SUCCESSFUL COMPLETION OF A CYCLIC GROUND TEST OF A MERCURY ION AUXILIARY PROPULSION SYSTEM

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ABSTRACT

An engineering model Ion Auxiliary Propulsion System (IAPS) 8-cm thruster (S/N 905) has completed a life test at NASA Lewis Research Center. The mercury ion thruster successfully completed and exceeded the test goals of 2557 on/off cycles and 7057 hr of operation at full thrust. The final 1200 cycles and 3600 hr of the life test was conducted using an engineering model of the IAPS power electronics unit (PEU) and breadboard digital controller and interface unit (DCIU). This portion of the test is described in this paper with a charted history of thruster operating parameters and off-normal events. Performance and operating characteristics were constant throughout the test with only minor variations. The engineering model power electronics unit operated without malfunction and the flight software in the digital controller and interface unit was exercised and verified. Post-test inspection of the thruster revealed facility enhanced accelerator grid erosion but overall the thruster was in good condition. It was concluded that the thruster performance was not drastically degraded by time or cycles. Additional cyclic testing is currently under consideration.

INTRODUCTION

The Ion Auxiliary Propulsion System (IAPS) experiment is planned for launch from the Space Transportation System (shuttle) on an Air Force Space Test Program satellite.[1] The primary objective of the experiment is to flight verify the 8-cm mercury ion thruster system for operational use in north-south stationkeeping applications. Secondary objectives are to measure the interactions between operating ion thruster systems and the host spacecraft, and to confirm the design performance of the thruster systems. Two complete 8-cm mercury ion thruster systems will be flown. One of these thruster systems will be operated for 2557 on/off cycles and 7057 hr, which represents the nominal operational requirements of a 7 year stationkeeping mission of a 1000 kg spacecraft.[1]

The principal objectives of the ground cyclic life test were to achieve the flight mission goals (2557 on/off cycles and 7057 hr) and to characterize the performance of the IAPS thruster over long term cyclic operation. This test also provided an opportunity for long duration cyclic operation using the DCIU and its software. Prior testing of the DCIU was limited to the short duration flight system test.[2] Another benefit of this test was the valuable data base obtained for planning of the IAPS mission operations for flight.

This paper presents the operational results spanning the final 1200 on/off cycles and 3600 hr of the cyclic life test. The initial 1400 on/off cycles and 3600 hr have been reported in Ref. 3. The final portion of this test is described in detail with a history of several of the thruster parameters. A nondestructive physical inspection of the thruster was conducted at the conclusion of the test and is also described.

EXPERIMENT DESCRIPTION AND TEST FACILITY

The thruster tested was an 8-cm engineering model thruster (S/N 905) which was upgraded to IAPS flight specifications. The only known anomaly is the neutralizer vaporizer flow transmissivity was significantly lower than the flight thrusters.

Power for the final segment of the test was provided by an engineering model power electronics unit (PEU) (which was operated in air). The input power to the PEU was supplied by a 70 Vdc lab supply. The PEU was controlled by a breadboard version of the IAPS flight digital controller and interface unit (DCIU), which contained all the flight control software, commanding, and telemetry algorithms. The DCIU input power was supplied by a 28 Vdc lab supply. A more detailed explanation of the PEU and DCIU appears in Refs. 4 and 5.

Thruster data was processed and displayed using a personal computer. The personal computer received the data in a 8 bit quantized form (0 to 255 counts) from the DCIU. The data was displayed in engineering units on a CRT screen. The unprocessed data was stored on magnetic tape for detailed processing on a mainframe computer. In the flight test the DCIU will provide telemetry data in the same format as in the cyclic test.

An automatic command generator was used to cycle the thruster ON and OFF. The automatic command generator sent a 16 bit command to the DCIU to turn the thruster ON and another 16 bit command to turn the thruster OFF. The DCIU control software performed the actual thruster startup and shutdown procedures on receipt of these commands. A cycle consisted of a 3 hr 20 min ON time which included the 25 min startup period, and a 1 hr 30 min cooldown (OFF) period. Figure 1 shows a block diagram of the electronics used to operate the thruster.

The test chamber consisted of a 0.89 m (35 in.) diameter by 1.96 m (77 in.) high cryopumped vacuum facility with a frozen mercury target (Fig. 1). The chamber is also equipped with a 0.31 m (12 in.) diameter bell jar for isolation of the thruster. When test chamber vacuum deteriorated, the thruster was retracted into the bell jar and flooded with gaseous argon. The operating pressures of the facility during full beam operation of the thruster was maintained at 3×10^{-6} torr or better and at beam off the pressure was 5×10^{-7} torr. A detailed description of the vacuum facility is given in Ref. 3.

RESULTS AND DISCUSSION

A history of the test from cycle 1400 to 2557 is shown in Figs. 2 to 15. In these figures the critical thruster parameters are plotted against cycle number. Overall the test ran smoothly with the only shutdowns being caused by facility anomalies and servicing requirements. After a facility anomaly that resulted in a loss of vacuum the thruster had to be reconditioned by baking out the cathodes before the test could be continued. No cycles were incomplete due to thruster problems. During the test two setpoint changes were made to the thruster operating parameters. The discharge keeper current was changed at cycle 1620 and the neutralizer keeper current was changed at cycle 2547. The changes made were compatible with the capabilities of the flight test. The reasons for these changes will be discussed in the following sections. These sections describe each of the

important thruster parameters. Each of the parameters is also plotted on a corresponding figure.

The data plotted in these figures were taken at 2 hr into each beam on period of the cycle. At this point the thruster was at steady state operation and provided the most representable data. Since the data is digital a resolution value is given in Table 1 for each parameter. As can be seen from the table, the resolution varied for each parameter. The data points on the plots were taken every tenth cycle and are indicated by open squares. The points are connected by straight lines to indicate the sequence and aid in reading the plots. Note that since the data is digital the straight lines on the plots do not actually represent a true thruster operating value (refer to the table of resolution values).

Screen Current

The screen (beam) current (SI) shown in Fig. 2 did not fluctuate more than 1.20 mA (3 counts) throughout the test. The nominal value was 71.0 mA. A slightly lower value of SI was experienced during the first cycle after the thruster was restarted, but this was corrected for subsequent cycles. The constancy of the plotted data demonstrates the effectiveness of the beam current control loop in the flight software.

Screen Voltage

The screen voltage was 1208 V and did not vary throughout the test (Fig. 3). The telemetry on this supply was near its upper limit. An actual measurement was made and it agreed with the telemetry value.

Power Draw

The power draw for the PEU-thruster at full beam was 178 W and did not vary significantly throughout the test. The constant power draw throughout the test is evident by the constant values of SI and SV. The power to the thruster was calculated to be nominally 130 W under these conditions which gave a PEU efficiency of 73 percent.

Discharge Keeper Current

Figure 4 shows the variation in the discharge keeper current (DKI). The DKI was initially set at setpoint 0 which is 60 mA. But at cycle 1520 the DKI began to fluctuate and as the test progressed the variations increased. The DKI varied from a low value of 40 mA to a peak value of 123 mA, which was apparently due to noise on the main discharge. At cycle number 1620 the DKI was changed to setpoint 1 (120 mA) and this corrected the DKI oscillations. From cycle 1620 to the end of the test the DKI did not vary more than 2 mA. The cause of the change in operation has not been thoroughly investigated at this time. A possible reason is that the PEU-thruster entered an unstable region of control and by changing the setpoint the PEU-thruster entered a stable region of operation.

Discharge Keeper Voltage

The discharge keeper voltage (DKV) was constant over the test except for the period of oscillations in the DKI. The nominal value of DKV was 11.2 V and as can be seen from the plot of DKV shown in Fig. 5 varied less than ±1 V throughout the test. The change in the DKI setpoint at cycle number 1620 did cause a slight increase in the DKV (less than 0.5 V).

Discharge Current

The discharge current (DI) also varied. As can be seen in Fig. 6 the DI varied about ±30 mA from a nominal 490 mA value. The largest values occurred when the oscillations in the DKI were observed and are believed to be due to the noise in the main discharge. The noisy discharge was a major contributor to the scatter in the DI data.

Discharge Voltage

The discharge voltage (DV) (Fig. 7) also had noticeable variations during the period of DKI's fluctuations. After the setpoint change in DKI the DV did not vary by more than ±0.75 V. The discharge (main) vaporizer had a feedback signal for control which was the difference between the discharge voltage and discharge keeper voltage. This difference was maintained at 26.5 V. The slight increase in DV after the DKI setpoint change reflects the slight increase of DKV at the higher setpoint.

Discharge Vaporizer Temperature

The discharge vaporizer temperature (DVT) remained fairly constant over the entire test. From Fig. 8 it can be seen that the temperature varied approximately ±2.5 degrees from a mean value of 268 °C during the test period after cycle 1620. The resolution of the data was not sufficient to make small flowrate changes observable. However, the slightly higher value of DVT recorded prior to cycle 1620 is significant. This higher value of DVT is due to the effect of the DKI and DKV oscillations on the main vaporizer control loop operation during this period of operation. This effect caused a higher than nominal discharge propellant flowrate.

Accelerator Current

The accelerator current (ACCI) which is shown in Fig. 9 declined from 490 mA at the re-start of the test to 390 mA at cycle 1620 then to 320 mA and finally to 310 mA at the conclusion of the test. The initial reduction shows the reacquisition of the nominal thruster performance after the long period of thruster storage and facility inactivity. The decrease at cycle 1620 is due to the reduced main vaporizer flowrate that occurred when correcting the DKI oscillations (see DKI section) by increasing the DKI setpoint. The reduced flowrate improved the propellant efficiency which reduced the neutral losses and the charge exchange ion production. The further decrease in ACCI is principally due to the reduced collection area of the accelerator grid caused by erosion. It should be noted[3] that a portion of the measured ACCI value is a constant facility effect arising from the contribution of back-sputtered neutrals from the frozen mercury target to the charge exchange ion production near the accelerator. Both this facility effect and the reduced propellant utilization up to cycle 1620 were major contributors to the charge exchange ion erosion of the accelerator noted at the conclusion of the test.

Accelerator Voltage

The accelerator voltage was -303 V and remained constant throughout the test (Fig. 10).

Neutralizer Floating Point Potential

Figure 11 shows the neutralizer floating point potential (NFPV) from cycle 1400 to cycle 2557.

The NFPV remained constant at -10.1 V for the first 400 cycles and then slowly began to rise. From cycle 2250 to 2533 the NFPV varied from -16 to -26 V. At cycle 2534 a loss of a liquid nitrogen supply caused a facility failure and contamination of the thruster. After the LN_2 failure the neutralizer failed to neutralize the ion beam. After re-conditioning of the neutralizer cathode and changing the neutralizer keeper current setpoint (see next section) full beam neutralization was reacquired at satisfactory floating point voltages. The process of achieving satisfactory neutralizer performance was gradual and by cycle 2557 the NFPV dropped to a value of -15.5 V. The increasing coupling voltage noted from cycle 2250 is apparently related to decreasing neutralizer flowrate (see NVT section). The coupling voltage increase was not due to an isolator leak or to the accretion of material in the keeper orifice (discussed in physical inspection section) which had been sputtered from the neutralizer tip. Both of these effects were observed in a prior durability test of an engineering model IAPS thruster (Ref. 6). Visual inspection of the thruster during operation and at the conclusion of the test showed no mass build up or aperture restriction of the neutralizer keeper orifice (see section on physical inspection).

Neutralizer Keeper Current

Figure 12 shows that the neutralizer keeper current (NKI) was maintained at the nominal 500 mA setpoint until cycle 2547. At cycle 2547 NKI was changed to the 600 mA setpoint to correct the coupling problem. At both setpoints the NKI remained constant and operated nominally.

Neutralizer Keeper Voltage

The neutralizer keeper voltage (NKV) is shown in Fig. 13. It was held constant at 15.2 V over the entire test because this value was the reference value maintained for the neutralizer vaporizer control loop. This evidently resulted in a significant decrease in the neutralizer flowrate, which is discussed in the following section. When the NKI setpoint was increased the NKV reference value was also increased to give a flowrate conducive to good coupling.

Neutralizer Vaporizer Temperature

The neutralizer vaporizer temperature (NVT) which is shown in Fig. 14 slowly decreased throughout the test. This resulted from a continual decrease of the NKV versus flowrate characteristic, which caused the flowrate and NVT (given the fixed reference value of NKV) to slowly decrease. The gradual decrease of the neutralizer flowrate is closely associated with the increase in the NFPV (Fig. 11). The jump in NVT at cycle 2547 was due to the deliberate change in the NKV reference value for the vaporizer control loop made when the NKI setpoint (Fig. 12) was changed. The new NKV reference value was chosen to achieve a flowrate giving good coupling.

Recycles

For the entire test (cycles 1400 to 2571) approximately 320 high voltage arcs that initiated recycle of the screen and accelerator supplies were observed. These recycles each required approximately 2 sec to reacquire nominal operating conditions. The recycles occurred in the following manner: cycles 1400 to 2300 approximately 20 recycles, cycles 2301 to 2450 approximately 94 recycles, 2451 to 2500 approximately 128 recycles, and from 2501 to the end of the test 76 recycles were observed. The recycles occurred in random groups and no correlation could be established. The recycles never caused a thruster shutdown nor resulted in any significant loss of beam ON time. Hence, these recycles do not reflect any degradation of thruster performance.

Startup Time

Another important factor for routine thruster operation is the time required for the thruster to achieve full beam from a cold start. Figure 15 presents the startup time for this portion of the cyclic test. For the first 150 cycles (1400 to 1550) the thruster was manually cycled twice a day. This led to the thruster reaching a colder OFF cycle temperature thus causing a longer startup period. After the automatic command generator was installed and automatic cycling initiated, the startup period was 23.5 min and remained constant throughout the remainder of test. The startup time was constrained by the PEU heater supply limits.

Thruster Electronic Equipment

The power processor (PEU) and controller (DCIU) used for this test operated flawlessly. The power electronics unit (PEU) was previously operated in a vacuum for a 10 000 hr thruster life test. The total PEU operation for both tests exceeds 14 000 hr of high voltage operation without any failure or malfunction. The breadboard version of the digital control interface unit (DCIU) used for the cyclic test also operated flawlessly. The DCIU software and control algorithms were fully exercised and no problems were encountered.

DATA FROM A TYPICAL CYCLE

Data from cycle 2125 is presented in Figs. 16 to 21. Cycle 2125 is a typical cycle of the test using the automatic command generator and IAPS flight software in the DCIU. The thruster parameters are plotted against time with the start of the cycle being time 0. From 0 to 90 min is the cooldown (OFF) period. At 91 min into the cycle the full beam (ON) command is given. From 91 to 114 min the thruster is heated up, the cathodes and main discharge are ignited, high voltage is applied and full beam is established. From 115 to 288 min the thruster is at full beam. At 289 min the thruster is commanded OFF and the next cooldown period (cycle) begins. The thruster parameters showing interesting histories are plotted in the figures and are discussed below. The remaining parameters were very steady and plots of them are not presented.

Power Draw

Figure 16 shows the input power required by the PEU to run the thruster during cycle 2125. The PEU power plotted is the product of the 70 V bus current and voltage. An initial draw of 90 W is needed to heat the two vaporizer heaters and the two cathode tip heaters at nearly their maximum power settings. The discharge cathode is ignited at 103 min, the main discharge is ignited at 104 min and the neutralizer is ignited 1 min later. The main discharge is operated at high current for 5 min to further heat the thruster and aid in evaporating mercury condensed on thruster surfaces. After the neutralizer ignites the power draw drops from 95 to 65 W while the neutralizer vaporizer cools from 360 to 290 °C. After neutralizer operation has been established at the normal running conditions and the

high current operation of the main discharge has been concluded, "pre-beam" operation begins. The "pre-beam" operation elevates the discharge keeper current to 380 mA and adjusts the discharge propellant flowrate for high voltage application. After 3 min of "pre-beam" operation the high voltage is turned on and this results in a peak power draw of 189 W. The beam current control software brings the beam current up to full beam by 115 min into the cycle, or 24 min after the ON command was issued. Once the thruster is at full beam the power decreases to 178 W and remains there for the duration of the cycle.

Screen Current

After the high voltage is applied, the screen current (SI) is rapidly ramped up to its full beam level of 71 mA 115 min into the cycle (24.0 min after the ON command). It is maintained constant at this value to within 1 percent by the beam current control loop in the software until the thruster is commanded OFF. The SI during cycle 2125 is displayed in Fig. 17.

Screen Voltage

The screen voltage (SV) shown in Fig. 18 rises to its fixed value of 1208 V 115 min into the cycle and remains at this level throughout the cycle.

Discharge Vaporizer Temperature

The discharge vaporizer temperature (DVT) history during cycle 2125 is plotted in Fig. 19. As seen from the plot, the discharge vaporizer cools to 65 °C during the 90 min OFF (cooldown) period. Once the ON command is given high power is applied to the vaporizer heater and the DVT reaches the cathode starting level of 285 °C in approximately 10 min. The cathode is held at the starting level for 3 min before ignition is attempted. The cathode ignition was immediately successful (which is typical of a normal startup for this test). Following ignition and up to high voltage application (at 115 min), the DVT is controlled at near its normal running level which is a few degrees below the starting level.

After the high voltage has been applied at 115 min into the cycle and full beam is achieved the discharge vaporizer power is controlled by the software control loop. The control loop maintains a fixed reference value for the difference between the discharge voltage and the discharge keeper voltage. The drop in DVT to 251 °C during the initial full beam operation is due to the evaporation of mercury condensed in the main isolator during startup from a cold condition. Supplementary tests demonstrated that the evaporation of the condensed mercury caused the vaporizer to be automatically controlled at a correspondingly reduced flowrate. After all the condensed mercury evaporates (as seen to have occurred at approximately 200 min into the plotted cycle) the DVT rises to a running level of 267 °C. The DVT remains at this level for the remainder of the cycle.

Neutralizer Vaporizer Temperature

The neutralizer vaporizer temperature (NVT) plotted for cycle 2125 in Fig. 20 cools down to 57 °C during the OFF period. When the ON command is given high power is applied to the neutralizer vaporizer heater and NVT rises to 364 °C within 14 min. It is then held at this level for three more minutes before ignition is attempted. The ignition was instantly successful. After neutralizer ignition, the vaporizer is allowed to cool down to below its normal running level and the neutralizer keeper voltage is tested to assure that there is not an excessive amount of mercury vapor in the thruster. After the test is successfully completed (110 min into cycle 2125) the operation of the vaporizer is placed into closed loop control for the remainder of the cycle. This control resulted in NVT holding within a one count range of 292 to 295 °C throughout the remainder of the cycle.

Neutralizer Floating Point Potential

The neutralizer floating point potential (NFPV) for cycle 2125 is plotted in Fig. 21. The NFPV remains at 0 V until the high voltage is applied, which occurred at 115 min into the cycle. Once the high voltage is applied the NFPV rises in steps (following the increase in beam current) until at full beam the value of NFPV is -12.1 V. Somewhat later the NFPV reached -12.5 V where it remained until the end of the cycle.

PHYSICAL INSPECTION OF THE THRUSTER

After completion of the cyclic test the vacuum chamber that contained the thruster was opened and the thruster was nondestructively inspected and tested. The thruster was not disassembled because of a possible decision to resume and substantially extend the durability test. The thruster was found to be in good condition with observable wear evident only on the accelerator.

Figure 22 shows the thruster exterior and the beam shield interior at the end of the test. The beam shield interior showed three regions (bands) of erosion/deposition. The boundaries of these bands were parallel arcs at successive downstream locations. The region at the beam shield tip was approximately 4 cm wide and showed significant net erosion. The shield thickness measured at the tip was 0.92 mm compared with its original thickness of 1.15 mm. This indicates that the shield could withstand another 25 000 hr of thruster operation at the same conditions before being completely eroded through by the high energy divergent fringing ions of the ion beam. The original 2000 Å molybdenum coating on the beam shield interior was also completely removed in the tip region. Point to point resistance measurements made in the tip region showed the high resistance of the bulk fiber-glass-epoxy composite of which the beam shield is constructed. The intermediate region visible on the beam shield interior extended back almost to the crease connecting the downstream cylindrical and the upstream conical sections of the shield (Fig. 22). This region closely resembled its original appearance and was uneroded in thickness. Since the surface resistance measurements of this region were 500 Ω, this region apparently retained a coating of molybdenum.

The upstream region visible on the beam shield interior included all of the conical mounting section. It showed net deposition of material which was significantly nonmetallic. This was evident both from its appearance and from surface resistance measurements of greater than 50 000 Ω. It is believed that this region accumulated material from the facility (such as silicone pump oil).

The neutralizer assembly appeared clean and free of visible deposits in the post test inspection. Figure 23 shows the enclosed neutralizer keeper cap. There was no deposition within the keeper orifice nor on the upstream or downstream surfaces adjacent to it. The absence of deposits on the upstream surface was verified by telescopic observation at an

oblique angle of the keeper orifice with the keeper discharge operating, just prior to the conclusion of the test. The keeper orifice also showed no erosion or enlargement and its diameter was unchanged from the initial value of 1.78 mm. To the extent it could be viewed through the keeper orifice, the neutralizer tip also showed no visible erosion. These observations are in substantial contrast to the post test condition of the neutralizer from the IAPS thruster life test reported in Ref. 6. That test resulted in extensive sputter erosion of the neutralizer tip, with deposition of the sputtered material in the keeper orifice and on the upstream surface around it.

Point to point resistance checks were made on the exterior surface of the tantalum neutralizer keeper cap. Resistance values were low (1 to 2 Ω) on the side surface. Near the orifice on the downstream surface the value was approximately 70 Ω and farther away from the orifice the resistance measured 150 to 200 Ω. It can be concluded from these measurements that dielectric material originating from the facility (such as silicone pump oil) had deposited on the keeper cap. The downstream surface of the keeper cap, with its full exposure to the likely sources of contaminants, would accumulate the heaviest coating of these materials. The problem of the neutralizer to neutralize the thruster beam near the end of the test may be attributed to these facility contaminants. Prior to the neutralizer coupling problem a LN_2 failure caused a shutdown with the thruster hot and allowed the facility surfaces to warm up above normal operating conditions. This failure may have caused contaminants (dielectric material e.g., silicone pump oil) to coat the keeper cap. The slow recovery of neutralization capability with operating time following the incident correlates with the slow sputter removal of the contaminant coating.

The accelerator grid downstream surface, seen in Fig. 24, showed substantial charge exchange erosion. This was concentrated in the central region of the grid and showed the normal pattern of a triangular pit in the webbing between each grouping of 3 grid holes. None of the pits was observed to have penetrated through the 0.51 mm thickness of the grid. The deepest pits were judged to be more than half way through the grid. The causes of the prominent charge exchange erosion are the same as those for the high accelerator drain current observed during the test and have been previously discussed.

Moderate ion beamlet impingement erosion of the accelerator grid holes was observed. The central region holes, originally 1.14 mm in diameter, were found to be between 1.17 and 1.27 mm with one hole near the center measured as 1.31 mm in diameter. The outer region holes, originally 0.89 mm in diameter, were all found to be greater that 0.91 mm. Most were 0.94 mm in diameter with the innermost ring of these holes measuring 0.97 mm in diameter. The peripheral holes of the outside region experienced some nonsymmetric ion beamlet milling. This is generally observed in the operation of 8-cm mercury ion thrusters and is attributable to the nonsymmetric repulsion of the ion beamlets of the outer holes by the beamlets of the surrounding inner holes. Overall, the increase in the total accelerator open area due to the impingement erosion over the entire life test operation of the thruster is estimated to be 17 percent.

Only rudimentary observations could be made of the thruster discharge chamber through the accelerator grid (Fig. 24). From these observations it was established that there were no loose flakes of material in the chamber and no prominent erosion or deposition on any visible surface. The visible components were the baffle, the cathode pole piece, and to a limited extent the upstream endplate of the chamber. The discharge cathode and the anode could not be observed without disassembling the grids.

High voltage (1000 V) isolation checks were made between all the thruster electrical circuits. These gave nominal values in all cases except for the isolation of the neutralizer keeper from the neutralizer common. Nominally this isolation value should be greater than 5.0 MΩ, but the value read was 1.0 MΩ. This somewhat degraded keeper isolation may be the result of the thruster contamination incident near the end of the test. Another possible cause may be the long term, higher than normal flux of the molybdenum sputtered from the accelerator at a high angle toward the neutralizer keeper. The reduced keeper isolation is not serious enough to threaten nominal cathode starting or operation.

In summary, the post test thruster inspection revealed no degradation effect seriously threatening to cause failure of the thruster during further extended testing. The most serious degradation effect observed was the charge exchange ion erosion of the accelerator. This erosion was enhanced by the constant facility-contributed neutral flux present throughout the test and by the reduced propellant utilization during the early part of the test (which was explained earlier).

CONCLUSION

An engineering model 8-cm mercury thruster was successfully tested in both a cyclic and hourly mode. The thruster was restarted 2571 times and operated at full thrust for 7112 hr. No detrimental change in thruster performance occurred during the test. No life threatening degradation of the thruster was observed in a post test inspection. The test finished without a failure and more testing is being considered for this thruster. The electronics used to operate the thruster for the second half of this test operated flawlessly. The engineering model PEU was used in two tests and has operated without malfunction for 14 000 hr. The DCIU which contains the flight software was operated for 3600 hr and was thoroughly exercised in the test and proved its flexibility and reliability. This was a successful test of both the thruster and engineering model flight electronics.

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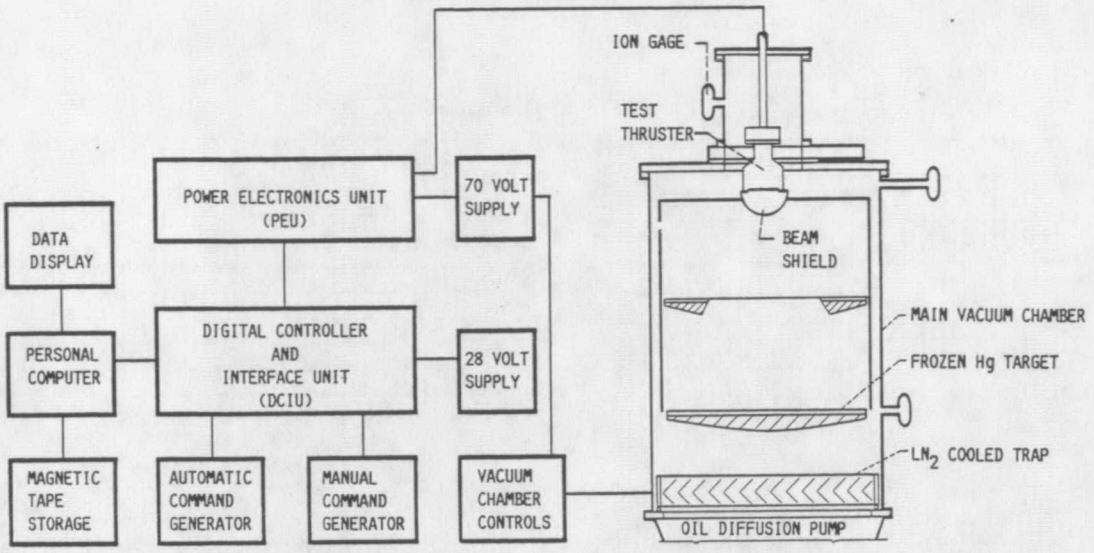

FIGURE 1. - GROUND TEST FACILITY AND ELECTRONICS BLOCK DIAGRAM.

THRUSTER 905 LIFE TEST DATA

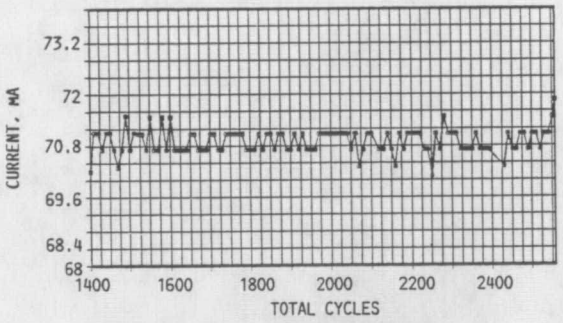

FIGURE 2. - SCREEN CURRENT.

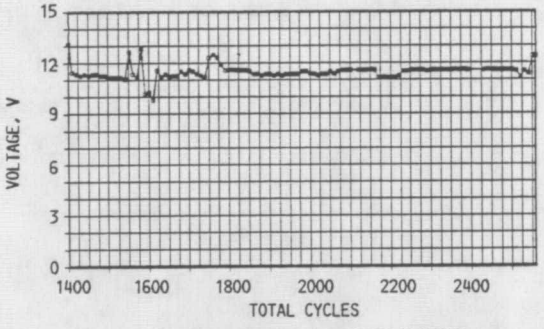

FIGURE 5. - DISCHARGE KEEPER VOLTAGE.

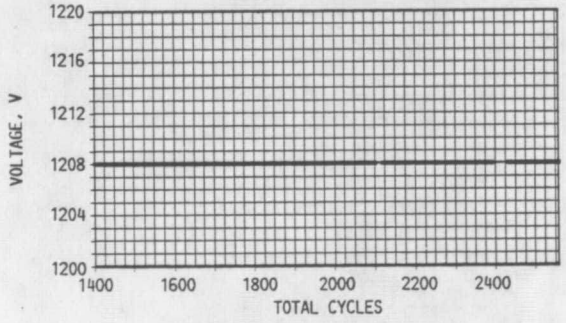

FIGURE 3. - SCREEN VOLTAGE.

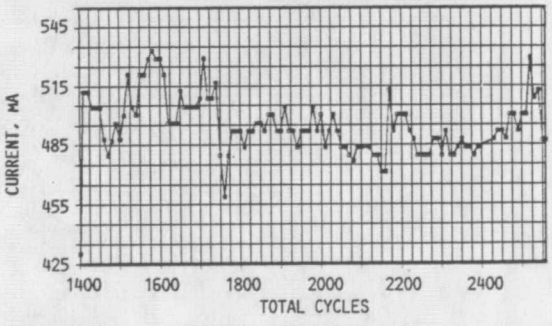

FIGURE 6. - DISCHARGE CURRENT.

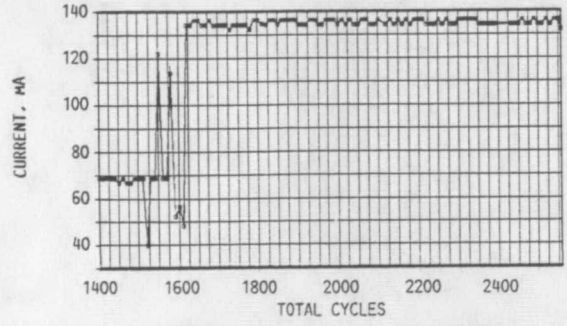

FIGURE 4. - DISCHARGE KEEPER CURRENT.

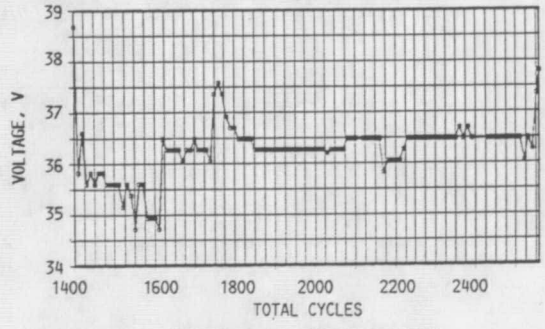

FIGURE 7. - DISCHARGE VOLTAGE.

AT CYCLE 1520.

THRUSTER 905 LIFE TEST DATA

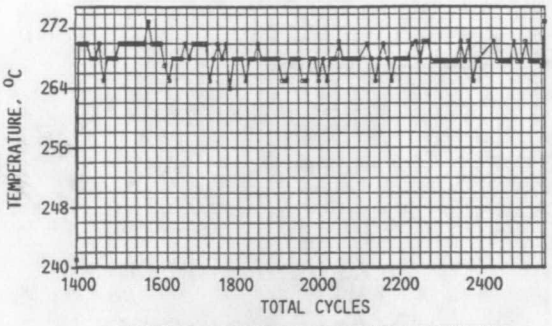

FIGURE 8. - DISCHARGE VAPORIZER TEMPERATURE.

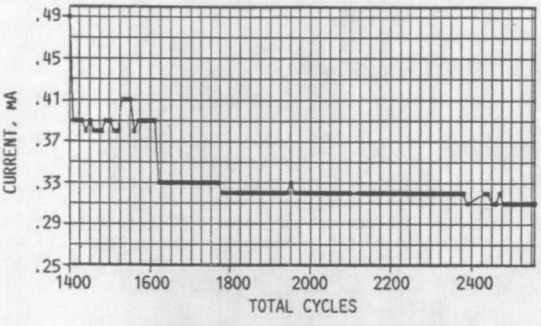

FIGURE 9. - ACCELERATOR CURRENT.

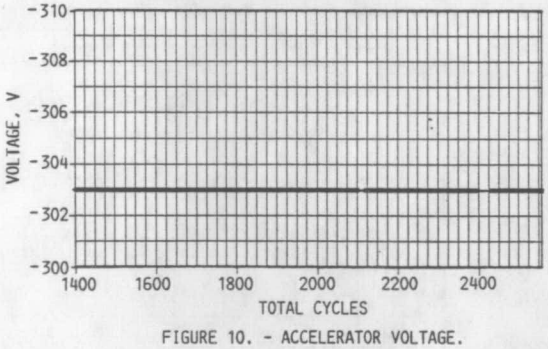

FIGURE 10. - ACCELERATOR VOLTAGE.

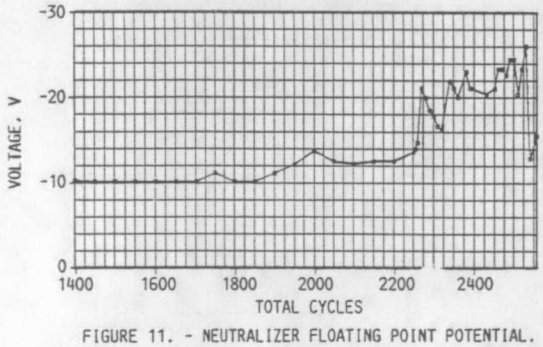

FIGURE 11. - NEUTRALIZER FLOATING POINT POTENTIAL.

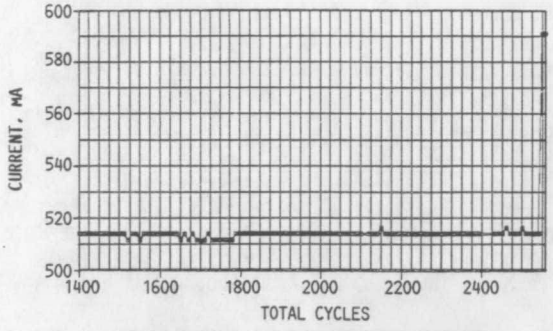

FIGURE 12. - NEUTRALIZER KEEPER CURRENT.

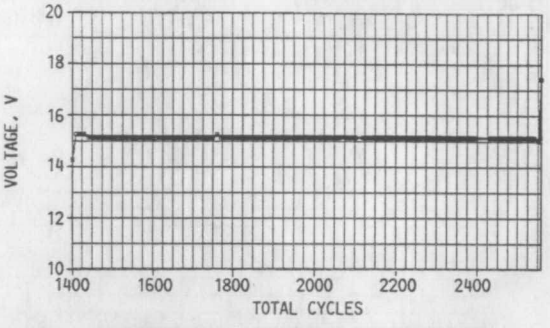

FIGURE 13. - NEUTRALIZER KEEPER VOLTAGE.

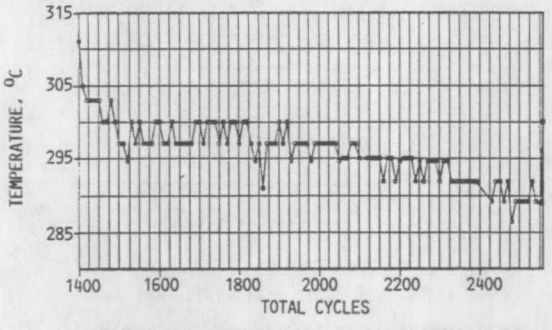

FIGURE 14. - NEUTRALIZER VAPORIZER TEMPERATURE.

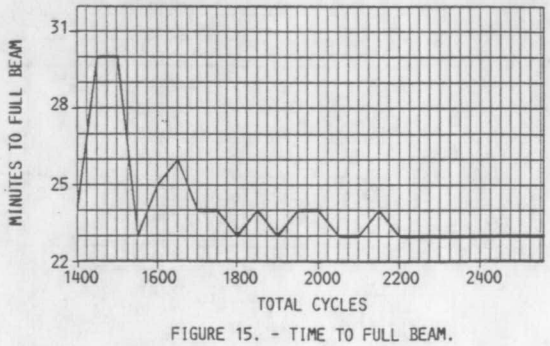

FIGURE 15. - TIME TO FULL BEAM.

NOTE: DISCHARGE KEEPER CURRENT SETPOINT CHANGE MADE AT CYCLE 1620.

DATA FROM A TYPICAL CYCLE (CYCLE NUMBER 2125)

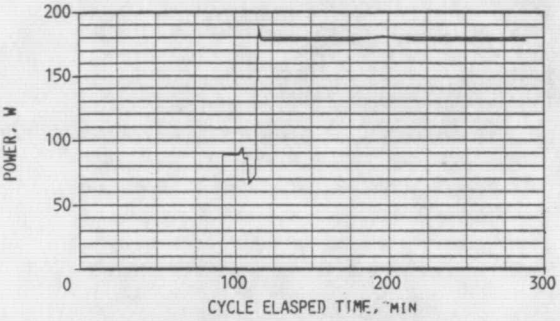

FIGURE 16. - TOTAL POWER CONSUMED.

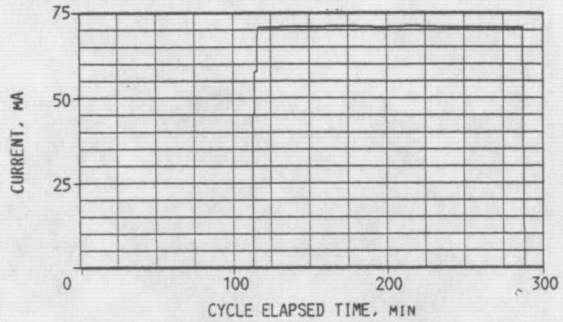

FIGURE 17. - SCREEN CURRENT.

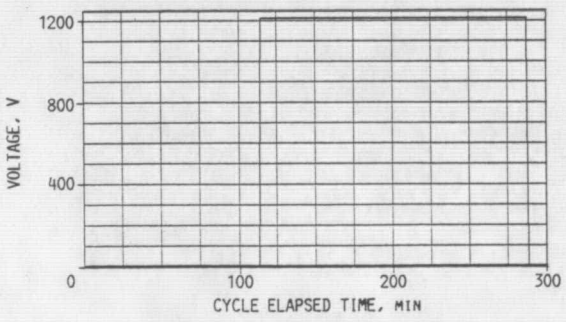

FIGURE 18. - SCREEN VOLTAGE.

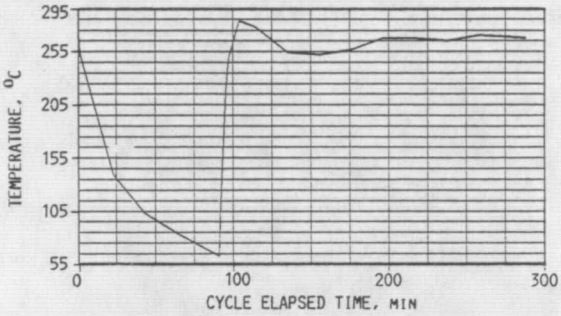

FIGURE 19. - DISCHARGE VAPORIZER TEMPERATURE.

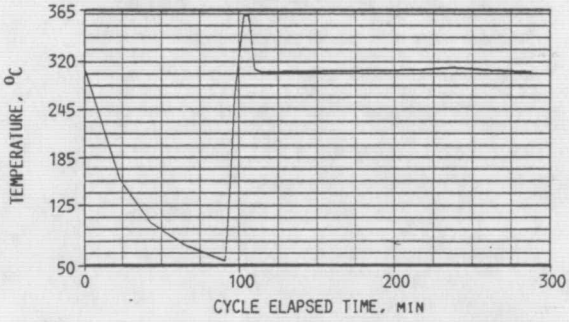

FIGURE 20. - NEUTRALIZER VAPORIZER TEMPERATURE.

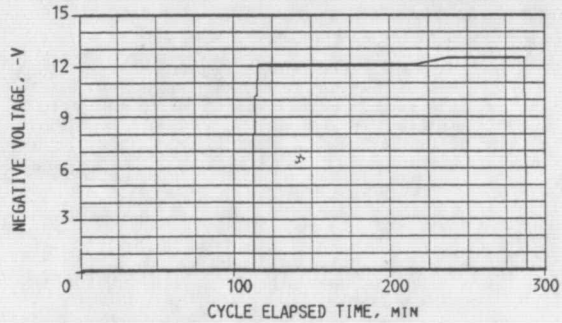

FIGURE 21. - NEUTRALIZER FLOATING POINT POTENTIAL.

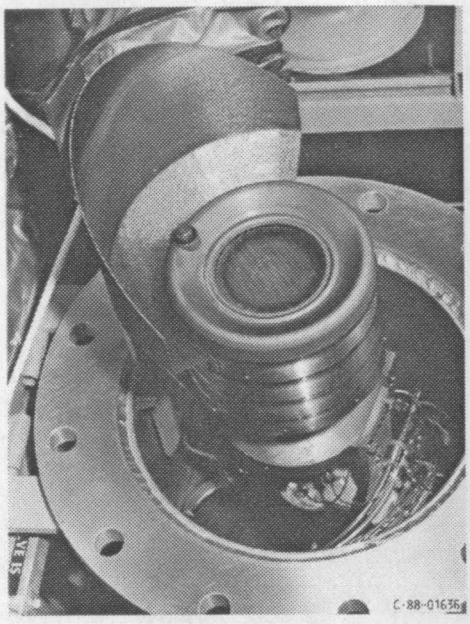

FIGURE 22. - THRUSTER-BEAM SHIELD UNIT (POST TEST).

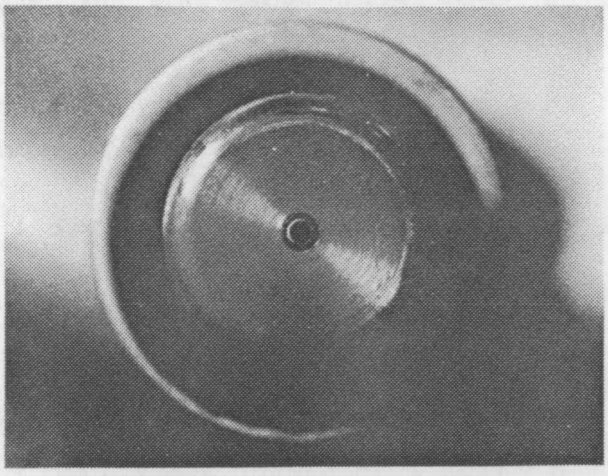

FIGURE 23. - NEUTRALIZER KEEPER CAP.

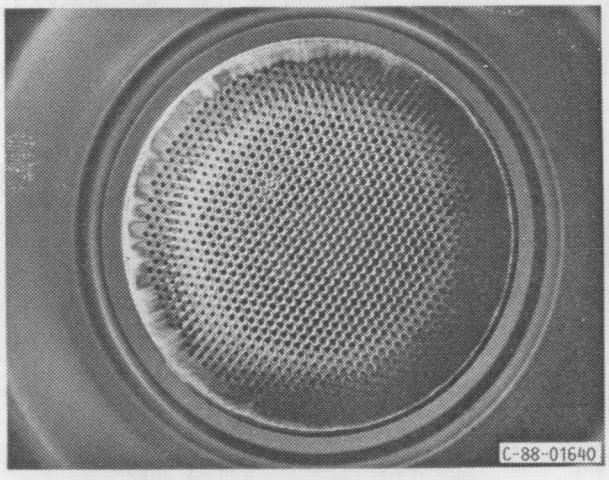

FIGURE 24. - POST TEST ACCELERATOR GRID.

TABLE 1. TELEMETRY RESOLUTION VALUES

Figure	Parameter	Symbol	Value per count
2	Screen current	SI	0.40 mA
3	Screen voltage	SV	4.70 V
4	Discharge keeper current	DKI	1.99 mA
5	Discharge keeper voltage	DKV	0.08 V
6	Discharge current	DI	3.68 mA
7	Discharge voltage	DV	0.19 V
8	Discharge vaporizer temperature	DVT	2.25 °C
9	Accelerator current	ACCI	0.015 mA
10	Accelerator voltage	ACCV	2.6 V
11	Neutralizer floating point potential	NFPV	0.375 V
12	Neutralizer keeper current	NKI	2.23 mA
13	Neutralizer keeper voltage	NKV	0.123 V
14	Neutralizer vaporizer temperature	NVT	2.25 °C