Initial Experiment Results of External Discharge Plasma Thruster

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ABSTRACT External Discharge Plasma Thruster (XPT) is a proof-of-concept prototype of erosion free low power Hall thruster. Previously, we investigated the viability of XPT through fully kinetic numerical simulations. In this study, we present the first experimental results of the I-V characteristics and thrust measurement. The thrust and the anode specific impulse ranged from 0.83 to 17 mN, and from 178 to 1212 sec respectively at anode potentials of 100-150-200 V with anode mass flow rates of 0.48-0.95-1.43 mg/s. The anode efficiency ranged from 7.5 to 32.4 % at discharge powers from 16 to 310 W. It was found that XPT has similar discharge characteristics with SPT and TAL, and its performance is comparable at the same power levels. Significantly, stable operation was obtained over wide range of operational conditions.

1. Introduction

Small satellite market is large, and growing due to low cost and short development time. Hall thrusters are potential candidates for propulsion requirements of the smallsats as they have extensive space flight heritage (Flown since 1970s) [1], simple structure (e.g. single cathode), reliable/ robust operation, and high thrust density/efficiency. However, low power Hall thrusters (up to 500 W, and 7 cm dia.) suffer from rapid discharge channel wall erosion, and thus short lifetime (< 5 kh), and low efficiency (< 45 %) [2,3] because of enhanced plasma-wall interactions caused by large surface area to volume ratio. Therefore, development of efficient low power Hall thrusters with longer lifetime remains an active area of research.

So far, there have been two major developments towards the lifetime improvement: HEMP-Thruster[4] and Magnetic shielding[5]. HEMP thruster employs cusped magnetic field has shown no erosion in the dielectric channel. Nevertheless, its anode efficiency drops drastically under 500 V (from ~40% to down till 15%). Thus, the thruster is not effective when low power-to-thrust ratio is required (e.g. low solar power available). As for the magnetic shielding, it has been shown to reduce the wall erosion rate by a factor of 1000 in high-power Hall thrusters (> 4 kW); however, the scalability to small geometry is difficult[6]. To overcome scaling-down and wall erosion problems, we proposed a novel alternative Hall thruster design[7], in which there are no physical walls to confine plasma, and evaluated its performance through a fully kinetic code[8]. It was shown that a Hall thruster having a fully external discharge can realize propellant utilization efficiency and beam divergence as much as conventional ones. Therefore experimental investigation was performed to verify the numerical simulations. XPT is a simple annular geometry Hall thruster. It consists of only three major components: 1) A metallic anode that also serves as a gas distributor, 2) Samarium cobalt permanent cylindrical hollow magnets, and 3) a cathode. Figure 1 shows a schematic of XPT.

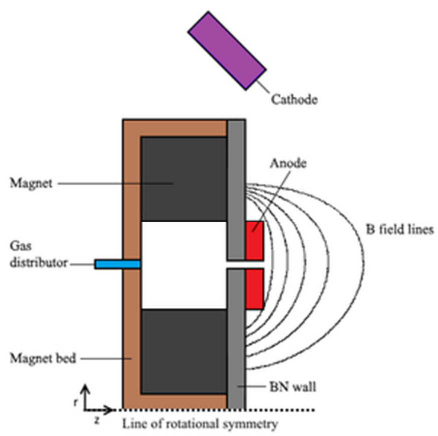

Fig. 1: A schematic of External Discharge Plasma Thruster (XPT)

This paper presents the initial experimental results of XPT.

3. Experimental Setup & Results

A two-dimensional dual pendulum thrust stand[9] was used to measure the thrust. Thrust was calibrated using a pulley and weight system. Four weights of 0.2 g each (~ 8 mN in total) are used. To obtain a calibration curve several measurements were taken before and after the thruster operation. Figure 2 shows the calibration curve.

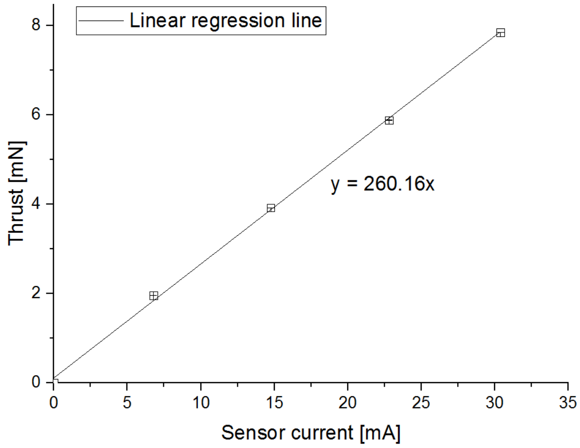

Fig. 2: Calibration curve.

During all tests the cathode mass flow rate (0.29 mg/s) was held constant while the applied anode potential, and anode mass flow rate were varied. The thruster was operated for a short period of time, and performance measurements were taken before the thruster reaches thermal equilibrium to avoid thermal problems. Xenon was used as a propellant gas for both the anode and the cathode. Measured maximum background pressure was 2.5x10^{-5} Torr at 1.43 mg/s anode mass flow rate, and 0.29 mg/s cathode (Iontech HCN-252) mass flow rate. Thrust measurement at each operation condition was repeated three times to obtain positive and negative error bar values. Average data is plotted and error bars shows the standard deviation. Furthermore, a high frequency (1 MHz) current probe was used to capture the oscillation characteristics because a discharge current oscillation amplitude of Δ<0.2 is desirable due to power processing unit (PPU) constraints[10]. Oscillation amplitude (Δ) is defined as below:

$$\Delta = \frac{RMS}{\overline{I_d}} = \frac{1}{\overline{I_d}}\sqrt{\int_0^{\tau}\frac{(I_d-\overline{I_d})^2}{\tau}},\left(\overline{I_d} = \frac{\int_0^{\tau} I_d}{\tau}\right) \quad (1)$$

where RMS is root mean square, I_d is discharge current, and τ is time.

Figure 3, 4, 5, and 6 shows the I-V curve, thrust, anode efficiency, and oscillation amplitude respectively.

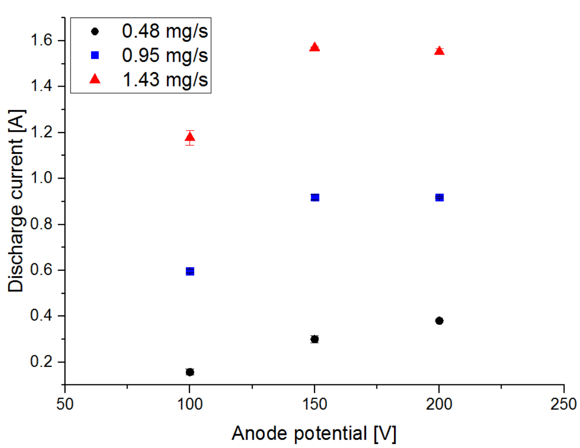

Fig. 3: I-V curve.

Figure 3 shows that the discharge current first increasing rapidly due to the increased mean electron energy (Ionization), then the ionization fraction reaches its maximum value leading to the discharge current either remains constant (Current saturation) or increases slightly due to changes in electron mobility. This is a general feature of conventional Hall thruster behavior.

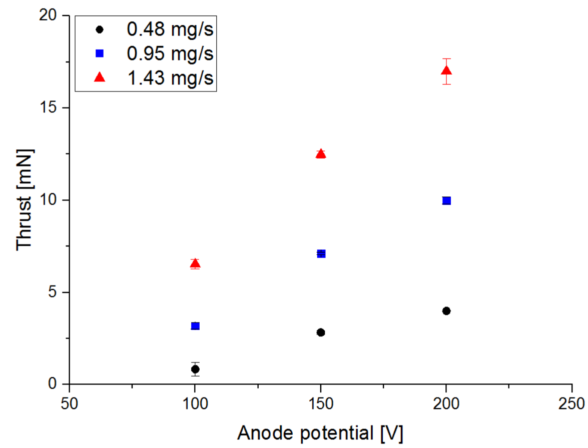

Fig. 4: Thrust.

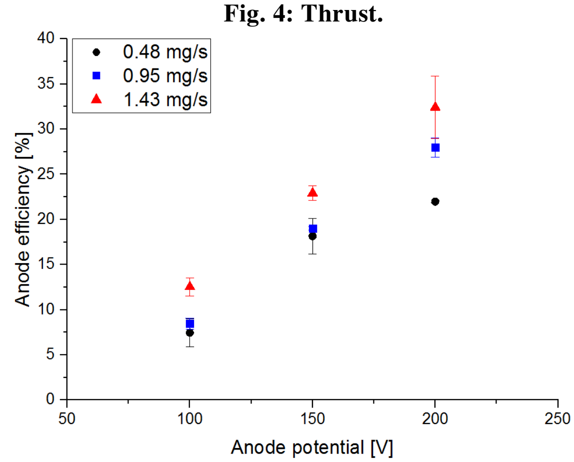

Fig. 5: Anode efficiency.

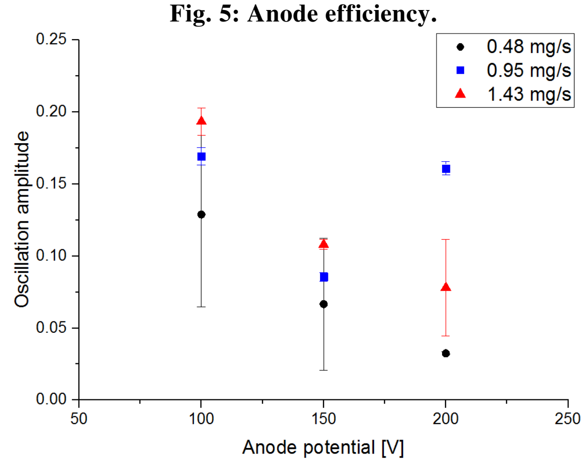

Fig. 6: Oscillation amplitude.

3. Conclusion

An unconventional Hall thruster design serving as a solution to wall erosion and efficient scaling down problem was tested. It was found that XPT has similar discharge characteristics with SPT and TAL, and its performance is comparable at the same power levels.

Acknowledgements

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