. The result of the calculation is shown in Fig.7. When a particle was deflected 45°, the difference between the ideal orbit and the calculated one was about 0.3 mm at the exit of the Mixing Magnet. If we want to cure this situation, we must install the magnet shifting about 0.2 mm upstream. But this shift is almost comparable to the installation errors. So we ignored this difference.

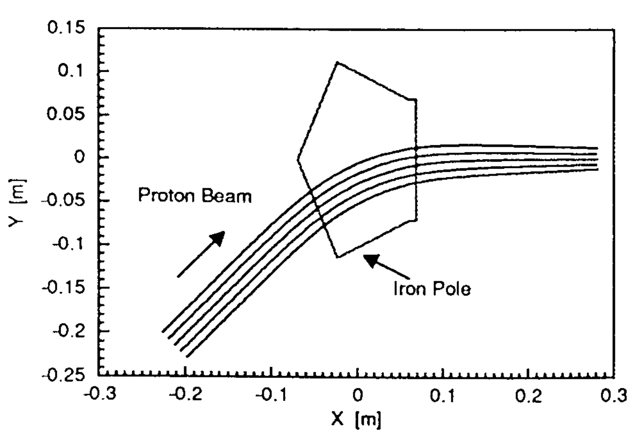

Fig. 7: The several orbits on the median plane. The distance between the neighboring orbits is 1 cm before entering Mixing Magnet.

Beam Test

The beam test to transport H^+ from the ion source to the entrance of the RFQ was done. The measured beam current are shown in TABLE 1. The transported current was 8.0 mA (at Faraday cup 4), while the current from the ion source was 20 mA (at Faraday cup 1). Because there were many types of ions such as H^+, H_2^+, and H_3^+, the current read at Faraday cup 1 contained the total current of these types of ions. At Faraday cup 2, we can measure the current of ions which go almost straight in the Mixing Magnet. The current of H_2^+ and H_3^+, which were measured at Faraday cup 3 by changing the field strength of the Mixing Magnet appropriately, were 5 mA and 4 mA, respectively.

TABLE 1: Current Measured at Faraday Cups

	F.C.1	F.C.2	F.C.3	F.C.4
Current [mA]	20	10	8	8

Summary and Discussions

We designed new ion optics which can transport the ions with the intensity up to 20 mA without emittance growth according to TRACE-3D simulation. We installed the Mixing Magnet for the improvement of the LEBT. The improvement of the LEBT is now in progress. In the preliminary beam test, the beam current has been increased up to 8 mA at the exit of the LEBT.

The proton current extracted from the ion source is the order of 10 mA. To increase the transported current, we will improve the ion source and add other focusing elements.

To make sure the validity of the simulation by TRACE-3D, further study of the characteristics of the beam is needed. For example, measurements of the emittance at the exit of the ion source and at the exit of LEBT line are needed.

References

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