Applied Ion Systems

AIS-TR-013

AIS-ILIS1 Ionic Liquid Ion Source Electrospray Thruster V6

Ignition Test 4 - 08/17/2020

Testing Report and Summary

Michael Bretti – 08/31/2020

I. TEST PARAMETERS

- **System:** AIS-ILIS1 Ionic Liquid Ion Source Electrospray Thruster V6
- **Fuel:** EMI-BF4
- **Maximum Chamber Pressure During Testing:** 2 x 10^-5 Torr
- **Testing Status:** COMPLETE
  - **Phase I:** Fueling – NOT REQUIRED
  - **Phase II:** Ignition – PARTIAL SUCCESS

II. OVERVIEW

This test is the fourth ignition test of the AIS-ILIS1 ionic liquid ion source electrospray thruster for nanosatellites. This thruster is one of many open-source, ultra-low cost, advanced electric propulsion systems in development at AIS, and is currently the most advanced thruster build at AIS to date.

FIGURE 1: *Completed AIS-ILIS1 V6 thruster assembly*

The AIS-ILIS1 aims to solve issues of ion thruster scaling and accessibility for nanosatellites, at significant cost reduction to currently available micro-ion thrusters on the market, as well as being the first ever PocketQube class compatible ion thruster, in size, power requirements, and fueling restrictions. The ILIS1 represents a new and fundamental shift in micro-ion thruster technology development, allowing for performance ion thrusters to be available for any nanosatellite team, serving a wide range of uses from main propulsion for station keeping, orbital transfers, collision avoidance, formation flying, and deorbiting, to secondary propulsion for fine attitude control.

The following report details the ignition test of the ILIS1 using the new V6 thruster board and standard 1mm aperture slit extractor, as well as analysis, results, and conclusions moving forward for future testing and system improvements.

III. PRELIMINARY THRUSTER MODIFICATIONS

During the prior test, while evidence of multi-site emission was observed in post-test video analysis, the tolerances of the 0.5 mm wide aperture extractor slit with flared edges resulted in too tight spacing for manual alignment, causing immediate shorting and failure of the thruster upon turn-on. As a result, it was decided to evaluate the operation of the new V6 electronics board with a very wide slit to prevent rapid failure. The original 1 mm wide standard slit, which was used during the first ignition test of the ILIS1, was selected. However, during the first test, the emitter-extractor spacing was found to be too high at 0.5 mm. This current test utilizes the most recently modified and adjusted housing, setting the extractor-emitter spacing to 0 mm. Taking lessons learned from the prior test setup, the original extractor was post-processed by polishing the slit edges, as well as top and bottom surfaces of the extractor plate with 3000 grit sandpaper.

IV. TEST PHASE I – FUELING AND BAKEOUT

Since only the extractor was changed between the prior test and this test, and the thruster being held in vacuum until the extractor swap, fueling and bakeout was not necessary to prepare for this current test.

V. IGNITION TEST SETUP

After the new extractor plate was polished and cleaned, the ILIS1 was taken out of the vacuum chamber, which was still held to roughing levels from the prior test earlier that day. Any charring or burned fuel residue on the porous glass emitter was carefully wiped away as much as possible. The thruster was re-assembled, with the emitter and extractor centered and aligned by sight. Due to the much larger aperture of 1 mm wide, alignment was significantly easier to achieve. The thruster was then mounted to the Faraday cup test stand, and the assembly was mounted into the micro propulsion testing chamber, centered in full view in the 6” conflat viewport, and wired up for thruster power and control.

VI. TEST PHASE II – IGNITION

The chamber was evacuated to a pressure of 2x10^-5 Torr before starting up the thruster. In order the better prep the thruster for long duration operation, and slowly bring it up to full power, a conditioning sequence was first employed, in which the thruster would be operated in manual monopolar mode. During this conditioning phase, thruster polarity would be set to one output continuously, and the voltage would be manually and very slowly increased, keeping the voltage set in various steps for several minutes, before switching polarities, and repeating.

The thruster controls were turned on, and the thruster set to manual monopolar mode operation starting with the +HV. Power was slowly increased over a period of several minutes. The thruster voltage was continuously increased in small increments up to 5kV, in which no visible emission was observed. Since the thruster electronics were operating stably otherwise, the oscilloscope monitor was turned on, and the Faraday cup output was connected. Across the Faraday cup output is a 100k shunt resistor to ground, giving a reading of 10uA/V. A small value capacitor was also placed in parallel with the shunt resistor to reduce high frequency AC noise. The thruster was turned off, and watching the monitor, turned on and voltage manually raised slowly again. Despite no visible ion emission from the thruster, the oscilloscope readout indicated emission was indeed occurring.

After running the thruster in manual mode and switching between both positive and negative polarities, it was decided to switch operation to automatic bipolar mode. The thruster was operated at 10 seconds per polarity, with a 2 second transition between polarities. The control program was uploaded to the controller, and again the thruster was started at low power, slowly raising the emitter voltage in steps. Positive and negative swings on the oscilloscope were observed, corresponding to the thruster polarity. At a voltage of +/-4kV, oscilloscope readouts were at +9mv and -4mV, corresponding to a measured beam current of +90nA and -40nA. The test was run for a period of about an hour, with stable emission observed at the prior indicated levels, and no arcing or shorting failures occurring during the duration of the test.

VII. POST TEST VIDEO ANALYSIS

During the test, video was recorded of both thruster operation as well as the oscilloscope readout. While emission could not be physically seen during the test, it was later discovered after analyzing the video that emission was in fact present at one corner of the emitter.

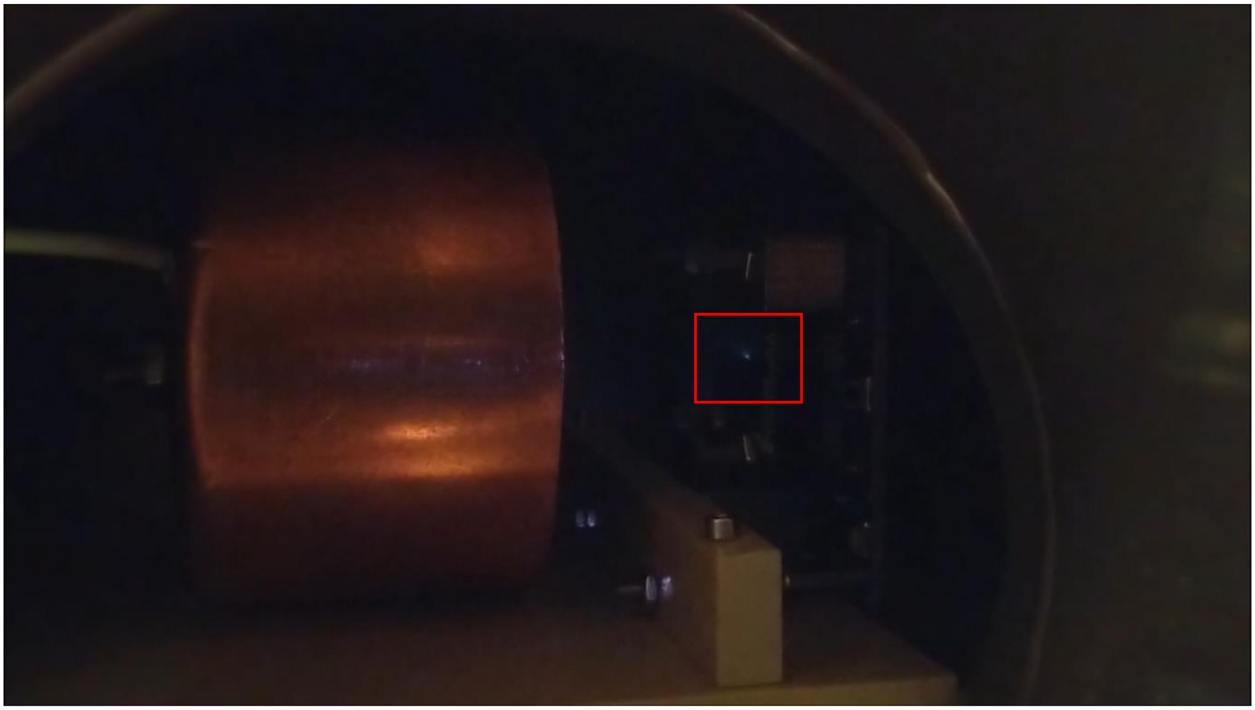

FIGURE 2: *Very faint ion beam emission captured during the test video (outlined in red)*

With the oscilloscope readout confirming beam, this is the first time the Faraday cup test stand has been used to collect and measure beam current.

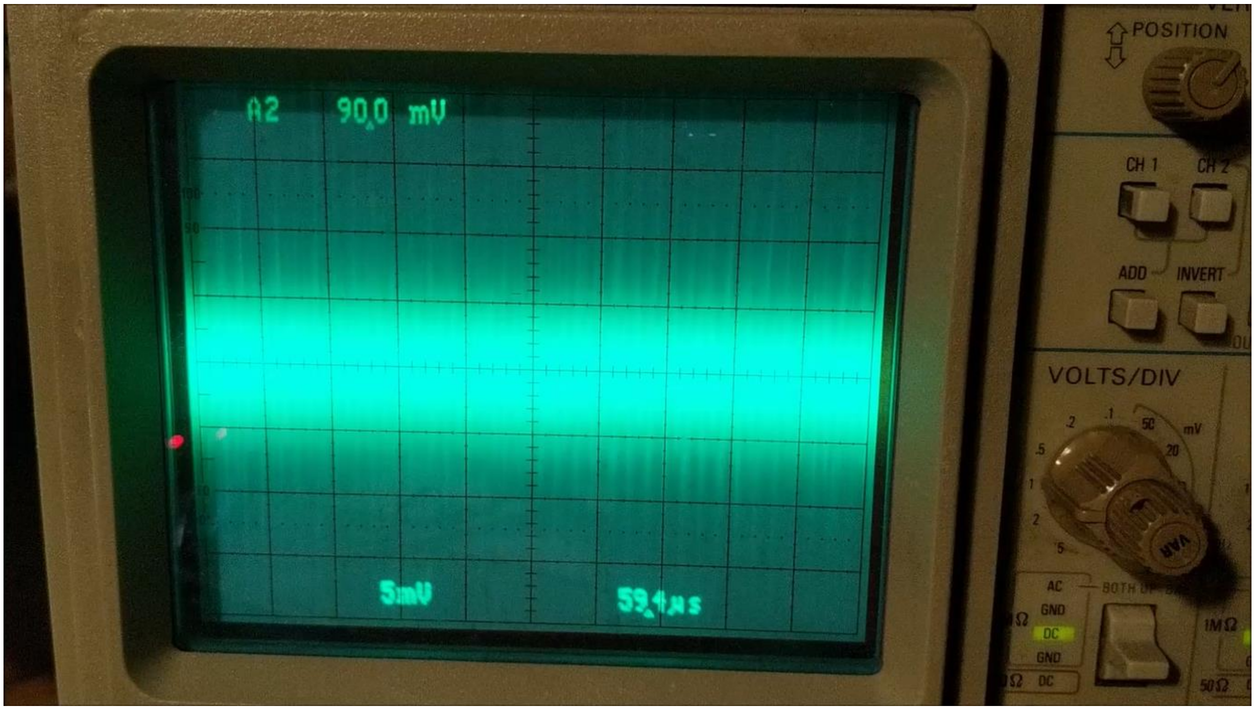

FIGURE 3: *Oscilloscope readout – 5mV/div, thruster is currently off, no beam recorded*

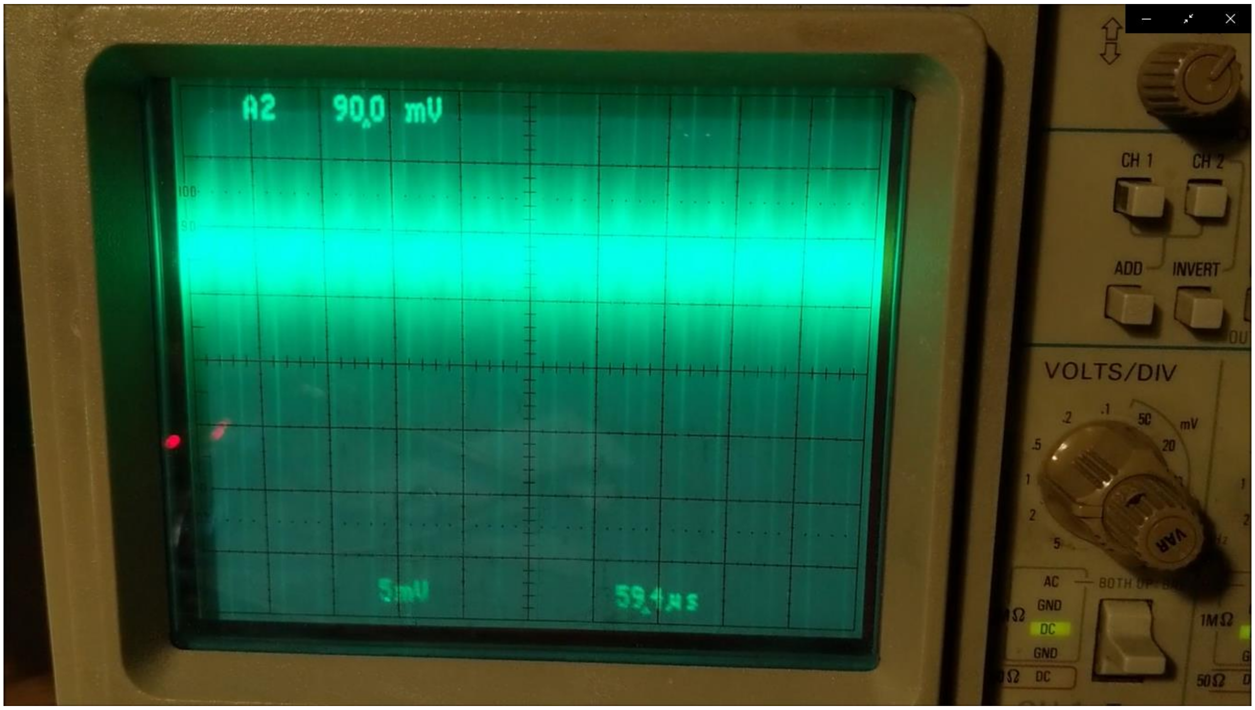

FIGURE 4: *Oscilloscope readout – 5mV/div, thruster is currently operating in +HV cycle, with corresponding beam reading*

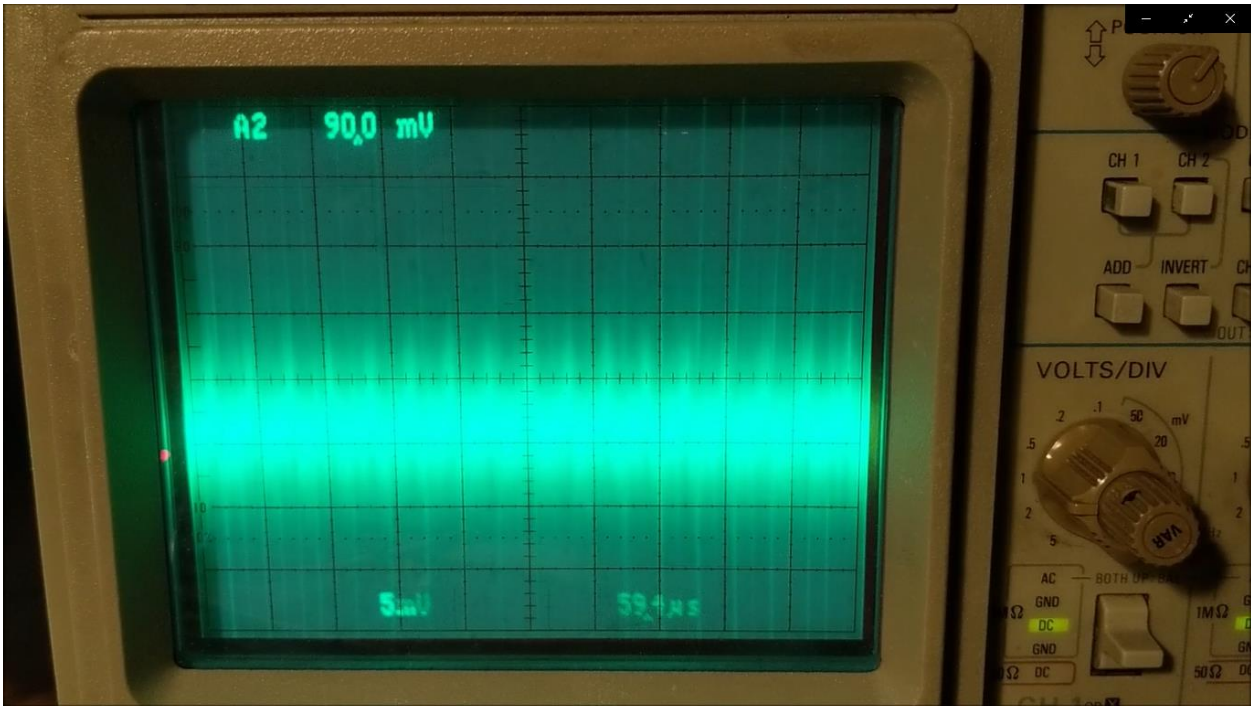

FIGURE 5: *Oscilloscope readout – 5mV/div, thruster is currently operating in -HV cycle, with corresponding beam reading*

Assuming purely ionic emission, we can calculate some rough initial performance estimates. For thrust, let's assume PIR with 50% monomers and 50% dimers. Averaging this for both monomer/dimer emission with EMI/BF4 beams, max theoretical thrust is 73nN. Taking into consideration non-ideal real-world operational losses due to thruster inefficiencies, assuming 30% for reasonable losses, this gives an average thrust of 51nN.

For ISP, assuming the same PIR mode of operation with 50% monomers and 50% dimers, at +/- 4kV this gives a max average theoretical ISP of ~7300s. However, in literature it has been shown that there is about a 50% discrepancy between measured ISP and theoretical max ISP, most likely due to polydispersive losses in the beam, which factored in gives a more realistic ISP of 3650s.

Although these numbers are very rough estimates based on operating mode assumptions, beam current readings, and emitter operating voltages, this can give a reasonable first approximation of performance currently expected from the thruster during this test.

VIII. POST TEST THRUSTER INSPECTION

Since no arcing, shorting, or any faults happened during the test, as well as the exceedingly low emission currents captured and the very short operating time, it was reasonable to assume that no damage or changes to the emitter occurred during the test, and the thruster assembly was left in the vacuum chamber while preparations were made for the next ignition test.

IX. CONCLUSION

The fourth fueling and ignition test of the AIS-ILIS1 ionic liquid ion source electrospray thruster was completed. During the test, for the first time emission current was read from the Faraday cup test stand. The thruster was successfully operated stably for around an hour at 10 seconds per polarity in automatic bipolar mode, with a 2 second transition between polarity, at 4kV with +90nA and -40nA beam currents, giving a rough corrected thrust estimate of 51nN, and a rough corrected ISP of 3650s.

Although emission was very minor and barely visible, it nevertheless marks an advance in the qualification of beamline instrumentation at AIS moving forward for micro-ion thrusters. This test also confirmed, that the 1mm wide aperture extractor is the upper limit for emission, and that a narrower aperture must be used going forward. However, with the prior test results, 0.5mm is the lower limit given the current slit emitter geometry. This test also showed again and consistently with prior tests that a standard linear extractor aperture with a ridge emitter produces undesirable emission concentration at the corner of the ridge.

Finally, the test also confirmed stable operation and control of the micro-ion thruster with the new V6 electronics, marking the first time that stable operation was achieved for an extended period of time in automatic bipolar mode. The earlier manual mode conditioning of the emitter also proved to be a very valuable tool, and helped establish preliminary thruster operation and readings.

Although successful ignition across the ridge emitter was not achieved, this test marks large advances in beamline instrumentation and ILIS electronics qualification. Summarizing the key lessons from the test,

- Faraday cup reading of beam current at 10uA/V has been successfully qualified, showing reading capabilities down to 10s of nA.
- Ion emission can occur and be detected even without visible plume formation.
- The ILIS1 can be stably operated in automatic bipolar mode for extended periods of time.
- Manual mode conditioning prior to bipolar mode operation is a valuable step in preparing the thruster for higher power output operation, as well as obtaining initial beam readings.
- 1mm width aperture for the slit extractor is the upper limit for beam for the current configuration, and narrower apertures must be used going forward.
- For this ridge emitter configuration, flared edges of the aperture slit are required to eliminate emission concentration at the emitter ends.
- If the thruster is kept at roughing levels from prior testing, additional bakeout and fueling is not required if keeping the same saturated emitter and reservoir as before.
- Charring and burning from the emitter can be carefully removed without damage to the emitter. While ion beam emission still occurs, further testing is required to see if this has detrimental effects to long term operation.

Going forward, the main improvement that can be made to increase the chances of success includes making the extractor aperture width narrower, which should ideally have the enhanced flares at the ends. Before a new extractor is designed and tested however, the next test will run the conventional linear slit extractor at 0.75mm width to achieve higher output beam and confirm stable operation with the electronics, before switching to a thinner extractor with enhanced flares.