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Multiple Hollow Cathode Wear Testing

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INTRODUCTION

A hollow cathode-based plasma contactor has been baselined for use on the Space Station to reduce station charging.[1] The plasma contactor provides a low impedance connection to space plasma via a plasma produced by an arc discharge. The hollow cathode of the plasma contactor is a refractory metal tube, through which xenon gas flows, which has a disk-shaped plate with a centered orifice at the downstream end of the tube. Within the cathode, arc attachment occurs primarily on a Type S low work function insert that is next to the orifice plate. This low work function insert is used to reduce cathode operating temperatures and energy requirements and, therefore, achieve increased efficiency and longevity. As discussed in Ref. 2, the operating characteristics and lifetime capabilities of this hollow cathode, however, are greatly reduced by oxygen bearing contaminants in the xenon gas. Furthermore, an optimized activation process, where the cathode is heated prior to ignition by an external heater[3] to drive contaminants such as oxygen and moisture from the insert absorbed during exposure to ambient air, is necessary both for cathode longevity and a simplified power processor. In order to achieve the two year (~17500 hour) continuous operating lifetime requirement for the plasma contactor,[1] a test program was initiated at NASA Lewis Research Center to demonstrate the extended lifetime capabilities of the hollow cathode. To date, xenon hollow cathodes have demonstrated extended lifetimes with one test having operated in excess of 8000 hours in an ongoing test utilizing contamination control protocols developed by Sarver-Verhey.[2]

The objectives of this study were to verify the transportability of the contamination control protocols developed by Sarver-Verhey[2] and to evaluate cathode contamination control procedures, activation processes, and cathode-to-cathode dispersions in operating characteristics with time. These were accomplished by conducting a 2000 hour wear test of four hollow cathodes with different xenon gas purities and activation processes. The following sections will present a description of the facility and test hardware, testing procedures and operating conditions, a discussion of test results, and conclusions.

FACILITY AND TEST HARDWARE

Tests were conducted in a 1 m diameter by 1.5 m long stainless steel tank. The facility was pumped by a 0.89 m diameter helium refrigerator cryopump horizontally mounted onto an end of the tank. The tank pressure with no gas load was 1.3×10^{-6} Pa (1.0×10^{-8} torr). The measured pumping speed of the cryopump was approximately 13000 L/sec of xenon.

There were two 0.33 m diameter by 0.41 m long stainless steel ports mounted on the end of the tank opposite the cryopump and to the side of the tank. A gas feed systems was installed at each port. The gas feed systems utilized ultra-high vacuum components and were wrapped with heater tape to permit a bake-out. For this test, each gas feed system supplied xenon propellant to two hollow cathodes through separate gas lines. Cathodes with and without a purifier installed in its gas line were tested in each port. This configuration permitted the testing of four hollow cathodes and enabled the utility of the purifier to be evaluated.

A computerized data acquisition and control system was used to record some data and to control some of the discharge power supplies used for the wear test. Recorded parameters included discharge currents and voltages, volumetric flows, cathode thermocouple temperatures, tank pressure, and elapsed time. Data for wear testing were acquired at 10 minute intervals. Two strip chart recorders were also used to continuously monitor discharge currents and voltages, pyrometer temperatures, and port pressures.

Two cathode-anode assemblies were mounted onto the flange of each port. The cathodes of each assembly pair were separated with a 0.20 m by 0.30 m stainless steel plate. The anodes for each cathode were 0.10 m square molybdenum plates. The assemblies were designed to allow the gap between anode and cathode to be adjusted. All cathodes were isolated from tank ground with propellant isolators. A photograph of one assembly is shown in Figure 1. The hollow cathodes tested in this study are similar to those being used on the plasma contactor. A description of the hollow cathode can be found in Ref. 2. Type R (platinum/platinum-13% rhodium) thermocouples were spot-welded on the cathode tubes approximately 1.5 mm from the orifice plate for cathode temperature measurements. As a secondary measure of cathode temperature, a pyrometer measured the orifice plate temperature of each cathode at a position below the orifice. The emissivity correction for all pyrometers was set to 0.39 to account for the emissivity of the orifice plate and the transmissivity of the quartz windows.[4]

TESTING PROCEDURES AND OPERATING CONDITIONS

A number of protocols were followed before igniting a cathode discharge. These protocols included evacuation, bake-out, and leak rate test of the gas feed system, followed by a cathode activation. Evacuation and bake-outs were conducted whenever the gas feed systems were exposed to ambient air. Leak rate tests were conducted whenever the gas feed systems were altered in any way, including after a xenon bottle replacement, to identify any possible leaks that may have introduced air or moisture to the xenon gas. Finally, to remove contaminants from the cathode insert, activation procedures were conducted whenever the hollow cathodes were exposed to ambient air. At the completion of testing, gas samples were taken from each gas feed line to quantify the impurity levels.

The operating conditions of the cathodes are shown in Table 1. The cathode designation number indicated the port in which it was mounted. The flows were standardized to a pressure and temperature of 1 std. atm. and 0 °C, respectively. The high currents and flows, compared to those of the plasma contactor,[1] were used to accelerate the effects of contaminants in the xenon gas on cathode lifetime. Two cathodes were operated with purifiers and two without to evaluate the utility of a purifier. The cathode gas feed systems with purifiers represented a configuration similar to that of Ref. 2 so that the transportability of cathode contamination control procedures could be evaluated. Finally, one cathode was operated with a simplified activation process which, if acceptable, could simplify power processor requirements.

RESULTS AND DISCUSSION

Discharge voltages, ignition voltages, and cathode tube temperatures were monitored for any significant changes, trends, or unit-to-unit disparities, as was the appearance of the cathode orifice plate at the test's completion. Any significant changes or noticeable trends would be indicative of a possible long term failure mechanism. All cathodes were operated in excess of 2000 hours. The discharge voltages and cathode thermocouple temperatures for all cathodes are shown in Figures 2 and 3, respectively. During the wear test, there were a total of six shutdowns, indicated in Fig. 2 and 3 with arrows, due either to facility failures or xenon bottle replacements. The average discharge voltages for all cathodes were 8.3-8.5 V, with maximum variations within ± 1V for each individual cathode. Voltage oscillations were due to oscillations in propellant flow. Voltage disparities between all cathodes never exceeded 1.5 V. There were no noticeable trends or significant changes in the discharge voltage. The ignition voltages for all cathodes remained at 15-22 V for all cathodes throughout testing, with disparities between all cathodes not exceeding 5.5 V. The average cathode thermocouple temperatures were 1050-1110 °C with variations within ± 60 °C for each individual cathode. Temperature disparities between all cathodes never exceeded 110 °C, due in part to slightly different thermocouple locations. There were no noticeable trends or significant changes in temperature other than those associated with ignition. The pyrometer results were typically 15-70 °C higher than the thermocouple measurements, partly due to the pyrometers measuring reflected light. The pyrometers measurements, however, verified the thermocouple measurements.

CONCLUSIONS

A 2000 hour wear test was conducted with four hollow cathodes. The objectives were to verify the transportability of contamination control protocols developed by Sarver-Verhey[2] and to evaluate contamination control procedures, activation processes, and cathode-to-cathode dispersions in operating characteristics with time. These were accomplished by conducting a 2000 hour wear test of four hollow cathodes with different xenon gas purities and activation processes. The gas feed systems were similar to that of Ref. 2 so that the transportability of cathode contamination control procedures could be evaluated. Two cathodes were operated with purifiers and two without to evaluate the utility of a purifier. One cathode was operated with a simplified activation process to evaluate the activation process. Finally, all hollow cathodes were operated concurrently to evaluate unit-to-unit dispersions with time.

There were no significant changes with time in the discharge voltages, ignition voltages, or cathode tube temperatures of all cathodes tested. The discharge voltages, ignition voltages, and cathode thermocouple temperatures were constant to within ± 1 V, ± 5 V, and ± 60 °C, respectively, throughout testing. These data imply that contamination control procedures have been successfully transferred. There were also no differences in operation with or without a purifier or with the use of a simplified activation process. Finally, cathode-to-cathode dispersions were demonstrated to be minimal, with maximum disparities in discharge voltage, cathode temperature, and ignition voltage at 1.5 V, 110 °C, and 5.5 V, respectively. More absolute conclusions can be made when the cathodes are sectioned, the inserts and orifice plates are examined with a scanning electron microscope, and the contaminant levels of each gas feed line are quantified.

REFERENCES

[1] Patterson, M. J., et al., "Plasma Contactor Development for the Space Station," IEPC Paper 93-246, September 1993.

[2] Sarver-Verhey, T. R., "Extended Test of a Xenon Hollow Cathode for a Space Plasma Contactor,", IEPC Paper 93-020, September 1993.

[3] Soulas, G. C., "Hollow Cathode Heater Development for the Space Station Plasma Contactor," NASA Contractor Report 191131, October 1993.

[4] Reick, G. D., *Tungsten and Its Compounds,* Pergamon Press, Oxford, 1967, pp. 22-23.

Table 1 Wear Test Operating Conditions

Cathode	Current, A	Xenon Flow, sccm	Purifier	Activation Process
1A	10.0	9.0	Yes	See Ref. 3
1B	10.0	9.0	No	Simplified
2A	10.0	9.0	Yes	See Ref. 3
2B	10.0	9.0	No	See Ref. 3

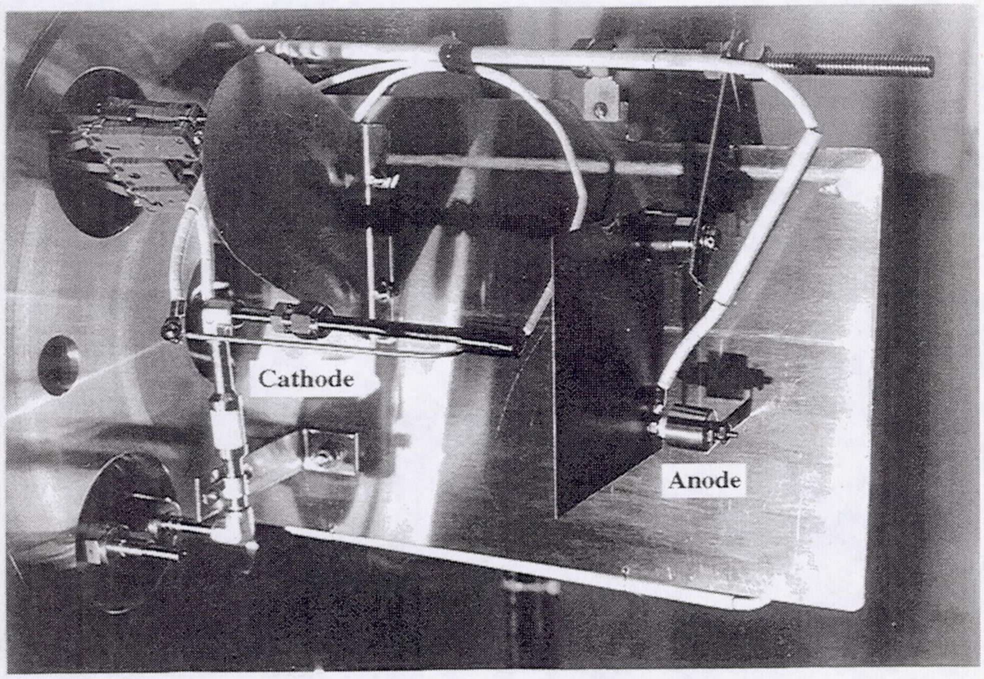

Fig. 1 Photograph of a Cathode-Anode Assembly

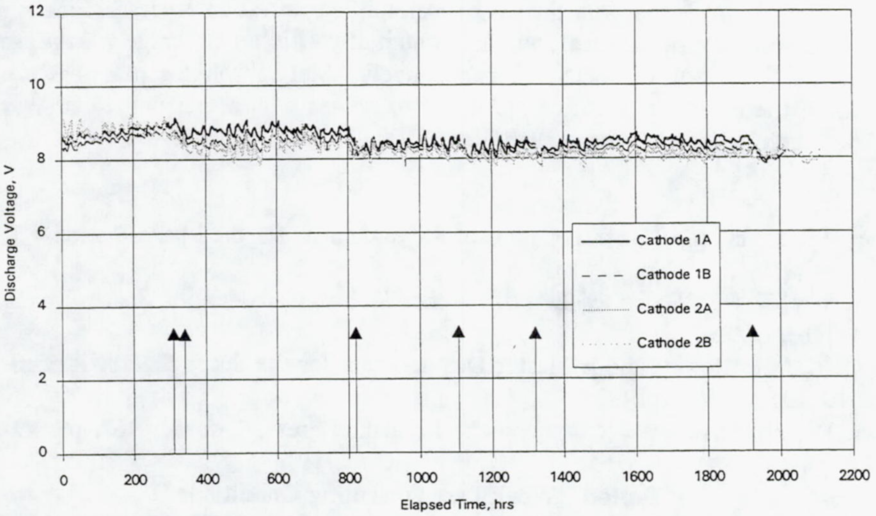

Fig. 2 Cathode Discharge Voltages (Arrows Indicate Shutdowns Due To Facility Failures or Xenon Bottle Replacements)

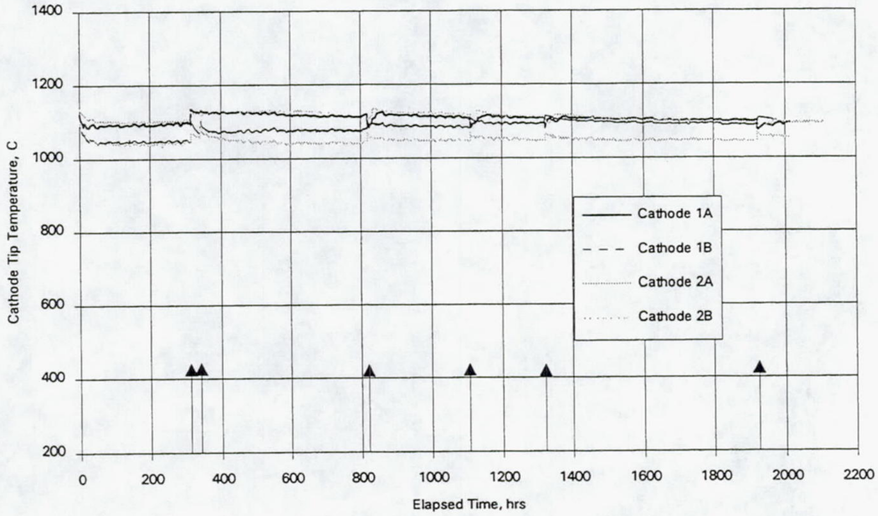

Fig. 3 Cathode Tip Thermocouple Temperatures (Arrows Indicate Shutdowns Due To Facility Failures or Xenon Bottle Replacements)

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13. ABSTRACT *(Maximum 200 words)*

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