Numerical Simulation of Space Charge Aberrations in Final Focusing*

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For a sufficiently intense beam, the size of the final spot will depend not only on the design of the final focussing system but also on the detailed distribution of the beam entering that system. In particular, any deviations from a uniform beam cross section give rise to non-linear space charge forces which can defocus the beam. Because space charge forces increase in relative importance as the beam expands, aberrations become most significant when a beam, already near the space charge limit, is propagated at an expanded size in the final lens system.

Actual quantitative calculations of the importance of space charge aberrations can be a difficult task since the very nature of the phenomenon involves the self-consistent evolution of the beam in its own non-linear space charge forces. The behavior of the system can therefore be quite sensitive to the details of the distribution of the entering beam. In addition, the number of possible lens designs is quite large. Accordingly, a few sample simulations have been performed with the intent of discovering the likely importance of space charge aberrations. Preliminary results indicate that these space charge non-linearities can significantly affect final spot characteristics.

In order to examine system scaling and to test the limitations imposed by the numerics, a series of simulations was run using a simple idealized focusing system. This system was formed by allowing a symmetric beam to expand in its own space charge forces and then passing the beam through a lens system which is focussing in both planes. The entering symmetric beam was obtained by placing an appropriate strength quadruple at the mid plane between an F and D lens of the thin lens AG transport system in which the beam was propagating. While a strong thin final lens, focusing in both planes, does not exist in practice, such an idealized lens was assumed for the simulation.

Computer simulations performed previously[1], have shown that intense beams with non K-V distributions can propagate down an alternate gradient channel with little emittance growth. Figure 1 is a contour plot of the vertical phase space at the spot when the self-consistent non K-V distribution obtained from one of these simulations was used as the input distribution. While the simulation was run in normalized units, for 10 GeV singly ionized uranium ions transported through an alternate gradient system with 50 percent lens fill and a 1 T pole tip strength, the simulation corresponds to an approximately 1 kA beam at an rms emittance of 7.5 cm-mrad. The final lens focal length, chosen to be the same as the focal length of the lenses in the AG system, is then 6.4 m, and the 90 percent spot size is 1.6 mm. By comparison, Fig. 2 is a similar plot of the spot resulting when a K-V beam, with the same initial rms emittance and radius, is focused in the same way. The 90 percent spot size in this case is 0.7 mm.

A more realistic focusing system, consisting of six thin lens quadruples, was provided by A. Garren. The design was generated by altering the one described elswhere in these proceedings so as to consist of thin lenses and thereby simplify the simulation. The lens system is designed to bring a beam of U+4 ions from the output of a 60-24 AG system with an emittance of 6 cm-mrad and a current of 0.78 kA (electrical) down to a 4 mm radius spot 60 m away. The transport line period is 4 meters and the lenses are placed at 2.5, 16.5, 29, 40, 50, and 54 meters from the center of the last lens which has half the strength of the others in the transport system. The quadrupole gradients relative to the gradients in the transport system are -0.412, 0.330, -0.2434, 0.1667, 0.3334 and -0.5177 respectively.

Figure 3 shows the vertical phase space at the spot. Since the starting beam distribution was K-V, the non elliptical shape of the spot phase space distribution indicates that small imperfections in the initial distribution have grown as a result of traversing the focusing system. Since any actual beam entering a final lens system will likely have much larger deviatons from a K-V form than the simulation, significant deviations from the calculated spot characteristics are possible. Simulations have in fact been run which seem to verify the possibility of major aberration generated spot growth.

Since only a small number of simulations have been run thus far, the systematic sensitivity of lens design to space charge aberrations has not been explored. However, significant effects have been observed. It may therefore be necessary to preceed any extensive design of final lens systems with a program of simulations coupled to some actual measurements of beam characteristics.

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References

1. I. Haber, IEEE Trans. Nucl. Sci., NS26, p3090 (Jun 1979)

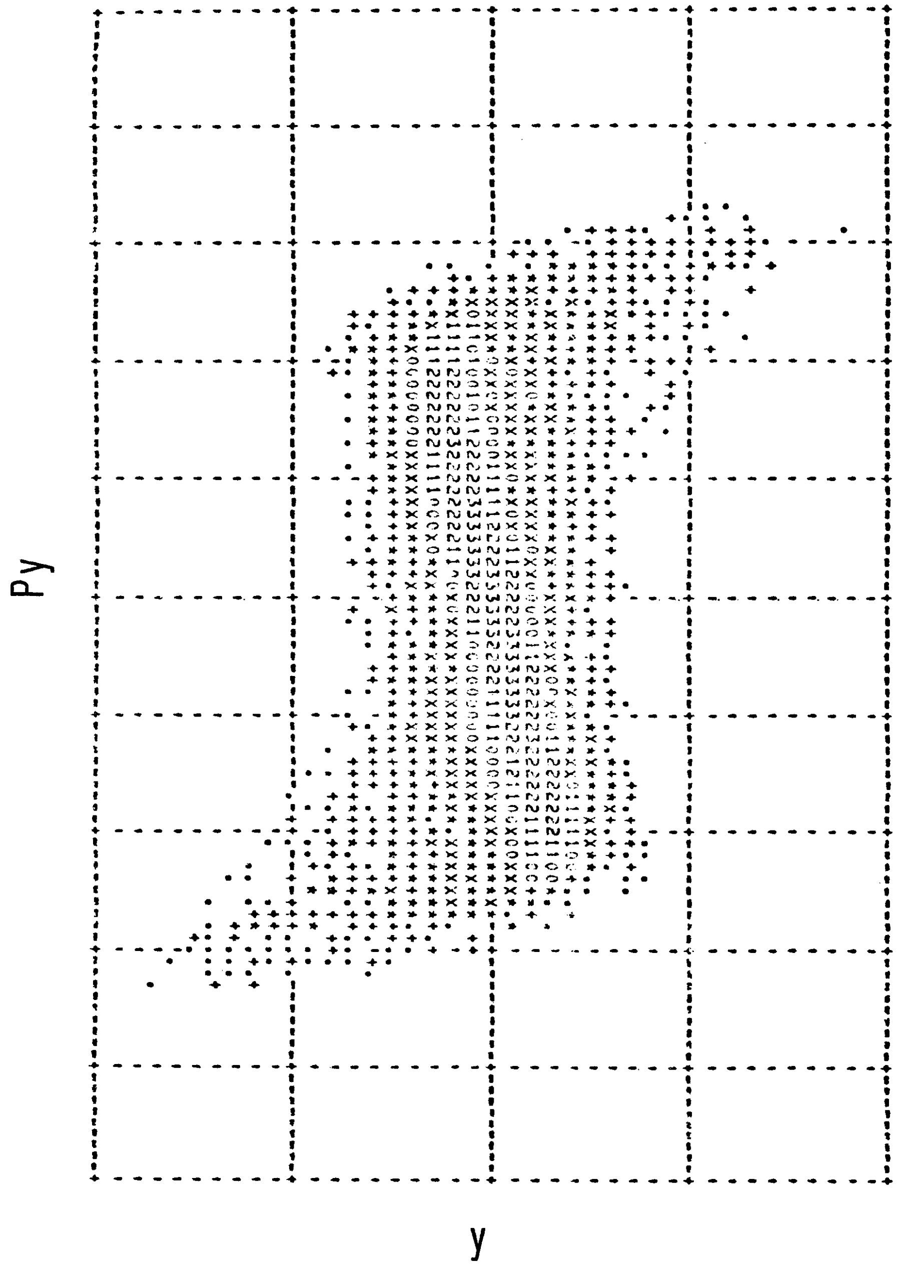

Figure 1 - Vertical phase space plot, at the spot, of a non K-V beam focused by a simple lens system.

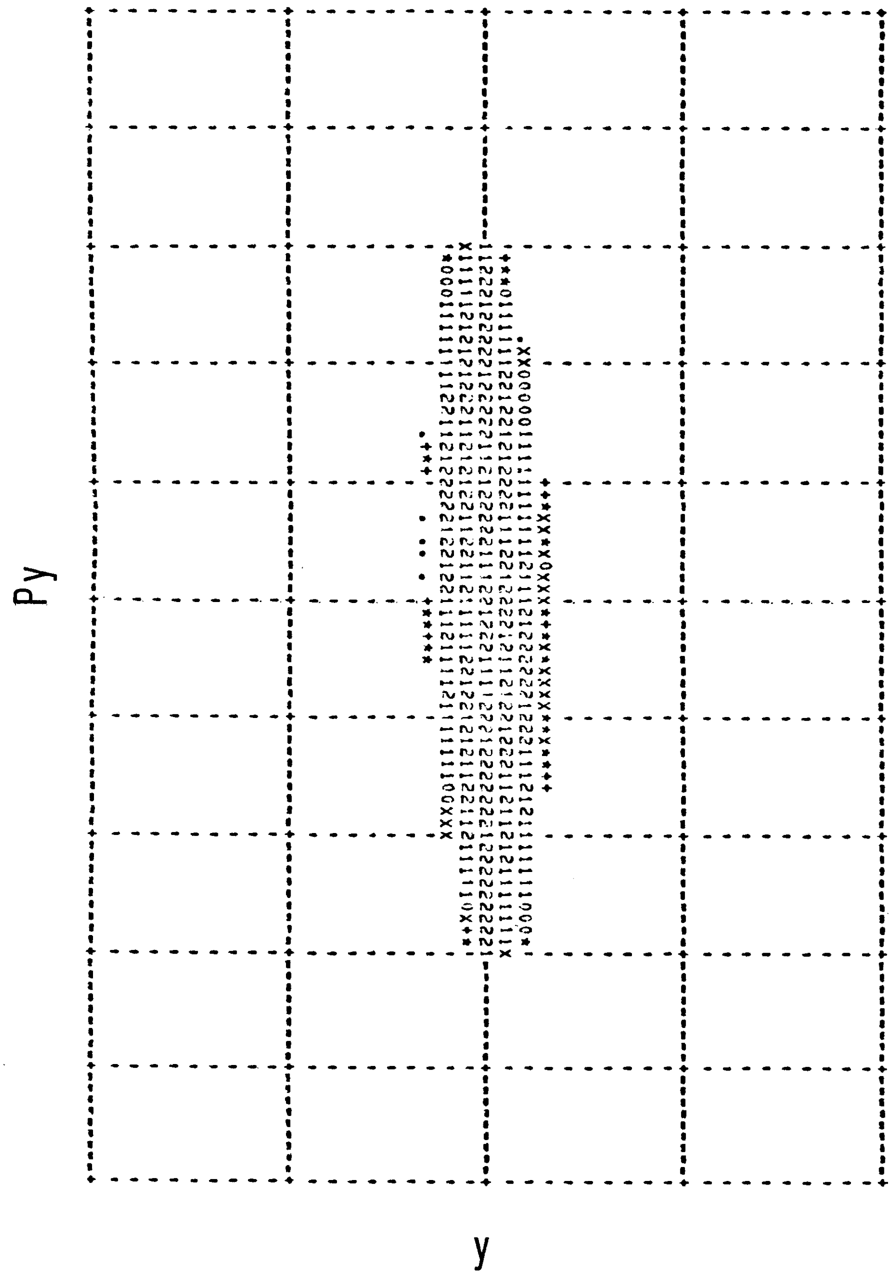

Figure 2 - Vertical phase space plot of a K-V beam with the same rms emittance and rms size and focused in the same way as in fig. 1.

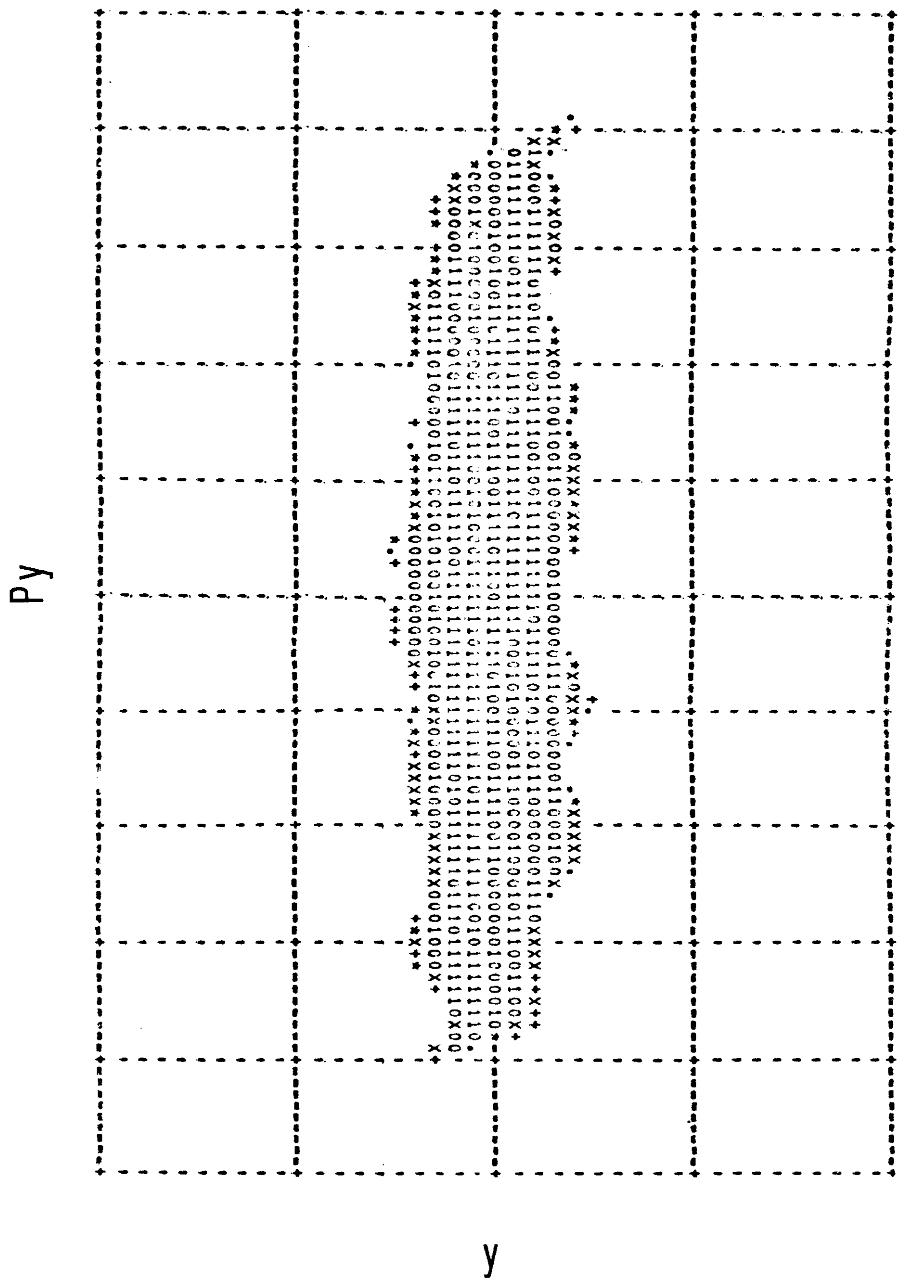

Figure 3 - Vertical phase space plot of a K-V beam after traversing a 60 m focussing system.