Applied Ion Systems

AIS-TR-002

AIS-gPPT1 Gridded Pulsed Plasma Thruster

Phase I - Ignition Testing - 05/07/2019

Testing Report and Failure Analysis

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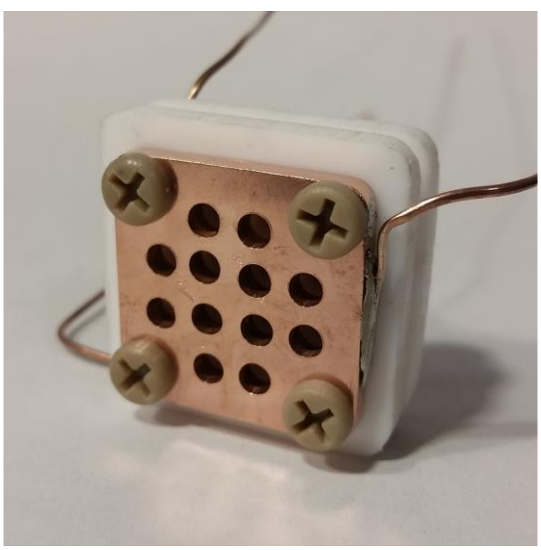
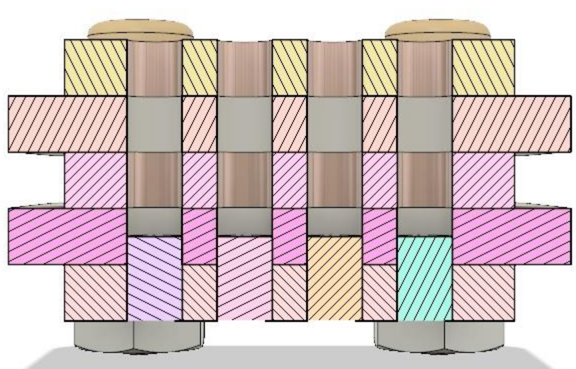
I. TEST PARAMETERS

- **Main Bank Capacitor** – 1uF polypropylene film capacitor
- **Main Bank Charging Voltage** – 0-2kV
- **Ignition Circuit** – hydrogen thyratron pulser
- **Ignition Capacitor** – 0.01uF plastic capacitor
- **Ignition Voltage** – 0-5kV
- **Pulse Repetition Rate** – 0.5-1Hz
- **Maximum Chamber Pressure During Testing** – 1 x 10^-5 Torr
- **Testing Status** – Unsuccessful

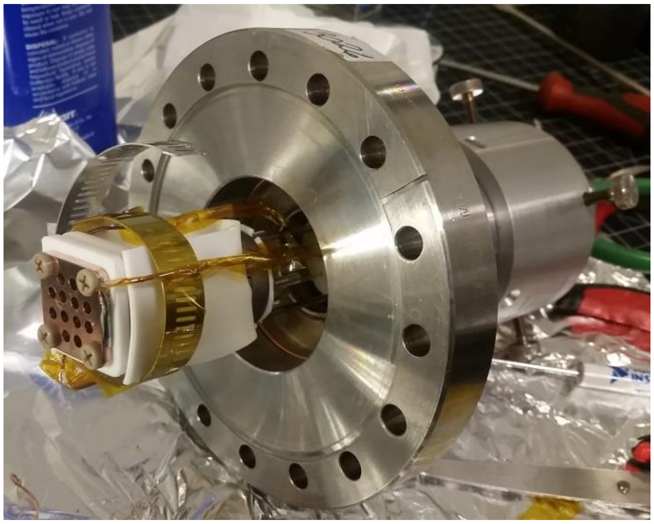
II. TEST SUMMARY

This test represents Phase I of testing and development for the AIS-gPPT1 Gridded Pulsed Plasma Thruster. The purpose of the test was to verify successful and reliable ignition of the thruster utilizing an unconventional flat-stacked plate electrode assembly with multiple ignition pins to improve ignition lifetime for a miniaturized PPT design.





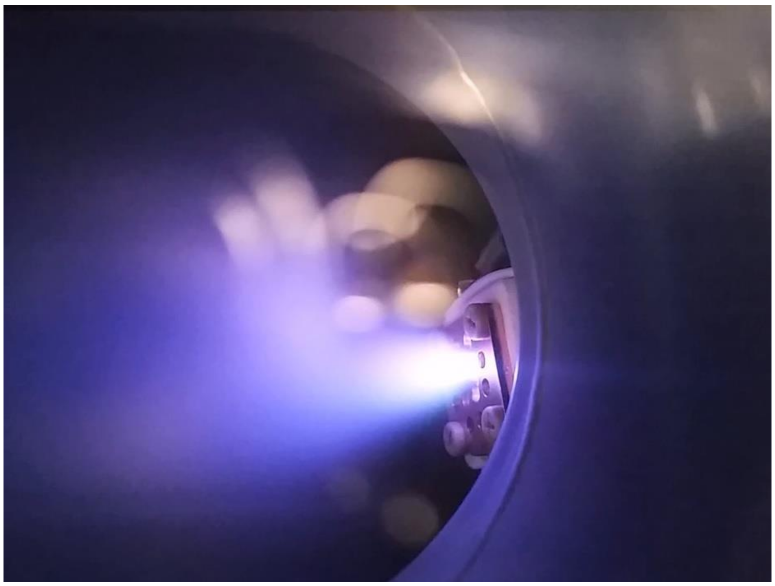
The AIS-gPPT1 thruster was mounted to the conflat feedthrough adapter utilizing a combination of Teflon clamps and a stainless-steel hose clamp. Connections to the high voltage feedthroughs were made with set screw clamps at the feedthrough end, and soldered connections to the thruster test connections at the other. Kapton tape was used to insulate all exposed wire in the vacuum chamber. 18 AWG bare copper wire was used for the cathode, igniter, and anode connections.



Testing was performed in the Micro Propulsion Testing Chamber using the Integrated High Vacuum Test Stand. Pumpdown conditioning of the system was achieved from atmosphere due to breaking vacuum of the chamber to mount the thruster. Ignition testing vacuum levels were first verified at 1 x 10^-5 Torr maximum before attempting ignition. Both the main high voltage charging supply and the thyratron trigger pulser supplies were started at 0V, and slowly raised. The ignition pulser was raised to levels until an excess of 5kV was achieved, where breakdown was observed behind the thruster. Pulser voltage was reduced, and main bank voltage was raised to 2kV. Ignition voltage was then raised, however continued breakdown behind the thruster in the connection area was observed at the ignition repetition rate of 1Hz. Repetition rate was reduced to 0.5Hz for safety. Several main discharges occurred behind the thruster, however the bulk of breakdowns was due to the ignition pulse.

During the failed ignitions, it was observed that external arcing was occurring between the 8020 test stand table and the cooling system thermocouple wire metal shielding. The wires were subsequently isolated from the table, however other arcing issues continued to occur. External arcing was observed between the connection pins on the conflat feedthrough on the atmosphere side, as well as the pins to the feedthrough casing. Pumpdown data was saved prior to ignition testing, however external arc faults caused the Arduino Mega to crash and lose subsequent data. Upon restarting the MegunoLink monitoring system, it was observed that communication to the Arduino, HPT-100 high vacuum gauge, and thermocouple conditioning board was lost. For the duration of the test after data loss, cooling levels and vacuum levels were unknown – however, it is highly likely that the system was operating at nominal conditions prior to the monitoring system crash.

It was determined that the chamber, which was previously assumed to be isolated, was in fact connected through ground at a single point through the HPT-100 connection. As a result, arcing that occurred from the high voltage supplies to the chamber travelled through the gauge and into the table, shielding wires, and monitoring system circuitry. Upon disconnecting the HPT-100 cable, external arcing around the table, as well as the chamber itself ceased. There was also visual confirmation of 4 successful, individual ignitions and firings of the thruster. However, these events were random, and not conducive to successful repeatable ignition of the thruster. It was shown that the thruster could be fired, however ignition in the current design has been deemed unreliable. One of these ignition events were captured on camera, discovered the following day after sifting through testing data and failure analysis of the system.



III. FAILURE ANALYSIS

Several key failures were identified during and after the Phase I ignition test. During the test, as ignition voltage was increased, the ignition pulse could eventually be observed flashing at the set repetition rate of the function generator, corresponding with the timed firing of the thyratron ignition pulser, behind the thruster. At several instances, when main bank voltage was at its peak, a plasma ignition occurred in this area as well. Upon disassembly and inspection of the system after testing, it was discovered that all arcing faults occurred at exposed edges of Kapton tape insulating the bare copper connection wire. This occurred in two major areas: at the high voltage feedthroughs at the base of the conflat feedthrough (*Figure 1*), and between the wires along the thruster holder, which are set and spaced with a Teflon wire holder (*Figure 2*). Yellowish discoloration around the Teflon and stainless steel thruster mounts also show that Kapton ignition had occurred during the main bank discharges. This can be seen clearly in *Figure 3*, on the underside of the Teflon thruster mount.

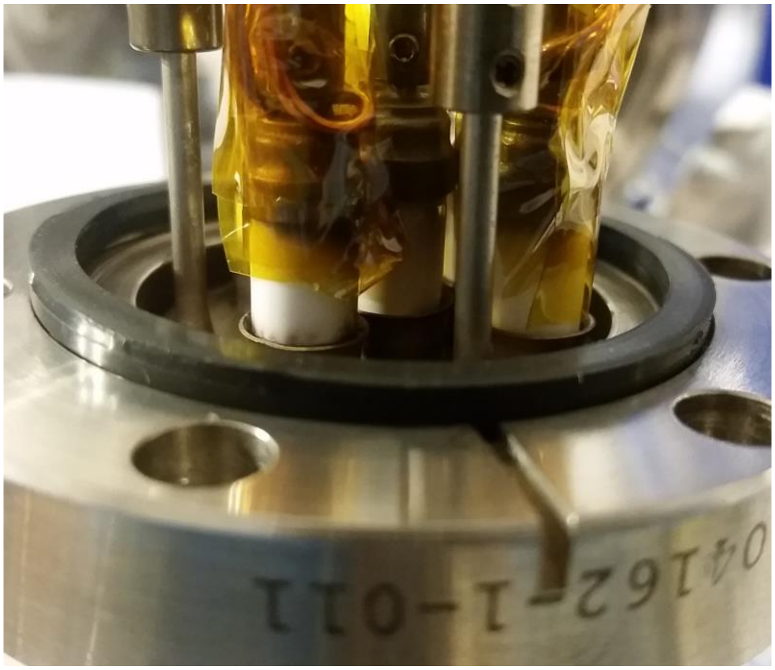


FIGURE 1 – Arcing around ceramic insulators at the base of the conflat feedthrough.

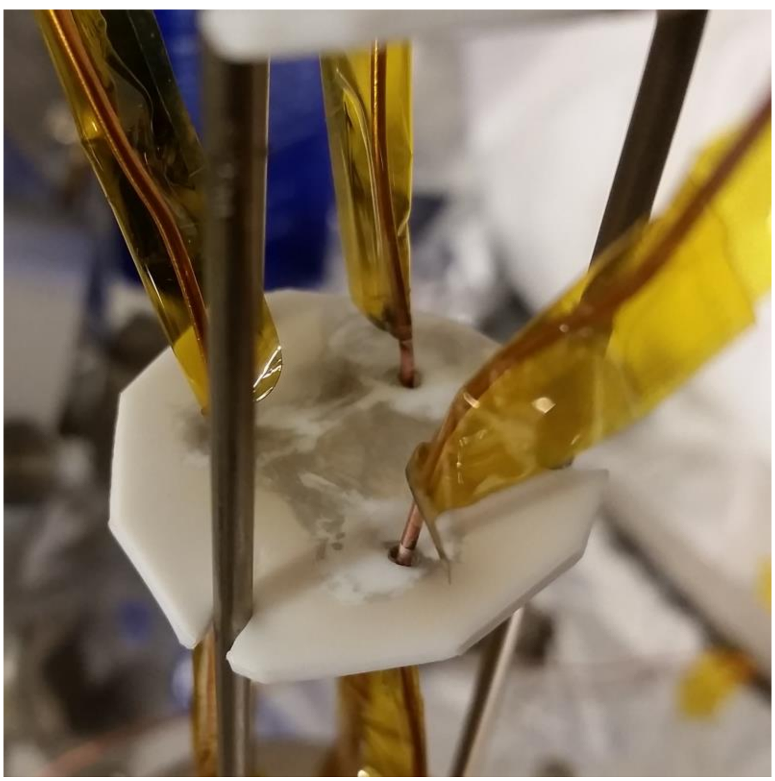


FIGURE 2 – Arcing at the wires around the upper Teflon wire spacer.

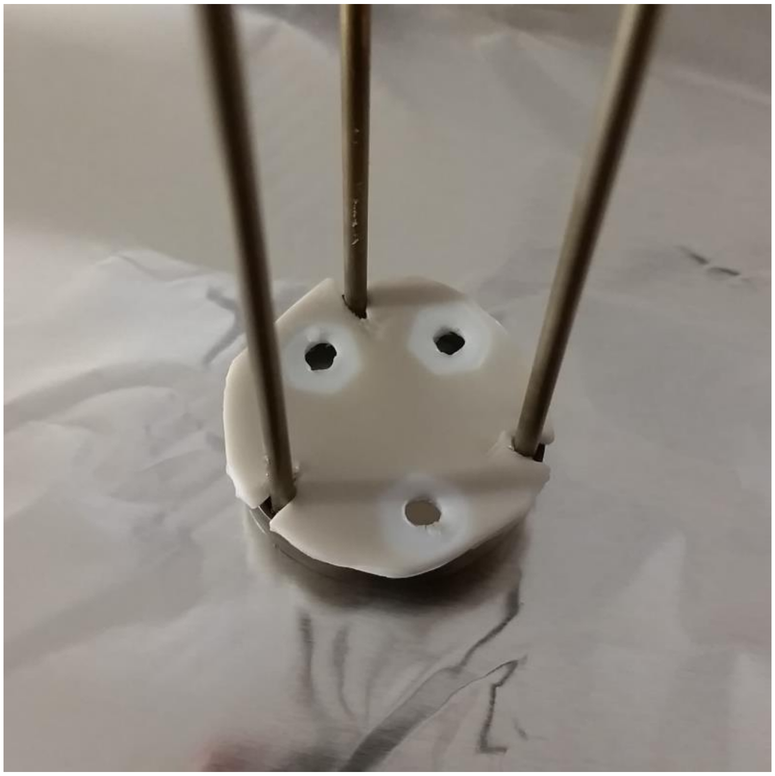


FIGURE 3 – Ablation residue from Kapton ignitions.

In the prior ignition test performed two days before with the AIS-uPPT1 Micro Pulsed Plasma Thruster, an identical setup was used, except that no Kapton tape was present along the connection wires in the chamber. It is therefore believed that the adhesive from the Kapton tape caused the arcing and flashovers at these locations. This is potentially due to higher outgassing of volatiles of the possibly lower quality generic Kapton tape.

The primary underlying cause of ignition failure ultimately results from the inherent design of the thruster. Although the ignition electrode to cathode spacing is around 0.0625, and much closer than the copper connection wires, arcing still occurred in the wrong location, and failed to reliably ignite the thruster. It is suspected that the spacing between the electrodes, as well as the highly polished surface and overall flat profile of the ignition pins contributed to failure to establish repeatable vacuum arcs inside the thruster assembly.

Finally, there were severe consequences and equipment failures as a result of the external arcing. Improper grounding of the vacuum chamber forced any arcs from the high voltage supplies to the vacuum chamber through the only ground point – the HPT-100 gauge, which was connected to the rest of the instrumentation electronics. As a result, the HPT-100 gauge was destroyed, as well as the Arduino Mega, DHT22 ambient temperature/humidity sensor, 24VDC power supply powering the HPT-100 gauge, UART to RS485 adapter, and three out of six thermocouple channels (channels 4, 5, and 6). This has caused significant testing setbacks and delays. Replacement of the HPT-100 gauge is also very costly, and imposes a very high and unanticipated financial burden on these testing efforts.

IV. FUTURE RECOMMENDATIONS

Based on observations during testing, as well as post-testing analysis, several major recommendations are presented going forward for the next generation of thrusters in the AIS-gPPT line. The primary underlying cause of reliable ignition failure of the thruster was the inherent design of the thruster itself. Due to the relatively ow voltages of only a few kV, coupled with high vacuum conditions, vacuum arc formation is very challenging under normal conditions with no source of gas load. Highly polished surfaces also make vacuum arc formation more challenging at high vacuum. While the highly polished surface, smooth edges, and large overall surface area would greatly improve erosion uniformity and electrode lifetime, ignition arc initiation becomes a greater challenge. It is therefore recommended to significantly reduce the gap between the ignition electrode and the cathode electrode. Using a slightly tapered ignition pin geometry to cause greater field enhancement, as well as slightly roughing the surface of the ignition pins may also help initiate proper ignition discharges.

The primary cause of internal arcing failures was determined to be the direct result of the Kapton tape adhesive. Arcing faults occurred consistently at exposed ends of the tape at the conductors, which was not present in prior ignition testing. It is recommended to refrain from using any Kapton tape for insulating any high voltage or pulsed connection wires in the vacuum chamber. Instead, if insulation is desired, Teflon or ceramic tubing should be used along the entire length of the wire. UHV compatible wire such as Kapton or Teflon insulated wire can also be substituted. Care must be taken to avoid any sharp connection points, or exposed conductors, keeping wires at a maximum distance as feasibly possible.

In addition, due to the space constraints of the relatively small testing chamber, it is recommended to reduce connection wire lengths as much as possible. Efforts are already underway to significantly redesign the thruster holder and connection assembly, which will call for the replacement of the current adapter to a more direct adapter to mount the high voltage conflat feedthrough to the chamber, therefore allowing wire lengths to be significantly reduced.

Finally, the major cause of electronics and equipment failures was due to improper grounding of the supplies and chamber. The chamber should not be floating or assumed floating, and must be well grounded, with direct paths back to the thyratron pulser and high voltage charging grounds. The HPT-100 gauge can also be completely isolated from the chamber using a high vacuum ceramic break. While this option is costly, it provides guaranteed isolation of the grounded gauge from any arc faults or transients travelling through it from the chamber walls, and destroying the gauge or other system instrumentation connected to instrumentation ground.