Test of the Transport Properties of a Helical Electrostatic Quadrupole and Quasi-Octupole*

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Abstract

A third-generation continuous helical electrostatic quadrupole (HESQ) lens has been built and tested. The new HESQ is 21.5 cm long and has a 3.6 cm diameter aperture. The HESQ has been tested under two separate conditions: with a pulsed 25 keV, 0.5 mA proton beam; and a 25 keV, 10 mA proton beam. The input emittance was fixed using a multi-aperture collimator. A comparison is made between experiment and numerical simulations for a wide variety of operating conditions. A second possible operating mode is the quasi-octupole mode[1] which offers significantly reduced aberration when compared to the quadrupole mode. The results of preliminary tests in this operating mode will be presented.

I. Introduction

The helical electrostatic quadrupole lens was originally proposed by Raparia[2] in 1990 as a way to transport a low-energy H^- beam from an ion source to a radio-frequency quadrupole accelerator. Several "proof-of-principle" tests[3] had been performed using a discrete helical structure which showed that the basic principles of Raparia's design were valid. These tests had shown that the lens would provide relatively strong focusing. Numerical tracking studies of this early HESQ have shown that various types of beam shape deformations in phase space are observed, with chromatic aberration being the dominant cause of distortion.

A continuous-type HESQ was used by Mori et al.[4] in 1991 to focus a 1 mA beam of Cu^- ions with much less emittance growth than was observed when an einzel lens was used in a similar test. Mori's test with copper ions was significant in demonstrating the potential of the HESQ to transport intense negative ion beams. Encouraged by KEK's success, we had designed a new continuous-type HESQ in January 1992. A summary of the design was presented in Reference 1. The present paper presents a summary of a series of in-beam tests during the fall and winter of 1992/93.

II. Quadrupole Operating Mode

A continuous HESQ was designed using both the experience gained from both experimental studies of the discrete HESQ, and from numerical simulations of it. Table 1 presents a summary of the basic design parameters.

For the testing program, a duoplasmatron proton source[5] was used to produce the ion beam. The duoplasmatron source had a single gap extraction system capable of being biased up to 25 kV. The extractro was followed immediately by an einzel lens operated in decel mode. A 2.5 cm diameter collimator mounting flange was located 20 cm from the einzel lens. Inside the collimator mounting flange, we were capable of installing a multi-aperture set of slits to generate a controlled emittance which was somewhat independent of the source's operating condition. For large diameter beams, this set of slits was removed from the mounting flange. Immediately after the collimator was a zero-length faraday cup[6] constructed on a PC-board. The HESQ was mounted with the alignment of each of the four segments being independent.

Table 1. Parameters for third generation HESQ.

Number of segments	4
Length of segment	5 cm
Helical pitch	27 deg/cm
Gap between segments	5 mm
Rod radius	1.3 cm
Aperture	36 mm
Total length	21.5 cm

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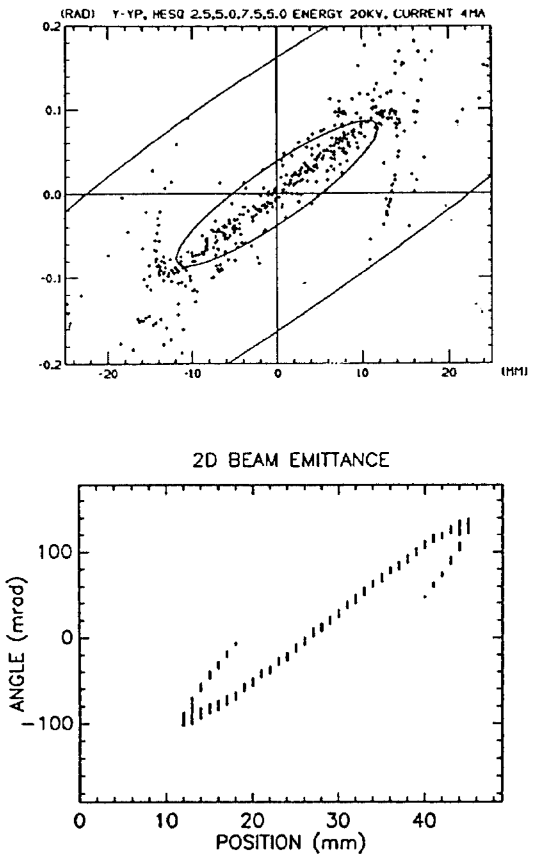

Figure 1 Comparison of numerical simulation (top) and experimental data (bottom) for a large diameter beam incident on the HESQ.

A. Large Diameter Beams

A large diameter beam of protons was injected into the HESQ. The emittance of the beam was measured without any voltage being applied to the HESQ. The electrode voltages were then set to 2.5, 5.0, 7.5, and 5.0 kV on first through fourth segments, respectively. The beam emittance was then measured one more time. (The other plane was not measured at this time due to a problem with the current pick-up in the emittance scanner: this measurement will be performed in the future.)

The results of an emittance measurement in one plane for a 30 mm diameter, 10 mA proton beam is shown in Figure 1a. A numerical simulation, which includes space charge, of the beam transport through the HESQ using the known initial source emittance is shown in Figure 1b. The qualitative agreement betweent the experiment and simulation show that we are properly including space charge in our calculation.

B. Low-Current Tests

A four-aperture collimator was constructed to simulate the emittance of the beam extracted from a magnetron ion source. The beam from the duoplasmatron was focussed onto the collimator. Due to the low acceptance of the aperture system, the beam was reduced from approximately 10 mA to 0.5 mA. This reduction in the intensity permitted us to examine the HESQ's transport properties when space charge was not a dominating factor.

A set of over 1000 low-current measurements were undertaken to map as much of the operating space as possible. The procedure followed in these measurements was similar to that used in Section A: the beam emittance was determined; voltage was applied to the HESQ electrodes; the final beam emittance was measured again. The results of a typical emittance measurement for both the X- and Y-planes are shown in Figure 2. The measured and calculated unnormalized beam emittances for this case are summarized in Table 2.

During the course of our measurements, we had noted that there was considerable steering as voltage was applied to the electrodes. After the measurements, we dis-assembled the HESQ and checked the alignment of the electrodes. We discovered that some of the electrodes were severely mis-aligned. This problem has been corrected, and a new set of measurements are underway.

Table 2. Measured unnormalized emittances in units of π mm-mrad.

	X	Y
Source	13.6	17.8
After HESQ	16.1	20.0
Calculated	24.7	40.3

III. Quasi-Octupole Operating Mode

The quasi-octupole operating mode for the helical electrostatic quadrupole structure was proposed in 1992 by Xiu et al.[1] The advantage of the quasi-octupole mode was that the lens would be able to transport higher currents with low electrode voltages. The HESQ was operated in quasi-octupole mode by connecting the four electrodes to a single power supply. The polarities of the power supplies for each segment were positive, and the potentials on the four segments were 4.0 kV, 10.0 kV, 7.5 kV, and 20.0 kV, respectively. A 25 kV proton beam was injected into the lens, and the output emittance was measured with the Allison-type electrostatic emittance scanner. We observed that we needed to apply 20 kV to the final electrode in order for the lens to focus the beam. This seems to imply the quasi-octupole mode for the operated as a thick einzel lens.

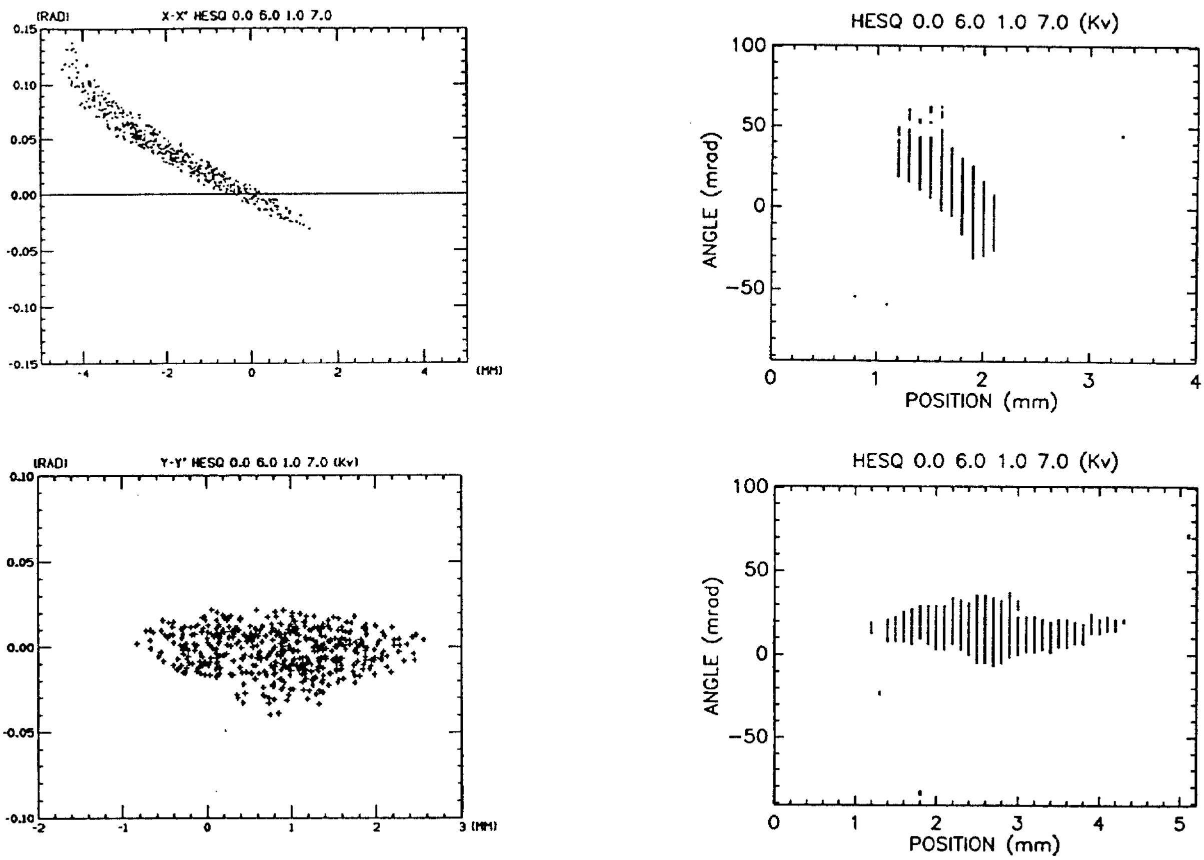

Figure 2 Measured and calculated emittances of a low-current proton beam transported through the HESQ. RIGHT: measured, LEFT: calculated

IV. Summary

Based on our experience with the first HESQ, we designed a new, continuous HESQ. The operating parameter space of the HESQ has been explored. There was some emittance growth of the beam as it passed through the lens; however, due to misalignments of the electrodes it is not clear how much the misalignments contributed to this growth. The quasi-octupole mode of operation did not provide the improved performance anticipated from numerical simulations.

V. Acknowledgements

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