HELICAL ELECTRO-STATIC QUADRUPLE FOR INTENSE NEGATIVE HEAVY ION BEAMS

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abstract

An intense low energy Cu- ion beam extracted from the plasma-sputter type of negative heavy ion source(BLAKE ion source) was focused and transported nicely by the helical electro-static quadruple(HESQ) system. In a preliminary experiment,it was observed that the emittance growth due to space charge of the beam seemed to be small at the exit of the HESQ.

Introduction

Recently, intense negative heavy ion beams have been generated by the plasma-sputter type of negative heavy ion source which was originally developed at National Laboratory for High Energy Physics(KEK).[1] This type of ion source is based on the surface-plasma interaction. More than 100mA of Cu- ion beam has been obtained so far in pulsed mode operation and even in DC beam operation, 10mA Cu- or Au- ion beams have been obtained. This type of negative ion source has a nickname of BLAKE ion source.

In order to transport efficiently these high current negative heavy ion beams at a relatively low beam energy of several tens keV, there is a big difficulty concerning to the beam emittance growth which is caused by a large space charge force in the beam. This problem could be overcome if the beam is transported with a strong and continuous focusing device. As for a focusing device, an electric lens is suitable compared with a magnetic lens for intense negative heavy ion beams because the charge state of ion is just one. An electro-static einzel lens has been frequently used in the beam injection line of the tandem electrostatic accelerators. However, the einzel lens is a second order lens and its focusing force is not so strong.

Recently, Rapparia has developed a helical electro-static quadruple(HESQ) for focusing and transporting an intense H^+ or H^- ion beam from the ion source to the RFQ.[2] The HESQ is a first order electro-static lens and it has a strong and continuous focusing force. Therefore, the HESQ is also useful for transporting a low energy and high intensity negative heavy ion beam without having a large emittance growth due to the space charge of the beam. At KEK, we have developed the HESQ for the intense negative heavy ion beams from the BLAKE ion source and more than 1 mA Cu^- ion beam of which energy was 16 keV was transported by the HESQ.

Emittance growth

Emittance growth due to space charge in the inhomogeneously distributed low energy ion beams can be estimated analytically and is expressed in the following equation.[3]

$$\varepsilon_f / \varepsilon_i \approx \left[1 + \frac{K(I) R^2}{2 \varepsilon_i^2} \frac{U_i}{W} \right]^{1/2} \qquad (1)$$

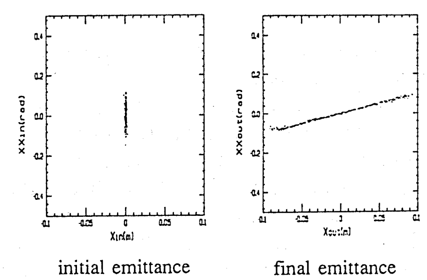
Here, R the averaged beam radius and

$$K(I) = \frac{2I}{I_0 (\beta\gamma)^3} , \qquad (2)$$

where I_0 is the normalized pearveance. When the charge distribution in the beam is gaussian, U_i / W in eq.(1) is 0.154. Clearly, seen from this equation, in order to reduce the emittance growth, an average beam radius during beam transportation should be kept as small as possible. Thus, a beam transporting system which has a strong and continuous focusing force is favorable. However, as described above, the ordinary beam transporting system for the negative heavy ion source, which is commonly used in the tandem electro-static accelerator, consists of an einzel lens and a relatively long drift space. In this system, it is rather difficult for intense negative heavy ion beams to avoid the emittance growth. In Fig. 1, growth of the rms emittance when an Au^- ion beam of 1.6mA is transported in the one einzel lens system at the beam energy of 25 keV, which is simulated by a PIC(particle-in-cell) computer code of BTRACM, is presented. The calculated emittance growth becomes more than five and it is obvious that the ordinary beam transporting system with one einzel lens and a drift space is inadequate for transporting intense negative heavy ion beams. Of course, if space charge of the beam is neutralized by feeding a gas into the beam transport system, the emittance growth can be reduced. But, this technique may be inadequate for negative heavy ions because electron stripping by the feeding gas must be severe.

Design of the HESQ

Calculations of the beam behavior in a helical quadruple system have been performed by several authors.[4][5][6][7][8][9] At KEK, based on these calculations, the TRACE-3D code [10] has been modified and used for designing the HESQ for negative heavy ion beams. The basic beam parameters used in designing the HESQ are summarized in Table 1.



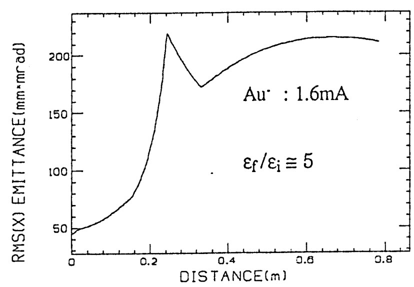


Fig.1 Calculated rms emittance growth for Au^- ion beam

Table 1 Beam Parameters

Beam energy	15~30keV
Ion species	$Cu^-(Au^-)$
Beam current	2mA for Cu^-
Beam emittance	<0.2 mm.mrad(90% normalized)

The mechanical structure of the HESQ is shown in Fig.2. The HESQ is divided into the same four sections and each section is electrically insulated for others. The length of each section is 112mm and the bore radius and one pitch length are 15mm and 100mm, respectively. The rods in helical shape are made of copper and each rod is supported by an insulator. In order to keep a good accuracy in construction, a small pin for each rod was driven through the insulator. The measured displacement errors were less than +- 0.2mm. We have used only three sections of them so far in the preliminary experiment because the the present vacuum chamber in which the HESQ was placed did not have an enough space for the four sections.

Figure 3 shows the calculated beam behaviors in the HESQ. The calculation was performed under the condition that the Cu^- ion beam energy was 16 keV, the rod voltage was 4 kV for all three sections. As for the beam intensity, zero beam current was assumed in this calculation because the TRACE-3D could treat only a linear problem. The TRACE-3D is useful for the beam with a homogeneous distribution if the space charge effect of the beam has to be in consideration. It is obvious that practical beam is not homogeneously distributed and the emittance growth due to a nonlinear effect in the inhomogeneously distributed beam can not be estimated by the TRACE-3D.

In order to examine the beam behaviors of high current and inhomogeneously distributed ion beams, a PIC(particle-in-cell) simulation code whose name is BTRACM has been developed. Figures 4-a ,4-b and 4-c show the results of the beam simulations performed by this code for H^-, Cu^- and Au^- ion beams, respectively.

In these simulations, the charge distribution in each beam is assumed to be gaussian and the beam intensity and energy were chosen as 1mA and 16 keV, respectively. The other parameters were same as those used in the TRACE-3D calculations.
Apparently, the beam size in the HESQ for the H^- ion beam keeps almost constant and no emittance growth is observed. For the Cu^- ion beam, the emittance growth is also negligible small, but, the beam size is somewhat increased at the middle point of the HESQ. For the Au^- ion beam, the beam size becomes much larger than that for the Cu^- ion beam and the beam hits the HESQ rods. It should be also noted that in the HESQ system, the beam emittance projected to a horizontal or vertical plane is used to be large except near by a focal point because of the coupling between two directions.

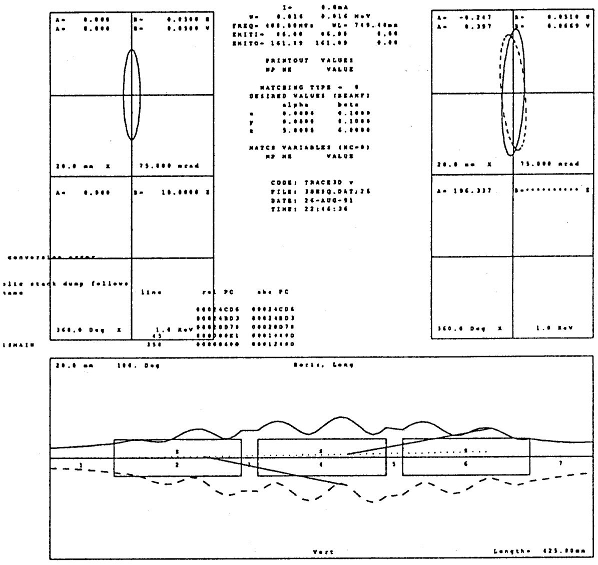


Fig.3 Calculated beam behaviors in HESQ.

Beam test with Cu^- ion beam

A preliminary beam test of the HESQ has been carried out with a Cu^- ion beam from the BLAKE-V negative heavy ion source. The BLAKE-V negative heavy ion source is a very compact ion source develpoed for SIMS. It is able to produce 1 mA Cu^-, Au^- ion beams in pulse and DC mode operations. The details of this ion source are presented in this symposium.[11] In this preliminary experiment, the BLAKE-V ion source was operated in pulse mode of which pulse duration and repetition rates are 500μsec and 20Hz, respectively. The ion source was placed at a high voltage station applied a potential of -16 kV and the beam was extracted by a single electrode which was grounded. The HESQ was placed right after the extraction electrode. The distance between the extraction electrode and the HESQ was about 5 cm. The emitttance monitor was placed at a distance of 4.5 cm away from the exit of the HESQ and a vertical direction emittance was measured . The total beam current transmitted trough the HESQ was measured by a Faraday cup which was placed at about 25cm away from the emittance monitor.

The measured beam emittance for the Cu^- ion beam when the rod voltage of the HESQ is varied is shown in Fig.5.
The beam intensities transmitted through the HESQ are also pre-

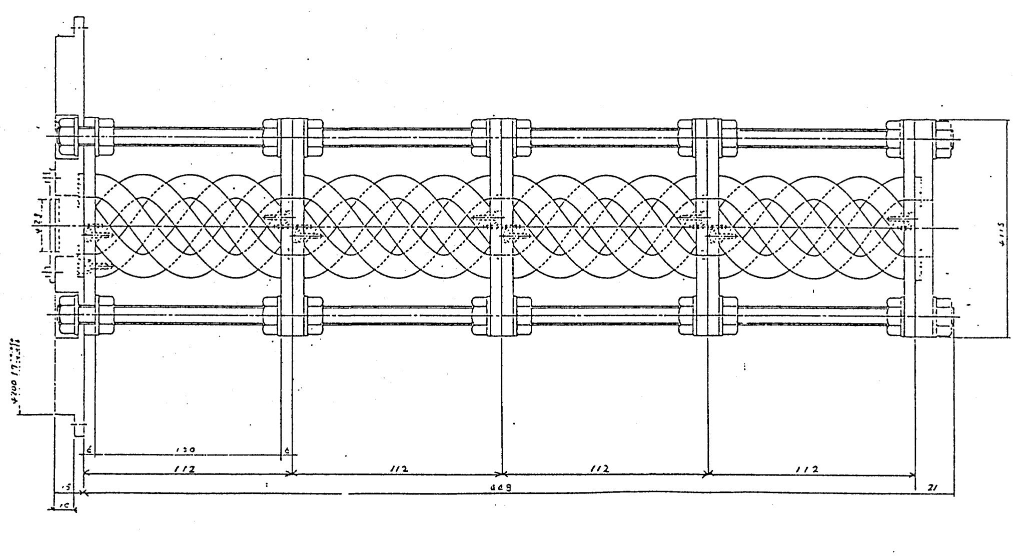


Fig.2. Schematic layout of the HESQ

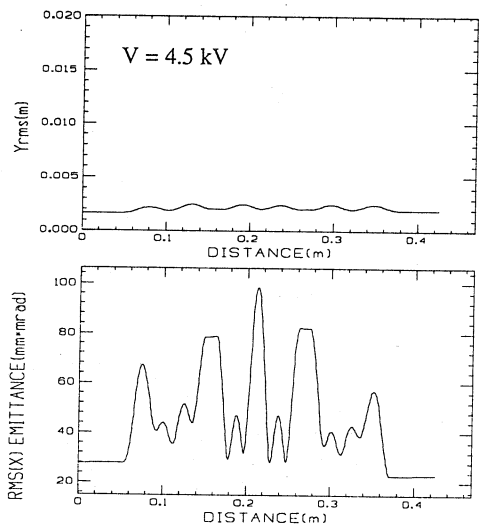


Fig.4-a Beam simulation for H⁻ ion beam.

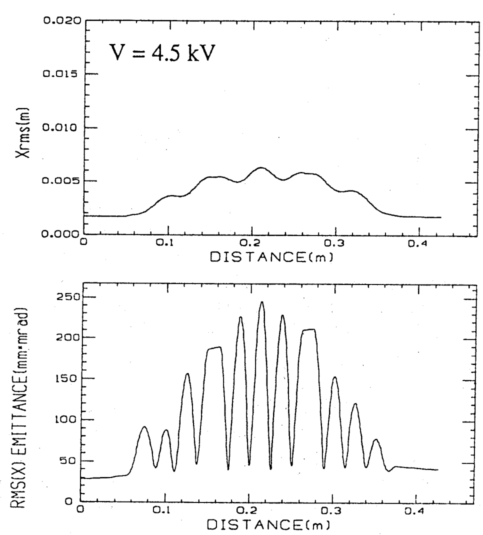


Fig.4-b Beam simulation for Cu^{-} ion beam.

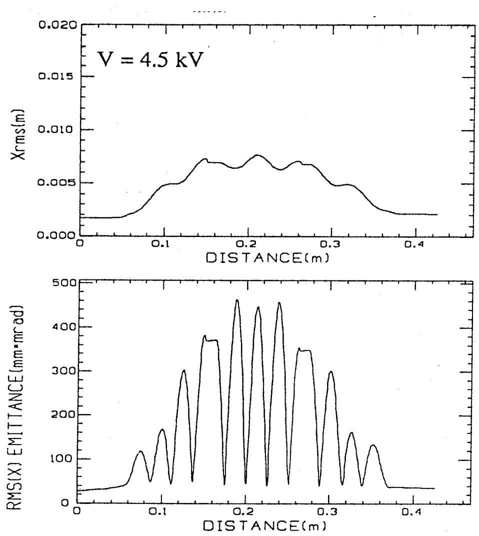


Fig.4-c Beam simulation for Au^{-} ion beam.

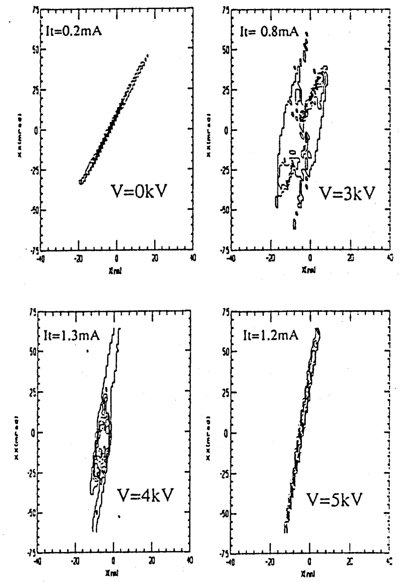


Fig.5 Measured beam emittance for Cu^{-} ion beam.

sented for the different rod voltages in the figure. When the rod voltage was 4 kV, the beam looked to be focused well and the 90 % normalized emittance was about 0.1 mm.mrad. In the previous experiment using a single einzel lens instead of the HESQ, we observed that the 90% normalized emittanee for the 1.5mA Cu^{-} ion beam was about 0.3 mm.mrad. Of course, we have not measured both emittances at the exactly same beam conditions, however, it may be pointed out that the HESQ worked nicely for transporting an intense Cu^{-} ion beam without a large emittance growth compared with the single einzel lens system.

Conclusion

A helical electro-static quadruple(HESQ) system was designed and constructed for transporting intense negative heavy ion beams from the BLAKE-V negative heavy ion source. In a preliminary experiment, the Cu^{-} ion beams whose intensities were more than 1mA have been successfully transported and it was found that the HESQ was useful for transporting intense negative heavy ion beams without large emittance growth.

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