IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

SENSITIVITY OF PERVEANCE TO CATHODE PLACEMENT IN A LOW PERVEANCE ELECTRON GUN

M.C. LAMPEL[a], R.E. RAND[a,b], D.Y. WANG[a], W.B. HERRMANNSFELDT[c],

a: Imatron Inc. b: University of California at San Francisco
c: Stanford Linear Accelerator Center

Abstract

The SLAC ELECTRON TRAJECTORY PROGRAM[1] (EGUN) has been used to simulate a low perveance electron gun which will produce an 800 mA space charge limited beam at 130 kV. The simulations indicate that axial displacements of the cathode by ±0.5 mm from its nominal position can produce a factor of two variation in the perveance of the electron gun. This sensitivity is due to the boundary conditions of the electrostatic potential near the cathode. Movement of the cathode relative to a fixed focus electrode produces an enhanced variation of the electric field near the cathode surface over that which occurs when both cathode and electrode are moved together. The simulations are in agreement with experimental data.

1. Introduction

It has been observed that the perveance of a low perveance Pierce diode electron gun is extremely sensitive to cathode placement, varying by as much as 50% for an axial cathode displacement of ±0.5 mm with respect to the focus electrode. The purpose of this research was to determine whether this unexpectedly large sensitivity was due to properties of the cathode itself (a 6.4 mm diameter dispenser cathode was used), or simply due to the electrode-cathode geometry. Possible causes in the first case would be hot spots on the edge of the cathode or enhanced emission from the edge or side of the cathode when it protruded beyond the electrode. In the second case it would be assumed that the plane cathode surface emitted uniformly in a well-behaved fashion. The two possibilities may be distinguished by comparing measured properties of the gun with a computer simulation. The presence of hot spots or edge emission would cause anomalies in the beam profile emitted from the gun.

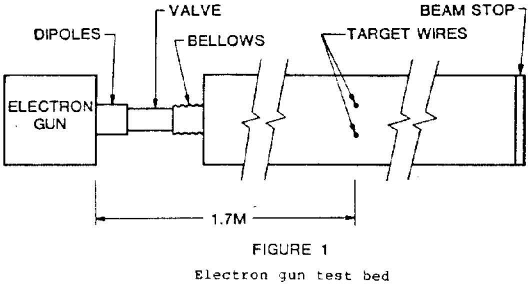

FIGURE 1
Electron gun test bed

2. Experiment and Equipment

2.1 Testbed

The experiment was performed on a testbed (Fig. 1) consisting of an electron gun connected by a valve and bellows to a drift tube. The system was evacuated by a VacIon pump and cryopump to a pressure on the order of 10^{-8} Torr.

The electron gun was demountable to allow reconfiguring of the cathode-focus electrode geometry as described below. The drift tube was 2.9m in length ending at a copper, water cooled, beam stop. The drift tube diameter was 0.24m.

Located near the gun were a pair of orthogonal dipole electromagnets. Magnetic fields up to 10 gauss were used to deflect the beam by as much as $\pm 2^{\circ}$ in any direction. The dipoles were used to step the electron beam across either of two tungsten target wires located 1.7m downstream.

The target wires were strung across the drift tube forming parallel chords 3 cm on either side of the vertical diameter. The wires were connected at either end to vacuum feedthroughs. One side of each was connected through 1 MΩ to ground, the other side of the wire being observed was connected to a Tektronix 454 storage oscilloscope. Signal levels which were from -0.1V to -4.5V were measured with an accuracy of ±0.05V or better. When the beam was on, but not directed at the wires, a background signal of -0.15V was measured due to secondary electrons in the drift tube.

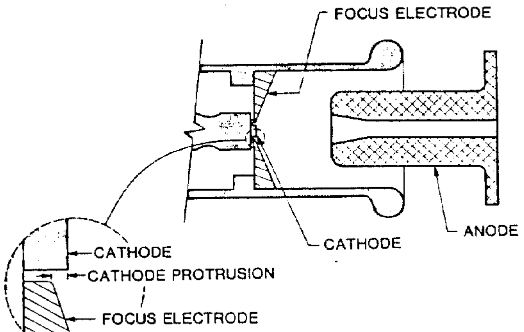

FIGURE 2
Geometric details of Pierce diode electron gun. The cathode and focus electrode are normally at negative high-voltage with the anode grounded. Inset shows the cathode protrusion. Not to scale.

2.2 The Electron Gun

To study the effect of varying the focus electrode and cathode positions the electron gun geometry must be known.

0018-9499/85/1000-1776$01.00© 1985 IEEE

precisely (Fig. 2). The (dispenser) cathode, a thermionic emitter heated by an embedded filament, is placed deep inside a conical focus electrode. The cathode diameter is 6.4mm and the outer diameter of the electrode is 7.2 cm. The anode cathode distance was nominally 4.25 cm. Ideally, the experiments would be done by moving the cathode axially relative to a fixed anode and focus electrode. However, the structure of the gun made it much simpler to leave the anode-cathode distance fixed and change the axial position of the focus electrode, which was mounted on a screw thread device allowing adjustments of 0.25mm with an accuracy of ± 0.013mm. The experiments reported on are those in which only the focus electrode was moved.

The electron gun voltage and current were measured through dividers on the high voltage power supply, both were accurate to 0.1%. Most measurements were made with an accelerating potential of 65kV and a pulse duration of 250 ms.

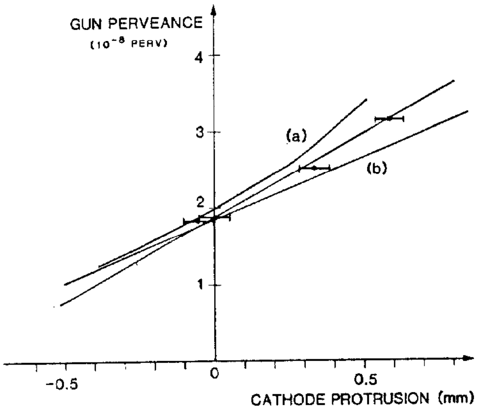

FIGURE 3

Electron gun perveance plotted against cathode protrusion. A straight line fit to the experimental data is shown. Curves (a) and (b) are computer simulations (E G U N) with 0.0625mm/mesh unit and 0.25mm/mesh unit respectively.

2.3 The Experiment

Data were obtained for four different electron gun geometries:

(a) The focus electrode at +0.05mm, in front of the cathode (cathode protrusion -0.05mm);
(b) the focus electrode flush with the cathode;
(c) the focus electrode at -0.33mm, behind the cathode (cathode protrusion +0.33mm);
(d) the focus electrode at -0.58mm, behind the cathode (cathode protrusion +0.58mm).

For each geometry, the electron gun saturation current was determined by measuring gun current as a function of cathode temperature (filament input power) at a given accelerating potential. Figure 3 shows the perveance data plotted against cathode protrusion.

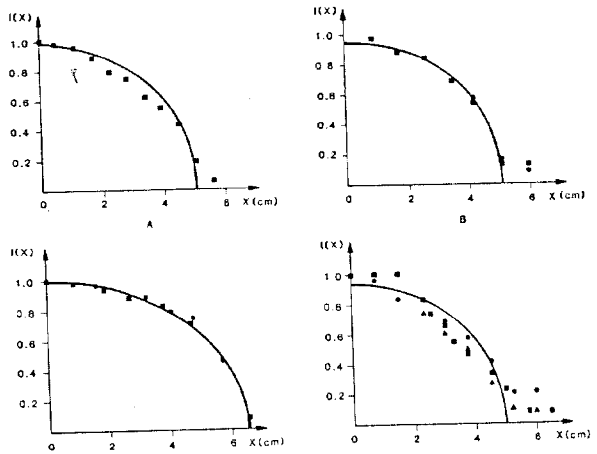

FIGURE 4

Projected electron beam profiles measured 1.7m downstream from the gun. The cathode protrusions are (a) -0.05mm, (b) zero, (c) +0.33mm, (d) +0.58mm. The signal I(x) is normalized separately for each data set. The fitted curves are ellipses which would be the signature of a uniform beam current density.

Beam profiles were measured by using the dipoles to step the beam horizontally across the target wires. This yielded a signal proportional to j(r) integrated along a line of constant x. The measured beam profiles were therefore projections onto the x-axis (the horizontal axis). Figure 4 shows the measured beam profiles. Typically, data were obtained every 8.6mm across the electron beam.

3. The Computer Simulation

The SLAC Electron Trajectory Program (EGUN) has been used to simulate the low perveance gun described above. The program solves Poisson's equation over a finite mesh containing at most 9001 mesh points; a limitation when attempting high resolution calculations over the large volume dictated by the geometry of a low perveance electron gun. To deal with this problem the simulations were done in two stages. First, a large scale calculation (1mm or 1/2mm/mesh unit) was performed. Then a small scale (1/4 or 1/16mm/mesh unit) calculation was performed with pseudo-boundaries taken in the interior of the gun. These pseudo-boundaries were the self-consistently calculated mesh point potentials at a radius R found by the large scale simulation. In this way, calculations with the appropriate resolution for the small changes in geometry could be done nearly self consistently with EGUN. If R, the pseudo-boundary radius, is several times the beam radius then errors due to loss of exact self-consistency are small. Figure 3 shows 1/4mm and 1/16mm mesh calculations which are seen to bracket the experimental data.

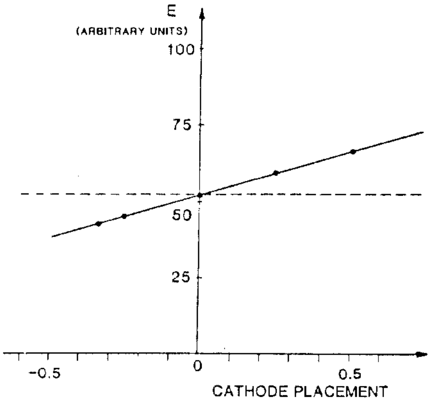

FIGURE 5

Axial electric field at cathode in the absence of space charge plotted against cathode placement. Dashed line: cathode and focus electrode moved together for a two-dimensional Pierce gun; solid line: cathode only moved (0.0625mm/mesh unit EGUN simulation). Electric field is in arbitrary units.

4. Discussion of the Data

The dramatic change in gun perveance seen in the experimental data and the computer simulations is much greater than one would intuitively expect. Consider, for instance, the variation of the electric field at the cathode, in the absence of space charge, for a two dimensional Pierce gun when both cathode and electrode are moved in unison. This slow variation is illustrated by the dashed line in Fig. 5. In contrast, the solid line in Fig. 5 shows the equivalent variation of the electric field at the cathode surface when only the cathode is moved for a cylindrical Pierce gun, as calculated by EGUN. Note that both variations are nearly linear, but the slopes of the two lines differ by a factor of about 18. The reason for this enhancement is that the axial field at the cathode is suppressed by the (radially) nearby electrode. When the cathode protrudes, the radius of the electrode at the axial position of the cathode is larger and the field suppression is reduced. The experimental data is consistent with this effect.

The possibility that hot spots on the cathode or enhanced edge emission could account for the increased perveance is inconsistent with the beam profile data in Fig. 4. The electron beam profiles, as measured by the signals on the target wires, I(x), are projections of the electron current density on to the x-axis. Assuming cylindrical symmetry for the electron beam, Abel inversion[2] could be used to find the radial current density, j(r):

$$j(r) = -K \int_{r}^{\rho} \frac{dI}{dx} \frac{dx}{\sqrt{x^2 - r^2}}$$

where K is a constant of proportionality and ρ is the beam radius, beyond which I(x) = 0. Hence, a beam with uniform current density would be consistent with an elliptical profile. In Fig. 4, it is seen that ellipses are good fits to the data for cathode protrusions zero and +0.33mm. Thus, for small protrusions the beam profile is consistent with uniform current density and with the EGUN calculations. For negative protrusion (-0.05mm) and large positive protrusion (+0.58mm), the measured profiles are closer to paraboloid in form corresponding to more elliptical current density distributions. Thus, for these extreme cases there may be a significant departure from a uniform current density, but only one in which the density decreases with increasing radius. Hot spots on the cathode or enhanced edge emission would presumably result in a hollow, "spikey" or assymmetric beam profile. There is no evidence that such mechanisms contribute significantly to the beam profile.

5. Summary

An experiment has been conducted in which the detailed geometry of a low perveance electron gun has been altered and both beam current and beam profile were measured. A parallel simulation was performed with EGUN and substantial agreement between the simulation and the experiment was found. The simulation suggests enhanced emission is uniform across the cathode surface and determined by the changing boundary conditions imposed on the cathode by the focus electrode. Although the beam profiles are not shown in great detail, there is no indication that emission is controlled by hot spots on the cathode or by enhanced edge emission.

References

1. W.B. Herrmannsfeldt, SLAC document SLAC-226
2. R. Bracewell, "The Fourier Transform and its Applications", McGraw Hill, N.Y., 1965, chapter 12, pp. 262-266.