A LOW ENERGY ION BEAM TRANSPORT SYSTEM WITH VARIABLE FIELD PERMANENT MAGNETIC QUADRUPOLES

Y. Mori
Institute for Nuclear Study, University of Tokyo (INS)
3-2-1 Midori-cho, Tanasi-shi, Tokyo, 188 JAPAN
A. Takagi, M. Kinsho, T. Baba*
National Laboratory for High Energy Physics (KEK)
1-1 Oho, Tsukuba-shi, Ibaraki, 305 JAPAN
K. Shinto
The Graduate University for Advanced Studies
1-1 Oho, Tsukuba-shi, Ibaraki, 305 JAPAN

Abstract

A compact beam transport system with variable field permanent magnetic quadrupoles has been developed at KEK. It aims to transport the intense negative heavy ion beam from the surface-plasma negative heavy ion source (BLAKE source) to the tandem electrostatic accelerator efficiently. The system consists of four permanent quadrupole magnets and the magnetic field strength of each magnet can be changed from almost zero to 46 T/m. The negative copper ion beam of about 500 μA was successfully transported by this system.

I. Introduction

In these days, development of negative ion sources for accelerators has been pushed strongly at various laboratories. Negative hydrogen ions are very important for intense proton synchrotron because its beam intensity can be increased by a charge-exchange multi-turn injection scheme using negative hydrogen ion beam. [1] Recently, negative hydrogen ion beams of more than 10mA beam current have been obtained from cesiated volume type of negative hydrogen ion sources.[2][3] On the other hand, negative heavy ion beams are very useful for heavy ion synchrotron using an electro-static tandem accelerator as its injector. Of course, intense negative heavy ions would be also very attractive for ion beam applications such as ion beam surface analysis[6], ion implantation and so on. Recently, negative heavy ion beams of more than a couple of mA have been obtained by a plasma-sputter type of negative heavy ion source.[7]

One of the difficulties for using intense negative ion beams is to transport efficiently such low energy beams extracted from the ion sources. There is a strong space charge force in such intense negative ion beams and the emittance of the beam is commonly deteriorated by it. The low energy beam transport system(LEBT) which transports the beam from the intense negative ion sources to the next accelerators such as an RFQ or a tandem accelerator is very important. In order to overcome this problem, a continuos strong focusing beam transport is preferred and various schemes have been proposed and tested. [8][9] [10]

Recently, we have perceived a variable field permanent quadrupole magnet(VFPQM) and developed a LEBT system for intense negative heavy ion beams using four VFPQMs. In this paper, a design of the VFPQM, and characteristics and performance of the LEBT system using VFPQMs are described. A preliminary result of the beam emittance measurement for a negative Cu ion beam in this system is also presented.

II. VFPQM

The VFPQM used for our LEBT system is based on the design of the VFPQM which was developed by Barlow for the SSC IMS.[11] This type of the VFPQM was conceptually proposed by Halbach.[12]

The Quadrupole field is shaped by the four ion poles, and the field strength can be adjusted by rotating a 90 degrees of the outer ring of the magnet material which also forms a quadrupole field. Since the LEBT system using this VFPQM aims to transport the various negative ion beams from mass = 1(hydrogen) to mass = 197(gold) ions whose energies are about 60 keV at the maximum, the field gradient strength of the VFPQM has to be widely changed from 1.56 T/m to 42.9 T/m.

Since the required maximum field gradient is quite high and also the machining feasibility is requested, it was decided to use the PrFeB magnet material.[13] This material has a high remnant field(BH_{max} = 29 MGOe) which is almost same as the NeFeB or Sm Co magnet, but contrary from them, this material is processed for producing with hot rolling. Therefore, an ordinary machining procedure like drilling and tapping can be used to treat it, which is very nice for our purpose.

The 2-dimensional program code, PANDIRA, was used to design the magnet. The calculated field lines where the two extremes of the magnetic field strength can be produced by a 90 degrees rotation of the outer ring of magnet martial. The calculated maximum field gradient is 48 T/m and the minimum one is less than 0.3 T/m.

The LEBT system in our case comprises the four VFPQMs as described later. The length of each VFPQM is 140 mm. Figure 1 shows the measured magnetic field strength at the position of 8 mm away from the center as a function of the rotating angle of the outer ring. As can be seen from this figure, the magnetic field strength can be changed smoothly by rotating the outer ring.

Figure 2 shows the variation of the magnetic field strength as a function of the position from the bore center when the outer ring

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[*] on leave from Nissin High Voltage Co.

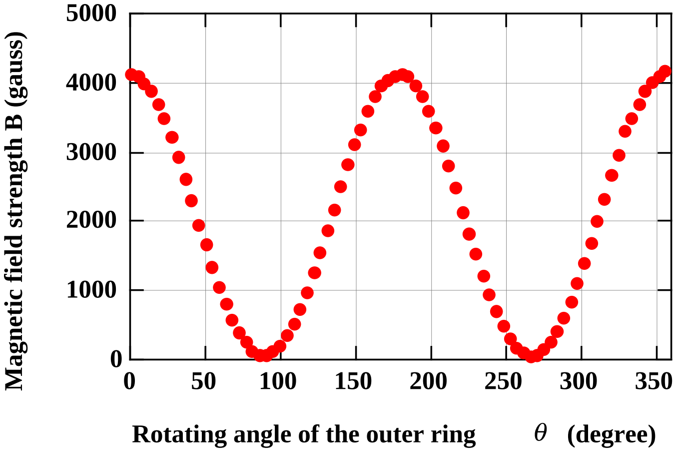


Figure. 1. Measured magnetic field strength at the position of 8 mm away from the center as a function of the rotating angle of the outer ring.

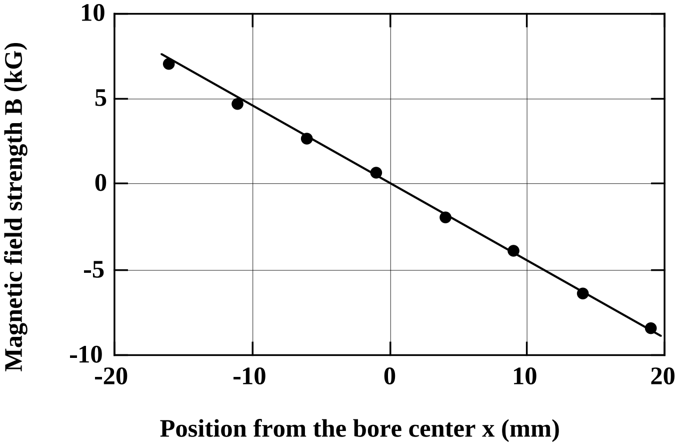
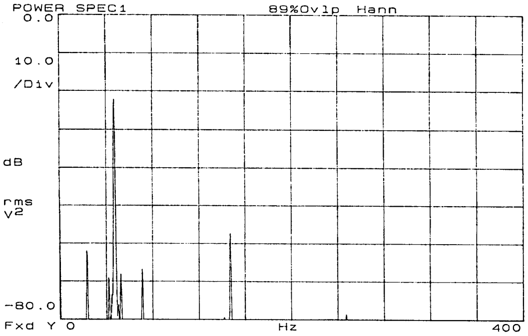


Figure. 2. Variations of the magnetic field strength as a function of the position from the bore center when the outer ring was set to have a maximum magnetic field at the pole tip. The measured maximum field gradient was 46 T/m.

was set to have a maximum magnetic field at the pole tip. The measured maximum field gradient was 46 T/m which is about 5% less than the 2-D calculated value. This is probably caused by the leakage of the magnetic field at the both ends.

The higher order multipole components of the magnetic field in this VFPQM such as 8-pole, 12-pole and so on, have been measured with a harmonic method using rotating coils. The diameter of the rotating coil was 25 mm. Figure 3 shows typical result of the measurement for the higher order magnetic field components. This figure presents for the case that it was rotated by 60 degrees from the maximum position. As can be clearly seen from the result, the 12-pole components were less than 10^{-3} compared with a fundamental 4-pole components. This might be good enough for transporting the beams without having serious aberrations due to the non-linear higher order components.



(b) θ = 60 °

Figure. 3. Typical result of the measurement for the higher order magnetic field components. This is the case that the outer ring of the VFPMQ was rotated by 60 degrees from the maximum position.

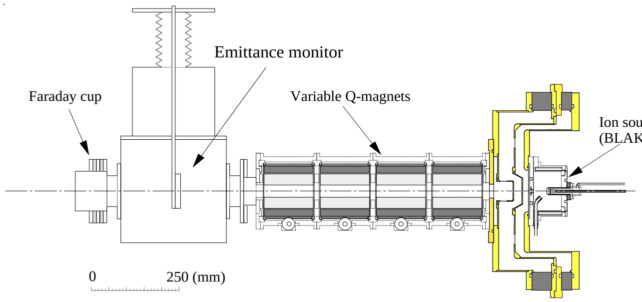


Figure. 4. Schematic configuration of the LEBT system

III. LEBT

The LEBT system consists of the four VFPQMs. The total length of the system is about 640 mm. A schematic configuration of the LEBT of the setup are shown in figure 4.

The negative ion source, BLAKE-V[14], was attached at the front of the LEBT system. The size of the anode hole in the ion source is 5 mm in diameter and the maximum available extracted beam current is about 1 mA in pulsed mode operation for negative copper ion beam. The negative ions generated by the ion source is extracted by two electrodes and the maximum beam energy allowed in the electrode system is about 60 keV. The vacuum in the beam extraction region is evacuated by a 1500 l/s turbo- molecular pump. The operating vacuum pressure was about 1×10^{-5}Torr. There is an optional gas feeding system in this region. A amount of Xe gas can be introduced into the beam extraction chamber through it and efficient space charge neutralization is expected.

The beam optics in this LEBT system was estimated with a multi-purpose accelerator design code ”SAD”. Because of the strong lens action at the anode hole which may be largely affected by the sheath condition at the plasma surface, it is rather difficult to estimate the beam emittance configuration before ex-

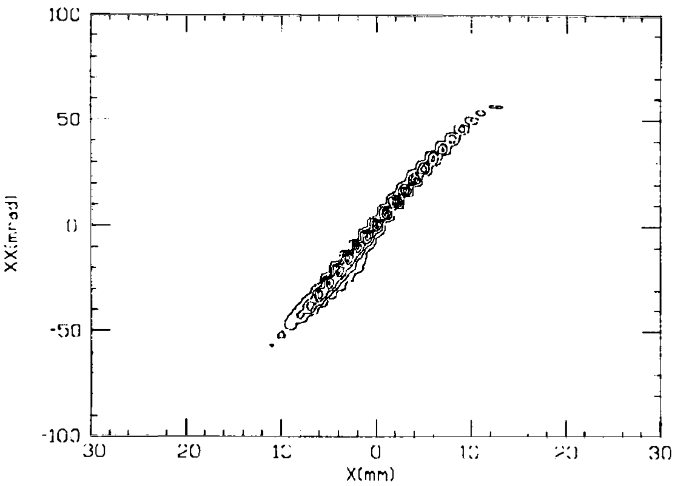


Figure. 5. The measured beam emittance at the designed value of the magnetic field strength of each VFPQM.

periment. In the beam optics calculation with SAD, the beam emittance configuration at the front of the LEBT was assumed to be an up-right shape. The space charge force was not included in this calculation. No electric lens is used in the system, therefore, complete space charge neutralization would be expected in areal beam situation by introducing an small amount of Xe gas. Electric lens such as einzel lens sweeps out the low energy positive ions produced by ionization, which are useful for neutralizing a space charge potential in the negative ion beam. Because there are four VFPQMs, the beam configuration can be adjusted arbitrary independently in 2-D(horizontal and vertical) phase space within acceptance limited by a inner diameter of the vacuum chamber of the beam transport line. A typical acceptance for 60 keV H^- beam in the present LEBT is about 0.74 πmm.mrad, which is normalized by bg and for 60 keV Cu^- beam is about 0.093 πmm.mrad.

IV. Beam Test

Beam test has been done with negative copper ion beams from the BLAKE-V ion source. The ion source was operated in pulsed mode and the pulse width and the repetition rate were 400 msec and 20 Hz, respectively. The beam was extracted from the ion source at the positive voltage of about 20 kV and the total energy of the beam was about 40 keV. The beam current through the system was measured with a Faraday cup placed at the position of 40 cm away from the exit of the system.

The beam emittance in the vertical direction was measured at the position of 20 cm away from the exit of the final VFPQM. The measured beam emittance when the magnetic field strength of each VFPQM was set to be a design value is shown in figure 5. The Cu^- beam of about 500 μA measured by another Faraday cup after the emittance monitor was successfully transported.

The measured emittance configuration is somewhat different from the calculated one. It is probably because the actual beam was more convergent at the entrance of the LEBT compared to the beam emittance assumed in the calculation.

V. Summary

A low energy beam transport (LEBT) with four variable field permanent quadrpole magnets(VFPQM) has been developed for the negative ion beams. The magnetic field gradient of the VFPQM was able to be varied from almost zero to 46 T/m. The 40 keV Cu^- ion beam was well transported by the LEBT.

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