ELECTRON BEAM EXPERIMENTS AT MARYLAND UNIVERSITY*

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1. Introduction

Plans for an experimental study of the stability of intense electron beams in long periodic focusing systems were described at the San Francisco Accelerator Conference in February 1979.[1] At that time, extensive analytical theory on beams with a K-V distribution had been developed,[2] and good agreement with computation had been found.[3] The objective of the experiments is to extend our understanding of what happens with more realistic distribution functions and to make comparisons with numerical simulations. Even in the absence of instability, it is of interest to study the emittance growth associated with aberrations arising from the non-uniform transverse density distribution in the beam, and to compare measurements with the result of computer simulations.

In planning a program of this type, two factors should be emphasized. First, the experiment is not intended to be an exact "scale model" of any proposed ion beam system. It is to map in a flexible way the general properties of high space-charge beams as the system parameters are varied. Second, reliable, accurate diagnostics on beams are notoriously difficult to make. The first stage of the program will concentrate on simple (though not necessarily well-understood) configurations so that the familiarity with the operational aspects of the apparatus can be obtained and reliable diagnostics developed.

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†Based on presentation by J. D. Lawson at Berkeley workshop.

Components of the apparatus and the proposed experimental program will now be described.

2. Beam Source.

The first experiments will be performed using a planar cylindrical Pierce gun with cathode diameter 1 cm. The perveance k can be varied by adjusting the cathode to anode spacing, within the range ½ to 1 μ-amps/(volt)$^{3/2}$; this corresponds to $K = 2Nr_0/\beta^2\gamma^3$ in the range $7\text{-}15 \times 10^{-3}$. Later, the convergent gun described in ref. 1 will be used.

These guns will be operated in the voltage range 5-10 kV, corresponding to currents of a few hundred milliamps. Pulses with length of a few μs will be used, firstly, to avoid space-charge neutralization effects, and secondly, to limit the power dissipation to a reasonable value. This will allow the use of grids; the first gun has a gridded anode to reduce aberrations, and it is hoped that grids can be used for emittance control.

3. Characteristics of Beam from Gun.

The reference beam in all calculations to date has been the unrealizable K-V distribution. This preserves linearity in the presence of self-fields so that paraxial theory can be used. At the exit of a well-designed practical gun or ion source, the beam density is uniform in space, but the transverse velocity distribution is gaussian, with temperature corresponding to the cathode or plasma temperature kT. Such a beam cannot be matched, even in a uniform focusing system. The velocity spread produces a non-uniform density as the beam travels, and this gives rise to a non-linear defocusing force; the beam cross section varies in a non-periodic way with z, the distance along the axis. For the operating conditions quoted above, the transverse thermal velocities are small, and their effects may be masked by aberrations. The parameter range of interest includes much higher values of emittance; it is therefore planned to increase this by the use of grids, as explained later.

4. First Experiments.

In the initial experiments, the gun is being mounted in a cylindrical vacuum vessel as shown in Fig. 1. Several ports are available for the insertion of diagnostic equipment, viewing windows, etc. In the first experiment, the space-charge spreading from the gun will be measured and compared with theory. The beam profile will be established by inserting a movable paddle into the beam until a small fraction (about 1%) is intercepted. The paddle is mounted on a shaft, which can be rotated and moved in the z-direction so that the beam radius can be found as a function of z.

The paddle also has a small hole at its center. By moving this across the beam and measuring the current intercepted by a Faraday cup, the transverse current density in the beam can be determined. By moving a straight edge across the beam emerging through the small hole, an estimate of its angular spread, and hence the beam emittance, can be made.

When the transverse temperature is negligible, the form of the "space-charge spreading" curve for a uniform beam is well known. If the spreading associated with finite temperature is appreciable, on the other hand, the way that the beam radius and density distribution vary with z must be found numerically. Calculations by I. Haber are already underway.

No lenses are required in the measurement of the beam spreading curve. The apparatus is simple, and many instrumental effects, such as secondary emission, the effects of the wall geometry, partial neutralization from residual gas, can be assessed.

5. Emittance Control.

As indicated above, it is desirable to increase the beam emittance for some experiments. This can be done with the aid of grids. Consider first a grid of horizontal parallel wires followed by a hypothetical transparent conducting plane, as shown in Fig. 2. The grids consist essentially of an array of "aperture lenses," which deflect the electrons upwards or downwards depending on their vertical position. The emittance diagram corresponding to an initially parallel beam is shown in the figure. If now the transparent conducting plane is replaced by a grid of vertical wires, it will act as a transparent conducting plane for vertical deflections but as a deflecting grid for horizontal deflections; in this case, the grid of horizontal wires will act as the transparent screen. The properties of such a grid will be measured by placing it in the beam and measuring the additional spreading produced. It is not clear whether deviations from axial symmetry will occur; this must be checked.

6. Second Stage of Experiments.

Assuming all goes well into the first series of experiments, described above, the beam will be fed through a pair of magnetic lenses. By adjusting the two lens strengths, it is possible to produce, at a given place, a waist whose size can be varied. A preliminary design, using the K-V approximation, but including the emittance changing grids, has been established. For a real beam, however, the current distribution will be non-uniform. This will be measured and compared with numerical simulations. It will be interesting both to see how good the K-V theory is in predicting the location and rms radius of the waist, and also to assess the relative effects of the departure from a K-V distribution and of conventional lens aberrations on the form of the waist.

Once this stage of the experiment has been completed, and experience with guns, diagnostics, and the various quirks of the apparatus established, the way will be clear for the study of long beams in long solenoids, interrupted solenoids, or quadrupole arrays. In Ref. 1, the emphasis was on interrupted solenoids. It will be interesting, however, to measure the beam behavior in a continuous solenoid, which was discussed above in section 3. This work will be essentially a continuation of earlier work, for example, by Lawson[4] and Brewer.[5]

By this time also, the convergent Pierce gun should be available. Indications are that this may have a density distribution that is higher at the outer radii than at the center, whereas the focused system will probably have higher density in the center. Comparisons between these two different distributions should prove interesting.

7. Status.

The first gun, together with paddle and Faraday cup, has now been assembled for the first tests. A good vacuum ($<10^{-7}$ torr) has been obtained, and the gun is being activated.

8. Concluding Remarks.

It is not possible to foresee in detail how this program will develop. The basic approach has been to maintain flexibility and to break down the problem into a series of easily manageable steps. The initial problems to be examined are of a general nature, and the work is in the same tradition as a great deal of experimentation in the late 1950's on microwave tube beams. We hope that the techniques can later be developed to help answer more specific questions pertaining to heavy ion fusion schemes.

9. Acknowledgement.

We look forward to the future participation of I. Haber of NRL in this program. The first calculations on the structure of a spreading beam are underway.

10. References.

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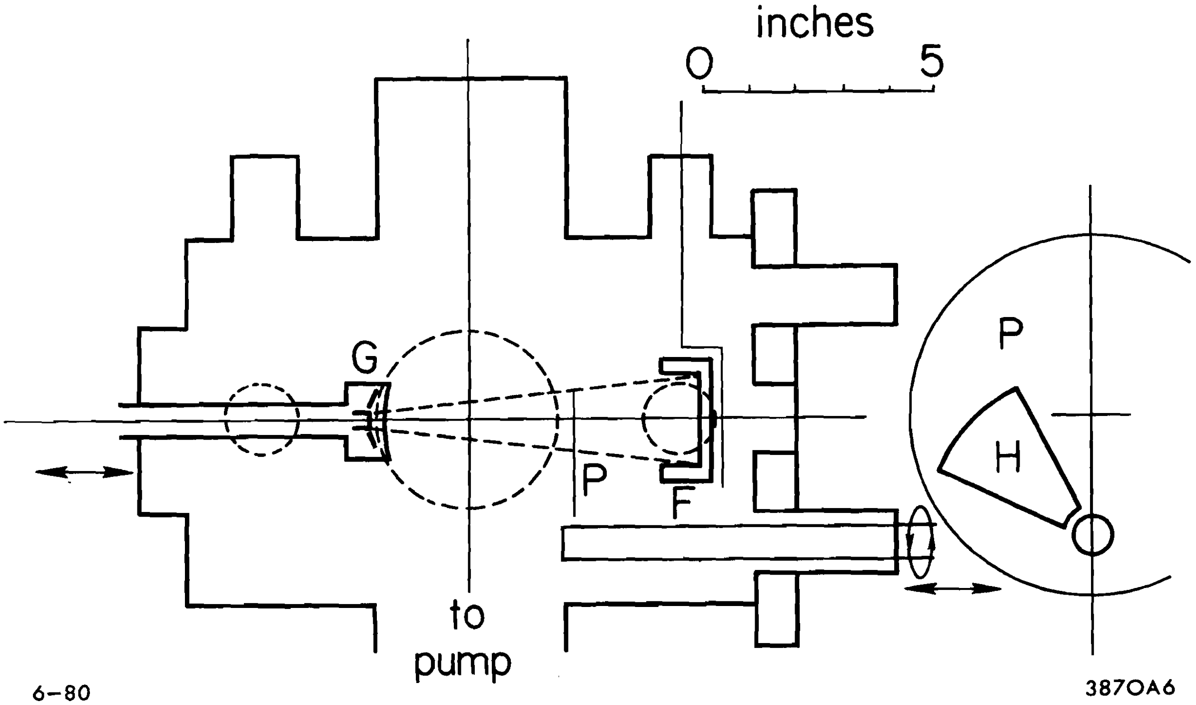

Fig. 1 Schematic plan diagram of first stage of apparatus, showing horizontal and vertical access ports (dotted circles). G = gun, P = paddle, H = pinhole, F = Faraday cup. The theoretical beam spreading curve for a 7.5 kV, 0.4 amp beam is shown ($K = 9.3 \times 10^{-3}$, $\varepsilon = 0$).

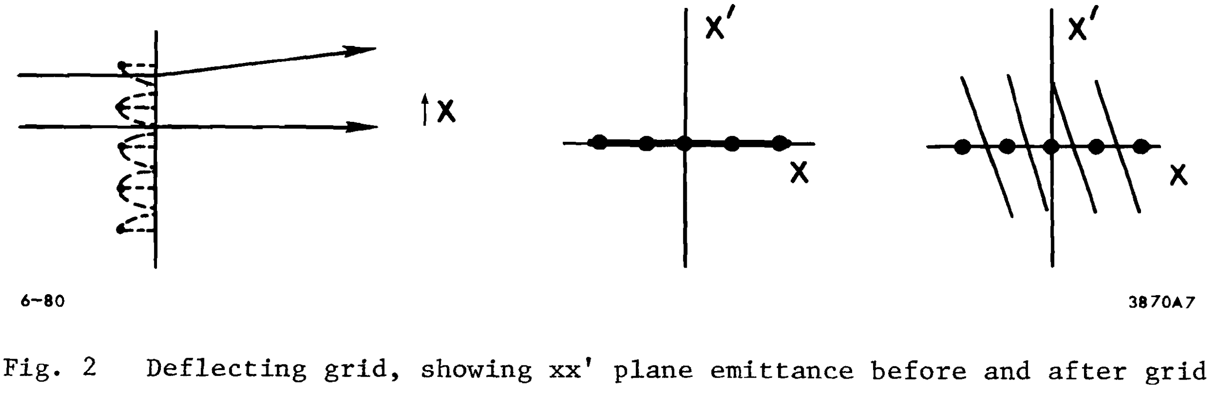

Fig. 2 Deflecting grid, showing xx' plane emittance before and after grid.