CubeSat ion thruster characterisation using Impedans' Semion Pulsed DC retarding field energy analyser

INTRODUCTION

Nanosatellites, also called CubeSats, are increasingly being utilized not only as teaching tools and technological demonstrators but for Earth observation and scientific applications. Because of their small size, limited available power, and restricted mass budget, the current generation of CubeSats is not equipped with a means of propulsion. In cases where a conventional propulsion system is installed, it takes a significant share of the available spacecraft volume. Nevertheless, in order to further develop the use of CubeSats, propulsion is a major requirement.

Vacuum Arc Thrusters (VATs) are uniquely suited to such applications because of their simple, scalable, and robust construction. VATs do not require cathode neutralizers and use compact solid metal propellant. CubeSats are exceptionally sensitive to magnetic interference and the VATs ability to operate with little to no external magnetic field is an important advantage. However, ablative pulsed thrusters, such as VATs, are particularly prone to damage due to their high current operation and are typically limited by the number of pulses they can produce. A long duration type of VAT known as the inline screw-feeding vacuum-arc-thruster (ISF-VAT) addresses the destructive effect of the vacuum arc discharge on thruster components, namely, the electrodes and insulator.

EXPERIMENTAL SETUP:

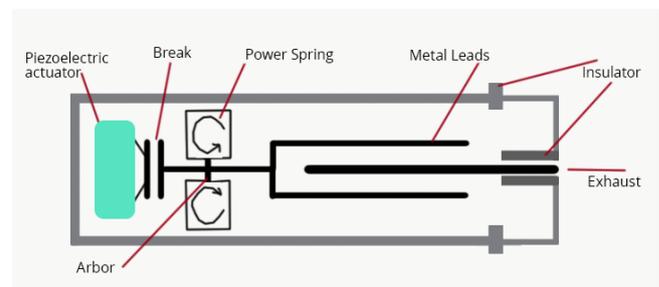The ISF-VAT concept, see figure 1, is built around a

Figure 1. Schematic of the SPL plasma generator.

central cathode rod that is within a concentric insulator tube. A second electrode, positioned at the outer edge of the insulator, functions both as the anode of the dc circuit and as the exit plane of the thruster. The cathode is connected to a metallic headless screw, which allows the cathode to be advanced at a precise rate inside the insulator, in a helical motion, which compensates from both the radial and azimuthal cathode erosion patterns allowing for constant thruster geometry throughout the lifetime of the thruster.

The thruster plume was characterized using a commercial retarding field enery analyser (RFEA) (Semion, Impedans) using a single sensor. The measurements are performed sweeping the RFEA around the thruster exit in an arc, at a distance of 150 mm in the plane of the thruster. The RFEA electronics signal sample duration is 1 µs.

RESULTS:

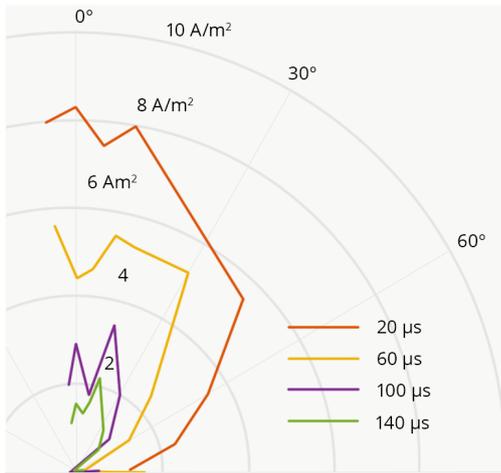The data was accumulated over thousands of pulses. An individual pulse was generated for each

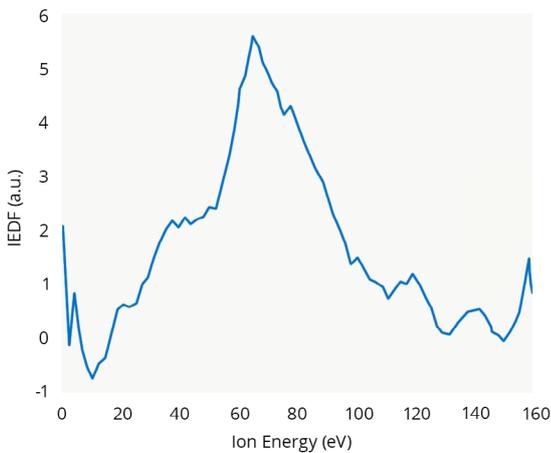Figure 2. Ion current Density vs Azimuthal angle. The thruster is pointed along the 0° radial co-ordinate.

Figure 3. Average IEDF measures at 20 µs delay with the thruster pointed in the 0° direction.

measurenemt (angular position, RFEA grid voltage, delay time). The measurements were performed at azimuthal angles of [90°, 15°] in 15° increments and between 15°, -5°] in 5° increments with 0° representing the thruster axis direction. The grid voltage was swept from 0 to 80 V in 1 V increments. The spatial distributions of the ion flux for different delay times are shown in figure 2 with the shorter delay times showing an increased ion flux.

Figure 3 shows an example IEDF measurement result with corrected grid voltages. The peak in the ion population corresponds to (E_{ion}) = 65 eV. Using this average energy, in conjunction with the ion mass (M_i = 7.95 × 10^{-26}) the average ion velocity is calculated as $v_i = \sqrt{(2E_{ion})} / M_i$) ≈ 16 km/s.

A comparison of the normalised measured total ion current and discharge current change over time is shown in figure 4. The two curves have very similar
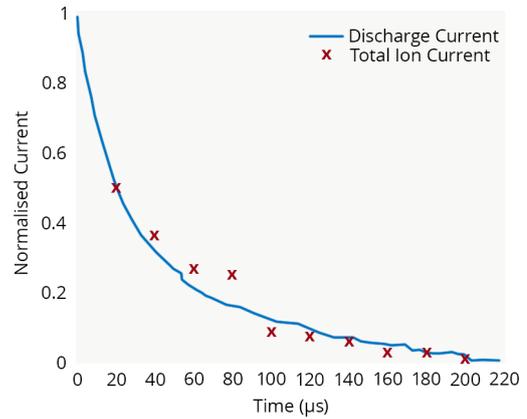

Figure 4. Normalised total ion and discharge currents vs time.

decay rates permitting the calculation of the ion fraction of the discharge current as decay rates permitting the calculation of the ion fraction of the discharge current as $f_i = I_{ion}$ (t) / I_d (t). At t_p = 20 µs the absolute measured values of I_d (t_p) and I_{ion} (t_p) are 11.5 A and 0.57 A respectively, giving f_i = 0.05. The half-angle plume divergence is θ ≈ 37° and the Impulse produced per firing is:

$$I_p = \int_0^{t_p} T_{ion}(t)dt = \dot{m}_{ion}v_i Cos(\theta) = \approx 1.77 \text{ mN}.$$

With a firing rate of 30Hz an average thrust of 4.3 µN is obtained. During the test run, 700,000 firing pulses (N_p) were produced generating a total impulse of $I_{tot} = N_p I_p$ ≈ 0.1 Ns. The total mass loss of the cathode rod was Δm = 12 mg leading to the thruster specific impulse of $I_{sp} = I_{tot} / $ Δm g_0 ≈ 850 s.

CONCLUSION

An ISF-VAT was operated continuously for 12 hrs with the main thruster parameters characterised using the RFEA measurements of the plume. The RFEA measurements show good agreement with the thruster parameters I_{sp} ≈ 850 s, and thrust to power ratio of ≈ 3 µN/W.

REFERENCES

*Kronhaus, I. et al, "Lifetime Characterisation of the Inline-Screw-Feeding Vacuum-Arc-Thruster"

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