Transport Properties of a Discrete Helical Electrostatic Quadrupole

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Abstract

The helical electrostatic quadrupole (HESQ) lens has been proposed as a low energy beam transport system which permits intense H^- beams to be focused into an RFQ without seriously increasing the beam's emittance. A stepwise continuous HESQ lens has been constructed[1], and preliminary tests have shown that the structure does provide focusing. In order to understand the transport properties of this device, further detailed studies have been performed. Emittances were measured 3.5 cm from the end of the HESQ at two different voltages on the HESQ electrodes. A comparison of these experimental results with a linear model of the HESQ beam transport is made.

I. INTRODUCTION

Modern accelerators usually require intense charged particle beams to be produced by the ion source and efficiently injected into the first stage of acceleration, typically an RFQ. The problem of capturing the beam from the ion source and focusing it into the acceptance of the RFQ has been the subject of considerable recent development. During transport, space charge forces cause the beam emittance to increase while the build up of neutralization in the back ground gas causes emittance to rotate. Both of these problems can be solved by using a purely electrostatic transport system. The following paper describes a measurement of the emittance of a Helical Electrostatic Quadrupole (HESQ) lens and compares it to a simulation of the transport properties of the lens.

II. DESCRIPTION OF HESQ STRUCTURE

The discrete HESQ structure was originally developed by Raparia[2], with construction and initial testing being done by Tompkins[3]. The structure consisted of thirty eight short quadrupole cells arranged to form a helix. The basic quadrupole cell consisted of four 0.5 cm thick stainless steel electrodes held in place by a G-10 insulator. The open bore of the quadrupole cell was 26 mm. A notch on the outside of each G-10 insulator was used to provide rotational alignment. Each cell was rotated 18 degrees from the previous one yielding a helical structure with a pitch of 36 deg/cm. The thirty eight unit cells were divided into four segments: three segments with ten cells each, and one segment with eight cells. The segments were separated by thin G-10 disks. The positive and negative voltages of each segment could be independently varied for flexibility during tuning.

A tandem faraday cup was used to initially show that the lens was capable of transmitting 55% of a low current H^- beam into the acceptance of an RFQ, although the emittance was not determined[1]. Furthermore, operational experience showed that the presence of the G-10 posed some voltage holdoff problems when the source was operated for extended periods of time. First, cesium from the ion source would deposit on the inside of the insulator causing sparking between the positive and negative electrodes along the inner surface. Second, gas seemed to accumulate in the voids between the insulator disks providing a break down path to the grounded outer supports of the structure. Numerous tracks were observed extending from the electrodes to the grounded support structure.

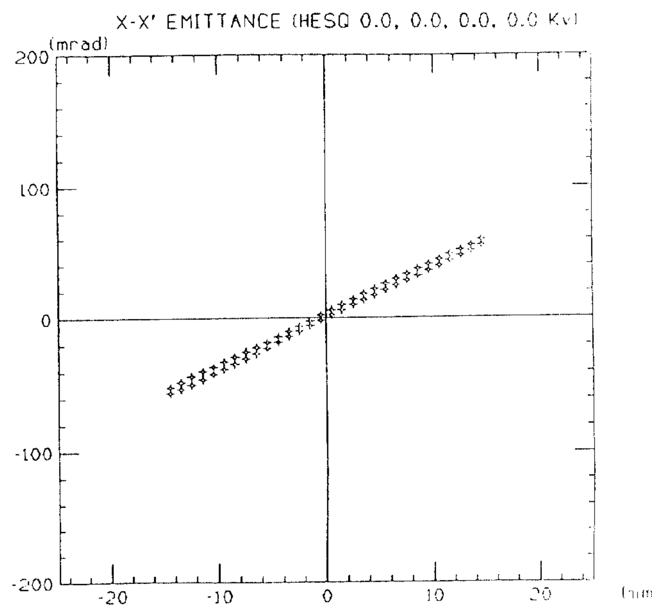

Figure 1. Emittance of beam drifting through HESQ.

The problems described above were overcome by redesigning the electrode structure while maintaining the same basic discrete helical structure as in the original design. The G-10 insulators were removed and the disks from each cell were welded to those in adjacent cells to form a self supporting structure. The four electrodes comprising each segment were located by G-10 insulators placed at the end of the segment. The inter-segment insulators were eliminated to provide an insulating vacuum between segments. This permitted better radial pumping than the original structure; however, the placement accuracy for each individual electrode disk decreased. This modification did not completely eliminate sparking between electrodes when the pressure in the vacuum chamber rose into the mid 10^{-6} Torr range.

III. EMITTANCE MEASUREMENTS

The emittance was measured with an electrostatic emittance scanner[4] located 3.5 cm from the output end of the HESQ. The plate voltages could be swept in one of two different modes: the plate voltage would be held constant during the beam pulse, or the voltage could be swept by a 2.5 kV high voltage amplifier. The current incident upon the front face of the scanners could be measured to provide pulse-to-pulse normalization of the EES signal. The analyzed signal was recorded for later off-line analysis. In the current set of measurements, the voltage on the deflection plates was held constant during the pulse.

IV. RESULTS AND DISCUSSION

In order to estimate the transport properties of the lens and show focussing, emittance data were collected for two HESQ conditions. First, the voltage on all of the electrodes was set to zero to allow the beam to coast through the lens. A second set of measurements was made with 8.5 kV on all of the electrodes which avoided complications in the boundary regions between different segments. The beam was provided by a magnetron H^- ion source whose current was 6 mA, the normalized horizontal and vertical emittances were 0.29 π mm–mrad and 0.36 π mm–mrad, respectively[1,3].

Figure 1 shows the horizontal 100% emittance contour when the beam is allowed to drift through the lens. The apparent cut-off of the contour at large radii is due to the 26 mm diameter aperture of the HESQ. The vertical emittance has a similar shape and is not provided here.

Figure 2 shows the horizontal 100% emittance contour when the electrode power supplies are all set to 8.5 kV, while Figure 3 shows the vertical emittance. The emittances shown in Figures 2 and 3 have very different shapes and possibly arise from non-linearities introduced by the fraction of the beam which goes out to large radii during transport.

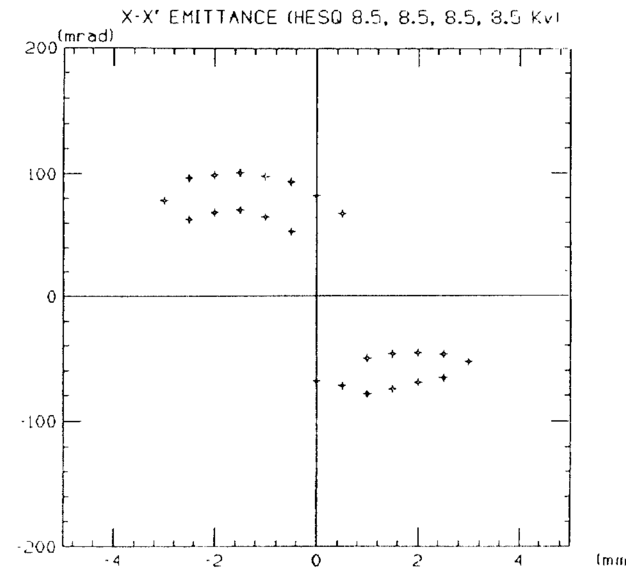

Figure 2. Measured horizontal emittance when the HESQ electrodes are set at 8.5 kV

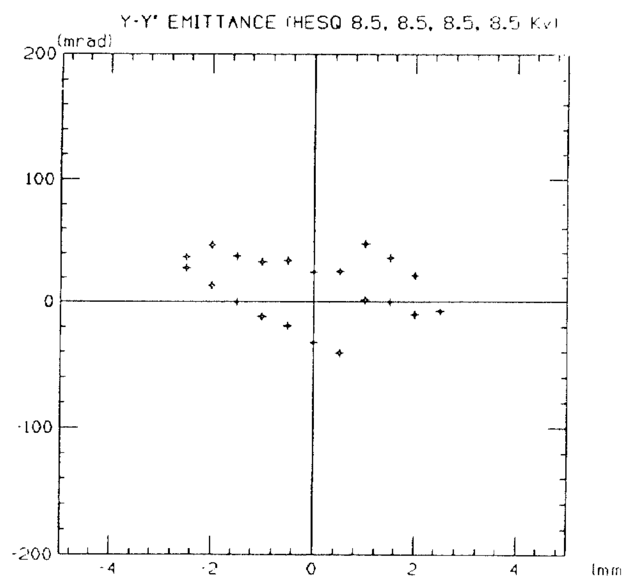

Figure 3. Measured vertical emittance when the HESQ electrodes are set to 8.5 kV.

The performance of the HESQ was simulated using the program HRK developed at TAC. The input emittance for this code was the measured ion source emittance obtained by Tompkins[3]. This tracking code analytically tracks the particles through a continuous with linear space charge forces and a linear fringe field at the ends. A calculation of the fringe field with RELAX-3D showed that the fringe field has a tilt as one gets closer to the first quadrupole cell; therefore, the first quadrupole in this model is skewed 45 degrees to simulate this behavior. Figure 4 shows the simulated horizontal emittance when all of the electrode voltages are set to 8.5 kV. Figure 5 shows the simulated vertical emittance under the same conditions. A comparison of these simulated emittances with the measured emittances above (Figures 2 and 3) shows reasonable qualitative agreement in both beam size and orientation; however, the distortions in the measured emittances are not reproduced by the simulations. This is because the model assumes that the electrodes create a pure quadrupolar electric field.

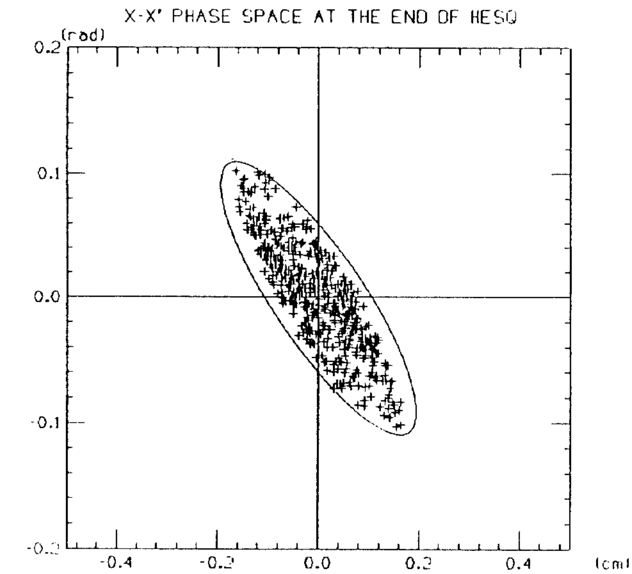

Figure 4. Simulated horizontal emittance for the HESQ.

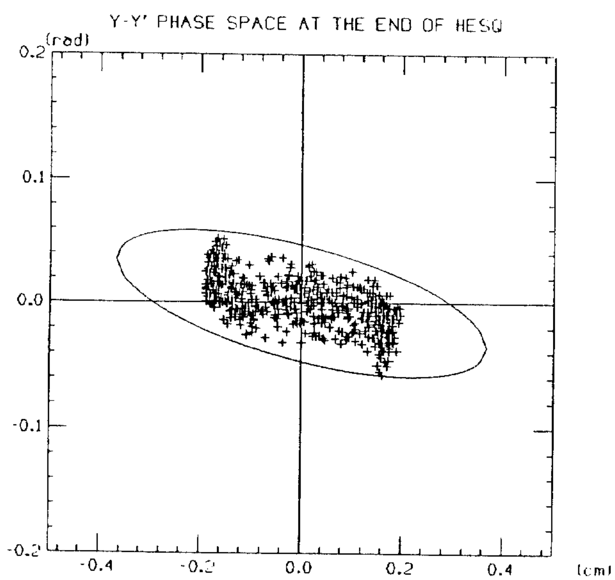

Figure 5. Simulated vertical emittance after HESQ.

IV. CONCLUSIONS

The HESQ is a promising structure for transporting intense low energy ion beams from an ion source to an accelerator. The discrete structure seems to introduce aberrations into the beam, presumably from the beam filling a large part of the open aperture of the lens. The general agreement between the measured and simulated emittances show that the fringe field has a slight tilt which must be included in any simulations. Finally, the first HESQ lens has been shown to provide focussing although there is still considerable work to be done to bring this new technology to a mature state.

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V. REFERENCES

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