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Ion Thruster Development at NASA Lewis Research Center

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ION THRUSTER DEVELOPMENT AT NASA LEWIS RESEARCH CENTER

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Abstract

Recent ion propulsion technology efforts at NASA's Lewis Research Center including development of kW-class xenon ion thrusters, high power xenon and krypton ion thrusters, and power processors are reviewed. Thruster physical characteristics, performance data, life projections, and power processor component technology are summarized. The ion propulsion technology program is structured to address a broad set of mission applications from satellite stationkeeping and repositioning to primary propulsion using solar or nuclear power systems.

INTRODUCTION

Ion propulsion components and systems have been ground and flight tested for three decades at institutions in Europe, Japan, Russia, and the United States (U.S.). Mercury ion thrusters were tested at power levels of 20 to 200 kW more than 20 years ago (Sovey et al. 1992). Due to the near-term prospect of modest space power capability, most of the recent technology work has been conducted at power levels less than 5 kW. The current programs at the National Aeronautics and Space Adminsitration's Lewis Research Center (NASA LeRC) are focused on the development of 30 cm xenon ion thruster technology for near-term, near-Earth missions which use thrusters in the 0.5 kW to 5 kW range. Applications include propulsion roles such as North-South stationkeeping (NSSK), spacecraft repositioning and maneuvering, and orbit transfer for small satellites. Near term missions will likely use xenon propellant because xenon provides a relatively high thrust-to-power capability, and xenon can be relatively easily and efficiently stored. NASA LeRC's goal is to develop and transfer the low power ion propulsion technology to U.S. government and industry users and also extend the technology to higher powers for solar and nuclear electric orbit transfer and planetary propulsion. Thirty and fifty centimeter diameter thrusters with dished ion optics satisfy most requirements in the 5 kW to 25 kW power range. Xenon, krypton, and argon thrusters provide thrust efficiencies of about 70% at specific impulses of 3000 s, 5000 s, and 7500 s, respectively (Patterson and Williams 1992 and Patterson and Rawlin 1988). In all power ranges the major efforts are directed towards developing long-life, light-weight thrusters as well as efficient, light-weight power processors.

This paper will review recent ion propulsion technology efforts at NASA LeRC which include development of kW-class xenon ion thrusters, high power xenon and krypton thrusters, and power processors. Thruster physical characteristics, performance data, life projections, and power processor component technology will be summarized.

LOW POWER XENON ION PROPULSION TECHNOLOGY

Several studies have shown that significant mass savings can be realized by using 0.5 kW to 5 kW xenon ion propulsion for stationkeeping or repositioning of spacecraft (Rawlin and Majcher 1991, Sovey and Pidgeon 1990, and Deininger and Vondra 1988). To minimize risk, a derated ion thruster (See Figure 1) is now being developed to NASA LeRC to eliminate known life-limiting issues, increase thrust-to-power, and reduce overall flight qualification schedules, costs, and risks (Patterson and Foster 1991). Xenon thruster performance data have been obtained at power levels from 0.5 kW to 5.5 kW and over a wide range of specific impulse. Detailed performance mapping was undertaken for operation in the specific impulse range of 1000 s to 3000 s because there may be mission enhancing benefits to power limited spacecraft in this range of performance (Patterson 1992). It is well-known that xenon ion thrusters operate efficiently at specific impulses greater than 3000 s, but little reported data exist at the very low specific impulse levels. Figure 2 shows typical xenon thruster performance in the low specific impulse range. Thrust efficiencies at specific impulses of 1500 s and 3000 s were about 40% and 66%, respectively.

Thrust-to-power levels in the 50 to 57 mN/kW range were obtained over a range of specific impulses of 1200 s to 2700 s. Because of present limitations on ion optics' performance, the thruster maximum input power using xenon varied from about 1 kW at 1500 s specific impulse to more than 3 kW at 3000 s. The negative grid erosion rate, due to charge exchange ions, varies directly as the negative grid voltage and the ion current density. Thus, for a given thruster diameter and power level, there is a minimum specific impulse that is consistent with projected lifetimes of 10,000 h (Patterson 1992). Using the life-limit rationale developed by Patterson and Foster (1991), the ion optics and hollow cathode projected lifetimes exceeded 10,000 h at power levels of 0.64 kW, 1.6 kW, and 5.5 kW when the specific impulses were > 1500 s, > 2200 s, and > 3800 s, respectively. Projected lifetimes are shown in Figure 3. The projected lifetimes are well beyond the North-South stationkeeping thrusting time requirements (2620 h to 7530 h) for a 2000 kg, 15 year geostationary satellite (Rawlin and Majcher 1991).

Because the derated thruster can operate at low ion current densities, low discharge voltages, and low negative grid voltages, the thruster life and reliability can be enhanced because of lower internal and external component erosion rates. The derated ion thruster positive and negative grid erosion rates have been estimated to be at least 16 and 41 times lower, respectively, than those of smaller NSSK thrusters operating at the same input power of 0.64 kW (Patterson and Foster 1991). Calculations using negative grid erosion rates, beam area, and required thrusting times predict about 10 to 20 times lower sputtered efflux from the negative grid of the 30 cm thruster compared to smaller two-grid thrusters. Additionally, the derated 30 cm thruster can be operated at thrust levels 25% to 80% higher than those obtained with smaller flight-type thrusters at a given power level (Patterson 1992). The higher thrust capability implies reduced on-orbit firing times and thus reduced qualification test times.

A potential disadvantage of the derated thruster approach for NSSK is thruster integration on mass and volume constrained spacecraft. The 30 cm thruster is larger and more massive than the small, present generation ion thrusters, which range in mass from 1 kg to 5 kg (Patterson and Rawlin 1991). A recent study of satellites using derated ion thrusters for NSSK indicated the satellite mass in geosynchronous transfer orbit decreased by approximately 17 kg for each kilogram reduction in thruster mass (Rawlin and Majcher 1991). This strong sensitivity occurs because there are four thrusters per NSSK system, each with a gimbal assembly whose mass was estimated to be 34% of the thruster mass. In addition, the reduced thruster and gimbal mass require less structure, contingency mass, and propellant for NSSK, attitude control, and orbit transfer. The need for gimballed NSSK thrusters will be spacecraft specific and will ultimately be based on tradeoffs between propulsion module mass and attitude control system complexity and/or propellant mass.

Design modifications were made to reduce the mass of the 10.7 kg baseline 30 cm laboratory thruster. In 1992, most of the mild-steel and stainless-steel components were replaced with aluminum; the number and size of magnets were reduced, and the cylindrical design was replaced by a conic geometry constructed primarily from aluminum (Figure 1). The thruster mass estimate including internal wire harness, propellant isolators, neutralizer, and mounting pads is ~ 7 kg. The thruster has recently undergone diagnostic vibration tests along three axes at sinusoidal levels of 0.5 g and 1 g. Vibration through the mounting pad axis indicated a primary natural frequency of 135 Hz. Based on the test results, the basic structural integrity of the thruster was verified, but minor modifications to the mounting pad interfaces and the neutralizer assembly will be required.

The LeRC program also includes the development of major thruster components such as ion optics, hollow cathodes, and neutralizers. In an ion optics investigation, nine ion accelerating systems were diagnosed to understand and extend the limits of ion extraction capability (Rawlin 1992). Increased ion extraction enables an increased thrust-to-power capability and reduced firing times for NSSK ion thrusters. Grid hole pair misalignment, due to electrode forming or intentional offsets for beam vectoring, was found to be the major factor that limited the ion extraction capability. Ion extraction capabilities improved by as much as 90% when the only change made was to insure alignment of the roll direction of the molybdenum sheets prior to forming the dished configuration. This procedure provided more uniform stretching of the hole patterns during the hydroforming process and resulted in better hole alignment. A test was also conducted to determine which locations on the negative grid limited the ion extraction capability. Diagnostic foil strips were placed over the negative grid apertures along a selected diameter, and the foil was eroded by the ion beam. The dimensions of ion beamlets exiting the negative grid of a 30 cm diameter system were measured as a function of radius. At the ion extraction limit, only the central 20% of the negative grid area showed evidence of ion impingement. Thus, if all hole pairs were aligned, the extraction limit would simply be dictated by the ion density profile uniformity. Ion optics' performance tests with xenon, krypton, and argon propellants led to impingement limited ion extraction values which increased inversely as the square root of the propellant mass as expected from theoretical considerations. Detailed performance comparisons of various grid geometries were reported by Rawlin (1992).

Hollow cathodes, operating on inert gases, have experienced destructive effects during extended tests in facilities in Europe, Japan, and the U.S. (Rohden et al. 1991 and Sarver-Verhey 1992). The causes of cathode deterioration are believed to be due to contamination and excessive cathode operating temperatures. At LeRC, very encouraging results have been obtained showing that hollow cathode degradation due to contamination was mitigated by making hardware and procedural changes. In this effort, three hollow cathodes have been wear-tested for periods of about 500 h each (Sarver-Verhey 1992) (See Table 1). It was found that by using electropolished feed tubes and ultra-high-vacuum gasket seals, employing a feed-line bake at 75 °C, reducing the propellant feed system leak-outgas rate to ~ $4X10^{-6}$ Pa-l/s, and using a gas purifier, the hollow cathode experienced significantly reduced changes to interior surfaces, and overall stability improved with respect to earlier wear-test cathodes. In addition, the external temperature at the cathode tip was lowered to ~ 1050 °C, which is a safe operating temperature verified during tests with mercury hollow cathodes (Mirtich and Kerslake 1976). Very small, highly localized amounts of tungsten, barium, and calcium compounds including Ba_2CaWO_6 were found on internal cathode surfaces, but none of these deposits impacted performance over the 500 h period. During the test with improved contamination controls, the discharge voltage was very stable at 16.7 V with a 0.7% standard deviation. Figure 4 shows the improvement in operational stability between the first test and the third test which employed a gas purifier and improved procedures. Research to develop detailed criteria for long-life, inert-gas hollow cathodes is continuing.

A series of xenon neutralizer performance diagnostic tests were completed at LeRC (Patterson and Mohajeri 1991). It was found that the plasma screen surrounding the ion thruster should be isolated from facility ground in order to insure that neutralizer electrons couple directly to the ion beam and do not find a return path via the plasma screen. Tests also indicated that stray thruster magnetic fields in the region of the neutralizer cathode could significantly degrade coupling to the ion beam. At power levels between 0.55 kW and 3.2 kW, the xenon neutralizer significantly penalized overall thruster performance because the ratio of neutralizer flow rate to total flow rate was about 9%. State-of-the-art xenon neutralizers generally require about 15 W to 20 W of input power per ampere of electrons emitted, and the ratio of neutralizer electron to neutral atom flow rate ranged from 15 to 35.

A simplified power processor effort is underway at LeRC to develop three dual-purpose power supplies that can provide cathode heater and main discharge functions, positive and negative ion extraction voltages, and neutralizer heater/keeper functions. Plasma discharges would be initiated from stored energy in a series inductor. The use of multipurpose power supplies for some of the thruster functions has been previously demonstrated by Rawlin (1979). After the power electronics simplification process, a power processor breadboard (PPB) will be developed. The PPBs developed for arcjets use switching topologies and circuit integration methods that are applicable to the next generation ion thruster PPBs (Hamley and Hill 1991). Recently developed power electronics make use of new switching topologies and a higher level of circuit integration to reduce parts count and mass as well as increasing reliability. Table 2 illustrates the major changes in parts count and specific mass of recent systems compared to early systems used for mercury ion propulsion.

Under an outreach program, the lightweight thrusters, power consoles, and propellant management systems are being assembled for delivery to user organizations to familiarize them with the technology. The ion propulsion technology has also been transferred to the Space Station Freedom program for the development of plasma contactors, which control spacecraft potential and eliminate arcing to structural components.

HIGH POWER ION PROPULSION TECHNOLOLGY

Ion thrusters operating in the 5 kW to 25 kW power range have primary propulsion applications for orbit transfer, spacecraft repositioning, and planetary missions. Ion propulsion in Earth-space will likely require high thrust-to-power and specific impulses in the 2000 s to 4000 s for the propellants xenon and krypton. Specific impulse requirements for planetary missions are generally in the 5000 s to 10,000 s range because of the fuel efficiency demands. Representative performance data obtained using inert gas 30 cm and 50 cm diameter thrusters at power levels up to 19 kW are shown in Table 3 and Figure 2, which indicate that the thrust efficiency is about 70% for xenon and krypton at specific impulses of about 3000 s and 5000 s, respectively. There are ongoing technology efforts at LeRC to provide efficient, long-life xenon and krypton thrusters operating in the 2000 s to 4000 s specific impulse range for Earth-space propulsion. Improved discharge chamber and neutralizer designs will provide performance gains, ion optics with improved extraction capability will provide greater power handling capability, and grids made from low sputter-yield materials such as carbon-carbon will provide longer life (Patterson and Mohajeri 1991, Garner et al. 1992, Patterson 1992, and Rawlin 1992).

During short-term tests with 30 cm diameter thrusters, close-spaced ion optics have provided xenon average ion current densities as high as 13 mA/cm^2 at specific impulse and power levels of 4600 s and 16.7 kW, respectively (Patterson and Rawlin 1988). The ion extraction with krypton and argon would be expected to exceed the xenon results by factors of about 1.2 and 1.8, respectively (Rawlin 1992). At present, operation at such high current densities does not yield long lifetimes because of the sensitivity of the negative grid to charge exchange ion erosion. Based on previous wear tests conducted by Rawlin (1988) and Patterson and Verhey (1990) and known sputter yields, it is projected that molybdenum two-grid systems using xenon, krypton, and argon will have maximum ion current densities in the 5 to 10 mA/cm^2 range in order to insure lifetimes > 10,000 h. To overcome this thrust density limitation, work is underway at LeRC and the Jet Propulsion Laboratory to both improve the extraction capability of molybdenum grids and fabricate carbon-carbon ion optics (Rawlin 1992 and Garner et al. 1992). Preliminary test results of Monheiser and Wilbur (1992) have shown that erosion depth profiles on molybdenum and graphite negative grids indicate that the graphite grid eroded at a rate ~ 3 times less than that of molybdenum.

Projections of hollow cathode and molybdenum grid system lifetimes have been derived from results of two xenon thruster endurance tests conducted for periods of 567 h and 890 h (Rawlin 1988 and Patterson and Verhey 1990) (See Table 1). Thrusters were operated at a discharge voltage of ~ 28 V, and the ion beam current density was about 5 and 8 mA/cm^2 for the 890 h and 567 h tests, respectively. In both tests there was evidence of oxidation of refractory cathode materials, and there were materials deposited within the hollow cathodes. These results and the test results of Brophy and Garner (1991) prompted the ongoing development of criteria and procedures to ensure long-life cathodes. After the endurance tests, erosion of the positive grid by discharge chamber ions was undetectable using micrometer measurements, which implied a grid erosion rate less than 3 nm/h. It was estimated that the time to wear the positive grid to half-thickness was between 7000 h and 21,000 h. Results of the 890 h test indicated that a xenon thruster could be operated in space for periods in excess of 11,500 h at a beam current density of 5 mA/cm^2 and a negative grid voltage of ~ 330 V (Patterson and Verhey 1990). Since the test facility background pressure was ~ 1.7 X 10^{-3} Pa, the lifetime of the negative grid in this environment was estimated to be less than 4200 h due to facility enhanced charge exchange ion erosion. The LeRC vacuum Tank 5, when operated with its 20 oil diffusion pumps and a mid-tank carbon target, had a xenon pumping speed of 55,000 l/s. By eliminating the mid-tank target, the pumping speed increased to about 90,000 l/s. Using the rationale developed by Patterson and Foster (1991), it is estimated that the tank is capable of providing an acceptable 5,000 h test environment for a 30 cm diameter xenon thruster operating at an input power of ~ 5.5 kW. Higher power thrusters will require the use of large area helium cryopumping and/or the use of conductance limiters to reduce the pressure in the vicinity of the thruster and minimize the facility enhanced charge exchange interactions.

In parallel with the thruster development, light weight power processor components are being developed. Table 2 shows that the power processor specific mass of some of the early ion propulsion systems exceeded 10 kg/kW (Bagwell 1971 and Anon. 1979). Transformers and other magnetics are the most massive power processor components. Efforts at the University of Wisconsin are involved in the optimization of coaxial-winding transformers which hold promise for low-mass and space-rated core materials (Divan and Kheraluwala 1991). Transformers will be mass optimized, and a DC/DC converter will be developed with goals of a component specific mass < 0.5 kg/kW and an efficiency > 94%. Additionally, a power processor simplification effort, using 3 power supplies and high current semiconductor switches to accommodate various thruster power demands, is being pursued at LeRC.

CONCLUDING REMARKS

Ion propulsion development and flight programs are now being conducted in Europe, Japan, and the United States. Most of the near-term applications involve xenon thrusters operating at power levels less than 5 kW. A 30 cm diameter, derated ion thruster is being developed at NASA LeRC to eliminate known life-limiting issues, increase the thrust-to-power, and reduce flight qualification test times. Thrust efficiencies, using xenon propellant, at specific impulses of 1500 s and 3000 s were 40% and 66%, respectively. Projected thruster lifetimes easily exceeded 10,000 h at power levels of 0.64 kW, 1.6 kW, and 5.5 kW when the specific impulses were > 1500 s, > 2200 s, and > 3800 s, respectively. The 30 cm thruster has recently completed diagnostic vibration tests, and the estimated mass of the thruster including wire harness, propellant isolators, neutralizer, and mounting pads is ~ 7 kg.

Inert gas laboratory thrusters operating in the 5 kW to 20 kW range have provided thrust efficiencies of about 70% for xenon and krypton at specific impulses of 3000 s and 5000 s, respectively. The major life-limiter of two-grid ion thrusters is erosion of the negative grid. Based on thruster wear test results, it is projected that molybdenum 2-grid ion optics using xenon, krypton, or argon will have maximum ion current densities in the 5 to 10 mA/cm^2 range in order to insure lifetimes of > 10,000 h. Because a 5.5 kW xenon thruster requires ~ 90,000 l/s pumping capability to perform an adequate 5000 h lifetest, the ability to conduct even longer life-tests and to test higher power thrusters will require the use of large area helium cryopumps and/or conductance limiters to minimize facility enhanced charge exchange ion erosion.

Near-term efforts with xenon and krypton propulsion systems will focus on development of light weight thrusters and power processors, improved ion extraction systems, long-life hollow cathodes, and an improved facility environment for extended tests.

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References

Anon. (1979) "30-Centimeter Ion Thrust Subsystem Design Manual," NASA TM 79191, 1979.

Bagwell, J. W. (1971) "Review of SERT II Power Conditioning," *Journal of Spacecraft and Rockets*, 8(3): 225-230.

Beattie, J. R., R. R. Robson, and J. D. Williams (1991) "18 mN Xenon Ion Propulsion System," IEPC Paper 91-010, presented at the AIDAA/AIAA/DGLR/JSASS 22nd International Electric Propulsion Conference, Viareggio, Italy, October 1991.

Brophy, J. R. and C. E. Garner (1991) "A 5,000 Hour Xenon Hollow Cathode Life Test," AIAA Paper 91-2122, June 1991.

Deininger, W. D. and R. J. Vondra (1988) "Electric Propulsion for Constellation Deployment and Space Maneuvering," AIAA Paper 88-2833, July 1988.

Divan, D. J. and M. H. Kheraluwala (1991) "High Power Density DC-DC Converters for Aerospace Applications," NAG3-804 Final Report.

Garner, C. E., J. R. Brophy, and L. Pless (1992) "Fabrication and Testing of Carbon/Carbon Grids for Ion Engines," AIAA Paper 92-3149, July 1991.

Hamley, J. A. and G. M. Hill (1991) "Power Electronics for Low Power Arcjets," AIAA Paper 91-1991, June 1991.

Mirtich, M. J. and W. R. Kerslake (1976) "Long Lifetime Hollow Cathodes for 30-cm Mercury Ion Thrusters," NASA TMX-73523, November 1976.

Monheiser, J. and P. J. Wilbur (1992) "An Experimental Study of Impingement-Ion-Production Mechanisms," AIAA Paper 92-3826, July 1992.

Patterson, M. J. and V. K. Rawlin (1988) "Performance of 10-kW Class Xenon Ion Thrusters," AIAA Paper 88-2914, July 1988.

Patterson, M. J. and T. R. Verhey (1990) "5-kW Xenon Ion Thruster Lifetest," AIAA Paper 90-2543, July 1990.

Patterson, M. J. and J. E. Foster (1991) "Performance and Characterization of a Derated Ion Thruster for Auxiliary Propulsion," AIAA Paper 91-2350, June 1991.

Patterson, M. J. and K. Mohajeri (1991) "Neutralizer Optimization," NASA TM-105578, October 1991.

Patterson M. J. (1992) "Low-I_{sp} Derated Ion Thruster Operation," AIAA Paper 92-3203, July 1992.

Patterson, M. J. and G. Williams (1992) "Krypton Ion Thruster Performance," AIAA Paper 92-3144, July 1992.

Rawlin, V. K. (1979) "Reduced Power Processor Requirements for the 30-cm Diameter Hg Ion Thruster," NASA TM-79257, October 1979.

Rawlin, V. K. (1988) "Internal Erosion Rates of a 10-kW Xenon Ion Thruster," AIAA Paper 88-2912, July 1988.

Rawlin, V. K. and G. A. Majcher (1991) "Mass Comparisons of Electric Propulsion Systems for NSSK of Geosynchronous Spacecraft," AIAA Paper 91-2347, June 1991.

Rawlin, V. K. (1991) "Advanced Ion Propulsion for Space Exploration," AIAA Paper 91-3567, September 1991.

Rawlin, V. K. (1992) "Characterization of Ion Accelerating Systems on NASA's Ion Thrusters," AIAA Paper 92-3827, July 1992.

Rohden, H. V., G. F. Cirri, and G. Matticari (1991) "Endurance Test of PROEL Neutralizer for the RIT 10: Review of the Activities at ESTEC Laboratories," IEPC Paper 91-026, presented at the AIDAA/AIAA/DGLR/JSASS 22nd International Electric Propulsion Conference, Viareggio, Italy, October 1991.

Sarver-Verhey, T. R. (1992) "Extended Testing of Xenon Ion Thruster Hollow Cathodes," AIAA Paper 92-3204, July 1992.

Shimada, S., et al. (1991) "Ion Engine System Development of ETS-VI," IEPC Paper 91-145, presented at the AIDAA/AIAA/DGLR/JSASS 22nd International Electric Propulsion Conference, Viareggio, Italy, October 1991.

Sovey, J. S. and D. J. Pidgeon (1990) "Advanced Propulsion for LEO and GEO Platforms," AIAA Paper 90-2551, July 1990.

Sovey, J. S., J. A. Hamley, M. J. Patterson, V. K. Rawlin, and R. M. Myers (1992) "The Evolutionary Development of High Specific Impulse Electric Thruster Technology," AIAA Paper 92-1556, March 1992.

Table 1. Recent Ion Thruster/Component Extended Tests at NASA LeRC.

Test Article	Propellant	Power (kW)	Discharge Current (A)	Beam Current (A)	Test Period (h)	Year
30 cm Thruster[a]	Xe	10	31	5	567	1988
30 cm Thruster[b]	Xe	5.5	19	3.2	890	1990
Hollow Cathode Wear Test #1[c]	Xe	–	23	–	504	1991
Hollow Cathode Wear Test #2[c]	Xe	–	23	–	478	1991
Hollow Cathode Wear Test #3[c]	Xe	–	23	–	508	1992

[a](Rawlin 1988) [b](Patterson and Verhey 1990) [c](Sarver-Verhey 1992)

Table 2. Power Electronics for Ion Propulsion Systems.

	SERT II[a]	SEPS[b]	XIPS[c]	ETS VI[d]
Propellant	Mercury	Mercury	Xenon	Xenon
Power (kW)	0.98	3.1	1.4	0.79
Efficiency	0.87	0.87	0.92	0.86
Specific Mass (kg/kW)	16.9	12.3	7.9	–
Approximate Parts Count	1100	4000	400	–

SERT: Space Electric Rocket Test SEPS: Solar Electric Propulsion Sysyem
XIPS: Xenon Ion Propulsion System ETS: Engineering Test Satellite

[a](Bagwell 1971) [b](Anon. 1979) [c](Beattie et al. 1991) [d](Shimada et al. 1991)

Table 3. Ion Thruster Performance.

Thruster	Propellant	Power (kW)	Thrust (N)	Specific Impulse (s)	Thrust Efficiency
30 cm[a]	Xe	5.5	0.20	3800	0.68
30 cm[b]	Kr	5.5	0.16	5100	0.71
30 cm[c]	Ar	5.5	0.12	3960	0.44
50 cm[d]	Xe	13.5	0.43	5000	0.75
50 cm[c]	Kr	5.4	0.17	3460	0.54
50 cm[d]	Ar	19	0.32	9200	0.76

[a](Patterson and Verhey 1990) [b](Patterson and Williams 1992) [c](This paper) [d](Rawlin 1991)

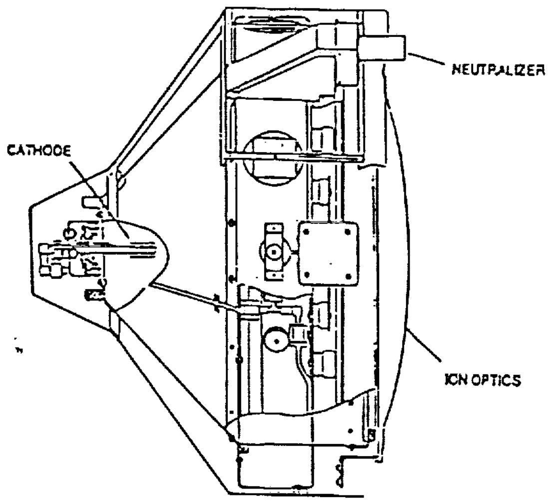

Figure 1. Light-weight 30 cm Ion Thruster.

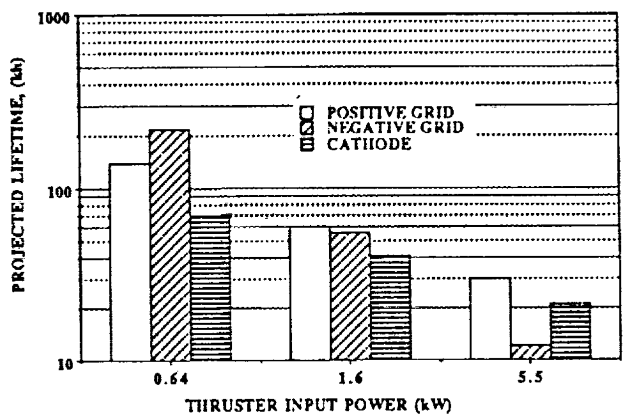

Figure 3. Projected Component Lifetime for the 30 cm Diameter Xenon Thruster.

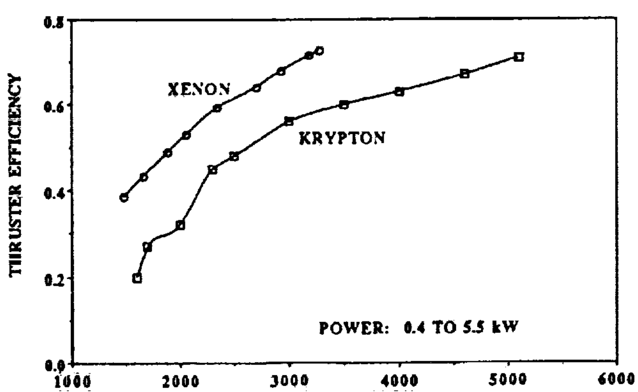

Figure 2. Performance of the 30 cm Ion Thruster using Xenon and Krypton.

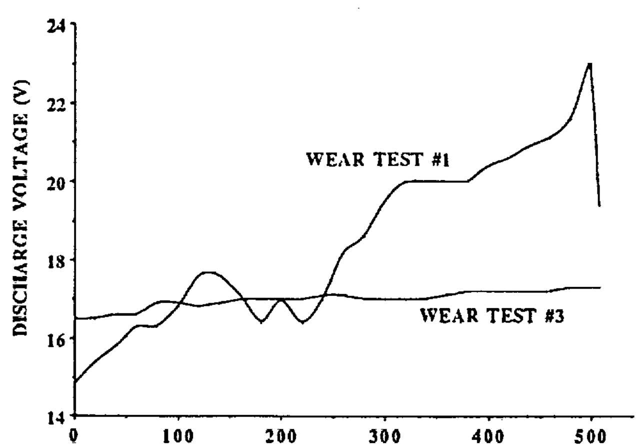

Figure 4. Discharge Voltage Versus Time for First and Third Cathode Wear Tests.

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