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SPACE CHARGE LIMITS IN ESQ TRANSPORT SYSTEMS*

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This report describes the results obtained in a series of experiments done with a variety of different electrostatic quadrupole configurations, using the precision optical bench system described elsewhere in these proceedings.[1]

The performance of a quadupole transport system can be described by a generalized perveance P defined by the equation:

$$i_{max} = P\left(\frac{Z}{A}\right)^{1/2} V^{3/2} \left(\frac{r_Q}{L_{cell}}\right)^2$$

i_{max} is defined as the maximum current obtainable for fixed quadrupole and beam parameters as the quadrupole strength is varied. Other definitions for a generalized peveance could be used. For instance, a beam brightness criteria could be used. However, for all the cases which we have investigated to date the maximum brightness occurred near the maximum current.

The experiments were done for the most part with singly charged Argon ions (A = 40) with energies of 1 or 2 keV. By varying the beam energy, and observing the correct $V^{3/2}$ behavior, we had confidence that we were saturating the channel and were not limited at the ion source. We also made runs with Xenon to verify the $A^{-1/2}$ dependence.

One possible source of error in the experiments could be impurities in the beam. For a two-component mixture with a current ratio $i_1/i_2 = X$, one can correct with the following formula:

$$i_{1_{sc}} = i_{tot} \times \frac{\left(1 + X \left[\frac{A_2 Z_1}{A_1 Z_2}\right]^{1/2}\right)}{1 + X}$$

The impurity levels were measured with a magnetic analyzer. Typically the argon beams were over 98% pure. The principal contaminant seemed to be Ar^{++}. The Ar^{++} tended to be largest when the source was just turned on, and diminished as the source cleaned up.

The current limits determined here were produced with an ion source of the Ehlers type, using coated nickel mesh filaments. The beam current injected into the channel was sufficienlty great to saturate the acceptance. Fig. 1 shows the currents obtained using a 2 keV Argon beam. The parameters of the quadrupole channel were r_Q = 4.08 mm, L_{cell} = 38.1 mm and the quadrupole length was 13.7 mm.

The only experimentally determined numbers are the beam current, the quadrupole voltages and the beam size. Using this data as input into a computer code SCTRAN, it was possible to get plausible estimates of the tune shift, and hence the brightness of the beam. Fig. 2 shows the space charge factor $K = 1 - (\mu/\mu_o)^2$ and the brightness $B = i/\epsilon_{NT}^2$.

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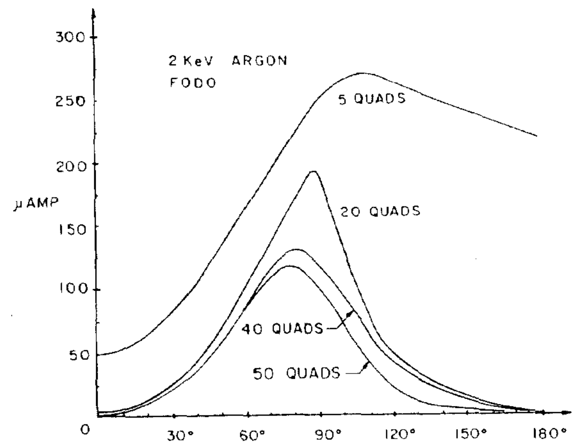

Figure 1

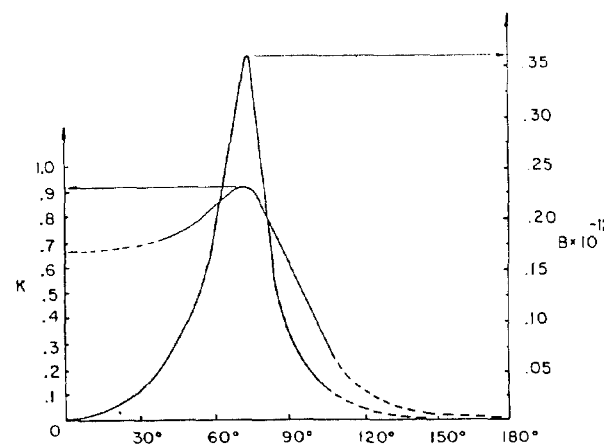

Figure 2

It is important to point out that the values for K and B obtained here are not necessarily the highest possible ones. They are the highest we have been able to achieve with our setup.

The question of "absolute" stability has not been answered here. We did one run with 50 quads and obtained a reduced current for the 80°-90° phase advance portion of the curve, but the same value at 60° as obtained with 40 quads. We plan in the future to extend this system to 80 quads. An interesting possiblity for the future would be a small electrostatic storage ring, where really stable beams could be investigated at their space charge limit.

The beam at the end of the 40 quad system used about 80% of the available aperture. The beam was perfectly centered, so that steering errors could not explain the failure of the beam to fill the system.

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Space charge non-linearities, image effects. and the natural non-linearity of an electrostatic lens are all possible explanations. Also, the quadrupoles themselves were cylinders and not pure linear fields. Future studies will clarify this problem. The weight of evidence at the present time is that it is probably the space charge non-linearity which is responsible for limiting the beam size.

The quadrupole transport system was arranged in a number of different configurations. A symmetric triplet arrangement, with L_{cell} = 90 mm was set up as well as a FOODOO lattice with L_{cell} = 76.2 mm. This compares to our other lattice, except that the quadrupole filling factor is smaller. The results of the 10-cell triplet. the 10-cell FOODOO, and the 25-cell FODO all gave a generalized perveance of 0.74×10^{-6}. Our 10-cell FODO setup gave us a perveance of 1.2×10^{-6}. For only 2.5 cells, the transmitted perveance was up to 1.7×10^{-6}.

We made one run with 25 cells arranged in a FODO lattice with an aperture plate at the end of the lattice. The plate was located at the lattice point where the horizontal and vertical beta functions are equal. The circular hole had a diameter of 3.4 mm. The Faraday cup was placed behind the aperture plate and the channel tuned for maximum current. Not surprisingly, this turned out to correspond to an unperturbed phase advance/cell of about 72 degrees. the same value that the SCTRAN computation had indicated for the maximum brightness (see Fig. 2).

Running a 2 keV Argon beam, we measured a current of 48 μamps in this aperture. When this beam size was fed into the SCTRAN program, it gave a value of K greater than .99 and a brightness over 100 times greater than that obtained from our earlier data. This indicates that it is possible to transmit an almost perfectly space charge balanced beam for at least 25 cells. This has important implications for the acceleration of very bright beams to high energies.

We would like to take this opportunity to acknowledge the skillful assistance of K. Riker in the operation of this experiment, and especially the ion source.

References

1. J. Brodowski, Design of a Versatile ESQ Transport System (these proceedings).