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PERFORMANCE OF A NEUTRALIZER FOR ELECTRON BOMBARDMENT THRUSTER

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Abstract

Results of the SERT II flight indicate that the hollow cathode neutralizer not only represents a power and propellant weight penalty but can be a contributing cause to accelerator grid erosion. Tests with a 30-cm diameter thruster have shown that a neutralizer position of approximately 9 cm axially downstream of the accelerator grid and approximately 9 cm radially away from the outer edge of the accelerator grid and pointing parallel to the thruster axis provides the best overall performance. The estimated grid wear rate was less than 0.08 mm in 10^4 hour. The coupling voltage (neutralizer to beam voltage) was approximately 17 volts at a neutralizer flow rate of 22 equivalent milliamperes of mercury and a beam current of 1.5 amperes. Neutralizer power (excluding heaters) was 31 watts and the effect of neutralizer flow on overall propellant utilization efficiency is a 1.2 percentage point reduction at a thruster utilization efficienty of 90 percent. The neutralizer position defined in tests with a 30 cm thruster was tested with a 15 cm SERT II thruster. When the neutralizer was relocated further downstream with this different orientation, accelerator impingement current due to neutralizer operation was reduced by approximately a factor of seven and was nearly independent of neutralizer operation. Further improvement in the design of the accelerator grid should reduce the expected wear rate from the 1.32×10^{-3} mm/hr observed in SERT II tests to less than 1×10^{-4} mm/hr.

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Introduction

Electron-bombardment thrusters require demonstrated lifetimes of order 10^4 hours for some space applications. A major lifetime problem encountered in the development of the SERT II thruster was the erosion of the accelerator grid by mercury ions originating in the region of the plasma bridge neutralizer and accelerator grid.[1] These ions were focused onto a small area of the grid with energies approximately equal to the accelerator potential (-1600 V to -2000 V), wearing a groove in the accelerator grid. The fragments that resulted when the grid eventually wore through caused a short circuit across the extraction system grids, resulting in the shutdown of the SERT II thrusters during the space flight.[2]

Two series of tests were conducted in the investigation described herein. The first tests were made to determine whether or not moving the neutralizer to a different location would significantly reduce expected grid wear rates. These tests were performed by mounting a movable neutralizer on a 30-cm diameter thruster using a single glass-coated accelerator grid. The neutralizer was moved while the thruster was operating. Accelerator grid currents over small areas near the neutralizer were monitored and used to determine an expected wear rate. The position where these currents were minimized was about 9 cm downstream of the accelerator grid just outside the beam edge and pointing parallel to the thruster beam axis.

Tests were then conducted with a SERT II prototype thruster with the neutralizer repositioned further downstream from the standard (orbital flight) position, as had been indicated by the first series of tests. The results and conclusions of these tests are then described.

Apparatus and Procedure

30-Cm Diameter Thruster

The 30-cm diameter thruster used in these tests is basically the same as described in Refs. 3 and 4. The thruster was equipped with a movable neutralizer system as shown in Fig. 1 and described in Ref. 5. The range of the movable neutralizer (Fig. 2) extended from 12.7 cm downstream to 13.6 cm upstream of the accelerator grid at radial positions ranging from 5.7 to 15.2 cm from the outermost row of accelerator grid holes. All positions are referenced to these component locations. The 6.3 mm diameter neutralizer has a 0.38 mm diameter orifice as described in Refs. 3 and 4. The neutralizer was operated at a constant propellant flow rate by using a proportional controller to maintain a constant propellant vaporizer temperature.

The thruster used a single glass coated accelerator grid[4] and produced a 1.5 amp beam at a net accelerating potential of 1000 volts and accelerator potential of -500 volts.

In one test the neutralizer orifice location was held fixed at 8.9 cm radial and 8.9 cm axial downstream (Fig. 2) and the neutralizer pointing angle with respect to the thruster axis, θ, was varied. The range of θ covered was -10° (pointing slightly away from thruster axis) to +90° (normal to thruster axis).

In all cases, the thruster operating conditions and neutralizer flow rate were maintained constant while the neutralizer position or angle was changed. In most tests with a 30-cm diameter thruster, accelerator impingement strips were mounted on the downstream surface of the accelerator grid[5]. These strips collected the localized current due to neutralizer and thruster operation. In some tests three strips were used (Figs. 1 and 2) with strip number 1 being the furthest from the thruster axis. Because strip number 2 (center) always collected the largest current, this strip was used alone for some tests.

15-Cm Diameter SERT II Thruster

The SERT II thruster (Fig. 3) is well documented in Refs. 1, 2, and 6. The prototype thruster used for these tests is virtually identical to the flight thrusters. The only changes were a different neutralizer position used in one test and a thin insulating layer placed between the doubler and the accelerator grid (Fig. 3). This insulation permitted the current to the doubler to be measured separately from the total accelerator current. The

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doubler served the same purpose as the accelerator impingement strips described for the 30-cm diameter thruster. The doubler area was 7.23 cm^2 compared to a total grid area of 98.6 cm^2.

Both main and neutralizer mercury feed systems were run off self-contained propellant reservoirs and no flow measurements were taken. Both vaporizers were run without controllers but reached thermal equilibrium quickly and held a constant operating point with no difficulty. The thruster was operated at a beam current of 0.25 amps at a net accelerating potential of 3000 volts. The accelerator potential was varied from -1600 to -2000 volts.

Results and Discussion

30-Cm Diameter Thruster

Effect of neutralizer pointing angle

Two tests were conducted to determine the effect of neutralizer angle on accelerator impingement strip current. The neutralizer was pointed at an angle, θ, of 70° with respect to the thruster axis (approximately the same as for the SERT II neutralizer). The same downstream region was investigated with a neutralizer at an angle, θ, of 10°(5). Two flow rates (59 and 76 equivalent mA) were maintained during separate mappings. Figure 4 shows the current to each of the three accelerator impingement strips (Figs. 1 and 2) as a function of axial position for coordinate angles α of 40° and 50° (see Fig. 2), as well as the corresponding strip currents for the θ = 10° case with a flow of 76 equivalent mA. These values of α correspond to an approximate beam edge. These data are typical of all coordinate angles tested. All the accelerator impingement strip currents are significantly higher for the neutralizer angle of 70° than for an angle of 10°. Other tests have indicated that the slight difference in flow rate shown in Fig. 4 would not cause such a large change in strip current. This is in agreement with the general conclusions of Ref. 3 that pointing the neutralizer away from the accelerator grid significantly reduces the interaction between neutralizer and accelerator. The coupling voltage did not change significantly while varying the neutralizer position.

A test was conducted with a system which could vary the neutralizer pointing angle during operation. The neutralizer orifice position was held at 8.9 cm radially by 8.9 cm downstream. This allowed for a beam edge of 45°. The neutralizer pointing angle was varied from -10° (pointing away from grid and thruster axis) to 90° (normal to beam axis). The neutralizer flow rate was held at 59 equivalent mA. Figure 5 shows the effect of changing θ on the current to accelerator strip 2. This current is constant at a base level value of 5μA (1μA/cm^2) from -10° to +10°. It then increases smoothly with θ with an increasing slope. The total increase from +10° to 90° is a factor of 76. The value at θ = 71° (the SERT II angle) is 135 μA, or an increase over the base level by a factor of 27. Thus a neutralizer pointing angle θ = 0° (horizontal) ±10° minimizes the current to the accelerator current strips for a position of 8.9 by 8.9 cm.

Upstream neutralizer position

Reference 5 defines neutralizer positions downstream of the accelerator grid of a 30-cm diameter thruster that result in acceptable grid wear rate. It does not preclude the possibility of an acceptable position upstream of the accelerator grid. These positions would offer mechanical advantages over downstream positions at large radial distances. The movable neutralizer system described in Ref. 5 was modified to cover positions 13.6 cm upstream to 12.7 cm downstream of the accelerator at radial positions from 5.7 cm to 15.2 cm from the outermost row of accelerator grid holes. The current to the accelerator impingement strip was used as an indication of potential accelerator grid wear in this region as was done in Ref. 5. Figure 6 shows this current as a function of axial positions at various radial locations for θ = 0. As noted in Ref. 5, moving downstream of the accelerator reduces this current for all radial positions. As the neutralizer is moved upstream, the strip current increases, reaching a maximum at a position slightly downstream of the accelerator grid at all radial positions. This position coincides approximately with the edge of the neutralizer shield screen (Fig. 1). The maximum value of the strip current decreases with increasing radial position. As the neutralizer is moved further upstream, the current decreases. For radial positions 8.9 cm and greater, the current approaches some base level with the larger radial locations having the higher base level current. For radial positions of 5.7 and 7.0 cm, a neutralizer operating limit (excessive coupling voltage) occurred at the locations indicated in Fig. 6. The best radial position tested upstream of the accelerator grid was 8.9 cm. This radial position was acceptable for downstream positions because it located the neutralizer outside the beam for most acceptable downstream axial distances.

At this position the base level current for the upstream position was 10 μA compared to a base level current of 4 μA for the downstream positions. Based on the lifetime estimates of Ref. 5, a current level of 10 μA to the accelerator strip would result in a wear rate of about 8×10^{-6} mm/hr or 0.08 mm in 10^4 hours. A typical metal thickness for glass coated grids and some 30-cm diameter two grid systems is 0.38 mm. Thus upstream positions at radial locations of 8.9 and axial locations >8 cm should provide adequate accelerator grid lifetime, although it would have an erosion rate 2.5 times that provided by the best downstream positions.

The major disadvantage of these upstream neutralizer positions is the degradation of neutralizer performance. Figure 7 shows the neutralizer to ground (coupling) voltage for both upstream and downstream positions for a neutralizer flow rate of 95 equivalent mA. The coupling voltage increases rapidly as the neutralizer moves upstream behind the plane of the accelerator at radial positions close to the thruster. This effect is reduced as the radial position is increased and is almost negligible for radial positions of 12.7 cm or more. The best compromise between accelerator lifetime and neutralizer performance for upstream positions appears to occur at a radial location of 8.9 cm and an axial upstream position of 10 cm or more. At this point the coupling voltage has decreased to less than 27 volts and the accelerator strip current has reached a minimum (Figs. 6 and 7).

Neutralizer performance

Both the downstream position of 8.9 cm x 8.9 cm[5] and the upstream position of 8.9 cm radial by 10.2 cm axial at a neutralizer pointing angle of 0° provide adequate expected accelerator grid lifetime. In order to better compare these two positions, the neutralizer keeper (V_{NA}) and coupling voltages (V_G) were determined as a function of neutralizer propellant flow rate. These data are shown in Fig. 8. The neutralizer keeper voltage is the same for both positions and does not change significantly until the flow rate is reduced to less than 30 equivalent mA. At this point, the keeper voltage for the upstream position did increase slightly, and was greater than 50 volts at a flow rate of 22 mA. However, the coupling voltage for the upstream position increased markedly as the flow rate was decreased. Extensive testing in the SERT II program indicated that 30 volts coupling represented a practical maximum to ensure neutralizer cathode lifetime. This means an upstream neutralizer would require a minimum flow rate of 95 equivalent mA to operate at 30 volts coupling.

Assuming the thruster alone were to operate at a beam current of 1.5 A, a net accelerating potential of 1000 volts, a propellant utilization efficiency of 0.9, discharge losses of 200 ev/ion, and a fixed power loss of 75 W, then a neutralizer located at the downstream position operating at a flow of 25 equivalent mA would reduce the propellant utilization efficiency to 0.887 with a typical power efficiency of 0.79. A neutralizer operating at the upstream position under the same assumptions would reduce the propellant utilization to 0.852 and drop the power efficiency to ~0.782. The total thruster system efficiency would be ~70.3 percent for the downstream position compared with 66.6 percent for the upstream position. Based on this performance, the downstream position is clearly preferred.

15-Cm Diameter SERT II Thruster

Neutralizer position

The conclusions drawn from results obtained with a 30-cm diameter thruster were verified on a 15-cm diameter SERT II prototype thruster. The doubler plate was electrically floating for these tests (Fig. 3). Two neutralizer positions were tested: the standard SERT II configuration of 1.75 cm axial downstream by 1.9 cm radial at a pointing angle θ of 71° and the configuration determined by the tests with a 30 cm thruster[5] of 8.9 cm axial downstream by 7.6 cm radial at a pointing angle θ of 10°. The current to the doubler plate is presented in Fig. 9 as a function of neutralizer keeper voltage for both positions. The keeper voltage provides the best indication of neutralizer flow rate in the absence of a direct flow measurement. A typical neutralizer propellant flow rate would be about 12 equivalent mA for a keeper potential of 40 volts to greater than 40 equivalent mA for a keeper voltage less than 15 volts[1]. The doubler plate current varied from 141 μA to 103 μA for the SERT II configuration. When the neutralizer was moved downstream, the doubler plate current was significantly reduced and was not as dependent on changes in neutralizer operation.

The thruster was also operated with the neutralizer off (no propellant flow) and a doubler plate current of 71 μA was measured. This current is not due to neutralizer operation and was subtracted from the total doubler current to give the doubler current due to neutralizer operation. This current is also shown in Fig. 9. At the typical SERT II neutralizer keeper voltage of 22 volts, the neutralizer doubler current was reduced from 50 to 7 μA by repositioning the neutralizer downstream. This factor of approximately seven reduction of doubler current should greatly increase expected accelerator grid lifetime.

Accelerator grid lifetime

The lifetime of a SERT II accelerator grid with a standard SERT II neutralizer is approximately 2300 hours (Table I). After this time, a groove caused by neutralizer operation wears completely through the accelerator grid and doubler, which have a combined thickness of 3.0 mm (120 mils). Figure 10 shows a typical groove after more than 4000 hours of testing. It is believed that the pieces of the metal webbing were the cause of the short between the two high voltage electrodes on both flight thrusters[2]. The wear rate on the flight thrusters (Table I) is based on the fact that the high voltage shorts were first noted after 2385 and 2011 hours on flight thrusters 1 and 2. Additional ground tests also indicate wear rates of 3.0 mm in 2300 hours. These tests are detailed in Table I.

Figure 11 shows the maximum depth of the groove as a function of position left and right of neutralizer as viewed from downstream for the grid of test 1 after 500 test hours. The groove itself is shown in Fig. 12. The groove reaches a maximum depth of 0.66 mm. This maximum does not occur at the center, however. It is located approximately 0.9 cm to the left of center (as viewed from downstream with neutralizer at top). This shift to the left is also seen in Fig. 10.

It is possible to calculate an expected wear rate for mercury ions on molybdenum (grid material for 30 cm and SERT II thrusters) assuming normal incidence.

$$\frac{t}{T} = \frac{J}{A} \times S \times 4.05 \times 10^{-6} \qquad (1)$$

where

$\frac{J}{A}$ current density, μA/cm^2

S sputtering yield, atoms/ion

$\frac{t}{T}$ wear rate, mm/hr

The constant 4.05×10^{-6} converts the atomic sputtering rate to a volumetric sputtering rate. The sputtering yield is a function of ion energy. For charge exchange ions formed in the beam downstream and falling back to the accelerator grid this energy is equal to the accelerator potential. The value of S for molybdenum ranges from 1.62 to 1.90 atoms/ion for energies from 1.6 to 2.0 kV[7].

The total current to the doubler, J_{AD}, consists of two components. The first is the current due to the operation of the thruster exclusive of the neutralizer, $(J_{AD})_T$; the second is the component added by the operation of the neutralizer. Thus $J_{AD} = (J_{AD})_T + (J_{AD})_N$. These measured and calculated values are listed in Table II for various accelerator potentials and neutralizer operating points.

Note that $(J_{AD})_N$ is relatively constant for all conditions. A current of 58 μA to the doubler area of 7.23 cm^2 (Fig. 10) gives a current density of 8 $\mu A/cm^2$. These figures result in calculated wear rates (using Eq. (1)) ranging from 5.2×10^{-5} to 6.2×10^{-5} mm/hr for accelerator potentials from 1.6 to 2.0 kV. These values are more than a factor of 20 less than the observed values given in Table I. A similar method used in Ref. 5 for a 30-cm diameter thruster produced agreement of calculated and experimental results to within a factor of 3. The most important cause of error is probably in the selection of a current density. The actual current to the doubler is certainly more focused than the assumption of all measured current being uniformly distributed over the entire area of the doubler. Thus the current density used in the calculation is certainly less than the actual maximum, resulting in small calculated wear rates. Another possible cause for increased wear rate on the SERT II thruster is the dependence of the sputtering yield for molybdenum on the angle of incidence. Reference 7 suggests that this yield increases by anywhere from 3 to 7 as the angle of incidence increases from normal (0°) to 40°. Measurements of the groove after 500 test hours in Test I show the angle of the groove wall with respect to the normal to the grid exceeds 37° in some places. Thus some impinging ions could be doing sputtering damage at a significantly higher yield resulting in higher wear rates after the groove has begun to form. Factors which could reduce this wear rate are an increase in the capture of sputtered materials by the groove and a change in ion focusing to minimize the angle of incidence.

Accelerator drain current

Another cause of the observed wear rates of the doubler being greater than the calculated rates is direct beam ion impingement. There is probably a significant component of the doubler current which strikes the grid at energies equal to the total potential difference between the two grids. These ions are primary ions formed in the discharge and have energies of from 4600 to 5000 volts rather than 1600 to 2000 volts. That primary ion impingement occurs on the doubler is evidenced in Fig. 12. This figure shows a hexagonal wear pattern on the downstream surface around the holes on the doubler plate. This pattern is noticed only around holes near the periphery of the grid, especially on the doubler. Primary ion trajectories are probably unaffected by the difference in accelerator thickness. However, the extra material at the edge of the holes on the doubler will intercept many ions which otherwise would pass through the grid apertures. This results in the hexagonal wear pattern of Fig. 12.

Figure 13 shows the current density to the doubler and to the entire grid as a function of accelerator potential with neutralizer off (Table II). The major portion of the total accelerator drain current for a well focused extraction system such as the SERT II system (at least in the area of single accelerator grid thickness) is charge exchange current. Wear patterns observed on many SERT II accelerator grids indicate that the major portion of the charge exchange wear occurs near the center of the grid. Thus the doubler current density would be expected to be less than the average current density over the total grid. Figure 13 shows that the doubler current density is greater and increases more rapidly with accelerator voltage than the average for the entire grid. Thus the extra doubler current is probably due to the increased direct ion impingement.

The expected doubler current due to extraction of the ion beam (thruster only) can be calculated using the current to the single thickness of the grid with the thruster only operating, $(J_{AG})_{TD}$ and the ratio of the doubler area to the area of the single thickness, A_D/A_G. This expected doubler current is then

$$(J_{AG})_T \frac{A_D}{A_G}$$

The excess current to the doubler is the measured less the calculated or

$$(J_{AD})_T - (J_{AG})_T \frac{A_D}{A_G}$$

This excess current is probably due to the increased grid thickness. The total current to the doubler J_{AD} is made up of $(J_{AD})_T + (J_{AD})_N$

$$J_{AD} = \left[(J_{AD})_T - (J_{AG})_T \frac{A_D}{A_G}\right] + (J_{AG})_T \frac{A_D}{A_G} + (J_{AD})_N \qquad (2)$$

Of these three components $(J_{AG})_T(A_D)/(A_G)$ is due only to thruster ion beam and is assumed uniform over the grid. It can be reduced by improved focusing, and reduced charge exchange current to the grid.

The component $(J_{AD})_T - (J_{AG})_T (A_D)/(A_G)$ is due to the fact that the doubler intercepts more primary ions than does the single thickness grid. This can be prevented by not locating the doubler in an area of the grid holes. This could be accomplished by a redesign of the shield screen and neutralizer in this area. This component of J_{AD} does sputtering damage at energies of 4600 to 5000 volts.

The third component, $(J_{AD})_N$, is due to neutralizer operation and can be minimized by repositioning the neutralizer further downstream (Fig. 9). This component of current does sputtering damage at energies of 1600 to 2000 volts.

Figure 14 shows these components of the total doubler current as a function of accelerator potential (Table II). Normal thruster operation accounts for 65 to 71 μA. The neutralizer operation accounts for 54 to 58 μA. The increased direct ion impingement due to the doubler thickness accounts for 6 to 37 μA of current. At 2000 volts energies, this latter component alone yields a calculated wear rate of 6.6×10^{-5} mm/hr, or more than the calculated wear rate due to neutralizer operation alone.

Most of the remaining wear could be reduced significantly by repositioning the neutralizer. This would reduce the observed wear rate to order 10^{-4} mm/hr and would limit the total wear for a SERT II mission to less than 0.4 mm (16 mils).

Conclusion

Tests on a 30-cm diameter thruster show that an optimal neutralizer position is about 9 cm axially downstream and 9 cm radially out from the last row of accelerator holes. This position minimizes wear on the accelerator grid due to neutralizer operation and permits neutralizer operation at coupling voltages and propellant flow rates which minimize the total efficiency penalty due to the neutralizer. Neutralizer performance with 17 volts coupling at propellant flow rate of 22 equivalent mA was obtained for this position. Further, operating the neutralizer downstream of the grid parallel to the thruster axis (horizontal) minimized the accelerator grid erosion due to neutralizer operation. The expected wear rate due to neutralizer operation is less than 1×10^{-5} mm/hr.

Tests with a SERT II prototype thruster showed that a similar repositioning of the neutralizer would reduce the wear rate due to neutralizer operation by about a factor of seven. An analysis of the current to various parts of the accelerator grid indicates a higher than expected current to the doubler area of the grid due to thruster (not including neutralizer) operation. This component of current does sputtering damage at a higher sputtering yield because the bombarding ions probably have a much larger energy. Repositioning of the neutralizer and elimination of the doubler plate should reduce the wear rate of the SERT II accelerator grid from 1.32×10^{-3} mm/hr to of order 1×10^{-4} mm/hr.

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TABLE I. - SUMMARY OF SERT II THRUSTER TESTS

Test	Hours	Neutralizer keeper, +volts	Accelerator -volts	Drain current mA	Wear rate mm/hr	Comments	Reference
I	2300	22.2	2000	1.2	1.32×10^{-3}	Extrapolated from 500 hr	1
II	~2300	22.0	1900±100	2.1	1.32×10^{-3}		1
III	2385	22.9	1490	1.49 to 1.60	1.28×10^{-3}	Flight thruster 1	2,6
IV	2011	23.4	1530	1.80	1.51×10^{-3}	Flight thruster 2	2,6

TABLE II. - ACCELERATOR AND DOUBLER CURRENTS ON SERT II

THRUSTER WITH MODIFIED NEUTRALIZER POSITION

[8.9 cm axial downstream, 7.6 cm radial, 10° pointing angle]

Accelerator potential kV	Neutralizer off		Neutralizer keeper 22.5V		Neutralizer keeper 21.0V	
	Total accelerator current mA, J_A	Doubler current thruster only mA, $(J_{AD})_T$	Total doubler current mA, J_{AD}	Doubler current neutralizer only mA, $(J_{AD})_N$	Total doubler current mA, J_{AD}	Doubler current neutralizer only mA, $(J_{AD})_N$
1.6	0.89	0.071	0.127	0.056	0.127	0.056
1.7	.91	.081	-----	-----	0.135	0.054
1.8	.95	.090	0.145	0.055	0.144	.054
1.9	.98	.098	-----	-----	0.155	.057
2.0	1.0	.108	0.166	0.058	0.163	.055

$J_{AD} = (J_{AD})_T + (J_{AD})_N$

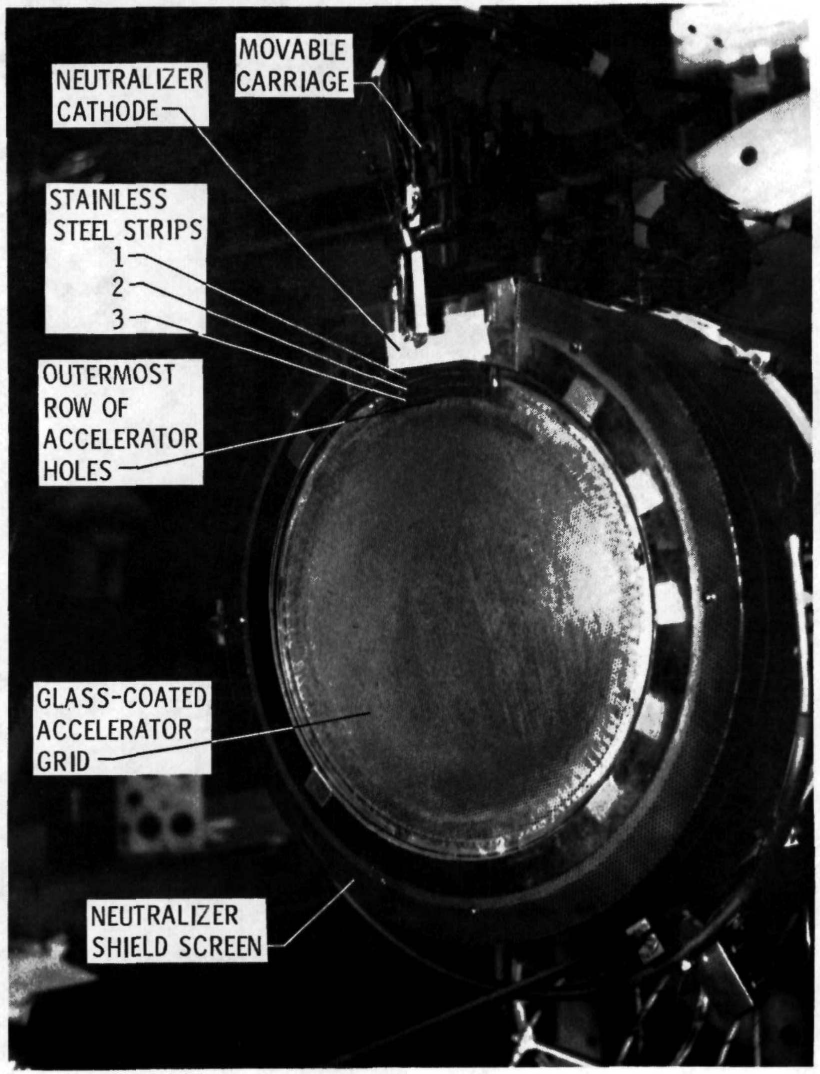

Figure 1. - 30-cm diameter thruster with movable neutralizer.

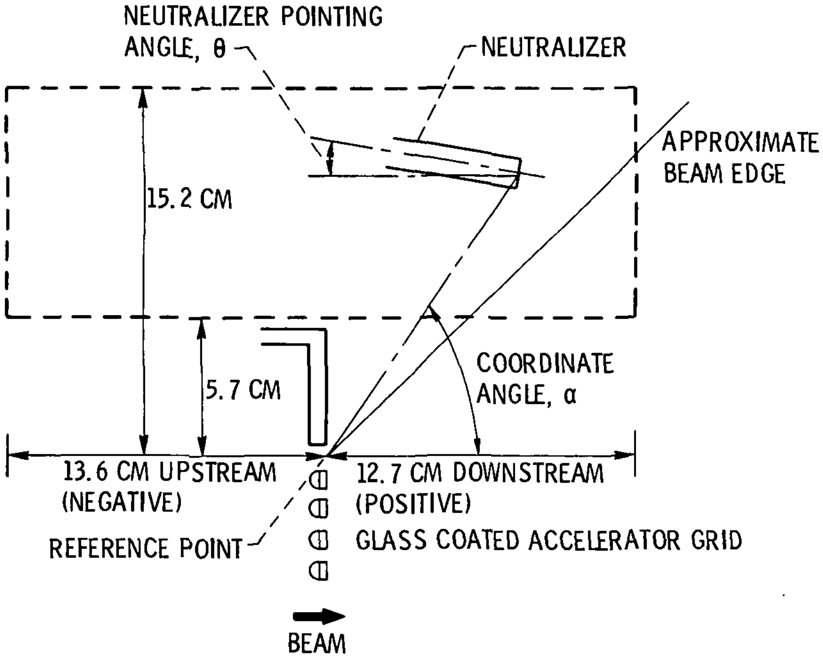

Figure 2. - Area mapped by movable neutralizer.

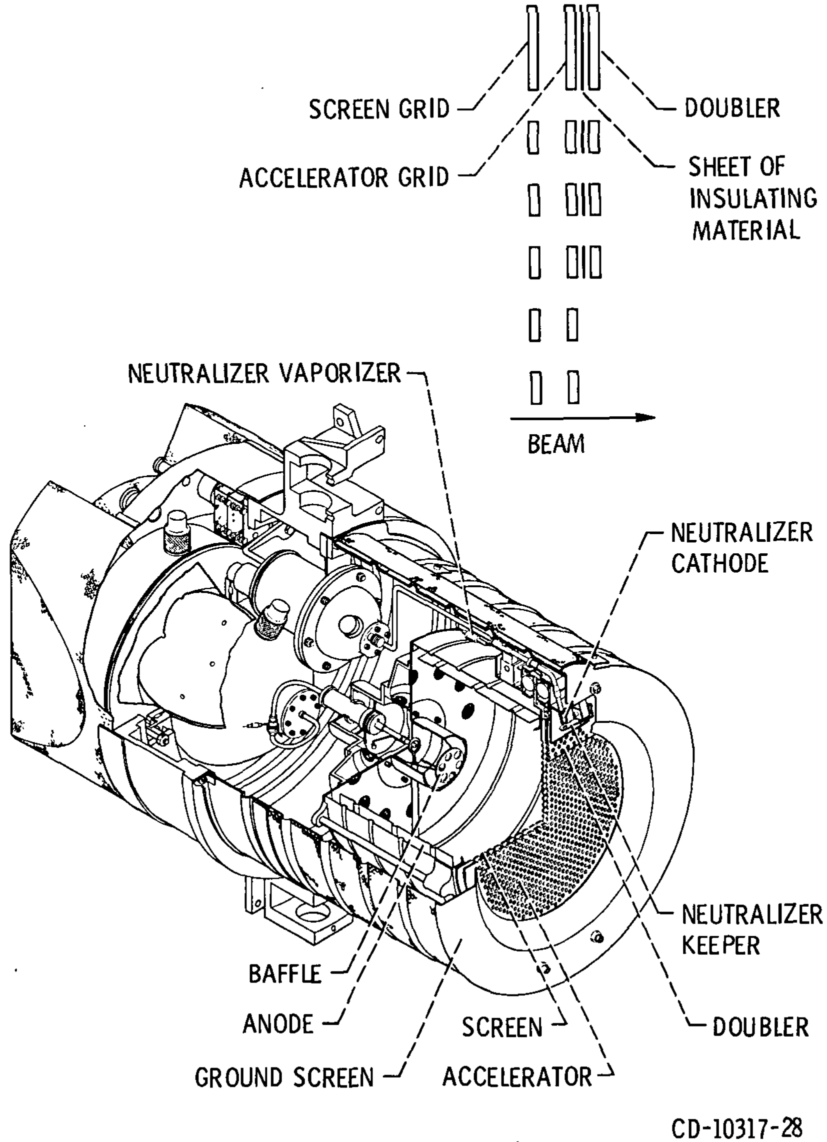

Figure 3. - SERT-II thruster. (15 cm diam.)

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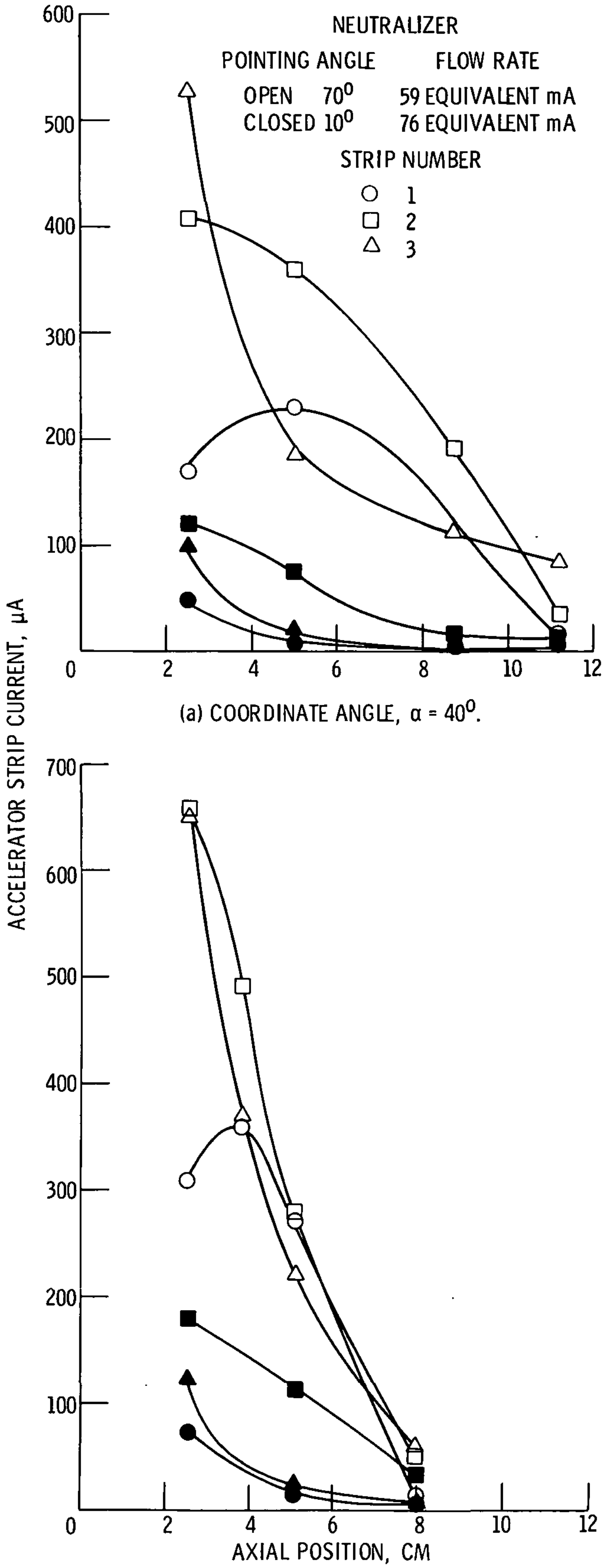

(a) COORDINATE ANGLE, $\alpha = 40^0$.

(b) COORDINATE ANGLE, $\alpha = 50^0$.

Figure 4. - Accelerator strip currents (30 cm thruster). (See fig. 2 for definition of coordinate angle.)

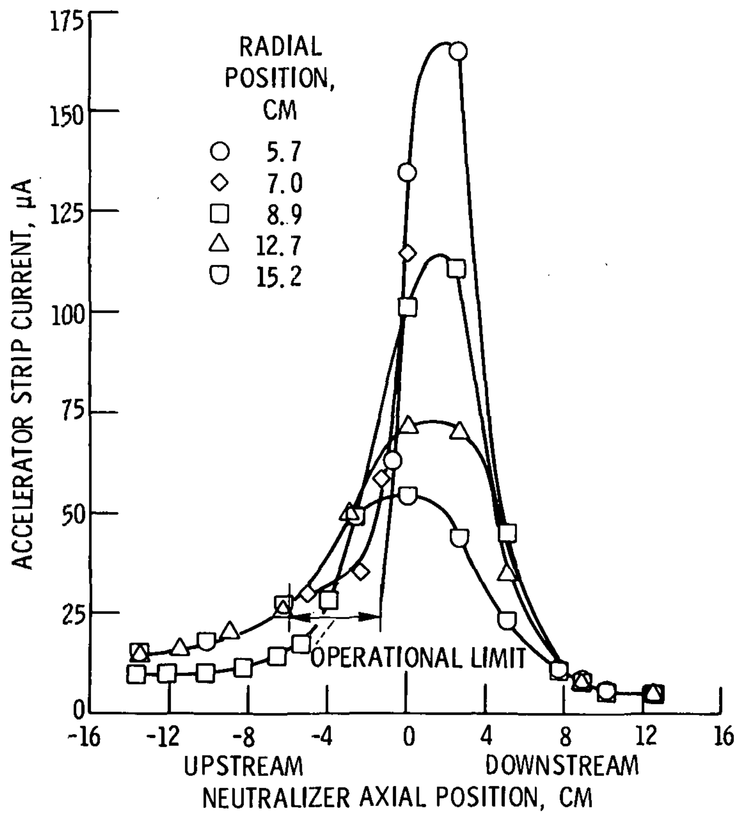

Figure 6. - Accelerator impingement strip currents for upstream and downstream neutralizer positions, 30 cm thruster; $\dot{m}$ equivalent 95 mA; $\theta = 0^0$; J_B, 1.5 A; V_I, 1000 V; V_A, 500 V.

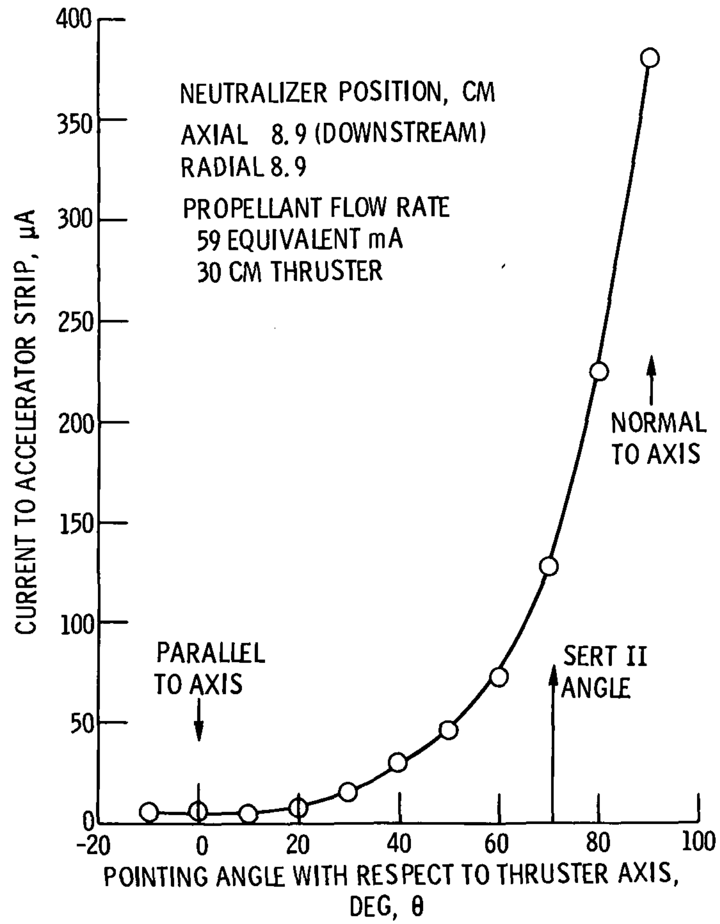

Figure 5. - Accelerator strip currents as function of neutralizer angle.

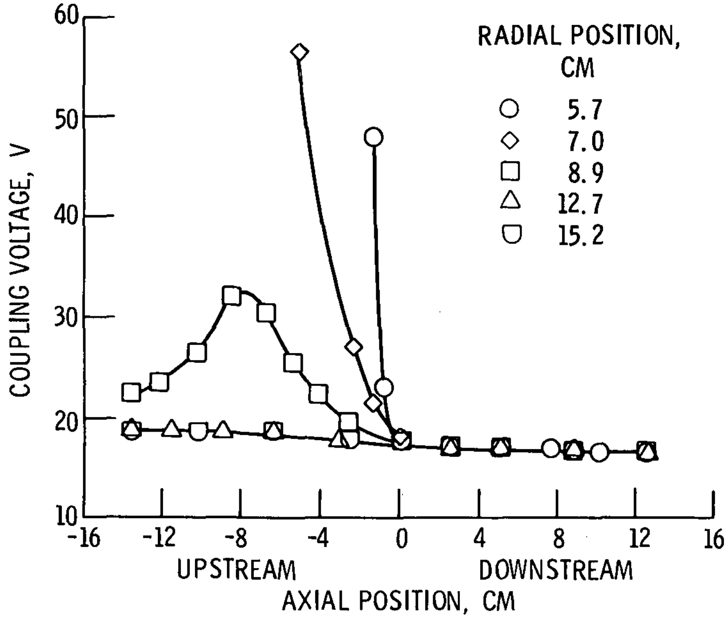

Figure 7. - Coupling voltage for upstream and downstream neutralizer positions, 30 cm thruster; $\dot{m}$ equivalent 95 mA; $\theta = 0^0$; $V_I = 1000$ V; $V_A = 500$ V; $J_B = 1.5$ A.

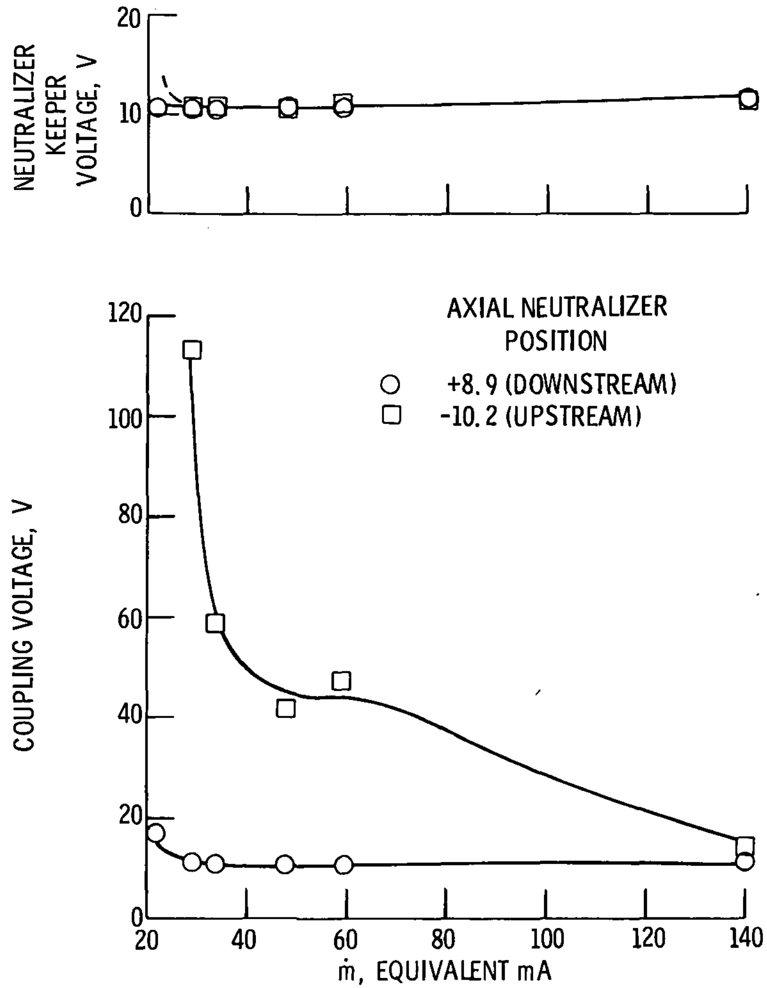

Figure 8. - Neutralizer performance at two locations - 30 cm thruster. V_I, 1000; V_A, 500; J_B, 1.5; radial position, 8.9 cm; neutralizer angle, 0^0.

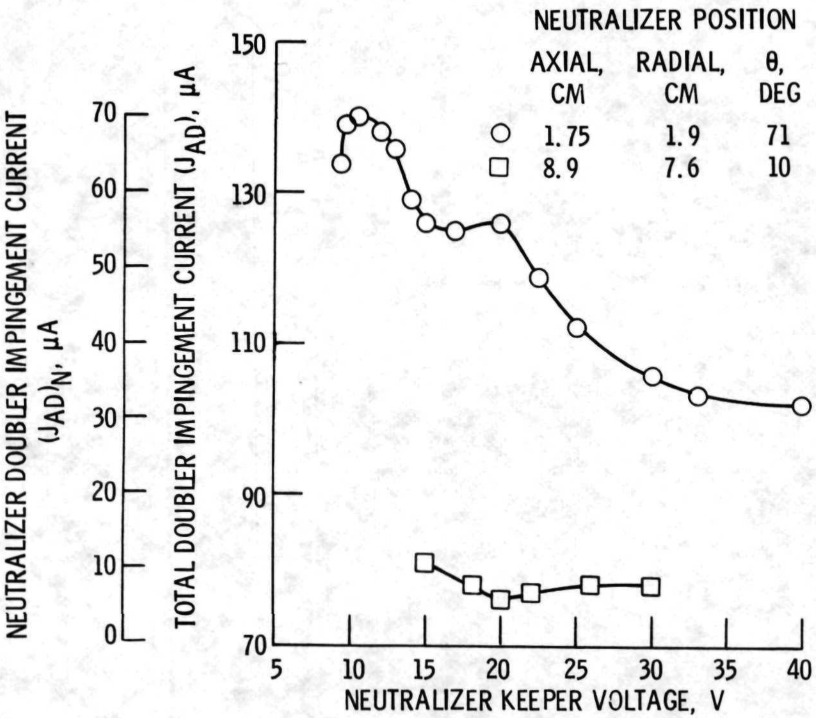

Figure 9. - Doubler plate currents on Sert II prototype thruster. Net accelerating potential, 3000 V; accelerator potential, 1600 V; beam current, 0.25 A.

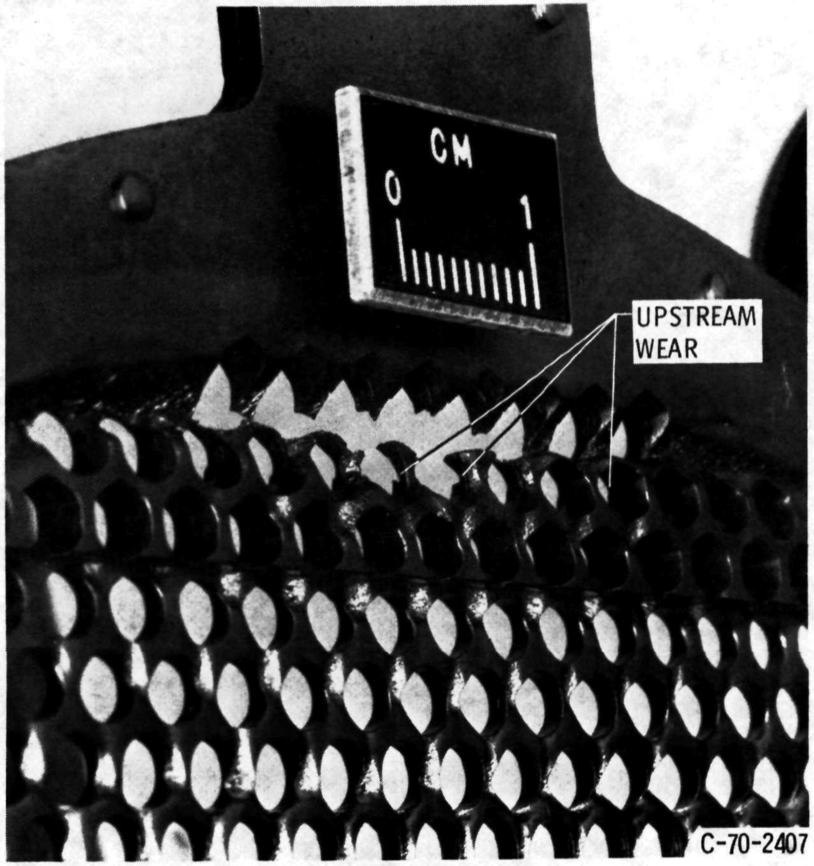

Figure 10. - SERT II accelerator grid.

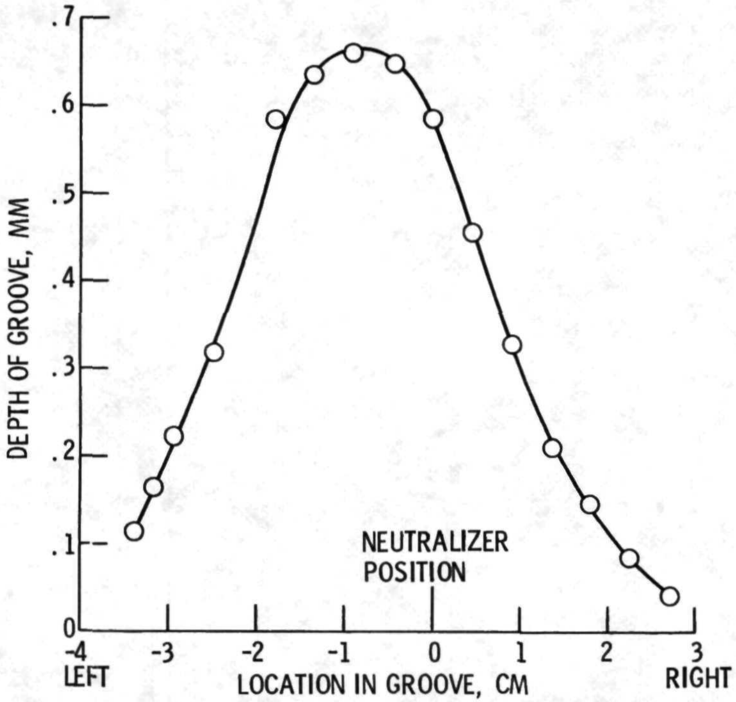

Figure 11. - Profile of groove on accelerator grid of SERT II prototype thruster after 500 hr of testing.

Figure 12. - SERT II accelerator grid documented in figure 11.

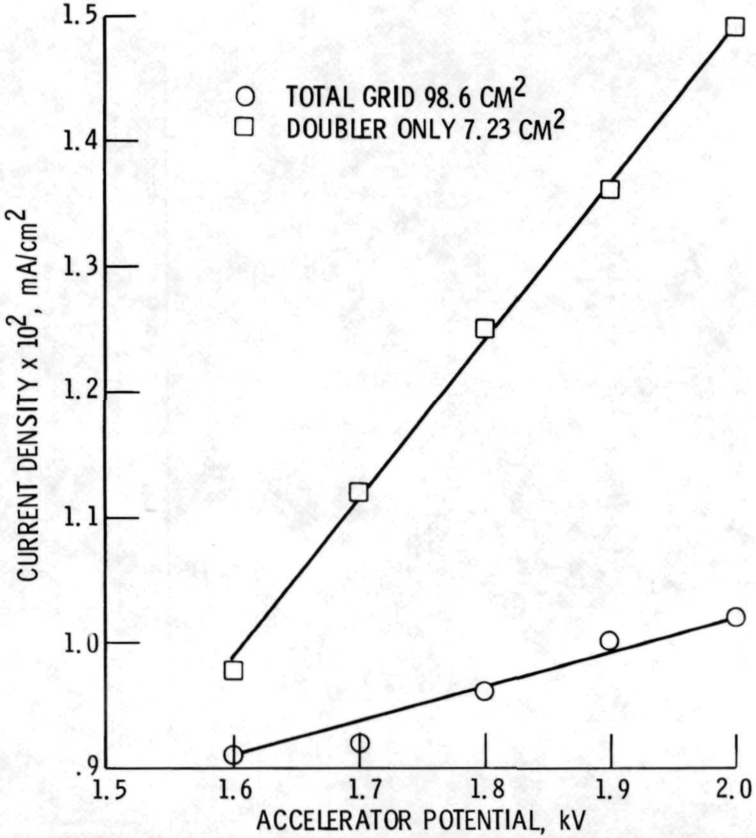

Figure 13. - Impingement current density as function of accelerator potential. Sert II thruster; neutralizer off; neutralizer position; 8.9 cm axial downstream; 7.6 cm radial; $\theta = 10^0$; $V_I = 3000$ V; $J_B = 0.25$ A.

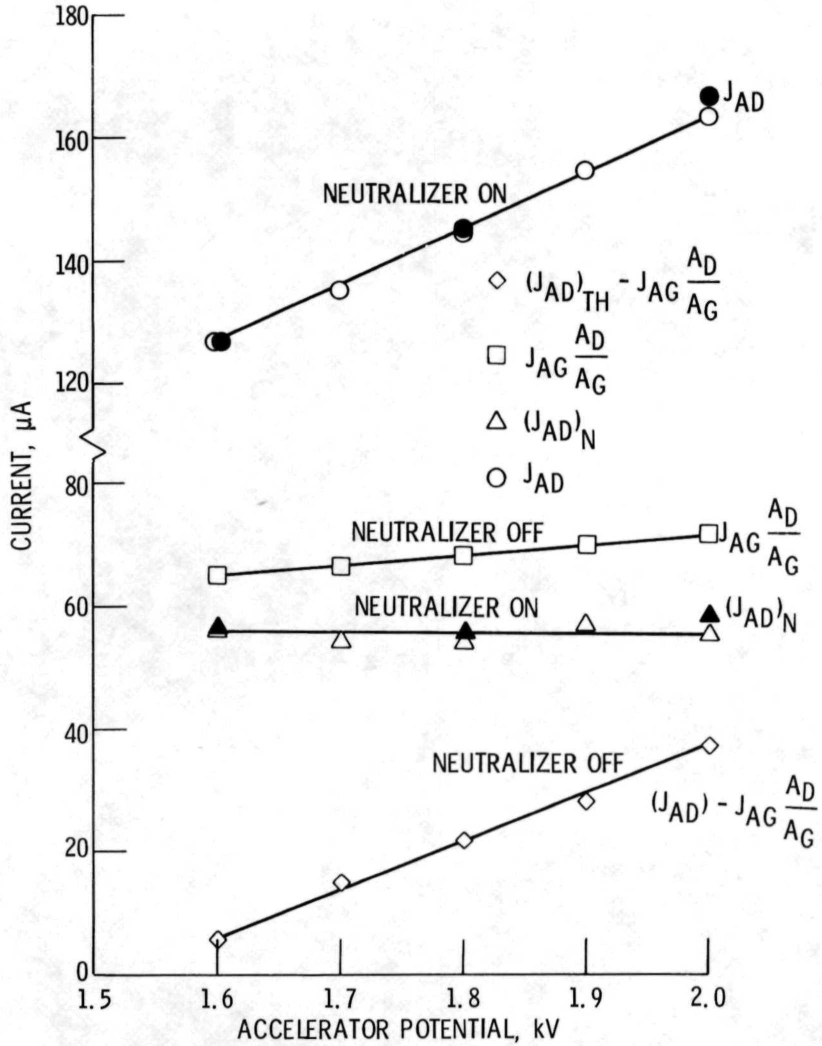

Figure 14. - Various accelerator grid currents neutralizer keeper, 21.0 open; 22.5 V closed. Data from table II.

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