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ELECTRON GUN TECHNOLOGY

W. M. Clark, et al

Hughes Research Laboratories

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# ELECTRON GUN TECHNOLOGY

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surface, hollow cathode discharge. The device is characterized by durability, low cost, low power consumption, small size, and fast turn-on in comparison with thermionic e-guns. Previously reported results of this program have shown that the plasma cathode e-gun is capable of producing large scale e-beams (demonstrated 1000 cm<sup>2</sup>) at 150 keV and with a cw current density of 1 mA/cm<sup>2</sup> extracted through a thin foil window. Recent studies have been made to characterize and optimize the pulsed (10 to 50 μsec pulses) operation of the gun. Operation at 100 kV with an extracted 62.5 mA/cm<sup>2</sup> beam has been obtained. Arcing and oscillations of the gun current have limited the attainment of higher output currents. Higher standards of vacuum integrity and a new kind of grid structure are believed to be solutions to existing problems which will allow the extraction of higher current densities.

Preliminary studies have begun on the plasma anode electron gun. In this device, a low voltage thin wire discharge at the anode creates ions which are accelerated to high voltage, collide with the solid, cold cathode surface, and produce the e-beam by secondary emission. Such a device offers two advantages over the plasma cathode gun: (1) lower operating gas pressure, hence better high voltage capabilities, and (2) control of the output by supplies and electronics located at ground potential (instead of at high voltage).

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## I. INTRODUCTION

The plasma cathode electron gun concept has been developed to the level of large area, operating cw electron guns during previous periods of this contract (N00014-72-C-0496). The objectives of the current program are (1) to investigate and optimize the repetitively pulsed operation of the plasma cathode electron gun, using the 4 cm x 40 cm coaxial gun as the test device, and (2) to carry out an experimental evaluation of a new Hughes invention, the plasma anode electron gun, which offers significant potential advantages over the plasma cathode gun for application to pulsed and cw e-beam lasers. During this reporting period (July 1975 through December 1975) the effort has concentrated on the following:

- a. Pulsed operation of the 4 cm x 40 cm plasma cathode e-gun. To accomplish this operation, significant alteration of the mechanical arrangement and of the electrical circuitry for the experiment was carried out. Pulsed operation of the gun, with pulse lengths of 10 to 40  $\mu$ sec, at 100 kV, with the output beam extracted through a thin foil window was accomplished.
- b. Design and construction of modifications to the 4 cm x 40 cm device for operation as a plasma anode e-gun for preliminary tests of this concept.

The basic concepts of the plasma cathode electron gun and a summary of previous accomplishments are reviewed in Section II for completeness, Section III of this report describes the experimental results of repetitively pulsed operation of the 4 cm x 40 cm plasma cathode e-gun. In Section IV the plasma anode e-gun concept is explained and the design of the preliminary 4 cm x 40 cm plasma anode test device is described. Section V is a summary of the conclusions of the results from this reporting period.

## II. PLASMA CATHODE ELECTRON GUN CONCEPT AND PREVIOUS ACCOMPLISHMENTS

### A. Basic Concept

A schematic diagram of a coaxial geometry plasma cathode electron gun is shown in Fig. 1 with the gun layout indicated in Fig. 2. This coaxial gun design has been utilized for two different guns built on this program; one with an e-beam extraction area of 4 cm x 40 cm and the other with an area of 5 cm x 125 cm. The larger gun has been successfully used with a cw e-beam sustained CO<sub>2</sub> laser device at the Hughes Aircraft Company (HAC) Culver City facility. The 4 cm x 40 cm e-gun has been tested extensively in this program in both pulsed and cw operation. These results for pulsed operation will be described in Section III of this report.

The plasma cathode e-gun device consists of three major regions: (1) the plasma generation region in which the beam electrons originate, (2) the extraction and control region where electrons are extracted from the plasma and transported in a controlled manner into the acceleration region, and (3) the high voltage acceleration region where the electrons are accelerated to high energies prior to passing through a thin metal foil window and into the laser medium. These regions are comparable to the thermionic cathode, control grid, and grid-to-anode space of a conventional triode.

The plasma generation region in the present device consists of a low pressure glow discharge in helium struck between the cold, hollow cathode surfaces and the anode grid, G1. This hollow cathode discharge runs at a voltage around 400 V which is largely independent of the discharge current but dependent upon the helium gas pressure (between 30 to 50 mTorr). Helium is used because He<sup>+</sup> ions have relatively low sputtering yields and because it has high voltage breakdown characteristics which are superior to those of other gases.

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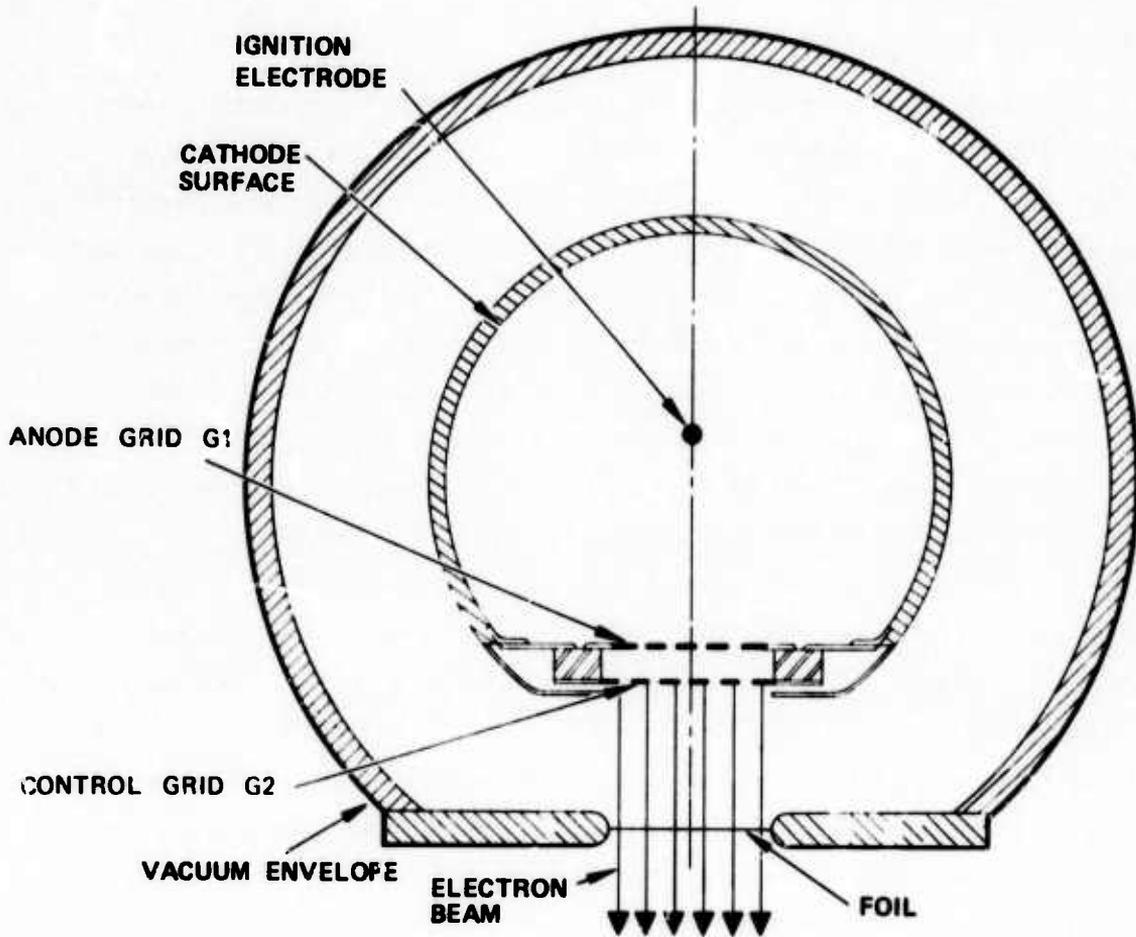


Figure 1. Schematic cross section of coaxial designed plasma cathode electron gun.

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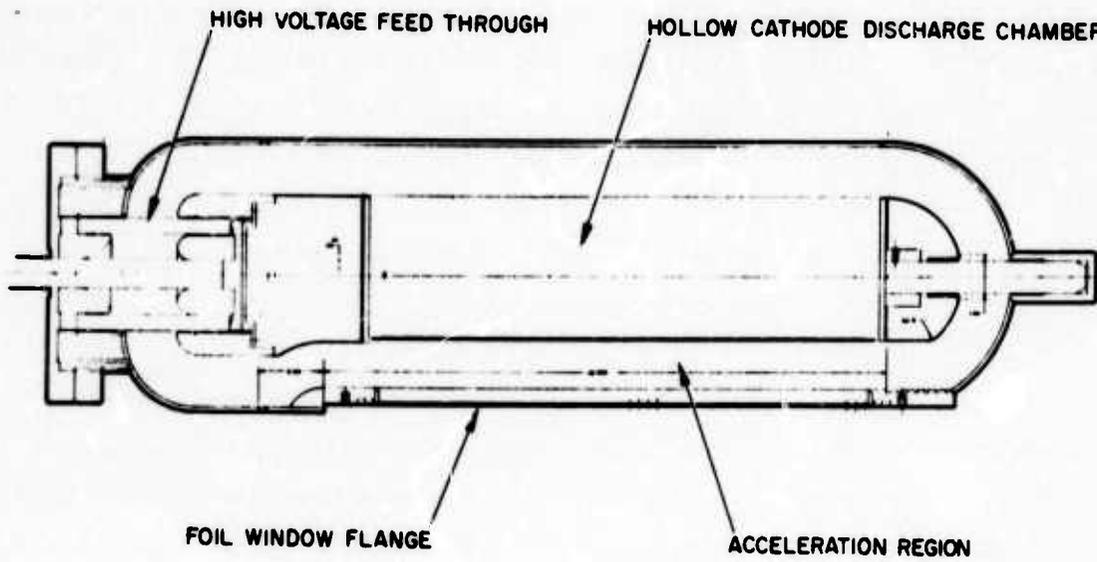


Figure 2. Layout of 4 cm x 40 cm plasma cathode e-gun.

The beam extraction and control region consists of the anode grid, G1, and the control grid, G2. Both grids are formed from a screen of square stainless steel mesh, having a 0.014 cm wire diameter and a transmission of 52%. The screen is spot-welded onto a 0.09 cm thick piece of perforated stainless steel with 0.4 cm diameter holes on 0.48 cm centers. The perforated metal backing for the screen is used for support and to define the plane of the grid. The control grid is located 0.8 cm from the anode grid and with operation at a negative voltage of 0 to 100 V, relative to the anode, the extracted beam may be varied from its maximum value to near cutoff. Grid G2 also serves to provide isolation between the low voltage hollow cathode discharge and the high voltage acceleration region. Control of the beam current may also be effected through the variation of hollow cathode discharge current through the potential of G1.

The acceleration region is the distance between G2 and the foil, across which distance the entire acceleration voltage is applied. This distance is critical and is chosen to be larger than that which would result in vacuum breakdown, and smaller than that which would result in Paschen breakdown for the helium gas pressures encountered. In the present case the inner and outer cylinders of the gun are contoured so that a spacing of 4 cm is maintained at all points between them, including points between the grid G2 and the foil. With this spacing the gun has been statically tested up to 200 kV. Maintenance of this 4 cm spacing is accomplished by use of field shaping electrodes. Electrodes are provided which extend the plane of the control grid, G2, smoothly into the cylindrical cathode surface. Contoured electrodes are also provided at each end of both the inner and outer cylinders which minimize the electric field concentrations. All parts of both cylinders are formed from nonmagnetic 304 stainless steel which is electropolished in order to minimize sharp surface protrusions.

Electrical power is supplied to the cathode, anode grid, control grid, and igniter electrode through the high-voltage feedthrough (refer to Fig. 2). This component must operate under the constraints of

Paschen breakdown in addition to those associated with the other forms of electrical breakdown usually encountered in vacuum high-voltage feedthroughs. A coaxial cable passes through the center of the assembly to a four-pin connector located within the innermost field shaping electrode. The center conductor of this cable is a copper tube which facilitates routing of four conductors to the connector. The copper tube carries current to the cylindrical discharge cathode. The field shaping electrodes within the ceramic tube are designed so that the electric field lines merge smoothly from the 4-cm gap into the coaxial cable.

The highest pressure at which the gun can operate is determined by the Paschen breakdown characteristic of the gun and the desired operating high voltage. Low pressure operation of the gun is determined by the characteristics of the hollow cathode discharge. The major characteristic of the hollow cathode discharge is that most of the plasma volume is surrounded by the cathode surface. The discharge, which is sustained by secondary electron emission due to ion bombardment of the cathode surface, is operated in a region where the rate of ion generation by ionization in the discharge volume is sufficient to maintain the plasma potential slightly above anode potential. Because of the large cathode-to-anode area ratio, most ions leaving the discharge are accelerated through the cathode sheath, and utilized with maximum efficiency for secondary electron production, thus minimizing the rate of ion generation required per emitted electron. Furthermore, the secondary electrons accelerated back through the cathode sheath are repeatedly reflected from opposing cathode surfaces. This results in a high probability for making ionizing collisions at low gas pressures where the electron ionization mean-free path exceeds the dimensions of the discharge. At sufficiently low pressure, however, the ionization probability drops to a level for which the discharge cannot be maintained. This determines the minimum working pressure. The igniter, which is a 0.5 mm diameter tungsten wire running the length of the gun, provides the background ionization to permit

initiation of the hollow cathode discharge without requiring excessive voltages. The igniter operates cw at typically 10 mA and 300 V.

## B. Previous Development

Some noteworthy results of the development of the plasma cathode e-gun program prior to the present reporting period are outlined below.

1. **Beam Generation** — Electron beams  $625 \text{ cm}^2$  in area (5 cm x 125 cm gun), have been extracted through a thin foil window, with a beam energy of 150 keV, an average current density of up to  $1 \text{ mA/cm}^2$  with operation of 1/2 sec.<sup>1</sup>
2. **Extracted Current Density Distribution** — Studies of a 110 kV cw e-beam extracted through a foil with the 4 cm x 40 cm gun showed a uniformity of  $\pm 5\%$  over the central 50 to 60% of the beam aperture, and of better than  $\pm 20\%$  over the central 80% of the aperture. The use of auxiliary electrodes within the hollow cathode discharge extended the above uniform regions by an additional 12% of the gun aperture.<sup>1</sup>
3. **Electron Energy Distribution** — A retarding Faraday probe was used to measure the electron energy distribution of a small portion of the beam. The energy spread was measured to be monoenergetic to within  $\pm 1.4\%$ . The actual energy spread is expected to be less than what these measurements indicate on the basis of instrumentation effects. In addition, transmission measurements through a 0.00125-cm thick titanium foil, in combination with calculated transmissions as a function of electron energy, verify that the beam is monoenergetic.<sup>2</sup>
4. **High Voltage, Large Area Plasma Cathode E-Guns** — Design and fabrication of a 5 cm x 125 cm coaxial geometry gun which has operated at 150 kV with an extracted beam of  $1 \text{ mA/cm}^2$  for 1/2 sec. After demonstration of a low voltage 200 cm device on this program a 5 cm x 200 cm e-gun has been built at the IAC, Culver City facility. This gun has operated with an extracted beam of  $200 \mu\text{A/cm}^2$ , 125 kV for 10 minutes with a uniformity of  $\pm 5\%$ .

### III. PULSED OPERATION OF THE 4 cm x 40 cm PLASMA CATHODE ELECTRON GUN

Most of the experimental data gathered on this program in the development of scaled-up versions of the plasma cathode e-gun have been for cw or long pulse operation of the devices. Two earlier guns, of rectangular geometry, and a beam cross section of 2 cm x 10 cm and of 10 cm x 15 cm, were capable of pulsed operation only. The experimental tests of these guns were taken at 100  $\mu$ sec pulse lengths and with the e-beam being collected by a solid collector plate positioned in place of the thin foil. Only recently the 2 cm x 10 cm gun has been reassembled and used to extract a beam through a 0.0013 cm aluminum foil. The spatial uniformity and the temporal behavior of the extracted beam of a pulsed plasma cathode e-beam has not been previously studied.

One of the objectives of this program is to characterize more completely the pulsed operation of the plasma cathode e-gun. To this end the 4 cm x 40 cm coaxial gun has been used in an experimental arrangement with which the spatial and temporal behavior of the pulsed (10 to 50  $\mu$ sec pulse widths), extracted e-beam may be studied. The details of the experiment and the results will be described in this section.

#### A. Experimental Arrangement

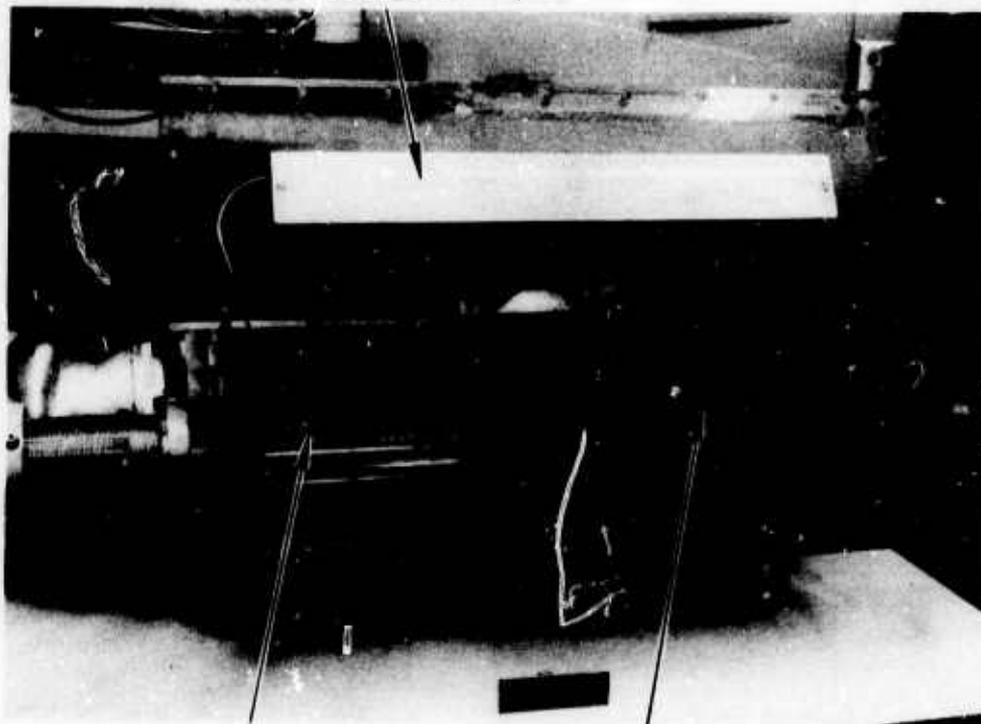
The 4 cm x 40 cm coaxial plasma cathode e-gun was described in Section II. This gun was mounted to a plexiglas diagnostics box which could be evacuated to less than 10 mTorr so that probe measurements of the transmitted e-beam could be made without complications from electron scattering and production from collisions with gas molecules. In the diagnostic box there were two different current collectors to measure the e-beam transmitted through the foil. The first of these, located just downstream of the foil, is a 6.35 mm diameter Faraday cup probe which may be positioned at any point within the

4 cm x 40 cm e-beam aperture. The Faraday cup consists of a solid plate placed behind a retarding screen which may be biased to eliminate the effects of secondary emission from influencing the measured current in the probe. This probe is used to take data on the spatial uniformity of the extracted e-beam. A solid, 6 cm x 45 cm aluminum collector plate which collects (approximately) the total transmitted e-beam is located behind the moving Faraday cup probe. The diagnostics box, along with the moving probe and collector plate, are shown in Fig. 3.

The thin foil structure is located between the gun region and the diagnostics box. The foil itself is made of kapton, coated on both sides with aluminum, and has a total thickness of 0.0013 cm. The foil is mounted on one side (the downstream side) of a 3/16 in. thick aluminum foil support which has milled slots to transmit 80% of the incident beam. On the other side of the foil support a 52% transparent stainless steel mesh screen, similar to that used for the grids, is mounted to precisely define the acceleration region gap. At 100 kV the total e-beam transmission of this structure is estimated to be 33%. At 150 kV the value would rise to about 41%.

The electrical schematic is shown in Fig. 4. The 115 V ac used with the igniter power supply and the Velonex model 350 pulse generator is supplied at high voltage through an isolation transformer. The igniter is on continuously and is run to supply a current greater than 5.4 mA (the experimentally determined minimum value to ensure proper operation). Pulsed operation of the anode grid and the hollow cathode discharge is effected by the Velonex pulse generator. The Velonex output, prf and pulsewidth, was controlled at low voltages by the operator, and transmitted by an optical line to the high voltage environment of the Velonex. Pearson current loops are used to measure the current flowing out of the high voltage energy storage unit ( $I_{ps}$ ) and the current collected by the solid collector plate ( $I_c$ ). The current,  $I_{ps}$ , is the net current leaving the control grid and incident upon the foil assembly. At lower beam voltages (<10 kV),

SOLID COLLECTOR PLATE



THIN FOIL WINDOW      MOVABLE FARADAY CUP PROBE

Figure 3. The diagnostics chamber.

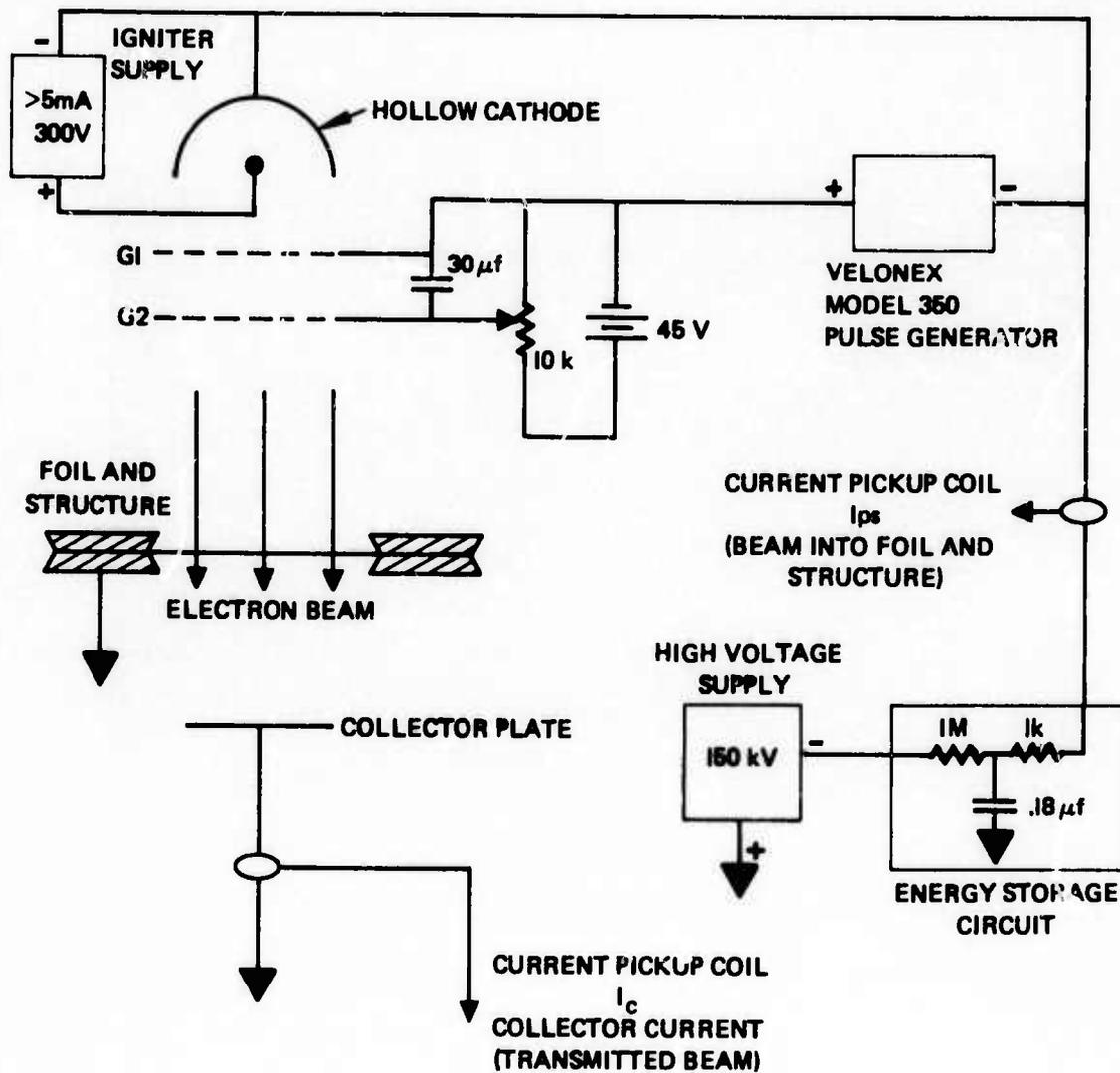


Figure 4. Experimental schematic.

additional current loops and voltage probes were used to monitor anode current and voltage, and cathode current. The control grid voltage could be continuously varied from 0 to 45 V (negative with respect to the anode grid as shown).

B. Experimental Results

The 4 cm x 40 cm plasma cathode e-gun was operated in the configuration described above at a variety of operating parameters. During this portion of the program the main effort was directed to obtaining the maximum peak pulsed current from the gun. To accomplish that, a variety of techniques, utilizing the Velonex pulser and adjusting the control grid voltage were examined experimentally. To date the most notable results are:

1. Maximum current output at high voltages (100 kV) and 20 to 30  $\mu$ sec pulses.

$$I_{ps} \approx 10 \text{ A (current into the foil)}$$

$$I_c \approx 1 \text{ A (current collected by the collector plate representative of but not equal to the total extracted current)}$$

2. Maximum current output at lower voltages (<60 kV)

$$I_{ps} \sim 30 \text{ A}$$

There were several factors which made stable, repetitively pulsed operation of the gun difficult to obtain. These are listed below and discussed.

1. Gun Cleanliness

In the midst of the experimental program, a foil rupture and other mechanical and vacuum difficulties with the gun necessitated disassembly and cleaning of the gun, and modification of the vacuum system. After reassembly the gun did not hold vacuum as well as before (the small leak was finally found just at the end of

the reporting period) and the gun did not operate as reliably as before. It was also found that minute amounts of  $N_2$  in the fill increases the current in the hollow cathode discharge, and dramatically increases the chance of arcing and Paschen breakdown. This means that a small leak can seriously degrade the operating characteristics of the gun.

## 2. Threshold for Arcing

Increasing gun contamination decreased the maximum peak current which could be drawn from the gun before arcing occurred. In a clean gun this arcing threshold for beam voltages  $>50$  kV was 10 to 12 A. While these values of  $I_{ps}$  were typical before the gun was torn down and reassembled; after reassembly, an  $I_{ps} \geq 1-2$  A was usually sufficiently to cause arcing. By controlling the Velonex output and the control grid voltage the output of the gun could be maintained to be just below the value at which arcing occurred. Experience has shown that if the gun operated satisfactorily above 50 kV, it would operate up to 100 kV without arcing at the same current level.

## 3. Beam Current Oscillations

Occasionally the gun would not arc at the higher output currents but the  $I_{ps}$  waveform would show large amplitude oscillations instead. The current level for the onset of the oscillations behaved the same as the arcing threshold described above. Sometimes the oscillation frequency was relatively low (1 to 5 MHz) and other times high (~100 MHz). Whether the gun would oscillate or arc, or oscillate in one mode or the other, was unpredictable. For a particular gas fill, however, the operation was consistent; i. e., the mode of operation remained the same. There were occasions, however, where the oscillation behavior went to an arc; the arc usually occurring on the first peak of the first cycle of the oscillation.

#### 4. Effect of Control Grid Voltage

At beam voltages below 40 kV the control grid voltage affected the beam current in a predictable way. In this case, the beam current followed the anode current waveform, and increasing the magnitude of the control voltage (negative with respect to the anode grid) decreased the beam current. At lower control voltages (0 to 6 V magnitude) the beam current pulse did not follow the (square) anode current waveform, but showed a long tail on the trailing edge and some other kinds of nonuniform structure as well. As the beam voltage was increased above 40 kV, larger and larger magnitudes of control grid voltage were needed to obtain stable operation of the gun with a good waveform. Often the gun would operate well only with the control voltage in excess of 30 V, for which the beam current would be very low, less than 2 A total. A possible explanation of this effect may be that at the higher beam voltages the fields from the acceleration region punched through the grids and affected the hollow cathode discharge. This may be partially offset by increased control voltage but at the expense of reduced output.

Figure 5 shows a typical oscillogram for operation of the gun at 100 kV where the pulse amplitude of the Velonex and the control grid voltage are adjusted to keep the gun current levels below arc threshold. The upper trace is the collector current for the beam transmitted through the foil (scale 100 mA/div.) and the lower trace is  $I_{ps}$  (scale 1 A/division).

#### C. Discussion

As explained in the previous section, the highest values of peak current extracted from the gun was limited by an arc and/or oscillation phenomenon. Reliable operation of the gun with a pulse length of from 20 to 50  $\mu$ sec was demonstrated. Depending upon the gun cleanliness, the current density upstream of the foil could vary from 10 to 70 mA/cm<sup>2</sup>. These values of current density are similar

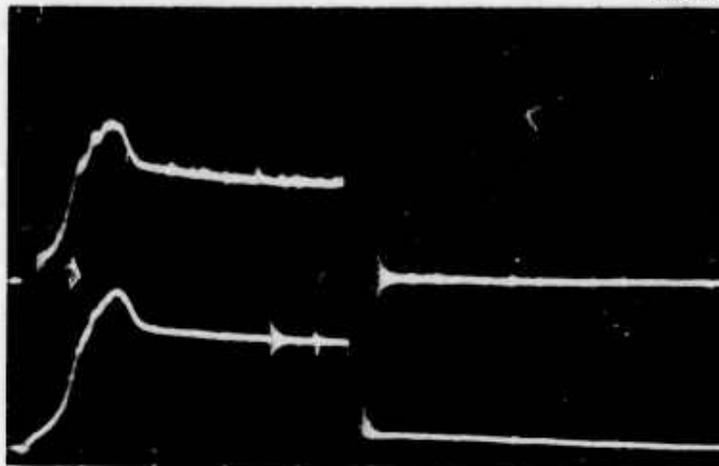


Figure 5. Pulsed current output of the 4 cm x 40 cm coaxial geometry plasma cathode electron gun at 100 kV.

Top Trace: Current transmitted through a 0.0013 cm thick aluminum coated kapton foil. 100 mA/division.

Bottom Trace: Current into the foil and support structure. 1A division.

Sweep speed 10  $\mu$ sec/division.

to those obtained in operating the rectangular geometry 2 cm x 10 cm and 10 cm x 15 cm guns. In these guns the maximum current density obtainable was also limited by a similar oscillation or arcing phenomenon, even though these guns were of considerably different mechanical design.

Circuit effects may be ruled out as a determining factor for the oscillatory behavior of the gun. In these recent data it has been noted how, with the same external circuitry, the gun may oscillate at low or high frequency. In addition, changing the circuit had no discernible effect.

As a result of the fact that these is the similar apparent maximum current density obtainable from several different pulsed plasma cathode e-guns, it may be that the current density output of 50 to 70 mA/cm<sup>2</sup> represents a limit to the capability of the gun. So far it is not known what any basic mechanism is that limits the gun output current, nor what are the causes and the nature of the observed oscillations. It is to be noted that an approximate calculation of the plasma current density in the hollow cathode discharge

$$\bar{j}_p = \frac{1}{4} \eta_e e V_d$$

where

$j_p$  = the current density in A/cm<sup>2</sup>

$\eta_e$  = plasma density in the discharge in cm<sup>-3</sup>

$e$  = electronic charge in coulombs

$V_d$  = average electron velocity in cm/sec

yields  $j_p \approx 30$  mA/cm<sup>2</sup> for values of  $\eta_e$  and  $V_d$  typical for the plasma cathode discharge ( $\eta_e \approx 10^9$ /cm<sup>2</sup>,  $T_e \sim 4-10$  eV).<sup>3</sup> This value of  $j_p$  is in the same range as the observed threshold for arcing and oscillation.

Whether or not the apparent similarity of this plasma current with the e-beam current density is significant can only be conjectured. In any case, continued efforts to improve the gun output by increased attention to the vacuum integrity of the gun and by structural modifications in the gun will continue. In particular, the control grid and anode grid structure will be modified to better ensure against the punch-through of the high voltage field into the hollow cathode.

Presently the 4 cm x 40 cm plasma cathode e-gun has been modified to operate as a plasma anode e-gun (as described in the next section). After the preliminary tests of the plasma anode gun are completed, a new plasma anode gun will be built and the 4 cm x 40 cm device will be reassembled as a plasma cathode e-gun. At that time additional pulsed tests of the plasma cathode gun will be carried out. As mentioned above, structural changes are also anticipated. First of all a new control grid will be installed, consisting of a 1/4 in. stainless steel honeycomb structure. It is believed that this new grid will provide better isolation between the fields in the acceleration region and those in the hollow cathode. Second, to determine the value of  $\eta_e$ , a Langmuir probe will be inserted in the hollow cathode discharge region. The two grids will be operated tied together so that the "extra" high voltage feedthrough can be connected to the probe. This will be an important diagnostic tool to ascertain  $\eta_e$  and  $T_e$  in the gun under actual operating conditions. Finally an amplifier is available to be used with the Faraday cup moving probe located in the diagnostic box downstream of the foil. This will allow the probe currents to be read and the spatial and temporal variations of the transmitted current measured.

#### IV. PLASMA ANODE ELECTRON GUN

While operating the plasma cathode guns under high voltage conditions and extracting a beam through the foil, outgasing from the foil and other parts of the gun subjected to the high energy electron flux has occasionally caused Paschen breakdown with a resulting arc to and rupture of the foil window. In the existing guns, a gas pressure of 30 to 40 mTorr of helium is required to produce enough ionization to supply the e-beam, especially if a large extracted current is desired. The Paschen breakdown limit of the gun is approximately 50 to 60 mTorr in pure helium, but the presence of contaminant gases with a lower Paschen characteristic could lower the arc threshold pressure considerably. For this reason, operation of the plasma cathode gun or other type of gun at a lower pressure (<10 mTorr) would be desirable. Operation of a gun at a low pressure provides the following advantages:

- Less chance of Paschen breakdown
- Less sensitivity to contamination
- Larger spacing of the components. If the pressure,  $p$ , is smaller, then  $d$ , the spacing of critical parts, may be increased so that ceramic path lengths for the high voltage feedthrough would be longer, less susceptible to tracking, and, therefore, more reliable.
- Simpler and less expensive construction. A rectangular end to the cathode and outer cylinder of the gun could be substituted for the spun, rounded ends presently required (see Fig. 2). In addition, the region of minimum  $pd$  could be restricted to the foil region alone with a larger  $pd$  away from the foil. The possibility of Paschen arcs to the foil would thus be virtually eliminated.

The plasma anode electron gun, a new Hughes invention, is a low pressure e-gun which has the advantages listed above and the additional advantage that the control and excitation of the gun may be accomplished with power supplies located at ground potential rather

than floating at high voltage (as is the case for the plasma cathode gun). This plasma anode gun concept will be tested during this program.

A schematic of the plasma anode electron gun is shown in Fig. 6. The discharge plasma for this gun consists of the thin wire discharge at the anode, which operates at low pressure. This thin wire discharge operates in a manner similar to the igniter discharge in the plasma cathode gun in that electrons are attracted toward the wire, generally miss the wire, are trapped in the potential well of the wire, and spiral around the wire in a long path length. This long electron mean free path enhances the probability of collision with a gas atom, even at low pressure, and the production of ions. The ions produced are accelerated to the cathode (150 keV) where they produce secondary electrons (yield coefficient of about 10 for 100 keV D+ ions on stainless steel).<sup>4</sup> These secondary electrons are accelerated back to the foil, suffering few collisions in the low pressure gas, and pass through the foil. Preliminary experiments with the 40 cm long igniter wire in the 4 cm x 40 cm plasma cathode e-gun indicate that stable operation of the thin wire discharge is possible to pressures as low as 2 mTorr (limit of the vacuum gauge) and with a current of 40 mA (cw) and 10 A (pulsed). For a thin wire discharge current,  $I_D$ , the anode current striking a rectangular cross-section cathode of width  $2d$  and distance  $d$  away is  $1/4 I_D$ . For a secondary yield of 10 and a grid-foil transmission of 0.5, the extracted electron beam current will be  $1.25 I_D$ . For a single 40 cm long wire, the average extracted beam current for a 4 cm x 40 cm foil aperture would be  $\geq 310 \mu\text{A}/\text{cm}^2$  (cw) and  $\geq 75 \text{ mA}/\text{cm}^2$  (pulsed).

For preliminary tests of the plasma anode gun concept, modifications of the 4 cm x 40 cm plasma cathode gun have been designed, fabricated, and are being assembled. These modifications include (1) replacing the grids G1 and G2 by a solid, flat piece of stainless steel so that the inner cylinder of the device with the flattened portion will act as the cathode, and (2) replacing the foil support and structure

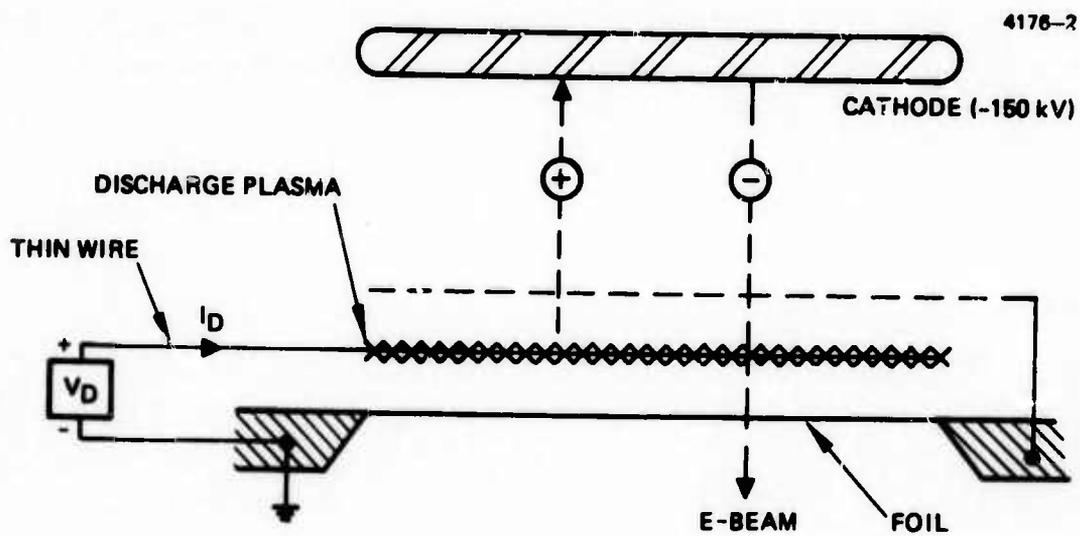


Figure 6. Plasma anode electron gun schematic.

with an expanded structure to allow the inclusion of thin wires near the foil. These modifications are shown schematically in Figs. 7 and 8. The thin wire anode discharge region is approximately a 4 cm x 4 cm cross section in which seven individual 0.3 mm diameter tungsten thin wire discharges may be run. The four wires running transverse are located 1.6 mm below the plane containing the three longitudinal wires. Screens of thin wire mesh are located, as shown, above and below the thin discharge wires to define the plasma discharge region and to fix the gap of the high voltage acceleration region. The seven different anode wires can be run individually with separately controlled currents. The same evacuated diagnostics box containing the moving probe and the solid collector plate, as shown in Fig. 3, is located downstream of the foil.

Using this arrangement, measurements of the transmitted beam intensity and the uniformity may be made. The gun will be operated with set (long) pulse lengths of 50 to 200 msec. Thin wire configurations using many different combinations of the seven wires will also be tried. In some tests, some of the transverse wires will be removed and Langmuir probes will be inserted at those ceramic stud positions.

The stability of the thin wire discharge in a high voltage environment has already been tested. In these tests the two grids G1 and G2 of the 4 cm x 40 cm plasma cathode gun were tied together and biased at +180 V relative to the cathode (well below the voltage to run the normal hollow cathode discharge). Then the igniter wire discharge was lit and 10 mA drawn. Under these conditions, the thin wire discharge was found to be stable at pressures as low as 6 mTorr of helium and at beam voltages up to 120 kV. Long term, stable operation at 120 kV with an output beam with an average beam current of  $20 \mu\text{A}/\text{cm}^2$  was observed.

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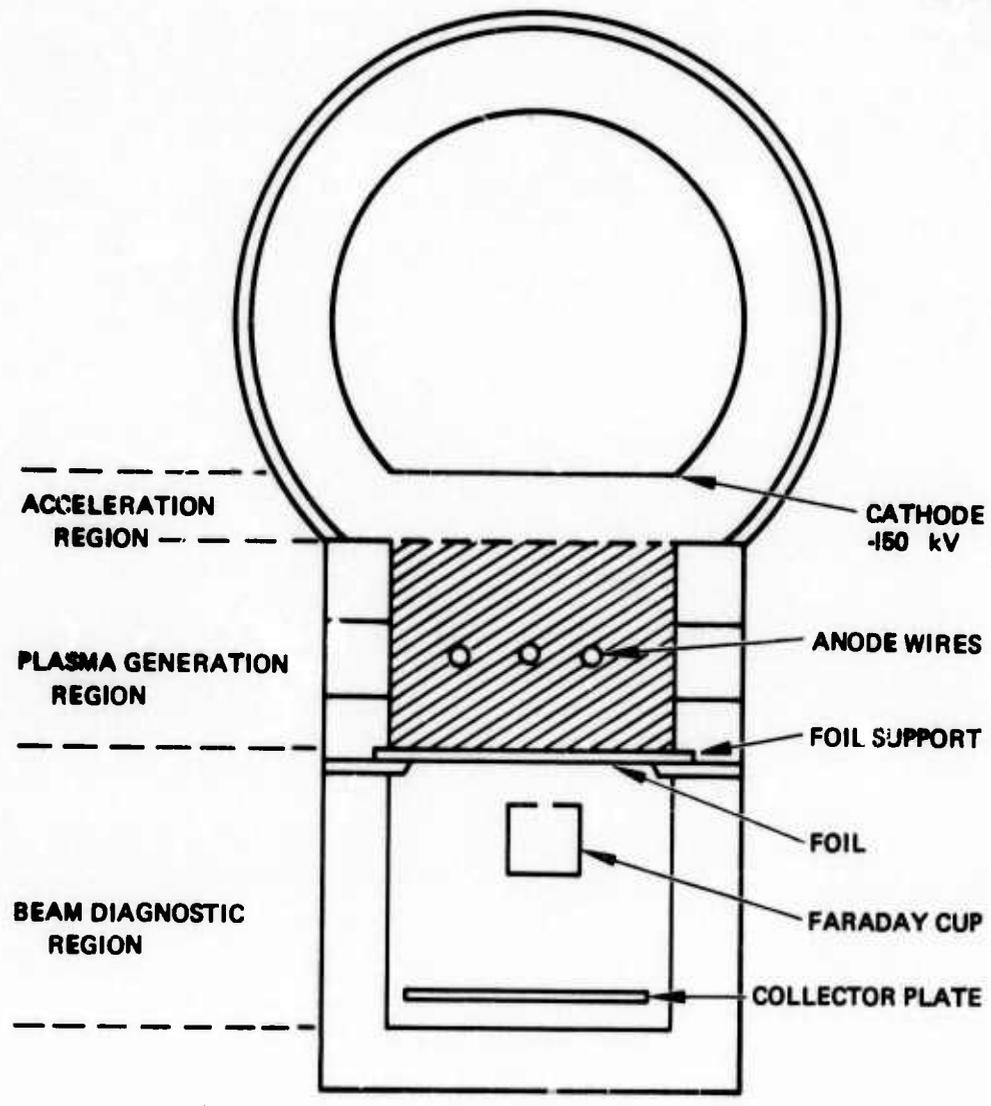


Figure 7. Plasma anode test device.

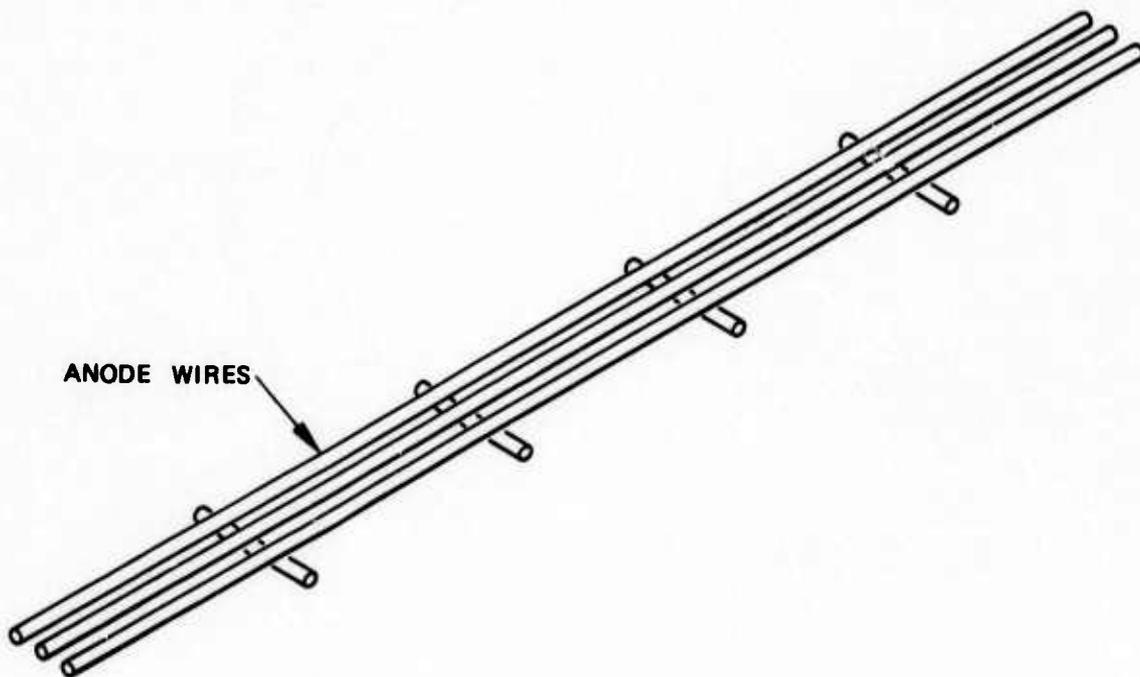


Figure 8. Perspective view of the alignment of the thin anode wires.

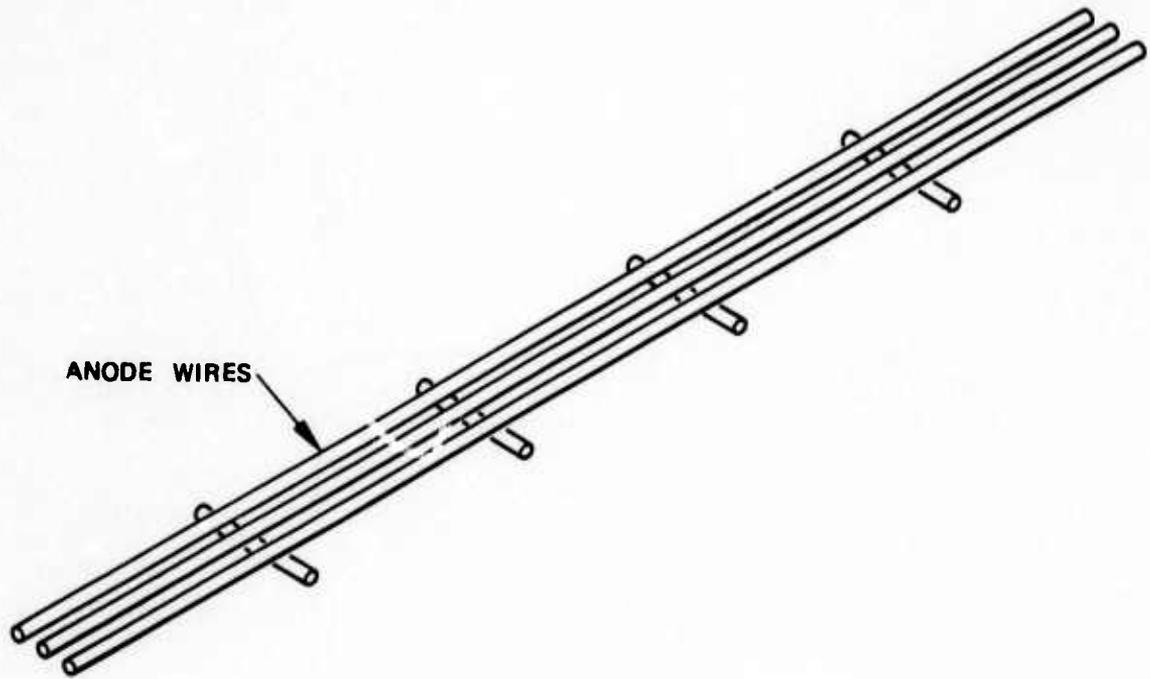


Figure 8. Perspective view of the alignment of the thin anode wires.

## V. CONCLUSIONS

During the past six months, the primary effort of this program has been directed to an experimental study of the repetitively-pulsed operation of the 4 cm x 40 cm plasma cathode electron gun. The gun was operated with a pulse width of 10 to 40  $\mu$ sec and at beam voltages as high as 110 kV. Measurements of the e-beam current upstream and downstream of a thin foil window were taken.

The best results obtained, for reliable and stable operation of the gun, showed a total current of 10 A at 100 kV upstream of the foil window (average current density of 62.5 mA/cm<sup>2</sup>). It is expected, based upon the properties of the foil and support structure, that 30 to 40% of this beam should be transmitted through the foil. The actual measured transmitted current was less than that (1 A total and 6.75 mA/cm<sup>2</sup>) due to the geometrical and electrical properties of the collector plate used. At a lower beam voltage of 60 kV, an upstream current of 30 A (187.5 mA/cm<sup>2</sup>) was obtained.

Operation of the gun was limited at the higher output currents and at the higher beam voltages by the onset of arc and oscillation phenomena. It is not known whether such a limitation is fundamental to the pulsed operation of the plasma cathode gun or due to the present experimental arrangement of gun structure. Efforts to improve the vacuum integrity of the gun, and planned modifications of the grid structure to maintain better isolation of the hollow cathode discharge from the high fields will characterize future pulsed operation studies of the gun.

In addition to the above, modifications to allow the present 4 cm x 40 cm device to be operated as a plasma anode electron gun were designed and fabricated. The device is presently being re-assembled in this new configuration and preliminary tests of the plasma anode concept will begin soon. The plasma anode gun is expected to have superior high voltage performance along with the advantage of being easily controllable from a low voltage environment.

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