Conclusions

From the results of this study, the following conclusions emerge:

1) The colloid core concept is feasible from the standpoint of reactor design. With a solid particulate fuel a specific impulse of 1200 lb-sec/lb_m is obtainable.

2) The preliminary design of the GTR resulted in a weight of about 41,000 lb (or 19,000 kg) for a thrust of 100,000 lb (45,000 kg). No attempt was made to optimize the weight of the ground test system.

3) Several technological problem areas requiring further examination may be recommended, i.e.: a) fuel vaporization losses, b) fuel particle fission fragmentation, and c) liner material erosion.

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Parametric Investigation of Mercury Hollow-Cathode Neutralizers

D. C. BYERS* AND AARON SNYDER†
NASA Lewis Research Center, Cleveland, Ohio

A parametric investigation of mercury hollow-cathode neutralizers for Kaufman ion thrusters was carried out in a bell jar over a range of collector (ion beam simulator) currents up to 2 amp. The parameters investigated included mercury neutral flow rate, neutralizer cathode geometry, collector geometry and spacing, keeper power supply impedance, keeper current, keeper electrode geometry and spacing. Agreement was found between neutralizer operation in the bell jar and on an active thruster. The influence of the various parameters on neutralizer performance and control characteristics is discussed for three distinct modes of neutralizer operation.

Introduction

HOLLOW-CATHODE neutralizers[1] appear to be suitable for use with thrusters which operate over a large range of ion beam currents.[2–4] Such neutralizers have been studied for a variety of specific thruster operating conditions.[5–8] Neutralizer optimization programs have been carried out or are in progress with 5-, 15-, and 30-cm-diam thrusters.[2–4] It was found in these programs that the optimum neutralizer design was specific to the emission currents (equal to ion beam currents) and neutral flow rates at which the neutralizer was required to operate. Studies have been made of the effects of various neutralizer parameters,[6,9] but most investigations have been concerned with a limited range of neutralizer operating conditions and/or a specific neutralizer configuration.

Neutralizer performance is defined in terms of the required neutral flow rates, operating voltages, and power levels. The neutral flow rate is charged directly against the over-all thruster system propellant utilization efficiency, the operating voltages are directly related to neutralizer lifetime, thrust, and over-all thruster system power efficiency. The neutralizer system must also be amenable to some type of control logic. Some parameters, such as coupling voltage, must generally be held or controlled within certain limits to avoid degradation of performance or lifetime.[5] On the SERT II thruster, for example, the keeper voltage (which is proportional to coupling voltage) is sensed and controlled via a feedback loop with the neutralizer vaporizer.[2] The relationship between the controlled and control parameters must be known and of such a form as to allow a stable control loop logic.

This paper presents the results of a bell-jar investigation of various hollow-cathode neutralizers over a wide range of operating parameters. A comparison also was made between

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* Aerospace Research Engineer. Member AIAA.

† Student Trainee.

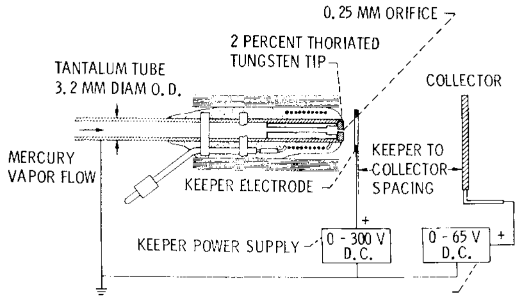

Fig. 1 Experimental setup with SERT II hollow cathode neutralizer.

bell-jar and thruster neutralizer operation. The collector current (corresponding to ion beam current) was varied from 0.030 to 2.0 amp. Over this range of collector current, the effects on performance and control of a variety of neutralizer parameters were studied.

Apparatus and Procedure

Figure 1 shows a sketch of the experimental setup, which is in many ways similar to that of Ref. 10. The neutralizer hollow cathodes were mounted at ground potential. The positively biased keeper electrode was mounted downstream of the cathode tip. A positively biased collector was positioned downstream of the keeper to simulate the ion beam of an operating thruster. An adjustable shaft could be connected to either the keeper or collector to allow movement of the keeper or the collector during testing. The reservoir for the mercury was a precision bore glass tube that allowed measurement of the mercury flow rate. All flow rates quoted herein were obtained via such measurements, which were repeatable to within 3%. They are expressed throughout in terms of equivalent milliamperes of neutral flow (J_m). All tests were conducted in a 0.46-m-diam by 1.5-m-high bell jar. Cryogenic pumping (LN_2), along with an oil diffusion pump, enabled neutralizer testing to be conducted in the 3×10^{-6} to 7×10^{-6} torr pressure range.

Five hollow-cathode neutralizers were tested. One was the SERT II type[4] (Fig. 1), for which the neutralizer consisted of a 2% thoriated tungsten disk welded to one end of a 3.2-mm-o.d. tantalum tube. A 0.25-mm-diam orifice was sandblasted into the thoriated tungsten tip. The upstream end of the tantalum tube was connected to the mercury vapor feed system. A rolled insert of barium-carbonate-coated tantalum foil was placed inside the tantalum tube directly behind the tip to assist in starting the discharge. The other four neutralizer cathodes tested were of similar construction, they are denoted A, B, C, and D, in order of increasing tip orifice size, in Table 1. All were 6.3-mm outside diam. The cathode tips were all about 1.5 mm thick, 2% thoriated tungsten disks. The orifice sizes of some of the cathode tips tapered slightly from a minimum at the upstream face to a maximum diameter at the downstream face. The minimum orifice diameters (listed in Table 1) ranged from the SERT II size of 0.25 mm up to 0.69 mm. A carbonate mixture, applied

Table 1 Geometry of the various cathodes tested

Cathode	Cathode outside diameter, mm	Upstream orifice diameter, mm	Downstream orifice diameter, mm
SERT II	3.2	0.25	0.25
A	6.3	0.25	0.25
B	6.3	0.41	0.41
C	6.3	0.53	0.56
D	6.3	0.69	0.76

inside the tantalum tube near the tip, was used in place of the carbonate-coated tantalum insert of the SERT II neutralizer to aid in starting cathodes A–D.

A standard SERT II-type keeper electrode was used with the foregoing cathodes. It was constructed of a 1.5-mm-thick tantalum plate with a 4.5-mm-diam hole. The cathode-to-keeper spacing was set at 1.5 mm. Unless otherwise noted, this keeper was used for all tests, but two additional designs were used to study the effects of keeper geometry. One was similar to the SERT II keeper but had a smaller hole of 2.4-mm diam. The other was the enclosed-type keeper, which has been operated successfully at very low neutral flows;[3] in this design, a porcelain cylinder, constructed to slip over the end of the 3.2-mm-diam cathode and project 1.5 mm beyond the tungsten tip, has a tantalum cap, 2.5 mm thick, with a hole of 1.5-mm diam placed on its end.

Three types of collectors were used. One was a hybrid formed of 1.9-cm-diam, dense mesh (5% open) tantalum screen set into a 2.54-cm by 3.18-cm rectangular tantalum plate. Unless otherwise noted, this collector was used throughout the tests. The other two collectors were made of stainless steel; one was a 68-%-open-area screen mounted on a 7.6-cm-diam support ring, and the other was a solid 7.6-cm-diam plate.

The keeper power supply was designed so that the output voltage dropped with increasing keeper current from the 300-v starting level to the 0-50 v operating region; a current limit control allowed fine adjustments in current. It was operated with three types of output circuit: a capacitive circuit,[9] in which a capacitor was added in parallel across the supply output; an inductive circuit, in which an inductor was added in series to the positive side of the power supply; and a resistive circuit, in which no impedance was added to the supply output. The collector (beam simulator) power supply was a voltage-unregulated, d.c. supply equipped with a current limit control.

A brief review of neutralizer performance in an operating thruster is in order. During thruster operation the neutralizer cathode (and thruster) assumes an equilibrium potential negative with respect to the local ground; this is referred to as the floating potential.[2,11] Potentials in the exhaust ion beam rise to values above local ground. The beam potential varies axially and radially and has a maximum value on axis near the thruster.[5] The difference between the maximum beam potential and the neutralizer floating potential is called the coupling voltage.[5] Values of coupling voltage have been measured during some facility tests,[6,8] but are not generally available because the measurement requires a probe in the beam plasma. Because of the axial and radial variation of the beam potential, it would be difficult to simulate the potential distribution in bell-jar tests. Instead, for simplicity, it was decided to use a single collector. The collector potentials used were in the range encountered in actual thruster operation.

Results with the SERT II-Type Neutralizer Cathode

Three distinct modes of operation existed with the SERT II-type neutralizer cathode, the plume, transition, and spot modes.[6,7] In general, the plume mode existed for collector currents less than about 0.5 amp. Above this level, the neutralizer operated in either transition or spot mode. The effects of the various parameters on neutralizer performance depended on the mode of operation.

Variation of Collector Geometry and Spacing

This series of tests was run to relate bell-jar and thruster operation. Typical plots of the keeper and collector voltages (referenced to ground) as a function of neutral flow rate J_m

are shown in Fig. 2 for three collector geometries and two keeper-to-collector spacings. Also shown are values for the SERT II thruster system from Ref. 2. The values of keeper current and collector current (beam simulator current) were at the nominal SERT II values of 0.2 and 0.25 amp, respectively, and the neutralizer operated in plume mode for all the data of Fig. 2.

The variation of keeper voltage V_{na} with flow rate was quite similar to that of the SERT II thruster system. At a fixed J_m, V_{na} was insensitive to both collector type and spacing (except for spacings less than about 0.6 cm, where back reflection of neutrals from the collector may have been a factor). The SERT II thruster tests[2] had shown that at a fixed J_m, V_{na} increased as the ion beam current J_B decreased. It was speculated[2] that this could have been due to a contraction of the beam edge away from the neutralizer. The data of Figs. 2a and 2b indicate, however, that increasing the beam coupling distance did not result in any variation of V_{na}. (This point is discussed later.) Figure 2 also shows that the collector voltage was very sensitive to both collector geometry and spacing. In general, the collector voltage increased with increasing collector open area and keeper-collector spacing. The strong effect on coupling voltage of neutralizer position relative to the ion beam has been observed in several investigations.[6–8]

For purposes of simulated neutralizer operation, the collector voltage should probably be held at a value between 2 and 4 times the absolute value of thruster floating potential, because with operating thrusters, the thruster coupling voltage is 2 to 4 times the absolute value of the thruster floating potential referenced to ground.[5] When compared to the SERT II floating voltage in Fig. 2, the collector voltages were in the right range for the hybrid and 68-%-open collectors at both keeper-collector spacings.

From Fig. 2 it is not completely clear which collector geometry-spacing configuration would best simulate the ion beam potential. Somewhat arbitrarily, the hybrid collector was selected for the balance of the data of this report and, unless otherwise stated, was located at a distance of 1.27 cm from the keeper. As will be seen later, many of the observed variations of neutralizer performance on a thruster were duplicated with this collector configuration. A hybrid collector, identical to the one of this paper, was the type used for a 10,800-hr neutralizer life test.[5]

Effect of Keeper Power Supply Impedance

Reference 9 noted that at SERT II operating conditions the variation in keeper voltage with J_m was strongly influenced by the impedance Z_K of the keeper power supply. The relationships between Z_K and performance over extended ranges of neutralizer operating parameters are presented here; all data were taken with the neutralizer operating in the plume mode.

Figure 3 shows the variation of keeper and collector voltages with J_m for several Z_K's. Several thruster data points are included for comparison.[2,9] Figure 3a shows that in agreement with Ref. 9, V_{na} was higher for the inductive and resistive circuits than for the capacitive circuits. At $J_m \gtrsim 35$ ma, the effect of Z_K on V_{na} was reduced. The collector voltage was sensitive to power supply impedance at $J_m \gtrsim 25$ ma.

The effect of Z_K on performance is believed to be related to the presence of oscillations in the voltages and currents of the keeper and collector discharges. For the conditions of Fig. 3a it was noted that, with a resistive circuit, as J_m increased from 17 to 30 ma, the oscillation frequency decreased from about 6 to 1×10^5 Hz; at ~ 35 ma, the frequency dropped sharply and the oscillation became very coherent. In general, the peak-to-peak amplitude of the oscillations decreased with increasing J_m.

The effect of impedance was also dependent on neutralizer keeper current. Figure 3b shows the variation of keeper and collector voltages with flow rate at conditions identical

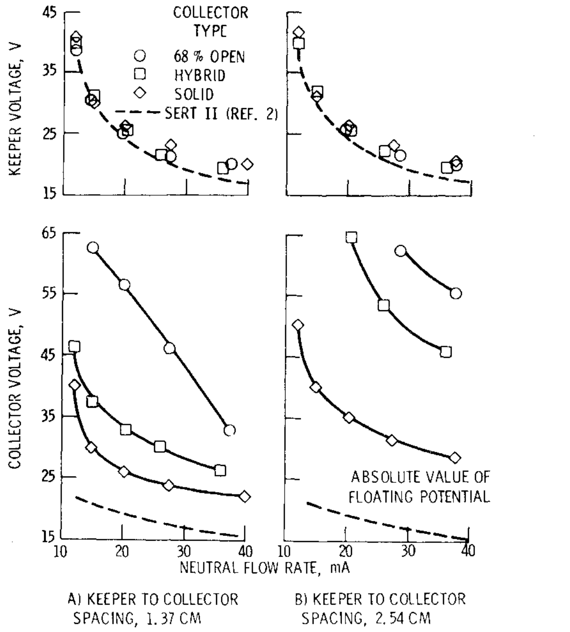

Fig. 2 Variation of keeper and collector voltage with neutral flow rate for various collector geometries at two keeper to collector spacings. Keeper current, 0.20 amp; collector current, 0.250 amp.

to Fig. 3a except that the current was reduced to 0.1 amp. The effect of impedance on the keeper and collector voltages was noticeably reduced from the conditions of Fig. 3a. This trend held over a range of keeper currents from about 0.05 to 0.4 amp. Review of the oscillations indicated that the peak-to-peak amplitude of the oscillations decreased with decreasing keeper current. For example, at a keeper current of 0.2 amp and a neutral flow of 15 ma the peak-to-peak amplitude of the oscillation of the keeper voltage was 55 v. At 0.1 amp keeper current, other conditions being equal, no oscillation of keeper voltage could be detected.

The effect of impedance also was studied over a wide range of collector currents (0.05–0.5 amp). Figure 4 shows the variation of the keeper and collector voltages with J_m for a resistive (Fig. 4a) and a capacitive (Fig. 4b) circuit. With a resistive circuit the shapes of the curves of keeper and collector voltage vs J_m were dependent on the collector current. At low collector currents, the voltages were rather insensitive to J_m. At a given J_m, the keeper voltage was not always a monotonic function of collector current. The collector volt-

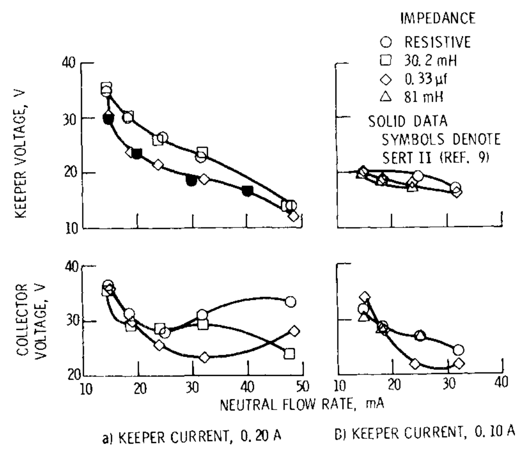

Fig. 3 Variation of keeper and collector voltages with neutral flow rate for various keeper supply impedances and keeper currents. Collector current 0.250 amp.

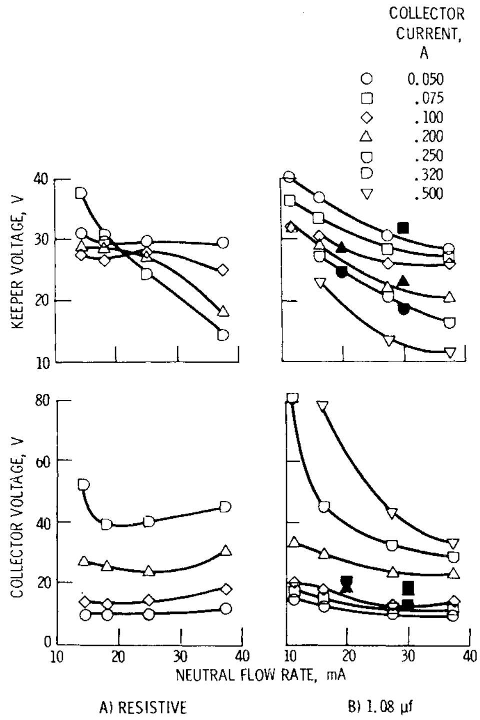

Fig. 4 Variation of keeper and collector voltages with neutral flow rate for various collector currents and keeper power supply impedences. Keeper current, 0.20 amp.

age curves exhibited minima with the resistive keeper power supply. With the capacitive circuit, however, the keeper and collector voltages were monotonic functions of both J_m and collector current over the range tested. The use of the keeper power supply voltage to control J_m (as on the SERT II system) probably would be impossible with a resistive circuit at low J_B's. On the other hand, with a capacitive circuit, such a control loop could be used over the range of collector currents tested (0.05–0.5 amp).

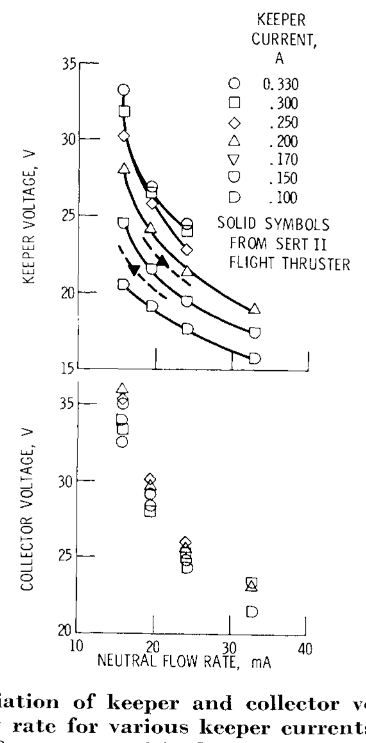

Fig. 5 Variation of keeper and collector voltages with neutral flow rate for various keeper currents. Collector current 0.250 amp; capacitive keeper power supply circuit, (0.33 μf).

A capacitive keeper circuit is superior to the resistive and inductive circuits on the basis of performance and/or control. The effect of impedance on lifetime, however, has not yet been demonstrated. In this investigation and in Ref. 9 it was found that the impedance type strongly affected the discharge oscillations. The use of inductive and capacitive keeper power supplies tended to hold the currents and voltages, respectively, constant. Both current and voltage may play a role in neutralizer lifetime.[5] At this writing, three SERT II neutralizer tests of the order of 4000 hr or greater have been conducted.[11] The keeper power supply for these tests was essentially capacitive. On the other hand, the 10,800-hr test reported in Ref. 5 was run with a supply which was not capacitive. Resolution of the influence of Z_K on lifetime requires further testing.

Figure 4b can be used to compare neutralizer operation in a bell jar to that on a thruster. Data from the SERT II flight thruster are shown by solid symbols. At a given J_m, V_{na} increased monotonically with decreasing collector current. The sensitivity of keeper voltage to collector (or ion beam) current obtained in the bell-jar study was about the same as that obtained on the SERT II flight thruster. The results of Fig. 4b then substantiate the conclusion, discussed previously, that the variation of V_{na} with J_B on the SERT II thruster was not due to a shift in the effective coupling distance.

Figure 4 also shows that the collector voltage increased monotonically with collector current. An increase of collector current from 0.075 to 0.25 amp (Fig. 4b) corresponded to an increase of collector voltage of about 22 v at a flow rate of 30 ma. A similar increase in J_B on the SERT II thruster[2] caused an increase in thruster floating voltage of only about 7 v. No beam potential measurements were made during the tests reported in Ref. 2. The variation of coupling voltage with J_B was then not known. If the coupling voltage remained at about 2 to 4 times the thruster floating potential, the results of the bell-jar tests are in reasonable agreement with the data of Ref. 2. On the other hand, comparison of Figs. 2 and 4 indicates that an increase of both collector current and collector spacing increases the collector voltage. It is possible that variation of the J_B of a thruster changes the effective coupling distance. Therefore, the decrease of floating potential with decreasing J_B could be a result of the competing effects of increasing coupling distance and decreasing J_B.

Effect of Keeper Current

The keeper and collector voltages are presented in Fig. 5 as a function of flow rate for a number of keeper currents with a capacitive (0.33-μf) keeper power supply circuit. For reference, data from the SERT II flight thruster are included on Fig. 5a, which shows that at a given J_m, the keeper voltage increased with increasing keeper current. To maintain a fixed keeper voltage, the required J_m increases with keeper current. It is seen from Fig. 5a that the data of SERT II are in the same range as that of this program.

It is also important to note that the shape of the curve of keeper voltage vs J_m changed with keeper current. In application, if the keeper current is expected to vary with mission time (as is the case with the SERT II flight), attention must be paid for the variation in performance and control loop characteristics that might be experienced. Fig. 5b shows that the collector voltage was not a monotonic function of keeper current. Over the range tested, the maximum collector voltage was obtained at a keeper current of from 0.20 to 0.25 amp.

Effect of Geometry

The effect of keeper geometry (see Apparatus section) was tested over a range of J_m's and collector currents. All data

Table 2 Variation of neutralizer parameters with keeper geometry Cathode to keeper spacing, 1.5 mm

Number	Keeper type	Keeper hole diameter, mm	Keeper voltage, v	Keeper current, amp	Collector voltage, v	Collector current, amp	Mercury flow rate, ma
1	Enc.[3]	0.76	15.5	0.250	22.0[a]	0.030	2.3
2	Enc.	1.52	20.7	0.250	16.8	0.030	2
3	Enc.	1.52	18.9	0.250	77.8	0.060	2
4	Enc.	1.52	11.0	0.200	42.5	0.250	24
5	Open	2.38	19.0	0.200	47.2	0.250	24
6	Open[2]	4.77	21.5	0.200	25.5[a]	0.250	24

[a] Thruster floating potential.

in this section were taken with a capacitive (1.08-μf) keeper power supply and a keeper current of 0.2 amp. In Table 2, lines 1 and 2 are operating points from Ref. 3 and this experiment, respectively. In Ref. 3, the keeper voltage and thruster floating potential were very sensitive to neutralizer cathode heater power, which was $\sim$9 w for the two cases compared (lines 1 and 2, Table 2). It is seen that the keeper and collector voltages for the enclosed keeper of Ref. 3 were lower and higher, respectively, than those for the enclosed keeper (larger keeper hole) of this experiment.

As pointed out in Ref. 3, the most noteworthy feature of the enclosed keeper is that very low J_m's may be obtained. On the other hand, in the simulation tests the coupling voltage was found to be very sensitive to collector current. When the collector current was increased to 0.06 amp (line 3, Table 2) at constant J_m, the collector voltage increased by more than a factor of four. This effect was anticipated because of the reduced keeper hole size.

Shown in Table 2 (lines 4–6) are data for the three types of keepers at constant J_m (24 ma), collector current (0.25 amp), and keeper current (0.20 amp). From Table 2 and other data, some general conclusions were drawn. At a fixed keeper-cathode spacing, the effect of reduction of the open area (keeper hole size) between the cathode and the collector generally reduced the keeper voltage and increased the collector voltage. Reduction of the open area also allowed operation at lower J_m's but caused an increase in the sensitivity of the collector voltage to collector current, which could limit the range of collector current at which the neutralizer could be operated.

Selection of an optimum keeper design will then depend on the constraints placed on coupling voltage and J_m. In general, however, the data indicate that as J_B increases, the keeper design should become more open for over-all optimum design. The sensitivity of the neutralizer performance to keeper spacing does indicate, in addition, the prudence of selection of a keeper design which guarantees fixed spacing. The enclosed keeper concept, with hole size selected for the particular application, would appear to answer this criterion.

Variation of Collector Current

Thrusters are currently being investigated that operate at $J_B \simeq 1.5$ amp.[12,13] For this reason the range of collector currents were varied up to that value. Figure 6 shows the keeper and collector voltages vs collector current at $J_m = 32$ ma. A SERT II-type keeper was used for all the data of this section. At collector currents $\lesssim 0.5$ amp the neutralizer operated in the plume mode. At higher collector currents, it would switch to the transition mode. The level of collector current at which the transition occurred decreased with increasing keeper current. The plume and transition modes were separated by a large range of collector current. Even with the current-limited power supplies used, the neutralizer would not operate in the region of collector currents between the plume and transition modes. In Fig. 6 the regions of collector current over which the neutralizer would not operate are shown by dashed lines. The performance shown in Fig. 6 was typical for J_m's from about 30 to 90 ma. The former flow was the lowest at which 1.5-amp collector current could be obtained at the 65-v limit of the collector power supply.

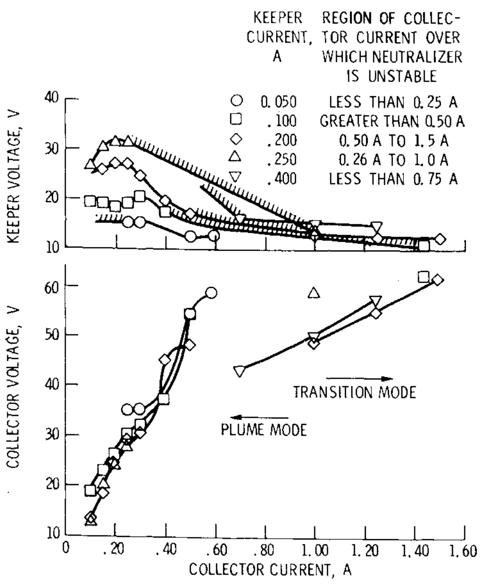

Fig. 6 Variation of keeper and collector voltages with collector current at several values of keeper current. Neutral flow rate, 32 ma, resistive keeper power supply circuit.

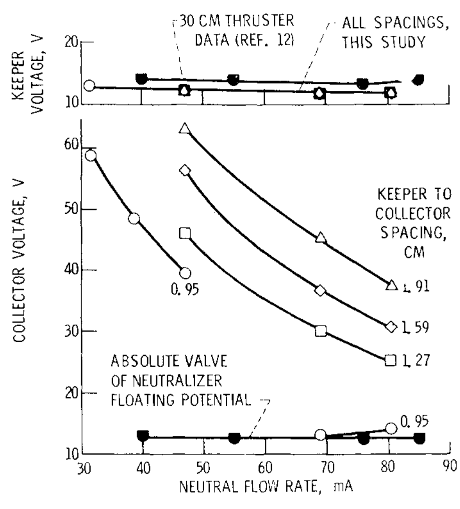

Fig. 7 Variation of keeper and collector voltages with neutral flow rate for various keeper to collector spacings. Keeper current, 0.20 amp; collector current, 1.5 amp; resistive keeper power supply circuit.

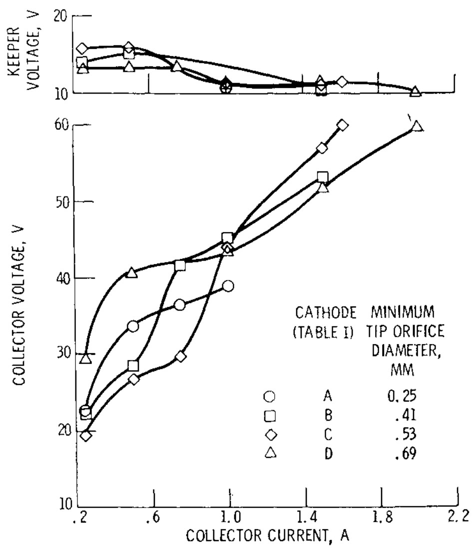

Fig. 8 Variation of keeper and collector voltages with collector current. Keeper current, 0.20 amp; neutral flow rate, 43 ma; resistive keeper power supply circuit.

Operation in Transition and Spot Modes

At J_m's higher than that of Fig. 6, the neutralizer also ran in spot mode. If a SERT II-type neutralizer were to be operated on a thruster system at currents in excess of 0.5 amp, the neutralizer would probably operate in either transition or spot mode. Figure 7 presents the voltages vs J_m at a collector current of 1.5 amp, for a constant keeper current (0.2 amp) and three collector spacings. For comparison, some data points from a 30-cm thruster are presented from another study,[12] in which the neutralizer cathode and keeper were essentially identical to the SERT II type. The neutralizer was in the transition mode, for most of the data of Fig. 7. In this mode the collector voltage varied smoothly with J_m and spacing, while the keeper voltage was insensitive to these variables. For the 9.5-mm spacing, however, at high flow the neutralizer switched to spot mode. In this mode neither the collector nor keeper voltage was significantly affected by J_m.

The data of this program agreed with the data of Ref. 12 (30-cm thruster) only in the spot mode. While not certain, it is estimated from the results in Fig. 7 that the effective coupling distance on thruster of Ref. 12 is of the order of 1 cm or less. It was noted in that program that the ion beam divergence was such as to impinge directly on the neutralizer at J_B of 1.5 amp.

The data of Fig. 7 suggest that the neutralizer control loop used on the SERT II thruster could not be used at the high J_B's of the 30-cm-thruster system since the keeper voltage is quite insensitive to J_m. The thruster floating potential (or in space, a spacecraft potential with respect to local ground) could possibly be used for closed loop vaporizer control if the neutralizer is operated in the transition mode. When the neutralizer operates in spot mode, it is unlikely that either keeper voltage or thruster floating potential could be used in a closed-loop vaporizer neutralizer control logic.

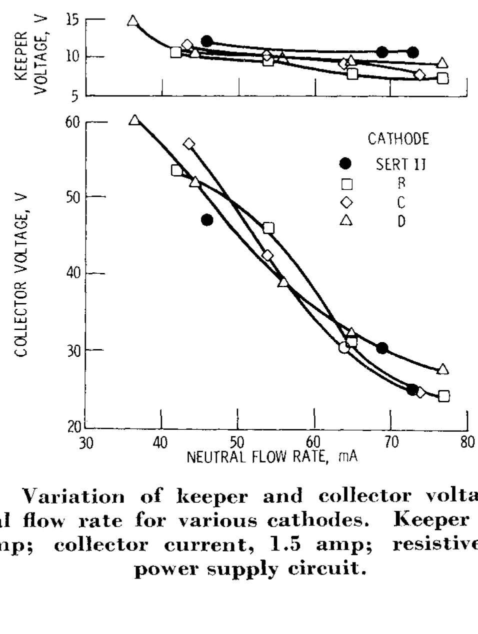

Fig. 9 Variation of keeper and collector voltage with neutral flow rate for various cathodes. Keeper current, 0.20 mp; collector current, 1.5 amp; resistive keeper power supply circuit.

Results with Other Neutralizer Cathode Geometries

It was of interest to test other cathodes (Table 1) with increased orifice diameters for two reasons: 1) The SERT II neutralizer cathode was not stable over the full range of collector currents of interest (Fig. 6), and 2) improved lifetime was expected.[12,13] A SERT II-type keeper, ~1.5 mm from the cathode face, was used for all the data of this section. As these cathodes had no insert, a triple carbonate mixture was applied to each cathode to insure repeatable starting.

Figure 8 presents keeper and collector voltages vs collector current for the four larger-diameter cathodes. The keeper current was 0.2 amp, and J_m rate was 43 ma. Cathodes B, C, and D were stable over the range of collector currents up to 1.5 amp. Cathode A, with orifice dimensions nearly identical to the SERT II cathode, exhibited an instability similar to that of the SERT II cathode (Fig. 6). Figure 8 also shows that the collector voltage, at a given collector current was not a monotonic function of orifice diameter. Data of the type shown in Fig. 8 were taken over ranges of keeper currents and J_m's from 0.1 to 0.7 amp and 35 to 94 ma, respectively. Over this range of keeper currents, the results were similar to those of Fig. 8. Cathodes B, C, and D provided stable operation for collector currents up to 1.5 amp while cathode A was generally unstable at collector currents greater than about 0.5 amp.

The effect of keeper current on keeper voltage was about the same at large collector currents (>0.5 amp) as at low collector currents. In general, the keeper voltage rose monotonically with keeper current. The collector voltage, however, generally exhibited a minimum at a keeper current of about 0.4 amp in some contrast to the data of Fig. 5.

For cathodes B, C, and D at collector currents >0.5 amp, Z_K had little effect on neutralizer performance when the neutralizer was operated in the transition mode. This is probably due to the fact that, as pointed out in Ref. 6, keeper discharge oscillations are strongly reduced in the transition mode compared to the plume mode. When the neutralizer was in the plume mode, the effect of Z_K with the large orifice cathodes was similar to that with the SERT II cathode. For example, at a collector current and J_m of 0.25 amp and 43 ma, respectively, the keeper voltage dropped ~2 v when the keeper circuit was changed from resistive to capacitive (1.08 μf).

Figure 9 shows the variation of keeper and collector voltages as a function of J_m at a collector current of 1.5 amp. For reference, data with the SERT II-type cathode is included. Cathode A is not shown because it would not operate at 1.5 amp collector current. At a fixed J_m, the collector voltage was similar for all cathode types tested. The shapes of the curves of collector voltage vs J_m in Fig. 9 indicate that the thruster floating potential, or some beam potentials possibly could be used in a closed-loop control of the neutralizer at high J_B's. However, as indicated in Fig. 7, for the SERT II-type neutralizer, care would have to be taken to insure that the effective coupling distance on the thruster was such as to avoid spot mode operation.

Summary of Results

A collector (ion beam simulator) geometry and spacing were selected that provided agreement between neutralizer performance in the bell jar and on the SERT II thruster system. The neutralizer was found to operate, in general, in the plume mode at collector currents $\lesssim 0.5$ amp and in the transition or spot mode at larger collector currents. A capacitive keeper power supply impedance Z_K was found to be desirable for neutralizers operating in the plume mode. At collector currents $\lesssim 0.5$ amp (transition and spot modes), Z_K had little effect on neutralizer performance.

Low neutral flows (J_m's) could be obtained with enclosed keepers, in agreement with previous results. On the other hand, minimum collector voltages were obtained with open keeper designs. Selection of an optimum keeper shape depends on the range of ion beam currents at which a thruster is to be operated.

The keeper current affected the required J_m and the slope of the curve of the keeper voltage vs J_m. In addition, the level of keeper current influenced the relationship between Z_K and neutralizer performance.

The SERT II neutralizer was unstable in a range of collector (ion beam) currents of interest for 30-cm-diam thrusters, but cathodes of larger orifice diameter allowed stable operation at 2-amp collector current.

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