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Status of the NEXT Ion Engine Wear Test

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The status of the NEXT 2000 hour wear test is presented. This test is being conducted with a 40 cm engineering model ion engine, designated EM1, at a beam current higher than listed on the NEXT throttle table. Pretest performance assessments demonstrated that EM1 satisfies all thruster performance requirements. As of 7/3/03, the ion engine has accumulated 406 hours of operation at a thruster input power of 6.9 kW. Overall ion engine performance, which includes thrust, thruster input power, specific impulse, and thrust efficiency, has been steady to date with no indications of performance degradation. Images of the downstream discharge cathode, neutralizer, and accelerator aperture surfaces have exhibited no significant erosion to date.

Introduction

The success of the NASA Solar Electric Propulsion Technology Applications Readiness (NSTAR) program's ion propulsion system on the Deep-Space 1 spacecraft has secured the future for ion propulsion technology for other NASA missions.[1] While the 2.3 kW NSTAR ion engine input power and service life capabilities are appropriate for Discovery Class as well as other, smaller NASA missions, the application of NSTAR hardware to large flagship-type missions such as outer planet explorers and sample return missions is limited due its lack of power and total impulse capability.

As a result, NASA's Office of Space Science awarded a research project to a NASA Glenn Research Center (GRC)-led team to develop the next generation ion propulsion system.[2,3] The propulsion system, called NASA's Evolutionary Xenon Thruster (NEXT), consists of a 40 cm diameter ion engine, a lightweight, modular power processing unit with an efficiency and a specific power equal-to or better-than the NSTAR power processor, and a xenon feed system which uses proportional valves and thermal throttles to significantly reduce mass and volume relative to the NSTAR feed system.

Ion engine performance requirements include a specific impulse of at least 4050 s at full power, and thruster efficiencies of greater than 0.63 at full power and greater than 0.42 at low power. Regarding service life, the ion engine must provide a 270 kg propellant throughput capability, which ultimately results in a 405 kg qualification throughput requirement.

The service life capability of the NEXT ion engine is being assessed by engine wear tests and modeling of critical engine components, such as the ion optics and cathodes. The first wear test of a NEXT ion engine will be for a 2000 hour duration. A high thruster input power level was chosen because modeling has predicted that this power level will cause the severest engine erosion. The objectives of this early wear test include: characterizing thruster operation and performance over the duration of the test; identifying thruster life-limiting phenomena; and measuring thruster component wear rates and comparing them with that predicted from life models.

This paper presents the status of the NEXT 2000 hour wear test. A description of the test article is discussed in the next section. This is followed by a description of the test support hardware, which includes the power console, gas feed system, vacuum facility, and diagnostics. The test operating condition is then described. Finally, wear test results to date are presented and discussed.

Test Article

The wear test is being conducted with an engineering model ion engine, designated EM1, which is shown in Fig. 1. The engine utilizes a 40 cm beam extraction diameter, which is double the area of the NSTAR ion engine. The technical approach here is a continuation of the “derating” philosophy used for the NSTAR ion engine. Doubling the beam area allows operation at significantly higher thruster input power while maintaining low voltages and ion current densities. Thus, potential complications associated with high-voltage electrode operations are avoided, and engine longevity can be maintained.

The discharge chamber design of EM1 utilizes a hollow cathode electron emitter and a semi-conic chamber with a ring cusp magnetic circuit for electron containment created by high strength, rare earth magnets. A flake-retention scheme is employed in the discharge chamber, which also acts as a magnet retainer. The material, preparation, and installation processes employed for the flake-retention system are identical to those implemented on the NSTAR engine.[4] The discharge chamber also incorporates a reverse-feed propellant injection process for the main plenum. Finally, EM1 utilizes new compact propellant isolators with a higher voltage isolation capability (about 1800 V) than those used by the NSTAR engine.

The ion engine utilizes a neutralizer design that is mechanically similar to the Hollow Cathode Assembly of the International Space Station Plasma Contactor.[5] Because the neutralizer cathode emission current range on the NEXT ion engine is similar to that of the Hollow Cathode Assembly, the NEXT neutralizer design can leverage off of the large cathode database already available with this design for risk reduction.[6]

The ion optics’ mounting assembly of EM1 is similar to that of the NSTAR ion engine, except that the diameter was increased to accommodate 40 cm beam extraction electrodes. The electrode geometry, referred to as Thick-Accelerator-Grid (TAG) ion optics, is similar to that employed with the NSTAR engine except that the accelerator electrode thickness was increased to enhance engine service life. The performance of this electrode geometry is described in detail in Ref. 7.

Test Support Hardware

Power Console and Gas Feed System

A power console similar to that described in Ref. 8 powers the ion engine. This power console utilizes commercially available power supplies that allow for ion engine input powers of over 10 kW with beam power supply voltages of up to 2000 V. A high purity gas feed system is used to provide xenon to the discharge cathode, main plenum, and neutralizer through separate mass flow controllers.

Vacuum Facility

The wear test is being conducted in Vacuum Facility 6 at NASA GRC. This 7.6 m diameter × 22.9 m long facility is evacuated with 12 cryogenic pumps and a turbomolecular pump. For this test, the facility pressure is monitored by two ionization gages, with one located in the facility about 0.5 m radially below the ion engine and the second located on the cylindrical section of the facility wall about 3.2 m downstream of the ion engine. The facility base pressure has been less than 1.3×10^{-5} Pa (1×10^{-7} Torr). Facility background pressures during wear testing have been 4.7×10^{-4} Pa (3.5×10^{-6} Torr) next to the ion engine and 2.9×10^{-4} Pa (2.2×10^{-6} Torr) at the facility wall. The facility pumping speed on xenon calculated with these ion gages is approximately 220,000 L/s next to the ion engine and 360,000 L/s at the facility walls.

The facility interior surfaces downstream of the ion engine are lined with a flexible carbon material to reduce the amount of facility material that is backsputtered onto the ion engine. The backsputter rate is determined with a quartz crystal microbalance located next to the ion engine. The backsputter rate during wear testing has typically been about 2 μm/kh.

Diagnostics

A computerized data acquisition and control system is used to monitor ion engine and facility operations and to control the power console. Data is sampled at a frequency range of 10−20 Hz and is stored once per minute. Ion engine currents and voltages are measured with current shunts and voltage dividers, respectively, and recorded. Facility pressures and individual mass flows to the ion engine are also sampled and recorded.

Ion beam diagnostics include circular planar probes mounted onto to a two-axis probe motion system for measuring beam plasma properties. There are a total of 9 planar probes with a 1 cm^2 circular current-collecting area. The positioning system sweeps the probes in the radial and axial directions downstream of the engine ion optics, with 1.5 m travel in each axis. To measure beam current density profiles, the probes are biased negative with respect to beam plasma potential to repel electrons and are grounded through separate resistors that act as shunts to measure collected currents. To measure electron temperatures, number densities, and beam plasma potentials, the three probes nearest the geometric center of the engine are rewired to act as a triple Langmuir probe.

Erosion of critical ion engine components is monitored by three CCD cameras. One camera images the downstream neutralizer keeper and cathode orifice plate surfaces and is mounted to the ion beam diagnostics positioning system. The other two cameras image the downstream accelerator grid apertures and the discharge keeper and cathode orifice plates. These cameras are mounted to a separate two-stage positioning system that moves the cameras radially in front of the engine.

Finally, the engine is periodically connected to an electrically floating power supply circuit used to determine the screen grid transparency to discharge chamber ions. The circuit electrically ties the screen grid to the discharge cathode during normal operation, but biases the grid negative relative to discharge cathode potential to repel electrons and measure the collected ion current.

Operating Condition and Performance Tests

The NEXT ion engine is designed for solar electric propulsion applications. Ion engine input power is, therefore, designed to be throttled from 1.1−6.1 kW. The NEXT engine throttle table is listed in Table 1. For the wear test, it is necessary to demonstrate the engine's propellant throughput capability at an operating point that causes the worst erosion and is the most stressful on engine operation. The highest engine input power, which corresponded to a 1800 V beam power supply voltage, met these criteria.

It was further decided that it would be advantageous to test the NEXT ion engine at an operating point that was more stressful than the full power point on the throttle table. A new, higher beam current of 3.52 A was selected as the wear test operating current. This beam current is twice the NSTAR beam current, so given that the NEXT engine's beam extraction area is twice that of the NSTAR engine, the derating approach used to design the NEXT engine is still maintained. The wear test operating point is indicated on Table 2.

As shown in Table 2, the wear test accelerator voltage was increased from −250 V to −210 V at the start of the wear test. Because there is a 74 V margin between the electron backstreaming limit and the −250 V accelerator voltage (presented later), reducing this margin to about 34 V would reduce accelerator grid sputter erosion. This lower margin was chosen because it is similar to that of the NSTAR engine.[9-11]

Prior to and throughout the wear test, performance tests are conducted on the engine and engine components. Engine performance tests include measuring engine operating parameters and determining engine performance at several of the power levels indicated in Tables 1 and 2.

Component performance assessments are periodically made on the discharge chamber, ion optics, and neutralizer. Ion optics performance includes electron backstreaming, perveance, and screen grid ion transparency measurements. Discharge chamber performance is assessed by measuring discharge losses as a function of discharge propellant utilization efficiency at fixed discharge voltages. Finally, neutralizer performance, which included keeper voltage measurements as a function of neutralizer flow, is assessed.

Results and Discussions

As of 7/3/03, NEXT engine EM1 has accumulated about 406 hours of operation at a thruster input power of 6.9 kW. There have been a total of 12 test interruptions; however, none were caused by abnormal thruster operation.

Pretest Performance Results

Table 3 lists pretest ion engine performance results for both throttle table operating conditions and the wear test beam current. For thrust calculations, the beam divergence thrust correction factor and the total doubly-to-singly-charged ion current ratio were assumed to be in the 0.976−0.977 and 0.034−0.044 ranges, respectively, based on Ref. 12. Ingested mass flow due to the facility background gas pressure was included in the total mass flow rate to the engine for determining thrust efficiency and specific impulse.[13]

The demonstrated throttling range was 1.1−6.9 kW, with a resulting thrust of about 50 mN at low power to 237 mN at the wear test full power point. The corresponding specific impulse range was 2210−4100 s. Thrust efficiencies were between about 0.50 at low power to 0.70 at the wear test full power point.

Table 4 compares EM1 engine performance results to NEXT requirements. As the table shows, EM1 satisfies all thruster performance requirements.

Along with engine performance data, pretest discharge chamber and neutralizer performance were also determined. Figure 2 shows discharge losses as a function of propellant utilization efficiency for all throttle table and wear test beam currents. At each beam current, the ratio of main to discharge cathode flow rate was adjusted to maintain the nominal discharge voltage. Ingested mass flow due to the facility background gas pressure was included in the calculation of discharge propellant utilization efficiency. All data were obtained for a beam power supply voltage of 1180 V because this was the lowest voltage that was both common to all beam currents in Tables 1 and 2 and provided the highest discharge losses.

As shown in Fig. 2, discharge losses at beam currents between 2.70 A and 3.52 A were within 10 W/A throughout all propellant utilization efficiencies examined. At each of these beam currents, discharge losses varied by less than 25 W/A between utilization efficiencies of about 0.85 to 0.95. Discharges losses increased more significantly for the 1.20 A and 2.00 A beam currents. The sensitivity of discharge losses to utilization efficiency was also more pronounced at higher efficiencies for these low beam currents. For example, discharge losses increased by 80 W/A when the propellant utilization efficiency was increased from 0.899 to 0.905 for the 1.20 A beam current. However, Fig. 2 shows that there is sufficient flow margin between the nominal operating utilization efficiency and this sudden increase in discharge losses.

Figure 3 shows neutralizer keeper voltage as a function of flow rate for all beam currents and without beam extraction. Data were measured at a beam power supply voltage of 1800 V. Plume mode, which is defined here as a peak-to-peak neutralizer keeper voltage oscillation of greater than ± 5 V, was only identified for the 1.20 A beam current and without beam extraction. At the higher beam currents, beam power supply instabilities prevented operation at neutralizer flow rates lower than those indicated on Fig. 3, so that plume mode could not be identified. As the figure indicates, however, there is at least 1.5 sccm flow margin between the nominal operating flow and plume mode operation for all beam currents evaluated. This margin is considerably greater than that of the NSTAR ion engine, whose margin was less than or equal to 0.5 sccm throughout the lower power levels of the NSTAR throttle table.[9]

Wear Test Results

Engine Performance

Engine performance parameters of value to mission planners include thrust, input power, efficiency, and specific impulse. Thrust and input power as a function of time are plotted in Fig. 4. Thrust was determined as described in the prior section. Between hours 70 and 80, the beam current, which is maintained by adjusting the discharge current, was inadvertently allowed to decrease to 3.48 A. This caused the decrease in thrust and input power shown on this graph, and decreases in specific impulse and thrust efficiency in a plot to follow. Regardless, both thrust and input power have remained steady at 237 mN +2.4/−3.2 mN and 6.87 kW +0.07/−0.09 kW.

Thrust efficiency and specific impulse as a function of time are plotted in Fig. 5. All engine mass flow rates, which are used to calculate thrust efficiency and specific impulse, have been within ± 1% of their nominal set points throughout the wear test. Specific impulse and thrust efficiency have been 4100 s ± 50 s and 0.694 ± 0.008.

Discharge Chamber

Discharge current and voltage as a function of time are shown in Fig. 6. As the figure shows, changes with time have generally been less than 3% of the nominal run values. The only noted trend, while small, has been with the discharge current required to maintain the beam current, which rose from a nominal start value of about 19.1 A to about 19.6 A by hour 140. As a result, discharge losses, shown in Fig. 7, increased from 127 W/A to about 130 W/A by hour 140. Discharge voltages to date have been 23.5 V +0.5/−0.3 V, as shown in Fig. 6.

This initial 3 W/A increase (i.e. a 2% increase) in discharge losses is considerably smaller than that exhibited by the NSTAR engine. In three separate wear tests, NSTAR engine discharge losses increased by 10−15 W/A within the first 500 hours of wear testing.[9-11] That the initial change in the NEXT discharge losses was so small contributes to a more constant thruster input power, and, therefore, a more constant thrust efficiency at beginning of life.

Neutralizer

Neutralizer keeper current and voltage as a function of time are plotted on Fig. 8. The keeper voltage has been at a mean value of about 10.6 V. The neutralizer keeper voltage exhibits voltage “spikes”, as shown in Fig. 8. These voltage “spikes” correspond to engine restarts, which is similar to NSTAR neutralizer behavior.[9-11]

Coupling voltage, which is a measure of neutralizer cathode potential relative to vacuum facility ground, is plotted in Fig. 9 as a function of time. The mean coupling voltage has been steady at −9.9 V +0.1/−0.6 V. The low coupling voltage magnitude is due to the high keeper current and neutralizer flow selected for operation. These high values were selected to ensure neutralizer operation in spot mode throughout ion engine service life while imposing only modest sacrifices in engine performance.

Both the neutralizer keeper and coupling voltages indicate no degradation of neutralizer performance to date.

Ion Optics

Accelerator current and voltage as a function of time are plotted on Fig. 10. The mean accelerator current has been steady at 12.6 mA. The “spikes” in the accelerator current correlate with engine recycles, as shown in Fig. 11. Immediately following an engine recycle, the accelerator current returns to an increased value. The current then decreases gradually for up to 10 minutes to its nominal value. This behavior may be the result of grid cooling during a recycle. During an engine recycle, the discharge power is momentarily reduced so that when high voltage is re-applied, another recycle is not inadvertently triggered. It is speculated that this momentary reduction in discharge power allows the ion optics to cool enough to change the hot grid gap, thus changing the accelerator current by a small amount. Regardless of the cause, these accelerator current “spikes” are not considered harmful to engine operation.

Beginning-of-life accelerator currents for the NEXT engine have been relatively constant while those of the NSTAR engine were not. NSTAR engine accelerator currents generally started higher-than-nominal, and required up to 1500 hours to decrease to nominal values.[9-10] The cause for this difference in behavior is presently unknown.

Total engine recycles as a function of time is plotted in Fig 12. The recycle rate during the first 84 hours of the wear test was high, with an average of 11.6 recycles per hour. The recycle rate gradually decreased between hours 84 and 200. The average recycle rate since hour 200 has been 2.5 per hour. In comparison, the NSTAR 8200 hour wear test operated with an average recycle rate of 1−2 per hour.[11] The slightly higher average recycle rate for the NEXT engine is expected because the NEXT engine’s beam extraction area and inter-grid electric field is 2X and 1.5X that of the NSTAR engine, respectively.

Impingement-limited total voltages, electron backstreaming limits, and screen grid ion transparencies throughout the wear test are plotted in Figs. 13, 14, and 15, respectively. Impingement-limited total voltages were determined from plots of accelerator current as a function of total voltage where the slope was −0.02 mA/V (i.e. the NSTAR criterion). Electron backstreaming limits were determined by lowering the magnitude of the accelerator grid voltage until the indicated beam current increased by 1 mA due to backstreaming electrons. Screen grid ion transparencies were calculated as described in ref. 14.

To date, impingement limited total voltages have been steady at 1050−1070 V. Other than the initial decreases in magnitude shown in Figs. 14 and 15, electron backstreaming limits and screen grid ion transparencies have been steady at −173 V to −172 V and 0.87, respectively. All three of these performance parameters indicate no significant ion optics’ performance degradation to date.

*Radial Beam Current Density Profile*s

Radial beam current density profiles were measured as close as 45 mm downstream from the geometric center of the ion optics. Regarding beam current density measurements, no attempt was made to repel charge-exchange ions from the probe or to account for secondary electron emission due to ion bombardment. Integration of the radial beam current density profiles (assuming azimuthal symmetry) yielded beam currents that were higher than the measured beam current by as much as 8%. Possible sources of error are discussed in Ref. 14

Radial beam current density profiles are plotted in Fig. 16 for hours 0 and 277 at 45 mm downstream of the ion optics. As the figure shows, the beam current density profiles have not changed. Measured peak beam current densities at this axial location have been 3.95 mA/cm^2 ± +0.05/−0.02 mA/cm^2. The resulting ion engine beam flatness parameter (i.e. the ratio of average-to-peak ion current density) has been 0.71 throughout the wear test.

Erosion

Discharge cathode keeper and neutralizer keeper orifices have been imaged several times throughout the wear test. Qualitatively, only the downstream cathode orifice plate surfaces show signs of slight texturing, due to sputtering from ion bombardment. Discharge cathode keeper and neutralizer keeper orifice diameters were measured from these images. These diameters have shown no discernable change as of hour 258. The estimated uncertainties in the discharge cathode and neutralizer keeper orifice measurements are 4% and 3%, respectively, of the in initial orifice diameters.

The downstream accelerator apertures at the grid center have also been imaged several times throughout the wear test. Qualitatively, the pit and groove erosion pattern surrounding the accelerator apertures has been forming. This sputter erosion pattern is caused by charge-exchange ions created in this region. Accelerator aperture diameters measured from these images have shown no discernable change as of hour 258. The estimated uncertainty in the measurement is 2% of the initial accelerator aperture diameter.

Summary

The status of the NEXT 2000 hour wear test was presented. The wear test is being conducted with a 40 cm, engineering model NEXT ion engine designated EM1. As of 7/3/03, NEXT engine EM1 has accumulated about 406 hours of operation at a thruster input power of 6.9 kW.

Pretest ion engine performance was determined over a throttling range of 1.1−6.9 kW, with resulting thrusts of about 50 mN at low power to 237 mN at the wear test full power point. The corresponding specific impulse range was 2210−4100 s. Thrust efficiencies were between about 0.50 at low power to 0.70 at the wear test full power point. Pretest results demonstrated that EM1 satisfies all thruster performance requirements.

Discharge chamber, neutralizer, and ion optics operation during the wear test was evaluated. Discharge losses increased during the first 140 hours, but only by about 2%, and have been steady since then. Neutralizer keeper and coupling voltages have been steady, with no indication of performance degradation. Impingement limited total voltages, electron backstreaming limits, and screen grid ion transparencies have also been steady, with no indication of performance degradation.

Overall ion engine performance, which includes thrust, thruster input power, specific impulse, and thrust efficiency, has been steady to date, with no indications of performance degradation. Images of the downstream discharge cathode, neutralizer, and accelerator aperture surfaces have exhibited no significant erosion to date.

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Table 1.—NEXT ion engine throttle table.

Anticipated Engine Input Power,[a] kW	Beam Current, A	Beam P.S. Voltage,[b] V	Accelerator Voltage, V	Main Plenum Flow Rate,[c] sccm	Discharge Cathode Flow Rate,[c] sccm	Neutralizer Flow Rate,[d] sccm	Neutralizer Keeper Current, A
1.07	1.20	680	−115	15.7	3.57	4.01	3.0
1.28	1.20	850	−125	15.7	3.57	4.01	3.0
1.49	1.20	1020	−175	15.7	3.57	4.01	3.0
1.68	1.20	1180	−200	15.7	3.57	4.01	3.0
1.94	1.20	1400	−220	15.7	3.57	4.01	3.0
2.14	1.20	1570	−235	15.7	3.57	4.01	3.0
2.42	1.20	1800	−250	15.7	3.57	4.01	3.0
2.40	2.00	1020	−175	27.1	3.87	4.41	3.0
2.71	2.00	1180	−200	27.1	3.87	4.41	3.0
3.15	2.00	1400	−220	27.1	3.87	4.41	3.0
3.49	2.00	1570	−235	27.1	3.87	4.41	3.0
3.96	2.00	1800	−250	27.1	3.87	4.41	3.0
3.18	2.70	1020	−175	37.6	4.26	4.75	3.0
3.61	2.70	1180	−200	37.6	4.26	4.75	3.0
4.20	2.70	1400	−220	37.6	4.26	4.75	3.0
4.66	2.70	1570	−235	37.6	4.26	4.75	3.0
5.30	2.70	1800	−250	37.6	4.26	4.75	3.0
4.12	3.10	1180	−200	43.5	4.54	4.95	3.0
4.80	3.10	1400	−220	43.5	4.54	4.95	3.0
5.33	3.10	1570	−235	43.5	4.54	4.95	3.0
6.06	3.10	1800	−250	43.5	4.54	4.95	3.0

[a]Nominal values.
[b]Power supply voltage.
[c]Main-to-discharge cathode flow split selected to result in a 23.5−27 V discharge voltage.
[d]Neutralizer flow with beam extraction; without beam extraction and for ignition, flow is set to 6.00 sccm.

Table 2.—NEXT ion engine high beam current and wear test operating points.

Anticipated Engine Input Power,[a] kW	Beam Current, A	Beam P.S. Voltage,[b] V	Accelerator Voltage, V	Main Plenum Flow Rate,[c] sccm	Discharge Cathode Flow Rate,[c] sccm	Neutralizer Flow Rate,[d] sccm	Neutralizer Keeper Current, A
4.66	3.52	1180	−200	49.6	4.87	5.16	3.0
5.42	3.52	1400	−220	49.6	4.87	5.16	3.0
6.03	3.52	1570	−235	49.6	4.87	5.16	3.0
6.85[e]	3.52[e]	1800[e]	−250/−210[e,f]	49.6[e]	4.87[e]	5.16[e]	3.0[e]

[a]Nominal values.
[b]Power supply voltage.
[c]Main-to-discharge cathode flow split selected to result in a 23.5−27 V discharge voltage.
[d]Neutralizer flow with beam extraction; without beam extraction and for ignition, flow is set to 6.00 sccm.
[e]Wear test operating point.
[e]Accelerator voltage increased from −250 V to −210 V just at the start of the wear test.

Table 3.—NEXT engine EM1 pretest performance test results for throttle table and wear test beam current operating conditions.

Beam Current, A	Beam Voltage, V	Thruster Input Power, kW	Discharge Losses, W/A	Thrust Efficiency	Thrust,[a] mN	Specific Impulse, s
1.201	670	1.08	190	0.495	49.6	2210
1.204	841	1.28	184	0.526	55.7	2480
1.202	1010	1.48	177	0.548	61.1	2710
1.204	1170	1.67	173	0.564	65.7	2920
1.202	1390	1.92	167	0.579	71.4	3180
1.203	1560	2.13	164	0.588	75.7	3370
1.203	1790	2.41	163	0.597	81.2	3610
2.002	1170	2.72	160	0.624	109	3180
2.005	1790	3.95	148	0.658	135	3930
2.703	1170	3.63	147	0.649	147	3260
2.705	1790	5.29	135	0.682	182	4040
3.098	1170	4.14	143	0.660	169	3300
3.101	1790	6.04	131	0.689	209	4070
3.518 [b]	1170 [b]	4.70 [b]	143 [b]	0.663[a]	192 [b]	3320 [b]
3.517 [b]	1390 [b]	5.44 [b]	137 [b]	0.677[a]	208 [b]	3610 [b]
3.521 [b]	1560 [b]	6.05 [b]	133 [b]	0.687 [b]	221 [b]	3830 [b]
3.521[b,c]	1790 [b,c]	6.85 [b,c]	129 [b,c]	0.696 [b,c]	237 [b,c]	4100 [b,c]

[a]Thrust correction factor due to beam divergence assumed to be 0.976−0.977; ratio of doubly-to-singly-charge ion current assumed to be 0.034−0.044.
[b]Not a throttle table operating point.
[c]Wear test operating point.

Table 4.—NEXT ion engine performance requirements and test results for EM1.

Performance Requirements	EM1 Test Results
Specific impulse ≥ 4050 s	4070 s
Low power thrust efficiency > 0.42	0.495
High power thrust efficiency > 0.63	0.689

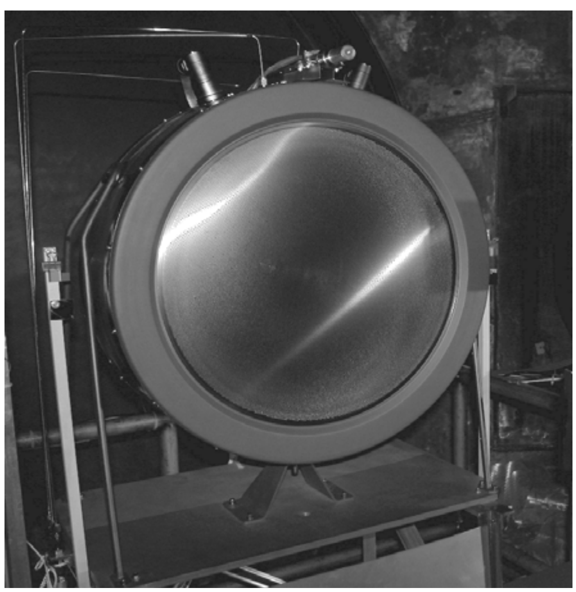

Figure 1.—NEXT engineering model engine EM1.

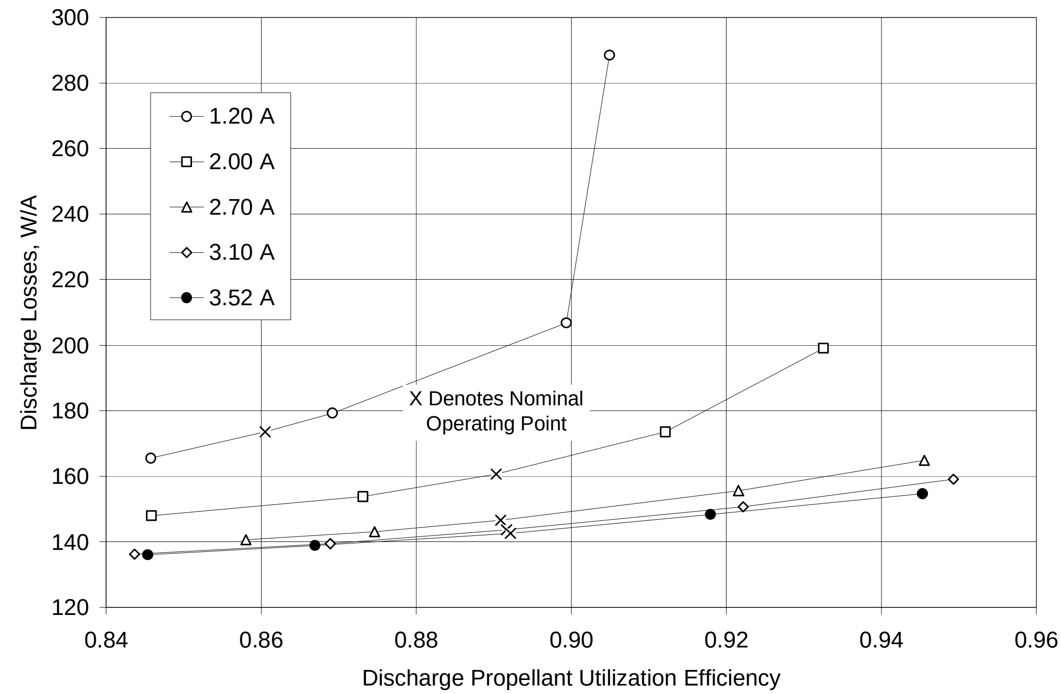

Figure 2.—Discharge losses as a function of propellant utilization efficiency for all beam currents at an 1180 V beam power supply voltage. Discharge voltages ranged from 23.5 V at high beam currents to 25.5 V at low beam currents.

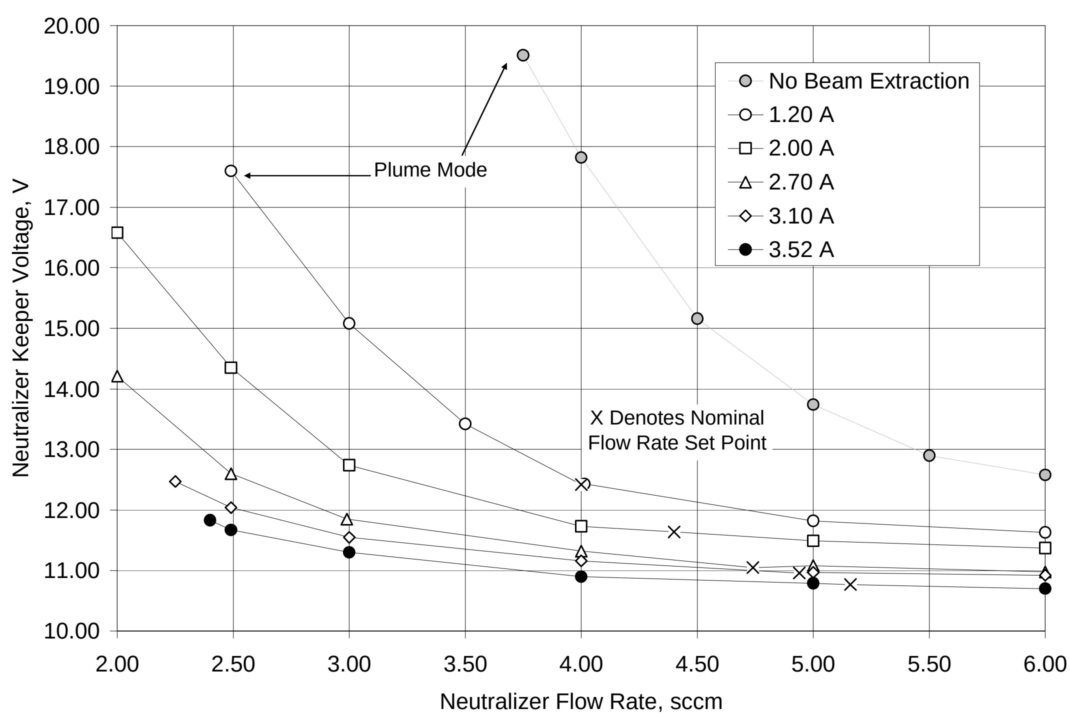

Figure 3.—Neutralizer keeper voltage as a function of flow rate for all beam currents at a beam power supply voltage of 1800 V and without beam extraction.

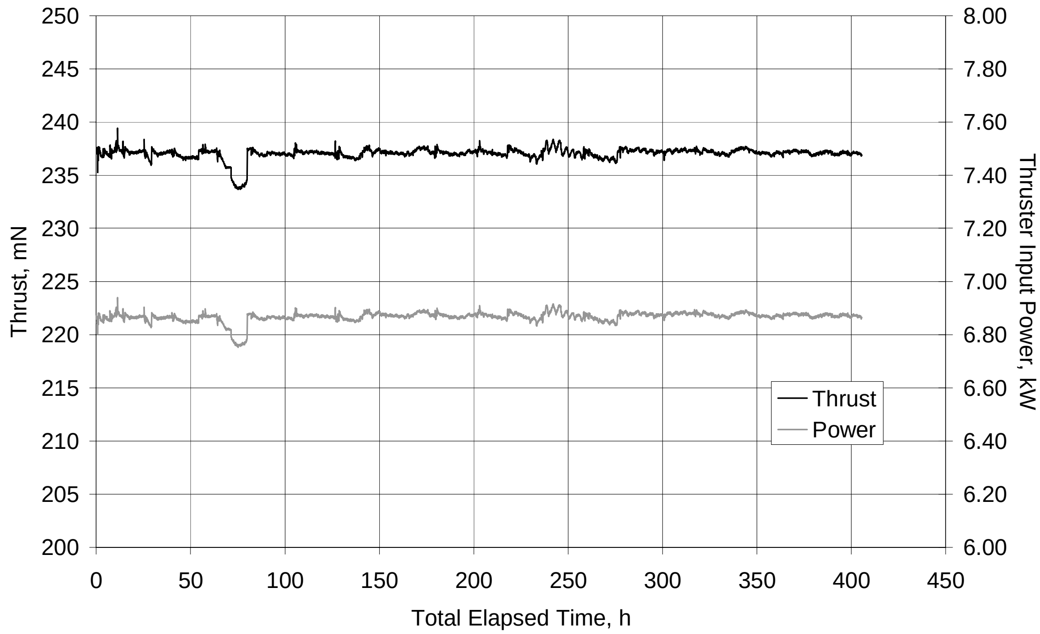

Figure 4.—Calculated thrust and engine input power as a function of time.

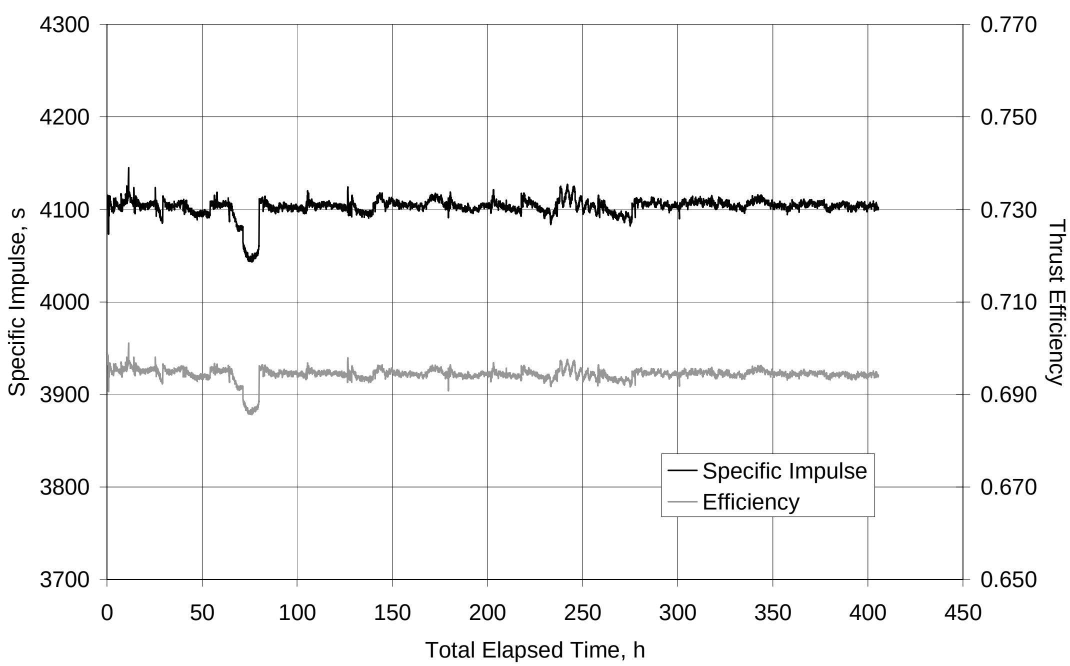

Figure 5.—Specific impulse and thrust efficiency as a function of time.

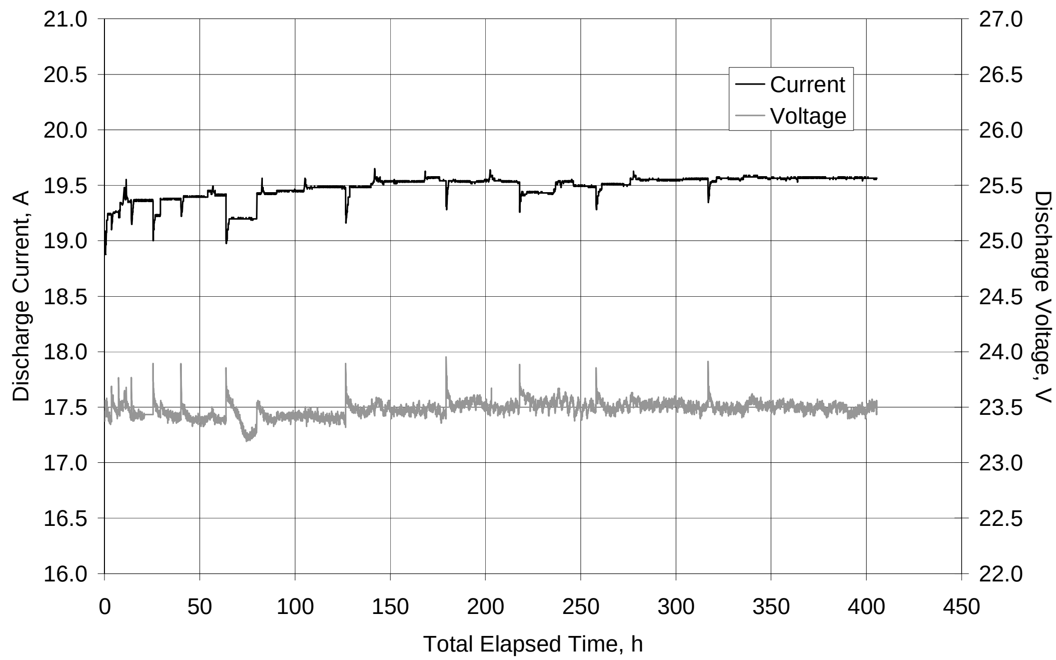

Figure 6.—Discharge current and voltage as a function of time.

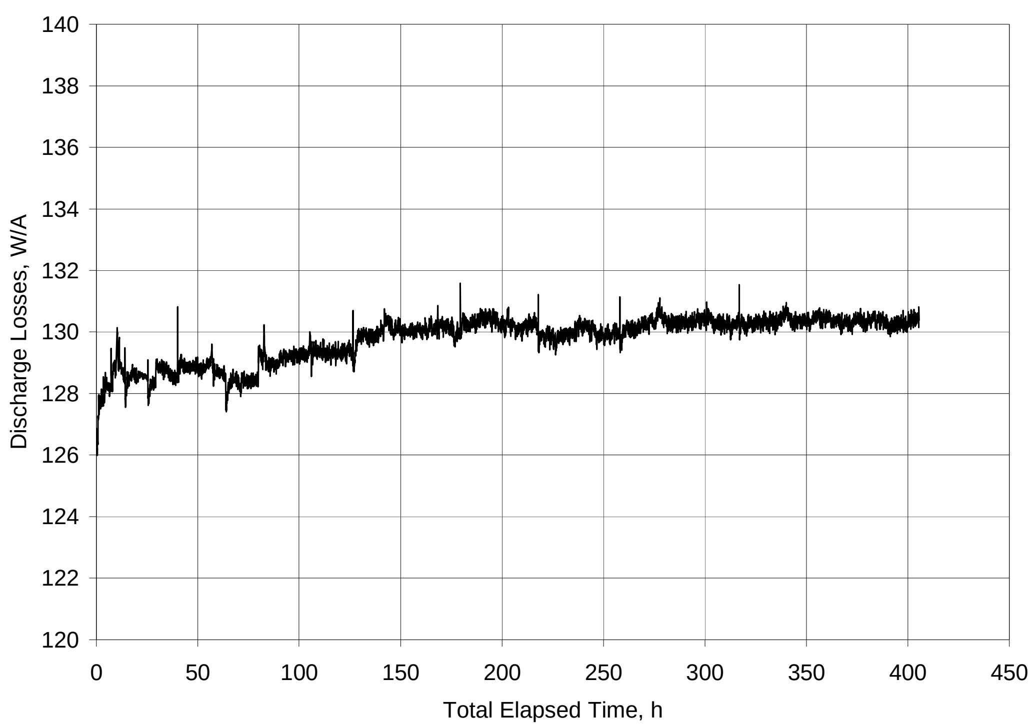

Figure 7.—Discharge losses as a function of time.

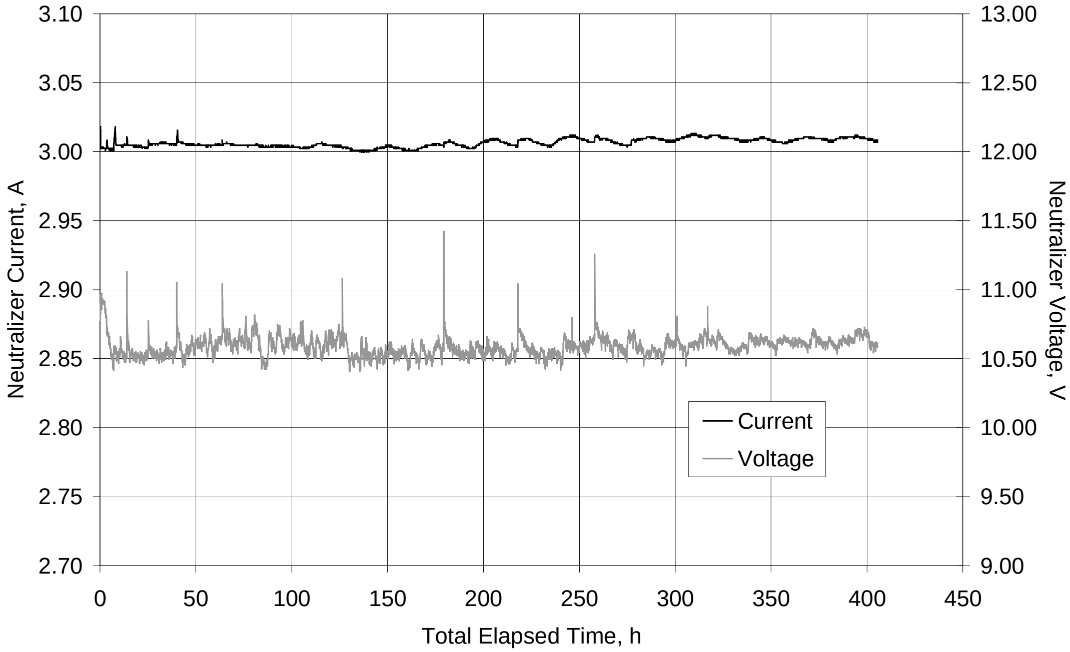

Figure 8.—Neutralizer current and voltage as a function of time.

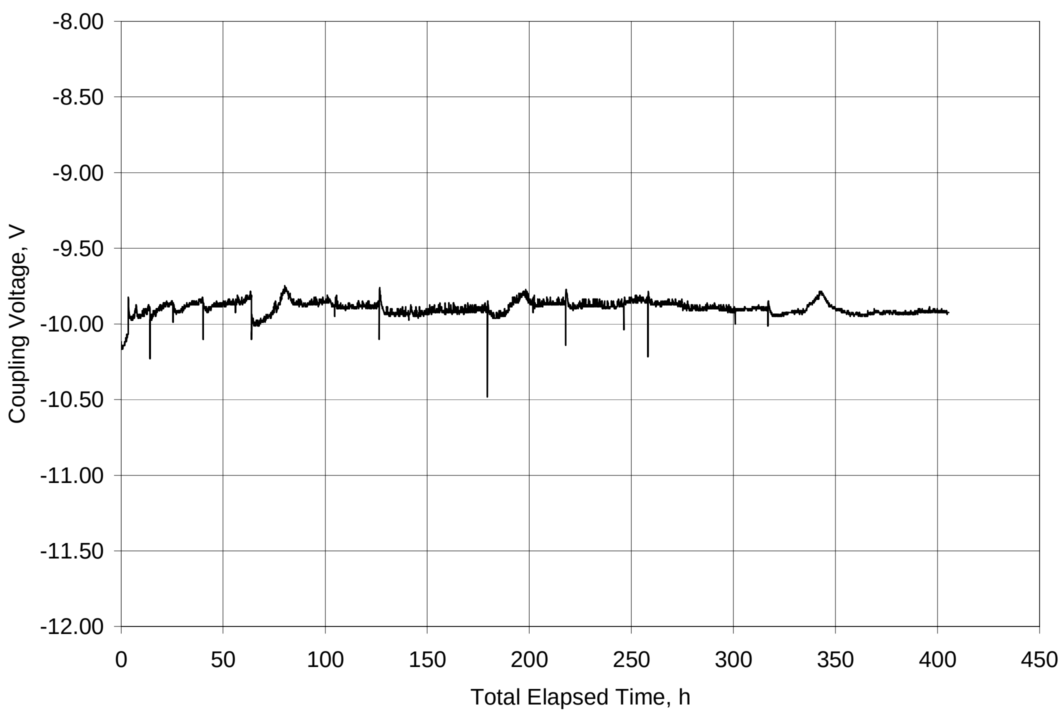

Figure 9.—Coupling voltage as a function of time.

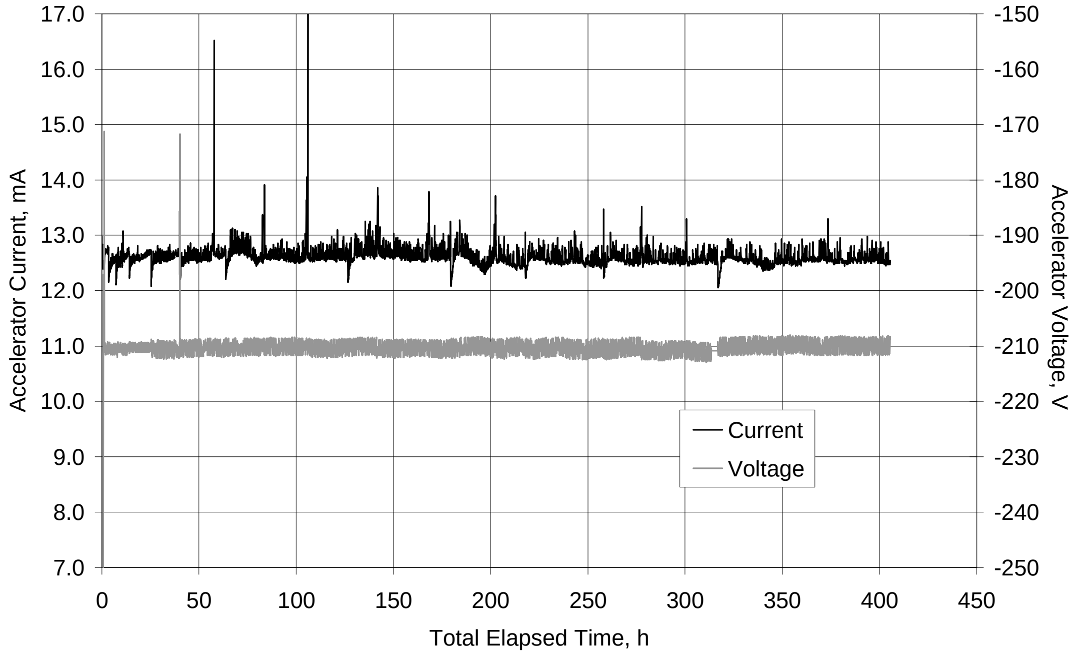

Figure 10.—Accelerator current and voltage as a function of time.

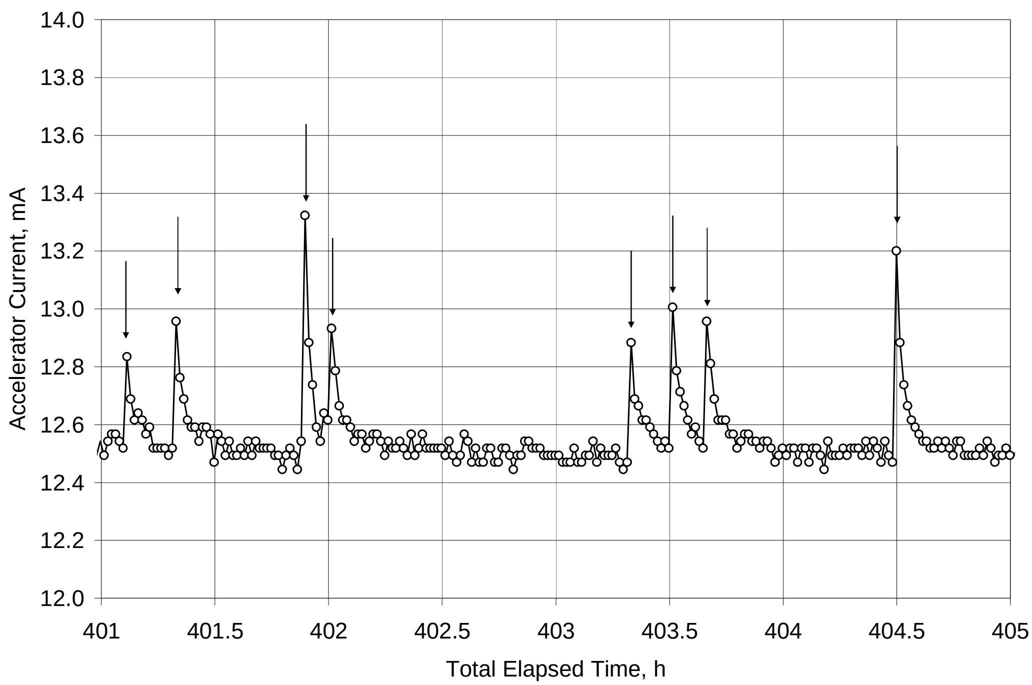

Figure 11.—Accelerator current as a function of time. Arrows indicate engine recycles.

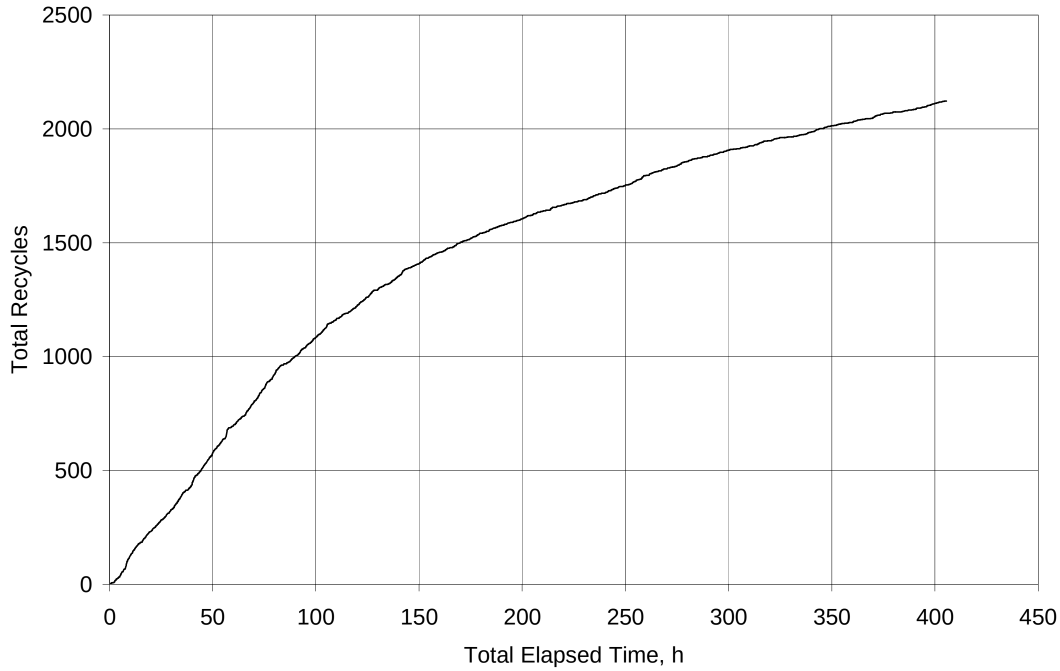

Figure 12.—Total recycles as a function of time.

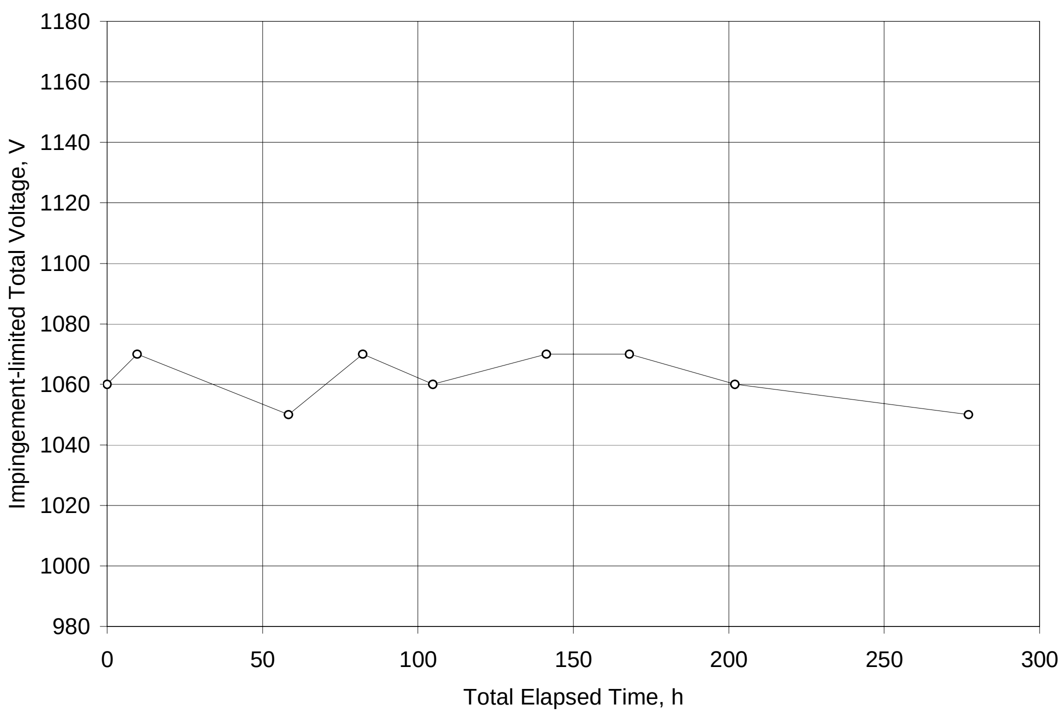

Figure 13.—Impingement-limited total voltage as a function of time.

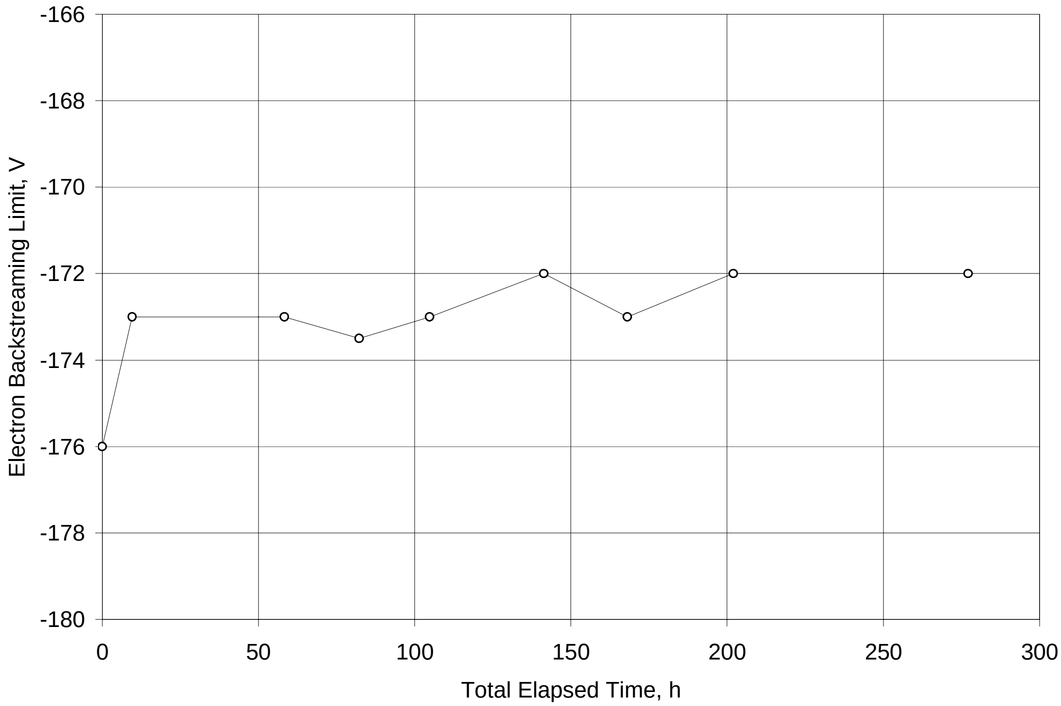

Figure 14.—Electron backstreaming limit as a function of time.

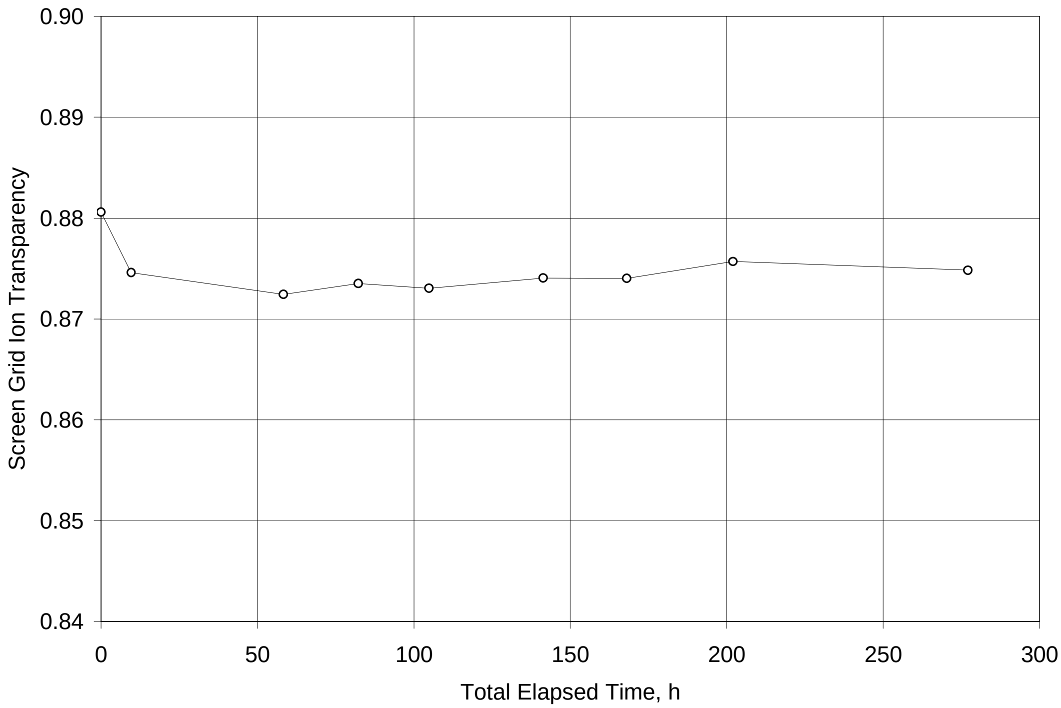

Figure 15.—Screen grid ion transparency as a function of time.

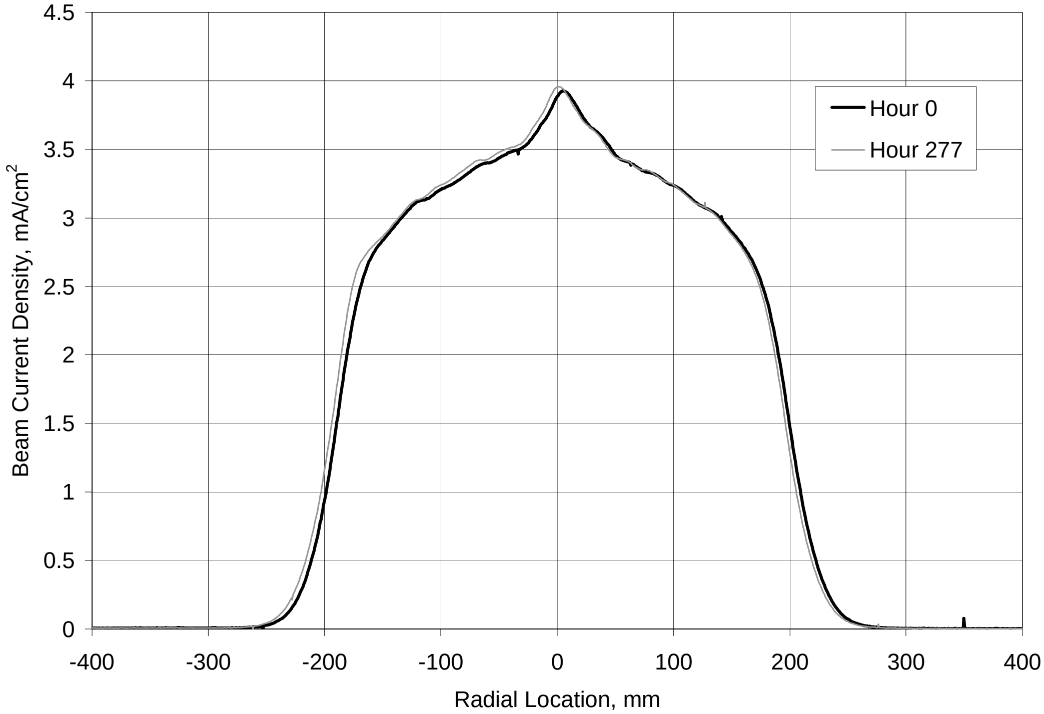

Figure 16.—Radial beam current density profiles 45 mm downstream of the engine during wear testing.

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13. ABSTRACT ***(Maximum 200 words)***

The status of the NEXT 2000 hour wear test is presented. This test is being conducted with a 40 cm engineering model ion engine, designated EM1, at a beam current higher than listed on the NEXT throttle table. Pretest performance assessments demonstrated that EM1 satisfies all thruster performance requirements. As of July 3, 2003, the ion engine accumulated 406 hours of operation at a thruster input power of 6.9 kW. Overall ion engine performance, which includes thrust, thruster input power, specific impulse, and thrust efficiency, has been steady to date with no indications of performance degradation. Images of the downstream discharge cathode, neutralizer, and accelerator aperture surfaces have exhibited no significant erosion to date.

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