Applied Ion Systems

AIS-TR-021
AIS-gPPT3-1C Micro Pulsed Plasma Thruster
Lifetime Test 2 - 12/06/2020
Testing Report and Summary

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I. OVERVIEW

Last October, the testing of the first ever fully integrated AIS propulsion system, the AIS-gPPT3-1C Integrated Propulsion Module, was completed, with two subsequent units sent out for integration aboard the AMSAT-Spain GENESIS N and L PocketQubes. Despite this major success, several key issues remained with the system, namely total lifetime and ignition reliability. The biggest challenge was the main pulse caps, which would catastrophically fail after only around 1300 shots, far before the fuel was even close to being depleted. Ignition reliability was also only around 85%, and was limited to 0.3Hz. Over the course of the past year, several attempts were made to improve performance with other thruster developments, including the AIS-EPPT1 and recent testing of the hybrid gPPT3/EPPT1 prototype system. However, these developments have not materialized into more reliable, improved systems over the original AIS-gPPT3-1C.

Despite the challenges and limitations, there has been continued interest in the AIS-gPPT3-1C as an ultra-low cost test and demo propulsion unit, for both orbital flights as well as ground testing. Although the system has significantly constrained lifetime capacity, it has nevertheless successfully passed TVAC, vibration, and satellite integration, and will soon have flight heritage. While it is not ideal for main propulsion, it is extraordinarily compact, low power, easy to use, and low cost, making it ideal as a demo thruster system.

As such, the decision has been made to revive the AIS-gPPT3-1C and provide it as a very low cost entry-level demo propulsion module to allow any team or lab access to micro-PPT technology to begin exploring its use for onboard thruster control and experimental testing. This report provides an overview of the recently completed second lifetime test of the AIS-gPPT3-1C in preparation of revival of the system development.

II. LIFETIME TEST ATTEMPT 1

Since the recent testing completed last October, the original AIS-gPPT3-1C propulsion module has been inactive. For this new lifetime test, the original V3 design was repaired for testing. Major components including the main pulse capacitor bank, thyristor, and load switch were replaced. The gPPT3 thruster head was also loaded with new Teflon insulator and fuel plates, and the electrodes cleaned of carbon charring and deposits from prior testing. In addition, the permanent magnet nozzle embedded in the anode plate was also removed. The thruster was loaded up into the vacuum chamber, and pumped down to a pressure of 1x10^-5 Torr before attempting ignition.

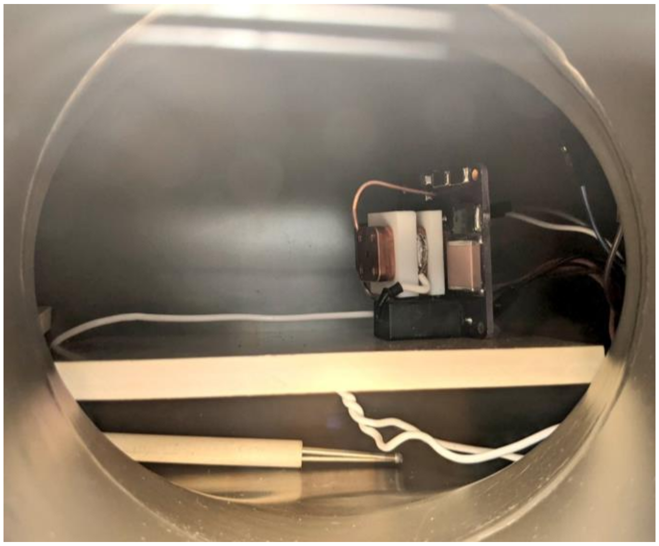

Figure 1: *AIS-gPPT3-1C thruster mounted in high vacuum chamber for first lifetime test attempt*

The thruster was started at a voltage of 3.3V in, at a low repetition rate of 0.2Hz. While all the thruster readouts indicated proper functioning of the power supply, no pulses were observed. Voltage was slowly increased to the nominal max input of 5V, where no further ignition occurred. After about 10 minutes, voltage was increased to 5.5V, where the thruster began to fire. After more reliable ignition was achieved, the thruster input voltage was turned back down to 5V. Despite initial pulsing, thruster operation was unreliable, with difficulty triggering on command. In an effort to make ignition easier, it was decided to remove the gPPT3 thruster head and modify it. The 3/16" thick Teflon fuel block, which includes a 1/16" diameter fuel bore, was replaced with a thinner 1/8" thick fuel plate with the same fuel bore diameter, effectively bringing the anode-cathode gap spacing closer.

 

Figure 2 and 3: *Modified 1/8" thick Teflon fuel plate*

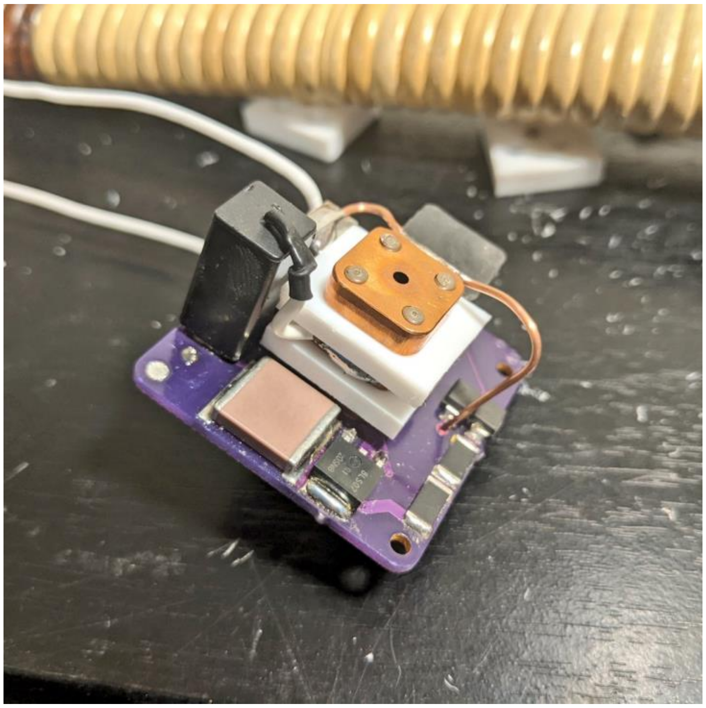

Figure 4: *Modified AIS-gPPT3-1C*

III. LIFETIME TEST ATTEMPT 2

After the thruster head was modified, the thruster was mounted back into the vacuum chamber, and pumped back down to nominal testing levels before operating the thruster again for the second attempt at the lifetime test.

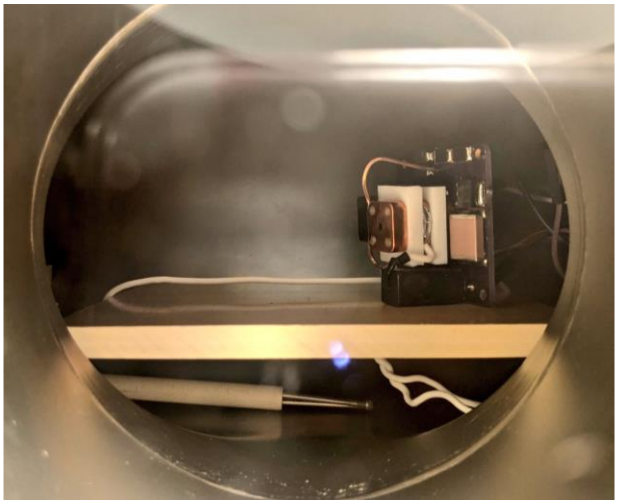

Figure 5: *AIS-gPPT3-1C thruster mounted in high vacuum chamber for second lifetime test attempt*

Starting at 3.3V in and a repetition rate of 0.2Hz, the thruster began firing. Startup was noticeably easier with the reduced anode-cathode spacing, however the thruster still suffered from significant misfires. The repetition rate was then increased slightly to 0.25Hz. At 3.3V in, the system draws a peak of 0.231W during the peak of the charging cycle. Shot energy is around 0.11J, operating at around 1300V on the main bank. At 0.25Hz, this translates to a thrust of about 0.16uN, determined from prior testing of the system.

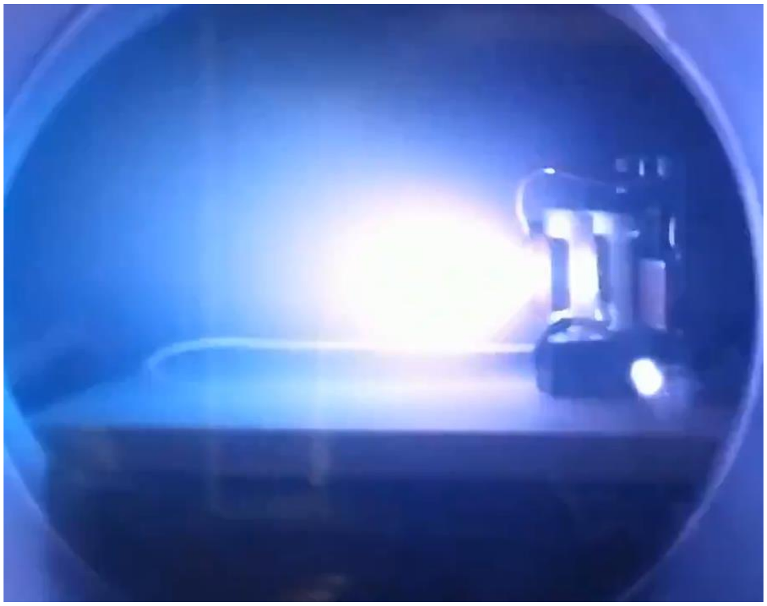

Figure 6: *Plasma plume during successful thruster ignition*

During operation of the thruster, the resulting pulse waveform was captured on the oscilloscope via induced EMF on the Faraday cup located in the chamber. During prior testing, it was found that the induced EMF was a reasonable indicator of pulse shape, both during successful ignition as well as misfires. In this case, the pulse appears as a sharp spike, with a slowly decaying tail. This differs from testing with the magnetic nozzle and standard fuel, resulting in a distinct double-peak waveform, and without the nozzle but standard fuel, resulting in a bipolar pulse.

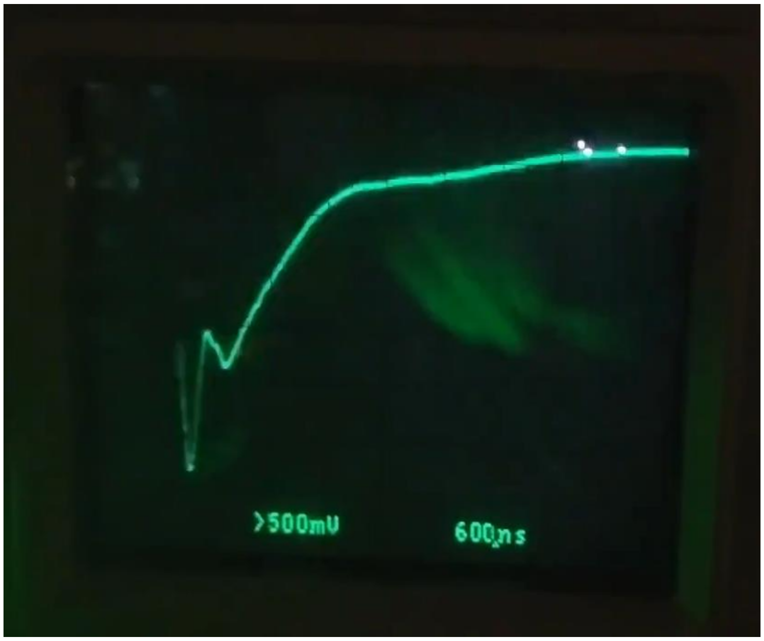

Figure 7: *Captured pulse waveform during successful thruster ignition*

Manually timing and counting pulses and misfires, for one minute intervals over a couple of minutes, the thruster averaged around 12 shots per minute right, varying widely anywhere from a 8% to 50% misfire rate. As a result, the input voltage was increased to 3.6V, which allowed for a very consistent misfire rate of around 20% for the one minute timed intervals at 12 shots per minute.

The thruster was run at 3.6V in at 0.25Hz for a total of three hours straight before catastrophic failure of the main pulse capacitor bank occurred, as in prior testing with the system. Final vacuum pressures at the end of the test were at 4x10^-7 Torr.

Based on average best and worst case scenarios observed for the misfire rate, it is reasonable to estimate a total lifetime of around 1400 shots, which is around where the thruster failed during the first lifetime test.

IV. CONCLUSION AND FUTURE DEVELOPMENTS

The AIS-gPPT3-1C micro pulsed plasma thruster has completed its second lifetime test. During this lifetime test, thruster lifetime was again confirmed to around 1400 shots, limited by failure of the main bank MLCC ceramic pulse capacitor. Like in prior testing, it was found that increased input voltage helps improve ignition reliability, however at the cost of lifetime. As a result, the recommended 4V in from prior tests will be implemented for the current update, balancing reliability and lifetime.

During the test, modifications were required to provide more reliable operation. Going forward, the gPPT3 thruster head will be built with a 1/8” thick fuel plate. The permanent magnet nozzle will also be removed, as it does not appear to improve performance. The anode plate will be redesigned without the magnet groove, and will be made thinner to reduce wall losses from the plasma. Other changes will include adjusting the cathode pin height to be closer to the Teflon fuel bore, as well as roughing the surfaces of the cathode pin and igniter bore to increase the probability of breakdown over a smooth polished surface.

While the AIS-gPPT3-1C exhibits limited performance, it provides a very simple, low-cost, low-power, compact, entry-level unit for exploring the use and integration of micro-pulsed plasma thruster technology for educational, research, and start-up applications. Further details about the thruster, as well as open-source hardware files for the thruster system, can be found on the Applied Ion Systems website (https://appliedionsystems.com/).