Radial and axial compression of a hollow electron beam using an asymmetric magnetic cusp

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The injection of hollow, relativistic electron beams through a narrow asymmetric magnetic cusp field has been investigated analytically. Preliminary experimental results are in good agreement with the analytical theory.

The motion of charged particles in cusped magnetic fields has been studied extensively in recent years. We wish to report analytical and experimental results which indicate that the injection of hollow, charged particle beams through asymmetric magnetic cusp fields may be a potentially simple and useful way of generating high local particle densities and self-colliding particle orbits. Possible applications of this technique include studies of plasma heating and confinement, ion or electron beam pellet heating, colliding beam fusion, intense microwave generation, electron beam excited gas lasers, and ion sources.

Solutions for the motion of charged particles in an asymmetric magnetic cusp field may be found in the same manner as in the symmetric case. Figure 1 shows
8, For the central ray, $\pi_1 = 0$ and $v_z^2 + p_z^2 k^2 \omega_e^2 = v_{s1}^2$, \(1\)\(1\)

Using Eq. (2), an expression is obtained for $\rho_z$ in terms of the cathode radius $\gamma_0$ and $k$:

$$\rho_z = [(k + 1)/2k] \gamma_0.$$ \(6\)

Typical particle orbits are shown in Fig. 2. Each central ray particle orbit is tangent to a circle about the axis of symmetry of radius given by

$$r_j = 2\rho_z - \gamma_0 = \gamma_0/k$$ \(7\)

and to a circle drawn about $\gamma_0$. Thus, as $k$ is increased, the particle density at $r = r_j$ should increase. As the field on the upstream side of the cusp is lowered to zero, all orbits will intersect the system axis.

A reasonable estimate of the beam density at $r = r_j$ (neglecting collective effects) may be obtained by noting that the total axial current must be a constant upstream and downstream of the cusp transition. Thus we may write

$$n_0 v_s v_x = n_r r_j v_x,$$ \(8\)

where $n_0$ is the upstream beam density and $n_r$ is the density at the inner focus $r = r_j$. In this approximation, the magnetic field is raised toward the cutoff value given by

$$1 - (k^2 + 1)/(2k) = 0,$$ \(10\)

the density should increase further. Thus, this technique produces both a radial and axial compression of the downstream beam. The actual final beam density at

FIG. 2. Projection of downstream particle orbits onto a $z$ constant plane for the case $k = 2$. 

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the inner focus will be determined by the collective interactions of the beam electrons.

A simple experiment has been performed to check the analytical results using the facilities of the University of Maryland Electron Ring Accelerator Experiment.\(^4\), \(^6\), \(^7\) The general experimental configuration is shown in Fig. 3. In the experiment, typical diode voltage and current were 2.5 MV and 3–10 kA, respectively. The radius of the cathode was 6 cm. Photographs of the time-integrated downstream beam cross section were obtained by photographing the light produced by the beam when it strikes a Plexiglas beam stop located in the downstream drift region. The radius \(r_f\) of the inner focus of the beam was measured as a function of \(k\) and results are plotted in Fig. 4. It is easily seen that the agreement between the analytical model and the experimental results is very good. Although the experimental geometry did not allow photographing the beam cross section for the case where \(r_f = 0\), there is, in principle, no reason that the upstream magnetic field cannot be reduced to zero.

In conclusion, it appears that the injection of hollow charged particle beams through asymmetric magnetic cusp fields is an attractive method of generating high local particle densities and self-colliding particle orbits.

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\(^1\)G. Schmidt, Phys. Fluids 5, 994 (1962).