Applied Ion Systems

AIS-TR-016

AIS-EPPT1 Micro Pulsed Plasma Thruster V1

Ignition Test 1 - 09/13/2020

Testing Report and Summary

Michael Bretti – 10/26/2020

I. TEST PARAMETERS

- **System:** AIS-EPPT1 Micro Pulsed Plasma Thruster
- **Fuel:** Teflon
- **Maximum Chamber Pressure During Testing:** 1.5 x 10^-5 Torr
- **Testing Status:** COMPLETE
    - **Phase I:** Fueling – NOT REQUIRED
    - **Phase II:** Ignition – PARTIAL SUCCESS

II. OVERVIEW

This test represents the first ignition test of the new AIS-EPPT1 micro pulsed plasma thruster for Cubesats and PocketQubes.

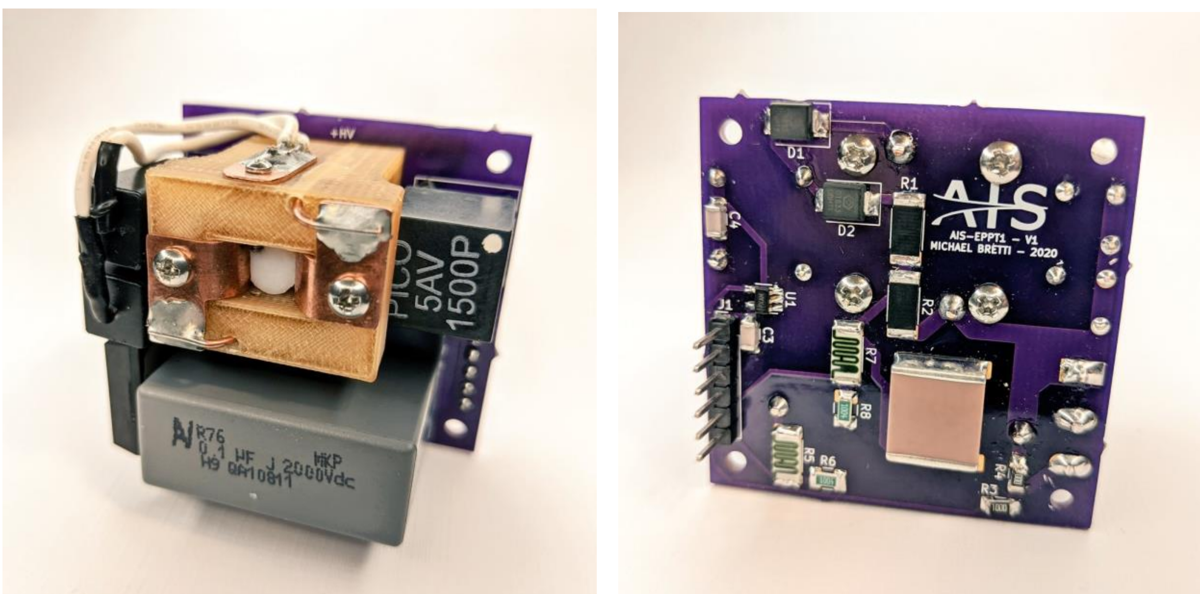

FIGURE 1: *Completed AIS-EPPT1 V1 thruster assembly.*

This system takes lessons learned from the original AIS-gPPT3-1C Integrated Propulsion Module and further expands its capabilities with massively increased fuel capacity, as well as aims for improved ignition, performance, and ultimately lower cost and simpler manufacturing. The thruster heavily utilizes 3D printing for the custom housing to provide integration with all mechanical and electrical components into a compact form factor, reducing size of the system.

Several new enhancements to the EPPT1 over the older gPPT series includes spring fed Teflon fuel, diverging rail electrodes, dual ignition transformers, higher-power trigger thyristor, higher power and more efficient Pico Electronics HV supply, 3D printed housing, and polypropylene film capacitor for the main pulse cap.

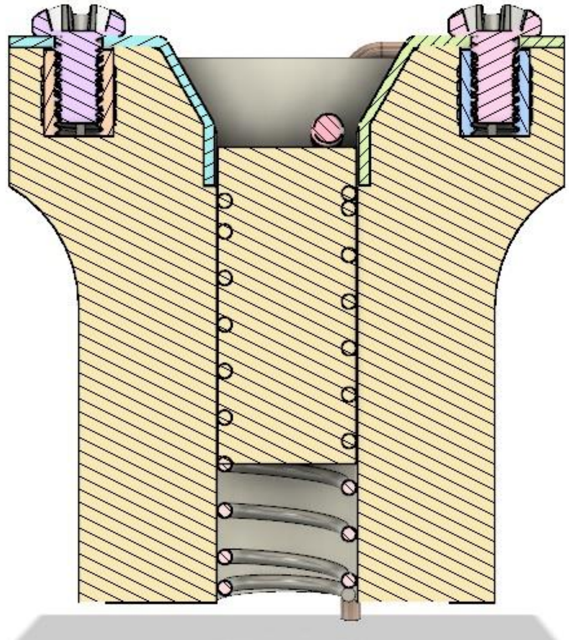

FIGURE 2: *EPPT1 thruster housing cross-section, showing spring fed Teflon fuel, anode/cathode rails, and the igniter pin.*

The entire thruster fits within a 45x45x25mm form factor, with the ability to be easily expanded to include much more Teflon fuel, and larger pulse capacitors for higher stored energy operation at reduced repetition rates. The same commands are used with the EPPT1 as the old gPPT3, with improved bank readouts at 1V/kV division.

III. IGNITION TEST SETUP

After final assembly and cleaning of the thruster, for simplicity the thruster was mounted to a flat PEEK baseplate loaded into the chamber to keep the thruster oriented properly during testing, as well as insulated away from the conductive metal vacuum chamber walls. Teflon coated wire was used to secure the thruster to the baseplate, tied through the corner mounting holes on the thruster board and wrapped around the baseplate. The thruster was then loaded into the chamber, positioned in clear view of the 6” conflat viewport, and wired for power, enable, and trigger pulse control. An external adjustable DC power supply and function generator was used to provide power and trigger control to the thruster.

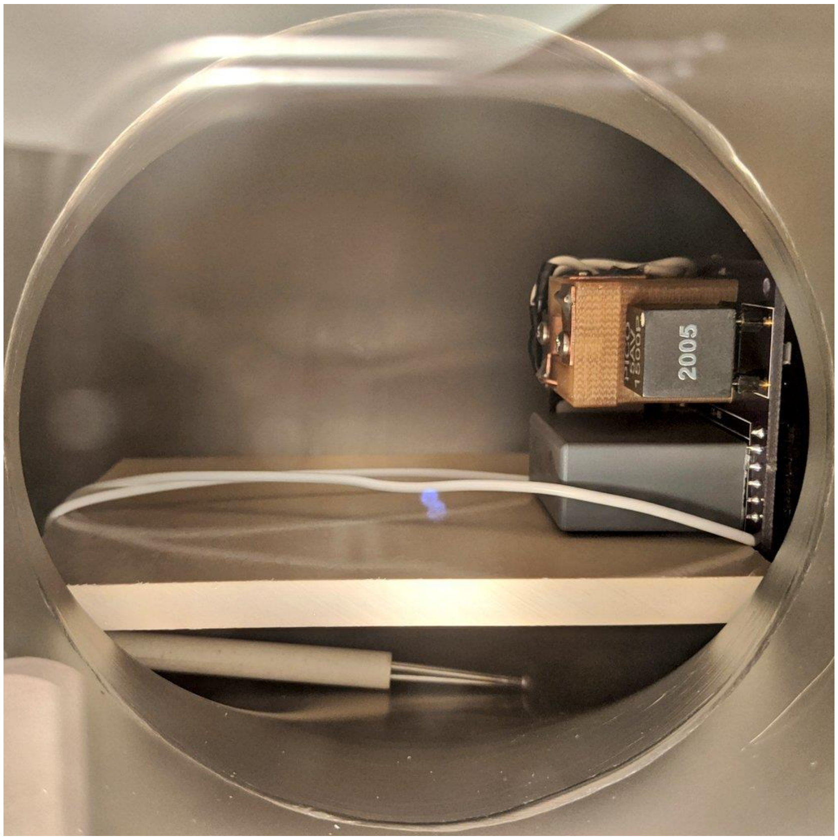

FIGURE 3: *EPPT1 mounted on the PEEK baseplate inside the vacuum chamber, tied down to the baseplate with Teflon coated wires.*

IV. TEST PHASE II – IGNITION

The chamber was evacuated to a pressure of 1.5x10^-5 Torr before starting up the thruster. Thruster power was turned on, and slowly raised to half voltage to start. Triggering was turned on and brought up to full signal voltage. During the initial start-up, the thruster proved difficult to successfully fire. Indications of potential outgassing or arcing through the layers of the 3D printed housing were seen, with some arcing and flashovers around the igniter connection between the internal anode connection wire, as well as to the top of the board. Thruster voltage was raised to near maximum, at 1.4kV, and the repetition rate was adjusted to less than 1Hz. After a period of continued arcing and flashovers, the thruster began to pulse.

After several tens of shots, operation became sporadic. While the ignition pulse could be seen, the thruster failed to ignite reliably. Towards the end of the test, there was evidence that arcing was occurring within the layers of the housing between the igniter pin and anode connection. It was also noted on a couple of occasions that thruster voltage would suddenly drop out. Initially, it was thought a component failure had caused this. However, cycling the thruster power, operation was resumed. This would happen in particular when a successful ignition occurred at levels around 1.5kV, and for the remainder of the test, the thruster was kept at reduced voltage levels.

V. POST TEST VIDEO ANALYSIS

During the ignition test, video was captured of successful thruster operation, as well as numerous faults. Below is a captured shot of the plasma plume during successful ignition.

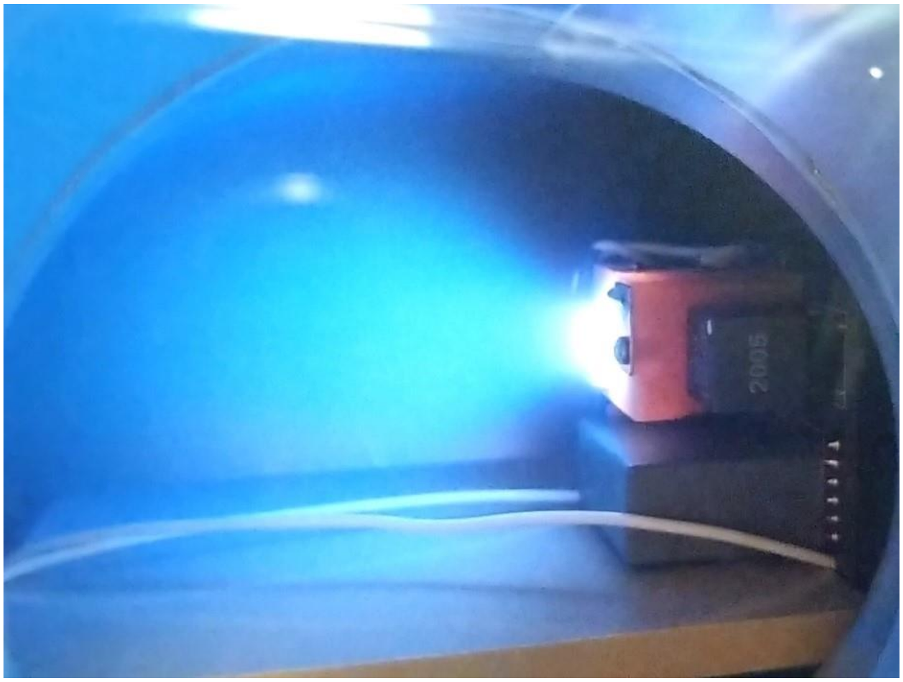

FIGURE 4: *Successful ignition and firing of the EPPT1 and resulting plasma plume.*

There are several immediate differences in this thruster output vs the prior AIS-gPPT3-1C. Although both thrusters operated at only 0.1J stored energy in the main bank, the EPPT1has a significantly larger plasma plume. Due to the larger surface area of the Teflon fuel block, as well as overall size, it is expected that thrust is significantly higher. In addition, the plume color appears blue, as opposed to pinkish-purple, indicating a higher degree of ionization of the Teflon fuel. This is most likely attributed to its configuration as a diverging rail PPT, whereas the gPPT3 operates as a coaxial PPT. Diverging rail PPTs are dominated by electromagnetic acceleration of the plasma via Lorentz force, whereas coaxial PPTs are dominated by electro-thermal acceleration, which leads to lower efficiency and ionization of the plume.

During startup of the thruster, the first fault that was noticed was a small arc that formed on the surface of the thruster, between the igniter connection and where the anode wire connection runs through the housing of the PPT. It is expected that trapped gases or outgassing lead to this initial arcing through the very thin walls, which eventually ceased after some time of pulsing.

FIGURE 5: *External arcing between the igniter connection and internal anode wire.*

Next, several surface arcs were observed along the length of where the anode wire runs through the housing to the board. This again is most likely attributed to trapped gases being ionized, arcing from the igniter and traveling along the length of the anode connection is several locations, down to the board. This external arcing also eventually stopped after some time of pulsing the system.

FIGURE 6: *External arcing between the igniter connection and along the length of the housing to the board, tracking along the internal anode wire.*

Finally, before successful thruster operation, very large and intense arcs began to occur between the igniter connection and anode rail, tracking around the surface and edge of the housing. This occurred several times during the pulsing of the system, attributed to outgassing or contamination.

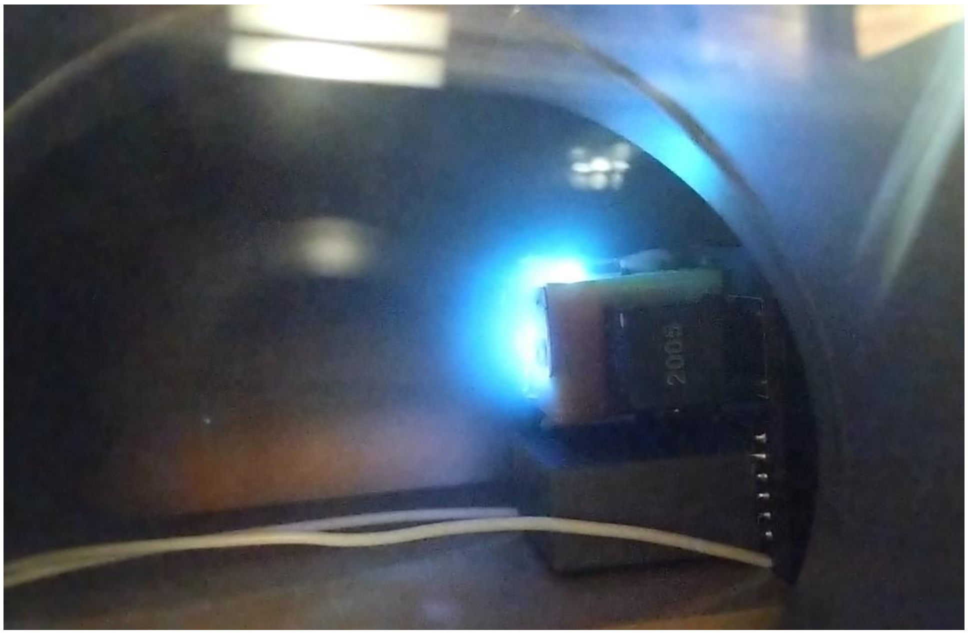

FIGURE 7: *External arc flashover between the igniter connection and anode rail along the outside of the housing.*

Towards the end of the test, as operation became more sporadic, it was observed that flashes were occurring inside the thruster housing itself, between the layers of the 3D printed plastic right under the anode rail. It is expected that the high voltage ignition pulse had broken through the layers after external arc faults and outgassing around the thruster was resolved, causing the thruster to no longer fire properly.

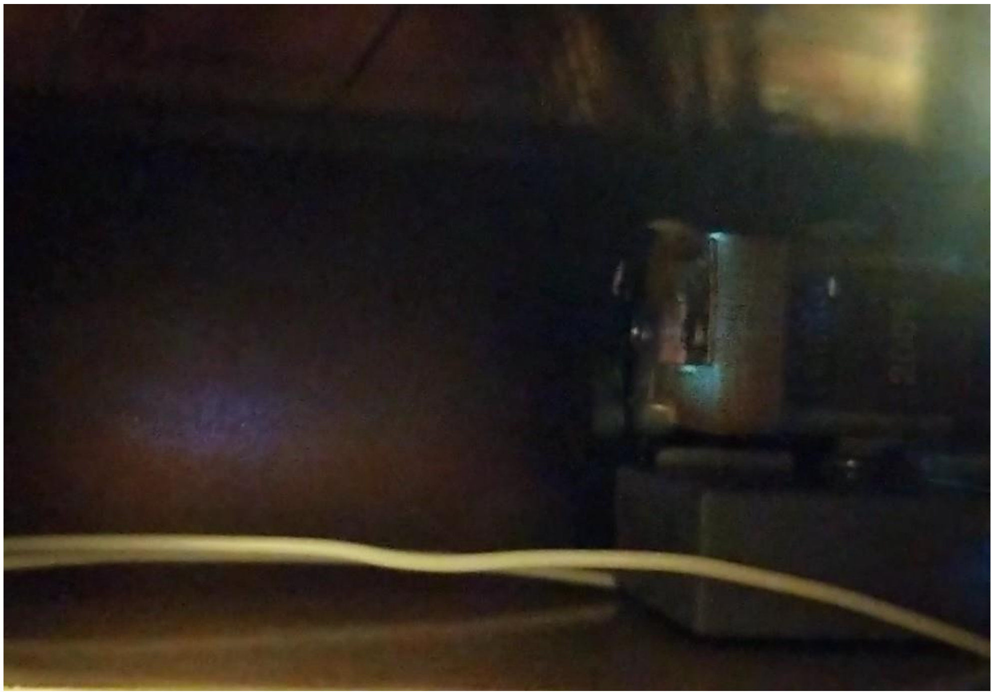

FIGURE 8: *Internal thruster arcing between the igniter connection and the anode between layers of the 3D printed housing.*

In addition, during the test a large board flash occurred during thruster operation, however no components were damaged, and the thruster continued to operate normally for the duration of the test afterwards.

FIGURE 9: *External board fault flashover.*

VI. CONCLUSION

The first ignition test of the AIS-EPPT1 micro pulsed plasma thruster has been completed. During the test, ignition was achieved for a brief period of several tens of pulses, indicating partial success of the test, and potential of the design moving forward. A summary of key takeaways from the test are as follows:

- Thruster plasma plume is significantly more intense than its predecessors at equivalent energy, with a larger and more ionized plume.
- The ignition pulse is more intense with the dual pulse transformers and larger thyristor.
- 3D printed housing presents serious challenges to be addressed in terms of outgassing, trapped gases, and failure between the print layers in pulsed applications.
- The igniter trends to arc towards the anode rather than the cathode significantly easier, despite the much larger spacing. This is most likely a result of the ignition pulse being around -10kV with the anode charged up to 1.4kV, creating a higher potential to the anode.
- The thruster does not fire reliably, which may be a combination of igniter and fuel layout, as well as anode-cathode gap being too wide.

Going forward, the biggest issue to address is the igniter electrode connection and placement, mitigating arcing issues to the anode and allowing for more reliable ignition. It may be possible to explore an unconventional use of anode-side triggering, taking advantage of the natural propensity of the igniter to arc to the anode or improved reliability. In addition, the test has revealed serious challenges with insulation of 3D printed housing in pulsed applications. Although the 3D printed Ultem 1010 has performed perfectly to date with the prior tested AIS-ILIS1 ionic liquid electrospray thruster, operating at +/-5kV in slowly alternating DC operation, the higher voltage pulses of the EPPT1 have proved problematic during operation. Redesign of the housing is required, with better attention paid to spacing and wall thickness, as well as potential insulation around the external connection of the igniter. Finally, ignition could be improved by reducing the anode-cathode spacing, which may be excessive at 0.25” at the min gap point. Once stable operation is achieved, characterization of thrust and lifetime can begin.