LOW ENERGY BEAM TRANSPORT AND MATCHING SECTION UNDER SPACE CHARGE EFFECT

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Abstract

The current of the 50 keV beam in the transport line between the ion source and the RFQ linac is limited by the space charge repulsion at the lower value of ~1mA with the existing optics. Modification of the beam optics is expected to enable the transport of beam current no less than 20 mA and perfect transverse phase space matching.

1 Introduction

At Institute for Chemical Research, Kyoto University, the 7 MeV proton linac has been operated since the beginning of 1992[1]. its beam current is limited by the space charge repulsion among low energy (50 keV) protons at the transport line between the ion source and the RFQ, because the existing beam optics is based on such an optics as focuses the beam at a few points in the beam line. In order to remedy this situation, the optics is to be modified based on a rather smooth optics with much larger beam aperture. With use of computer code TRACE-3D including the space charge effect[2], the beam current of 20 mA is found to be transported with the modified beam line. The aperture of the existing bending magnet with the deflection angle of 45° (called Mixing Magnet) has a too small gap (35 mm). Therefore new one with larger gap (60 mm) and edge angle of 23° for vertical focusing is fabricated[3].

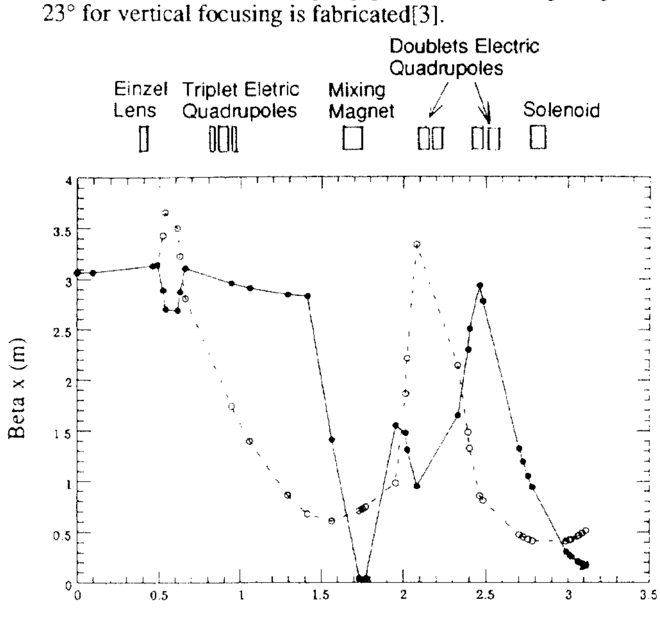

Fig. 1 β-functions of the existing transport line from the ion source to the RFQ.

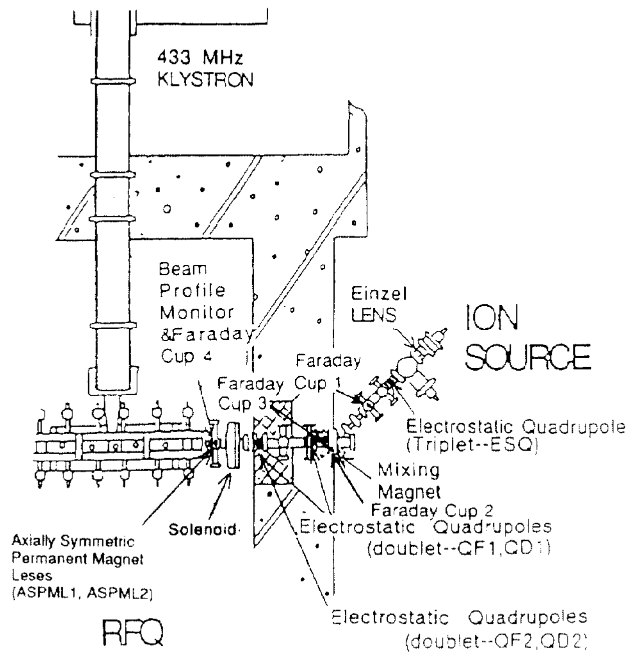

Fig. 2. Layout of the transport line and beam monitors.

In order to make perfect matching with the acceptance of the RFQ in transverse phase space, the beam is required to be strongly focused and has a large taper angle. For the purpose, axially symmetric lenses made of permanent magnets are to be used together with a solenoid.

In the present paper, the design of the beam line including space charge effect is presented together with the present status of the hard ware fabrication.

2 Current Limit in the Existing Beam Line

The existing beam line from the ion source to the entrance of the RFQ consists of an einzel lens, a triplet of the electrostatic quadrupoles, the Mixing Magnet, a pair of doublets of the electrostatic quadrupoles and a solenoid as shown in Fig. 1. In this optics, parallel beam from the einzel lens is assumed and it is sharply focused just after the Mixing Magnet and around the solenoid as shown in Fig. 1. In this situation, the Coulomb repulsion among proton beam with the kinetic energy of 50 keV becomes prominent when beam current increases more than 1 mA. Typical beam currents at Faraday cups 1, 3 and 4, which are indicated in Fig. 2, are 10 mA, 2 mA and 1.2 mA, respectively[4]. Because of the radial focusing in the Mixing Magnet, the horizontal beam size becomes very small as is understood from Fig. 1 and the

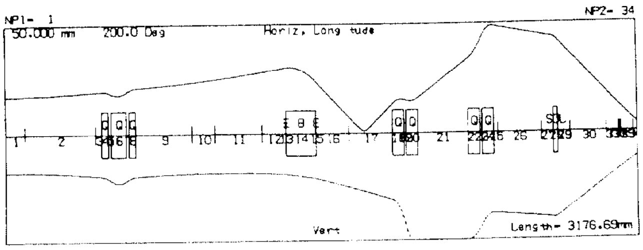

Fig. 3 Imaginary beam envelope when beam of 20 mA is transported at the existing beam line.

current transmitted through the line is limited just above 1 mA. In this configuration, even if the current extracted from the ion source is increased, the transported current to the Faraday cup 4 is rather decreased because the stronger space charge repulsion causes larger divergence of the beam, which leads heavier beam loss. Typical illustration is given in Fig. 3, where the imaginary beam simulation of 20 mA is applied for the existing beam optics with use of TRACE-3D. The very small horizontal beam size just downstream of the Mixing Magnet caused by its radial focusing action is the origin of the catastrophic divergence.

In the existing beam line, the strength of the final focusing before the entrance of the RFQ is not enough and the fraction of the beam which can be safely accelerated through the RFQ is not so large (less than 74 % and for higher current ~50 %), which will be largely improved by adding the axially symmetric permanent magnet lens.

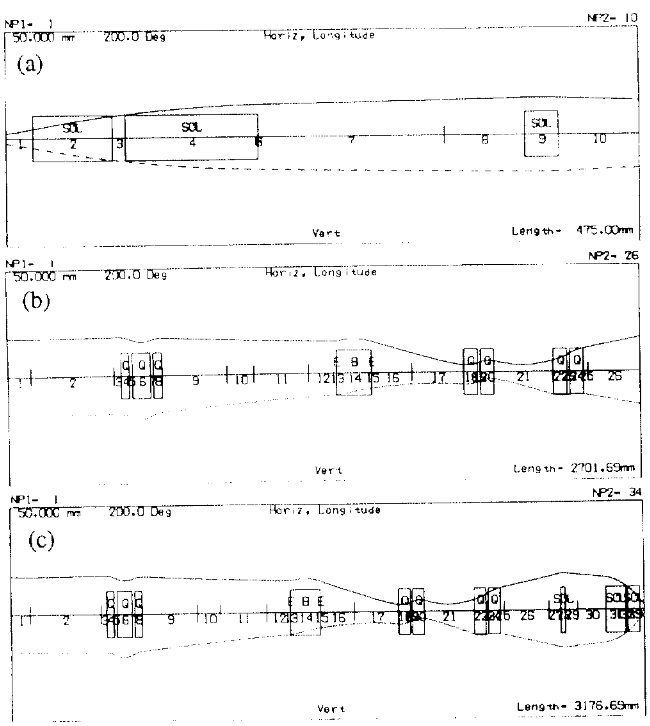

Fig. 4. Design procedure of transverse phase space matching at the new beam optics for 0 mA.

3 Modification of Beam Optics

3.1. Increase of the Limiting Current

So as to reduce the space charge effect and enable the transport of the beam with higher intensity up to 20 mA, the beam optics is needed to be modified to be a rather smooth one with larger beam envelope. For this purpose, the gap of the Mixing Magnet is increased from 35 mm to 60 mm. In addition, the edge focusing in vertical direction as large as 23° is applied at the entrance of the Mixing Magnet so as to avoid the too small horizontal beam size due to radial focusing action of the Mixing Magnet with the radius of curvature of 19.3 cm.

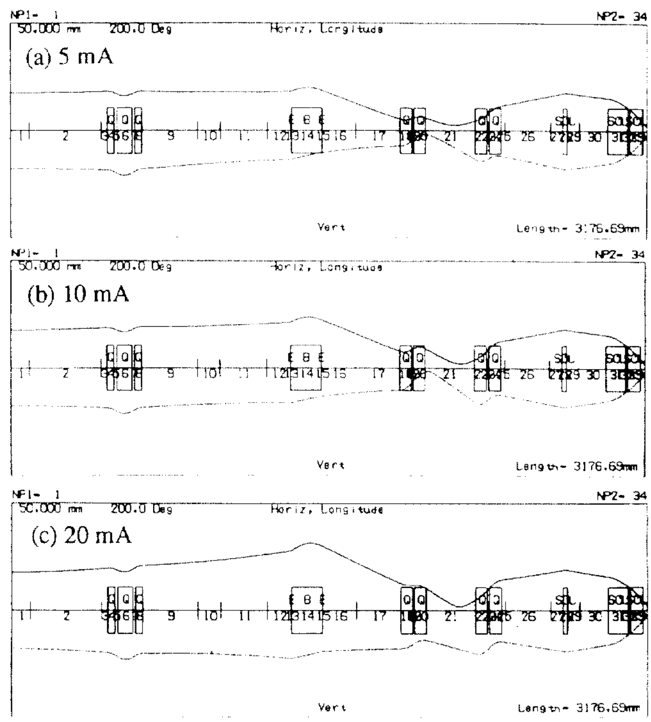

Fig. 5 Beam envelopes for various currents at the modified transport line.

3.2. Transverse Phase Space Matching

As the acceptance of the RFQ is axially symmetric, the transport line is also designed to be axially symmetric at the positions downstream from the solenoid. At the entrance of the RFQ, β and α are to be 5.7 cm and 2.508, respectively both in x and y directions. Here x and y directions correspond to the directions 45° rotated counterclockwise viewing from the upstream from the horizontal and vertical directions, respectively. In Fig. 4 (a), the beam envelope is shown tracing back from the entrance of the RFQ to the solenoid through a pair of axially symmetric permanent magnet lenses (ASPML1 and ASPML2 in Fig. 2) for zero beam current. Next, the transverse phase space matching is made between the einzel lens and the solenoid as shown in Fig. 4(b) utilizing

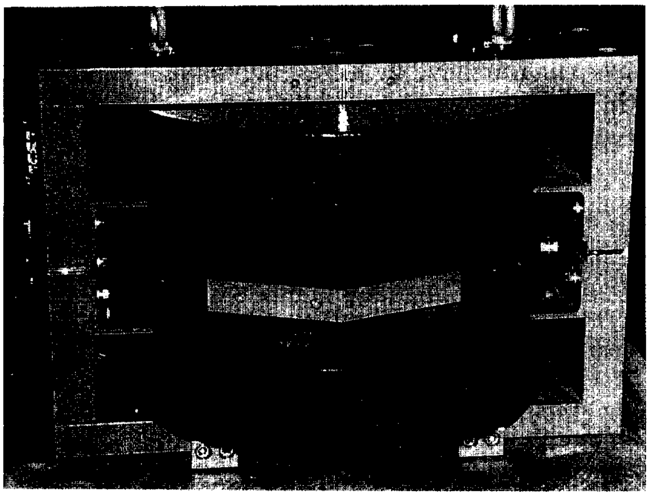

Fig. 6(a) Overall view of the new Mixing Magnet.

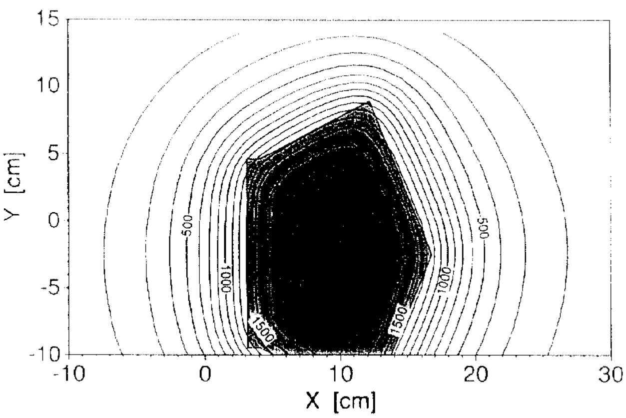

Fig. 6(b) Mapped field distribution of the Mixing Magnet.

the field gradients of four electrostatic quadrupoles as free parameters. Finally, combining Fig. 4(b) with Fig. 4(a) reversed in s-direction to real beam passage, the total low energy beam transport line, which satisfies transverse phase space matching, is obtained as shown in Fig. 4(c). In the above calculations, zero beam current is assumed.

The situation when beam current is increased is shown in Fig. 5 (a), (b) and (c) for beam currents of 5 mA, 10 mA and 20 mA, respectively. Because of the stronger repulsion by the space charge effect, the beam size becomes larger as the beam intensity goes up. However, in the modified configuration, the beam size is kept rather larger value owing to the edge effect of the Mixing Magnet and large divergence can be avoided. Comparison of Fig. 5(c) with Fig. 3 shows the improvement in ion optics quite well.

4 Hard Ware Construction

4.1. Mixing Magnet

The mixing magnet with larger gap of 60 mm and edge angle of 23° has been already fabricated and its field distribution is being mapped. In Fig. 6, the overall view of the magnet(a) and the typical example of the field mapping(b) are shown. In order to precisely align the injection beam line to the RFQ, the effecetive beam orbit including the fringing field effect is required to be evaluated correctly. The Mixing Magnet is fabricated with demountable end shims at the entrance and exit and iteration procedure is now proceeding based on the field measurement.

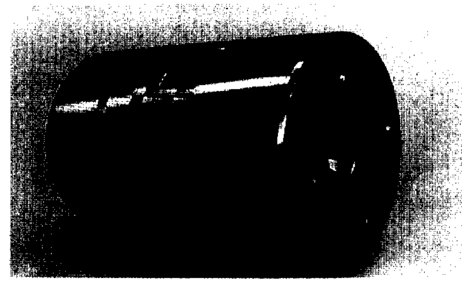

Fig. 7. An overall view of the axially symmetric permanent magnetic lens for final focusing.

4.2. Axially Symmetric Permanent Magnet Lens

A proto type of the axially symmetric permanent magnet lens has been already fabricated(Fig. 7). Its focal length for 50 keV proton beam and bore radius are 16.2 cm and 0.5 cm, respectively.[5]. Inorder to make perfect matching in transverse phase space, a pair of axially symmetric permanent magnet lenses with similar focal lengths are needed and are now at the design stage for fabrication.

5 Ackowledgement

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6 References

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