J-Series Ion Thruster Isolator Failure Analysis

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Abstract

ISOLATOR failure was observed on three J-series ion bombardment thrusters[1] while operating in the Xerox Electro-Optical System (XEOS) Mission Profile Life Test (MPLT) facility.[2] This high-voltage isolator failure was characterized by a rapid rise in the temperature of the isolator/vaporizer assembly leading to a loss of vaporizer and hence propellant flowrate control. As temperatures and flowrates increased uncontrollably, neutral mercury atoms saturated the main discharge chamber reducing the ionization efficiency and hence beam current (i.e., thrust).

Subsequently, a three-phase effort was initiated to address this problem. The objective of the first phase was to verify the premise that the isolator itself, under certain conditions, became an ohmic heat source; the second was to determine the underlying reasons why the isolator became more conductive as thruster run time increased; and the third was to determine what corrective approaches, if any, were available to thruster designers.

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Isolator Operation

The purpose of the propellant isolator is to electrically isolate the discharge chamber, which is at a net accelerating potential of 600-1000 V, from the mercury propellant reservoir. This permits the reservoir to be operated at ground or spacecraft potential and allows a single reservoir to provide propellant to several thrusters without the danger of a high-voltage fault in one thruster affecting operation of the other thrusters. The 30-cm J-series thruster utilizes two propellant isolators; one to carry the cathode propellant flow and one to carry the main discharge chamber propellant flow (Fig. 1).

A hypothesized leakage resistance of 1 MΩ across the main cathode isolator would result in a power dissipation of $(1090\ V)^2/10^6\Omega = 1.2$ W, a sizeable fraction of the nominal steady-state heater power of 4 W for the cathode vaporizer and 9 W for the main vaporizer. This extra power would result in joule heating of the isolator body thus raising the temperature of the ceramics. The increase in ceramic temperature would decrease the surface resistance further, thus increasing the leakage current and power involved. Eventually the power which arrives at the vaporizer via thermal conduction from the isolator would exceed that needed to maintain nominal operating temperatures. Vaporizer temperature and flowrates would begin to increase uncontrollably, and total loss of

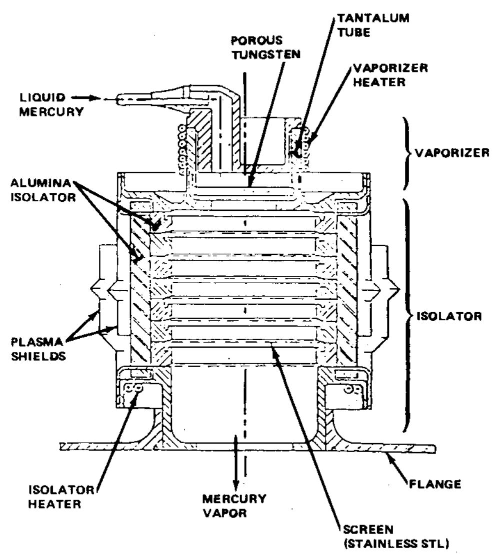

Fig. 1 Main isolator vaporizer.

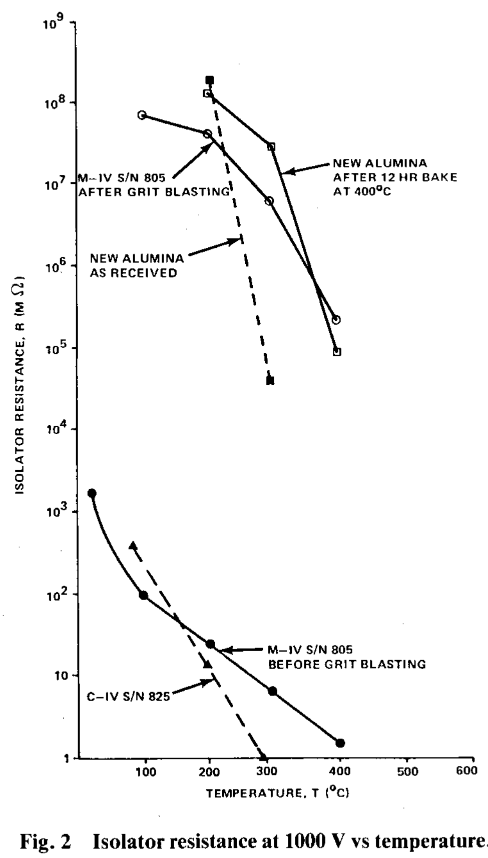

Fig. 2 Isolator resistance at 1000 V vs temperature.

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control over thruster operation soon would become inevitable.

Isolator Failure Analysis

Based on the isolator and MPLT test histories, two possibilities were chosen for initial investigation: semiconductor-type behavior in the alumina isolator material at high temperatures and conductive coating formation on the alumina surface. The most direct method for analyzing these possibilities seemed to be a resistance test at various isolator operating temperatures ranging from ambient to 400°C. As suspected, isolator C-IV 825 (from thruster J3) showed a very low resistance/temperature characteristic as shown in Fig. 2. Since M-IV 805 was exposed to the same environment as CV-825 on J3, it was also tested, and, as suspected, it also demonstrated a very low resistance/temperature characteristic curve very similar to that of C-IV 825. Following this test, M-IV 805 was grit blasted to remove a few microns of surface and retested. The characteristic increased several orders of magnitude and looked very similar to that of new alumina thus indicating the principle cause of the decrease in isolator resistance to be due to a surface effect.

An Auger analysis revealed the presence of carbon, oxygen, and aluminum atoms on the surface of C-IV 825. The latter two elements make up the alumina itself (Al_2O_3); hence, carbon was concluded to be the culprit in drastically lowering the isolator's resistance.

Possible Contamination Sources

Once carbon deposition on the surface of the isolator was identified as the cause of decreased isolator resistance, the next step was to identify the source of this carbon. As mentioned previously, one potential source was poor isolator material. However, this possibility appeared to be eliminated by a temperature/resistance check on a new alumina isolator.

The XEOS MPLT chamber was examined with a residual gas analyzer (RGA). These scans revealed significant levels of diffusion pump oil in the chamber environment. In addition, quartz, stainless steel, and aluminum witness samples confirmed the presence of carbon contaminants. These results strongly suggested that there were sufficient background contaminants present which contributed significantly to isolator surface coating growth. Furthermore, it appeared that the large majority of the contaminant flux was highly directional, possibly having been frozen on the mercury target during nonoperating periods and subsequently sputtered from the target surface when operation was resumed. Similar findings were made when the Hughes 2.7-m facility was examined. Fortunately, a test hardware evaluation suggested that the thruster could be significantly shielded from the facility-caused contamination.

In addition to facility contamination, other contamination effects were observed. This contamination was suspected to have come from the following components: nylon cable ties, vespel harness guides, and teflon/kapton wire and terminal insulation. As a general rule, temperatures to which these types of materials are exposed should be less than 150°C to prevent outgassing.

To investigate the possibility of outgassing occurring during operation, testing was undertaken with both standard open- and closed-configuration[3] thrusters. The basic objective of the closed design was to shadow shield-critical thruster components from facility contaminants. The closed design ran about 10-20°C hotter than the open one. In the cathode region, the temperature ranged from 280 to 360°C depending on beam current.[3] At the outer periphery of the thruster backplate assembly, the temperatures were the lowest, ranging from 115 to 170°C, depending on beam current. Thus, even at its cooler locations, thruster temperatures were marginally acceptable to allow the use of the suspect insulation materials without outgassing.

Conclusions and Recommendations

The major contributor to isolator overheating was a carbon layer on the surface of the insulating alumina which increased in thickness as a direct function of run time. As the contaminant layer grew, isolator resistivity decreased leading to ohmic heating of the isolator. Diffusion pump oil was found to be a major contamination source and reached the thruster by way of two mechanisms. The first was the background contribution of hydrocarbons from the facility vacuum pumps, while the second was oil sputtered off the mercury target by the thruster beam. Also, insulation material outgassing seemed to be a major contributor to carbon layer growth.

A variety of thruster modifications was identified to minimize the probability of contamination from directional back-sputtered contaminants. These included enclosing the back and neutralizer cover and adding an L-shaped shield within the ground screen to block line-of-sight trajectories from the sides.[4]

In addition, all organic materials were recommended to be eliminated from the thruster and replaced with ceramics.

References

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