HELICAL ELECTRO-STATIC QUADRUPOLE FOR INTENSE NEGATIVE HEAVY ION BEAMS

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Abstract

A helical electro-static quadrupole(HESQ) for focusing low energy and high current negative ion beams has been developed at KEK. Various negative ions such as Cu^- and Au- ion beams of more than several mA have been transported and focused with the HESQ. Comparison of the focused beam emittance between measurements and calculations are presented.

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 negative heavy ion beams such as Cu^-,Au^- and so on have been obtained so far. This type of negative ion source has a nickname of BLAKE ion source. In order to transport these high current negative heavy ion beams efficiently at a relatively low beam energy of several tens keV, there is a big difficulty concerning to the beam emittance growth 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. Because the charge state of negative ion is unity, an electro-static lens is rather easier than a magnetic lens. An electro-static einzel lens has been frequently used so far, but the einzel lens is a second order lens and its focusing force is not so strong.

Recently, Rapparia has developed a helical electro-static quadrupole(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 which is also useful for transporting a low energy and high intensity negative heavy ion beam.

At KEK, we have developed the HESQ for the intense negative heavy ion beams from the BLAKE ion source and more than several mA of low energy negative heavy ion beams such as Cu^- and Au^- ion beams.

Design of the HESQ

Calculations of the beam behavior in a helical quadruple system have been performed by several authors.[3][4][5][6][7][8] At KEK, based on these calculations, the TRACE-3D code [9] 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.

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.1. 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 2 shows the beam behaviors in the HESQ calculated by the modified TRACE-3D. The calculation was

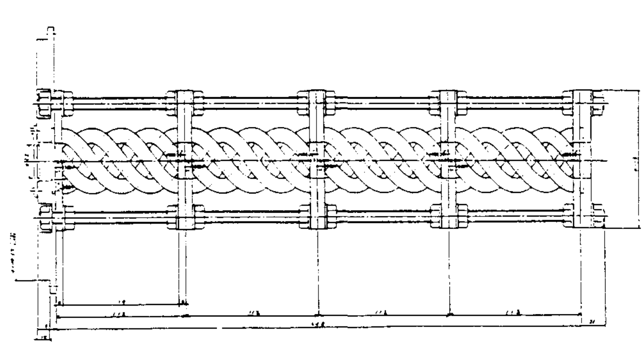

Fig.1. Schematic layout of the HESQ

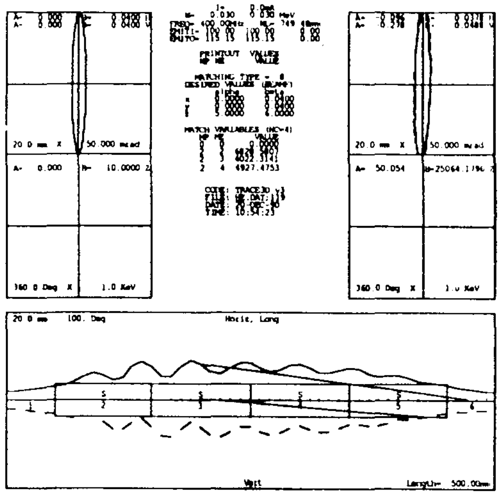

Fig.2 Beam calculation in HESQ by TRACE3D.

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 off center beam in the HESQ is, in principle, longitudinally accelerated or decelerated and this causes an aberration. The aberration effects of the HESQ are not inculded in the above TRACE-3D calculations.

Beam behaviors in the HESQ

In order to examine the behavior of high current and abberative beam in the HESQ, a PIC(particle-in-cell) simulation code whose name is BTRACM has been developed. Figures 3 show the results of the beam simulations performed by this code for Cu^- ion beam for various rod voltages. 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 21 keV, respectively. The other parameters were same as those used in the TRACE-3D calculations. 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.

A beam test of the HESQ has been carried out with Cu^- and Au^- ion beams in order to compare with the beam simulations. The experimental set-up is shown in Fig. 5. The low energy Cu^- and Au^- ion beams was extracted from the BLAKE-V negative heavy ion source, which has been developed at KEK and more than 1 mA Cu^- and Au^- ion beams are obtained from this ion source both in pulse and DC mode

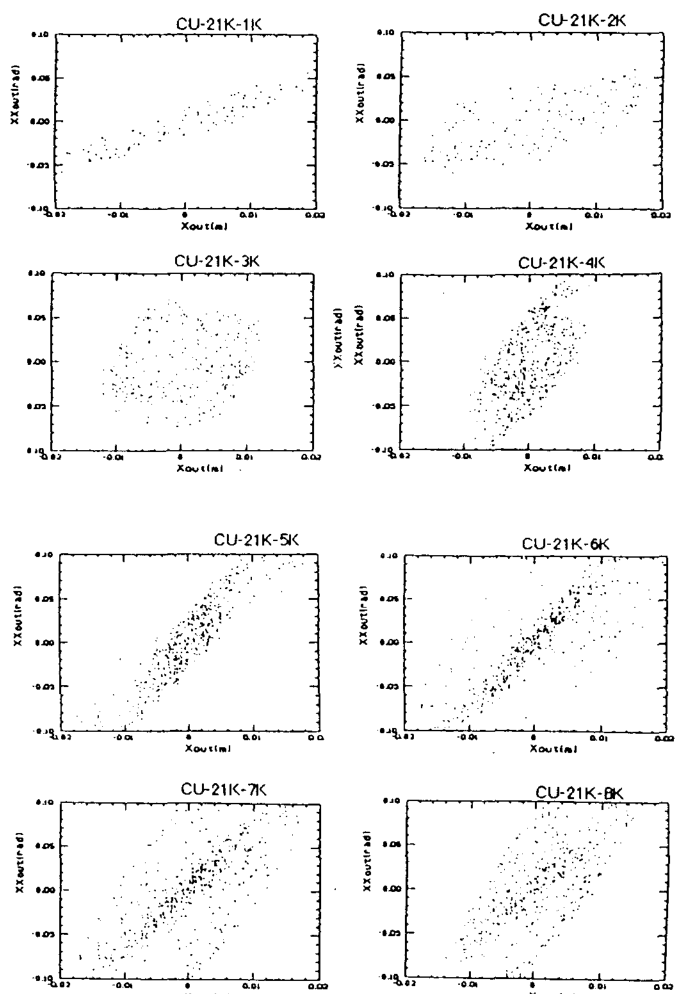

Fig. 3 Calculated beam emittance for 1mA Cu^- ion beam by simulation code of BTRAC.

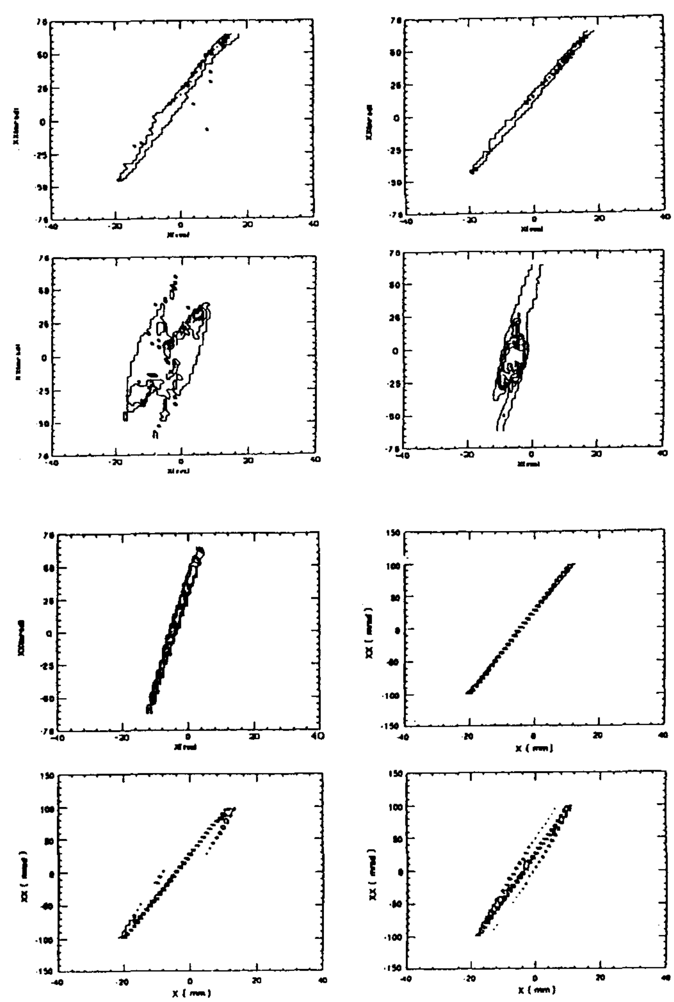

Fig.4 Measured beam emittance of Cu^- ion beam.

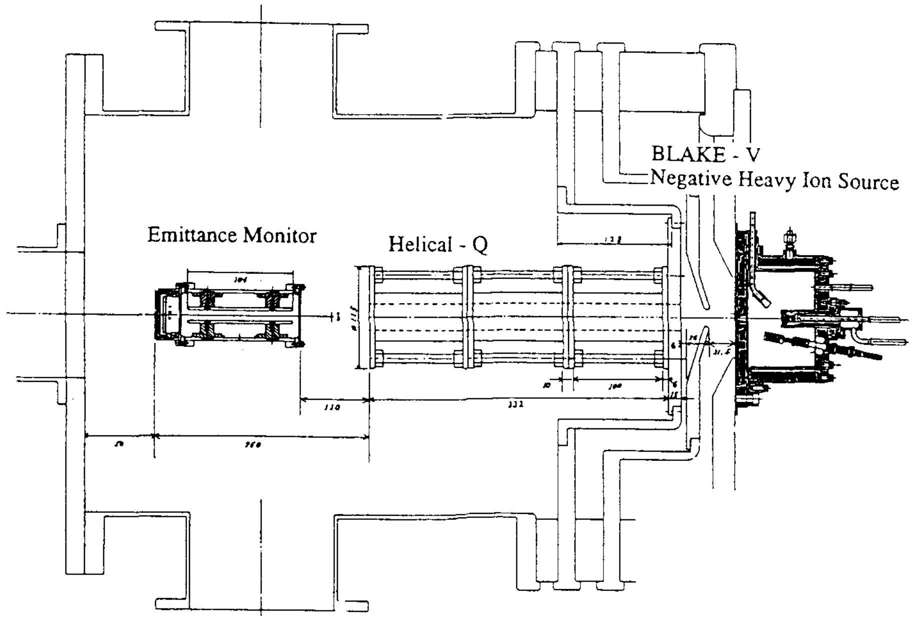

Fig. 5 Experimental setup of emittance measurement.

operations. In this experiment, the BLAKE-V ion source was operated in pulse mode and the pulse duration and repetition rate are 500μsec and 20Hz, respectively. The ion source was placed at a high voltage station 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 vertically at a distance of 4.5 cm away from the exit of the HESQ. 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 for various rod voltages of the HESQ are shown in Fig. 4. Compared with the beam simulations shown in Fig. 3, good agreement between the experiment and the calculation has been observed. At the beam focusing point, the measured 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 emittance 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 can be pointed out that the HESQ works nicely for transporting an intense negative heavy ion beams such as Cu^-, without having a large emittance growth.

Conclusion

A helical electro-static quadrupole(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, more than 1mA of Cu^- and Au^- ion beams 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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