MATCHING SECTION TO THE RFQ USING PERMANENT MAGNET SYMMETRIC LENS

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Abstract

Permanent magnet symmetric (PMS) lens is considered as the final focusing element for the RFQ linac at ICR. The PMS lens, which produces strong axial magnetic field like a solenoid lens, is composed of radially magnetized permanent magnet rings. Because of the low injection energy (50 keV) and a relatively high beam current intended (20 mA), space-charge effects should be taken into account. The beam tracking code PARMSYL is developed for the purpose, which first reads an output file (TAPE35) from PANDIRA for the PMS field and then numerically integrates the equation of motion including the space-charge force The matching section to the RFQ is designed using this code and TRACE-3D.

I. INTRODUCTION

At Institute for Chemical Research (ICR), Kyoto University, the proton linac consisting of a 2 MeV RFQ linac and a 7 MeV Alvarez linac has been operated since 1992[1]. Various mechanical improvements are in progress to increase the beam current up to 20 mA. In this paper, the design of a new focusing element for matching the beam to the RFQ acceptance is reported.

Figure 1 illustrates the layout of the low energy beam transport (LEBT) of the ICR proton linac. It is composed of an einzel lens, a triplet of electrostatic quadrupoles (ESQ), two doublets of ESQ, a bending magnet (called Mixing Magnet) having the deflection angle of 45°, and a solenoid lens. The estimated beam emittance in LEBT is about 100 π mm·mrad (unnormalized), which is used in the calculations in this paper.

In preliminary experiments, it was found that the transportable beam current was strongly limited by space-charge effects.[2] After the improvement of the Mixing Magnet, the current is now 8 mA roughly ten times higher than before[3]. The current measured after the Alvarez linac was only 0.7 mA due to beam mismatch at the entrance of the RFQ. An extra focusing device is thus needed to achieve a higher transmission efficiency.

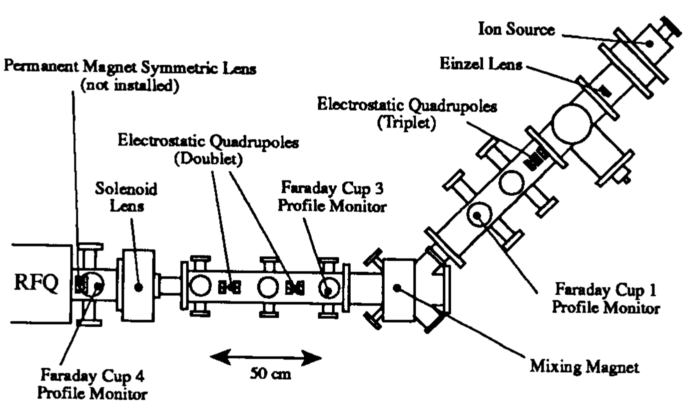

Figure. 1. Layout of the LEBT

For the simultaneous acceleration of both positive and negative ions planned in the future, focusing elements with axially symmetric fields are suitable for LEBT. Since the beam should be strongly focused and has a large taper angle, it is effective to put a focusing device near the entrance of the RFQ. This, however, causes the space limitation for the lens.

One candidate for such a focusing device is PMS lens, since the use of a strong permanent magnet material allows us to reduce its size and, further, the PMS field is axially symmetric. The evaluation of the performance of the PMS lens is made in the following sections.

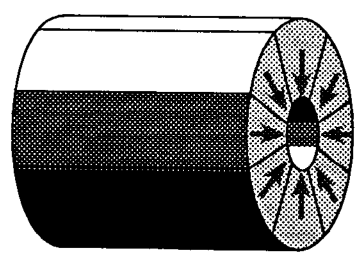

Figure. 2. Radially magnetized permanent magnet ring.

II. PERMANENT MAGNET SYMMETRIC LENS

A radially magnetized permanent magnet ring (see Figure 2) with anisotropic material such as Nd-Fe-B generates axial magnetic field and works like a solenoid lens[4][5]. The magnetic field of one ring indicated either by 'Ring 1' or 'Ring 2' is shown in Figure 3, where Ring 1 and Ring 2 are oppositely magnetized. Putting these two rings side by side, the superposed magnetic field in the axial direction becomes like the thick solid line. Since the focusing strength of a solenoid lens is proportional to the integration of the square of the magnetic field strength along the axis, this axial superposition is quite effective.

As the permanent magnet material, the anisotropic permanent magnet NEOMAX-40 (nominal remanent field B_r = 1.29 T) produced by Sumitomo Special Metal Co.LTD. was adopted. Because of the low beam energy (50 keV) and the low duty factor (1 % maximum), the radiation damage is expected to be negligible and no special cooling device will be attached.

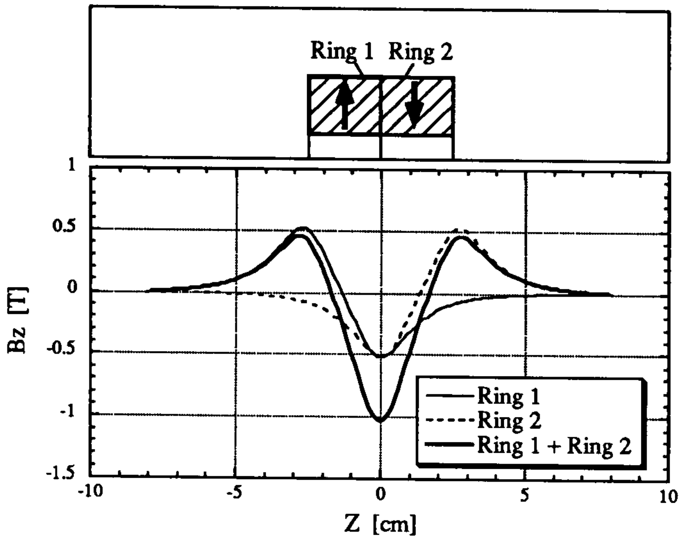

Figure. 3. Magnetic field distribution generated by Ring 1 (thin solid line), Ring 2 (dashed line) and their superposition (thick solid line).

III. PARMSYL

The magnetic field of a PMS lens is calculated with PANDIRA[7]. To estimate the focusing strength and aberration of the lens, we developed the tracking code PARMSYL (PARticle Motion in SYmmetric Lens). The code interpolates the magnetic field data from PANDIRA stored in the output file (TAPE35) and then integrates the equation of motion of a charged particle. In the integration process, space-charge is considered assuming a uniform beam density.

The code tracks particles on beam boundary in phase space, and outputs the focal length and aberration factor of the considered lens. The aberration factor is defined as the ratio of the focusing strength felt by the particle close to the lens axis to that felt by the outermost particle (i.e. $\int B_z^2(r = 0mm)dz / \int B_z^2(r = r_{max})dz$).

IV. BEAM MATCHING

A. Acceptance of the RFQ

The RFQ acceptance was evaluated with the computer code PARMTEQ[8]. From the simulation, it was found that the transmission of the RFQ was over 90 % with the input beam emittance of 160 π·mm·mrad (unnormalized) in the intensity region of 0 $\sim$ 20 mA. Although the value depends on beam current, 160 π·mm·mrad is used, in the following calculations, as the RFQ acceptance.

B. Design of a PMS lens

At present, the best PMS design for the final focusing device is the three-ring PMS lens shown in Figure 4. The beam comes from left side in the figure. It has two small rings installed in the endplate of the RFQ and a large ring placed outside of the endplate. The inner surfaces of the magnets are tapered following the shrinkage of the beam envelope. The edges of the magnets

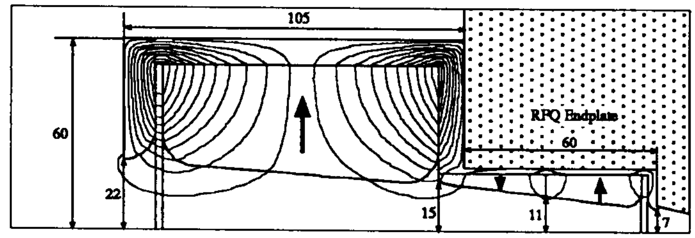

Figure. 4. Shape of the PMS lens. Only upper half is shown.

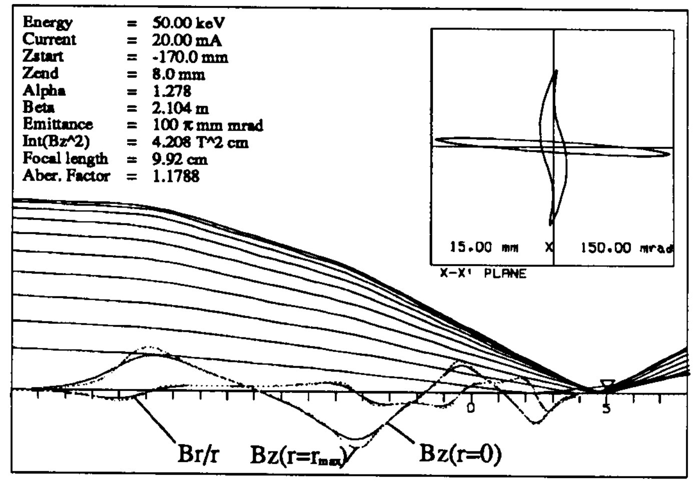

Figure. 5. Output from PARMSYL at the current of 20 mA.

are rounded to reduce the aberration which distorts the beam ellipse. The typical output from PARMSYL is given in Figure 5. The axial field B_z and radial field B_r/r as well as particle orbits are shown.

The Twiss parameters (α, β) appropriate for matching were found to be (-1.49, 1.44), (0.00, 1.44) and (1.28, 2.10) at the PMS entrance when the beam currents were 0 mA, 10 mA and 20 mA, respectively (see Figure 6). In the figure, the distorted beam ellipses are shown together with the RFQ acceptance (dotted line). More than 90 % overlap of the two ellipses is achieved in each case.

C. Matching to the PMS section

TRACE-3D[6] is employed to adjust the Twiss parameters at the entrance of the PMS section by using the strength of the ESQ doublets (see Figure 1) as free parameters. Figure 7 shows the matched beam envelope at the current of 20 mA.

V. SUMMARY

The PMS lens was designed with PARMSYL as the final focusing device to the RFQ. Although the beam ellipse is somewhat distorted due to the aberration of the lens, the overlap of more than 90 % is achievable between the input beam and the RFQ acceptance at the beam current up to 20 mA.

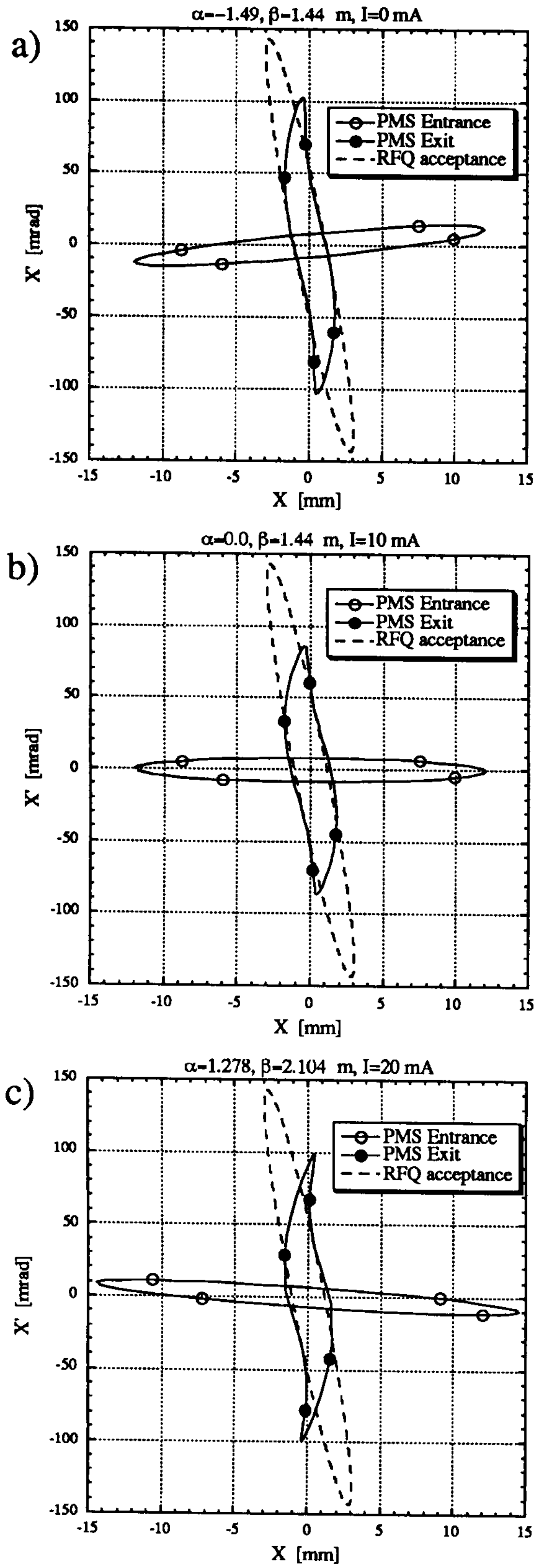

Figure. 6. Phase space plots from PARMSYL.

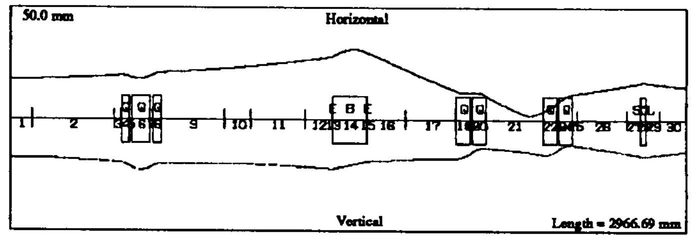

Figure. 7. The matched beam envelope between the einzel lens and the PMS section at the current of 20 mA (calculated with TRACE-3D)

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