Development and Performance Test of a 50 W-class Hall Thruster

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Abstract: A 50 W-class Hall thruster was developed and its performance was evaluated. The combination of a permanent magnet and electromagnet was utilized to produce magnetic fields. The developed thruster showed stable operation in the power range 42–74 W with anode voltage of 160–280 V. The measured values of thrust, specific impulse, and anode efficiency are 2.6 mN, 817 s, and 20%, respectively, at 52 W anode power. Current and propellant efficiencies are 0.59–0.65 and 0.55–0.63, respectively, in this power range.

Nomenclature

\[ I_i = \text{Ion current} \]
\[ I_d = \text{Discharge current} \]
\[ e = \text{Electron charge} \]
\[ m = \text{Xenon atomic mass} \]
\[ \dot{m} = \text{Xenon mass flow rate} \]
\[ U_c = \text{Current efficiency} \]
\[ U_p = \text{Propellant efficiency} \]

I. Introduction

Hall thrusters are one of the most widely-used electric propulsion systems that have steadily been utilized in various space missions over several decades¹. The utilization of Hall thrusters has been advantageous because of their high specific impulse and thrust-to-power ratio²; thus, they have been employed in various missions including orbit transfer⁴,⁵, attitude/altitude control⁶, and lunar exploration⁷.

Nowadays, with the active development of microsatellite and multi-unit CubeSat technologies, commercial off-the-shelf small satellites can be obtained at a relatively low cost⁸. Therefore, the demand for such micro-satellites below 100 kg is rapidly increasing, particularly for low-Earth orbit space missions⁹, many of which are carried out by means of constellation flights¹⁰. For this reason, low-power, sub-100 W Hall thrusters are in high demand for drag compensation as well as fine positioning of these satellites, which elevates the importance of low-power Hall thruster research and development.

Numerous low-power Hall thruster studies are ongoing to meet this demand¹¹-¹⁴. However, the development of low-power Hall thrusters with smaller sizes is accompanied by problems associated with the increased importance of plasma-facing surfaces. The particle and power loss to the channel wall are inevitably more severe in low-power Hall thrusters.
thrusters because of the increased surface-to-volume ratio\textsuperscript{15}, which leads to the degradation of thruster performance. In this study, we developed a 50 W-class Hall thruster and evaluated the thrust performance and plume properties.

II. Experimental Setup

Initial tests of the developed Hall thruster were carried out in a 1.5 m in length and 3.0 m in diameter vacuum chamber equipped with two cryogenic pumps (ULVAC, U22HB), as shown in Fig. 1. The base pressure was maintained as low as $8 \times 10^{-7}$ torr and the operating pressure was less than $7 \times 10^{-6}$ torr with Xe mass flow rate of 0.49 mg/s. For the experiment, 99.9999\% Xe gas was supplied to the anode and cathode through flow controllers (MKS, 1179A00651CS1AV-K).

The developed Hall thruster is shown in Fig. 2. The magnetic field of the thruster is provided by the combination of a permanent magnet and electromagnet. The magnetic field was designed to form a convex shape toward the anode, which is expected to reduce charged particle collisions into the channel wall near downstream\textsuperscript{16,17}. The mean diameter of the discharge channel is 15 mm, with total thruster head diameter of 56 mm. A low-power hollow cathode developed in-house was utilized for the experiment. This hollow cathode was stably operational at keeper current of 0.2–1.0 A and total power consumption of 10–30 W. During the operation, the cathode was mounted right below the thruster body to avoid direct damage from the accelerated ions.

A pendulum-type thruster stand 1.3 m long with two knife-edge pivots was utilized for the thrust measurement, which has a thrust resolution of $\pm 0.016$ mN. The displacement of the thruster body was monitored using a laser-based position-sensitive detector, and the converted signals were recorded through a DAQ system. A magnetic damper consisting of permanent magnets is located below the thruster stand to reduce unnecessary oscillations. Calibration by known mass was performed for every data acquisition.

An 8-mm-diameter Faraday probe consisting of molybdenum disks was used for ion plume diagnostics. The probe was mounted on a rotating arm, which revolved around the thruster by a single step motor for measuring angular distribution of the ion current density. The distance between the probe and thruster exit center is 480 mm. The probe bias voltage was set at $-25$ V relative to the ground to repel the electrons being collected.

III. Results and Discussion

The performance and discharge characteristics of the developed Hall thruster were evaluated at 0.32 mg/s Xe mass flow rate through the anode at different voltages. The measurements were carried out after at least 30 min to 1 h of discharge operation for stabilization of both the thruster and hollow cathode. It was repeatedly observed that the discharge current decreased by approximately 10\% as the thruster operation stabilized. Since the discharge current level is much lower than that of kW-class Hall thrusters, the currents were monitored and recorded by a discrete
current meter which can read three decimal points. Figure 3 shows the operation range of the anode voltage and power. The thruster showed stable operation in the anode voltage range of 140–280 V, where the consumed anode power was 42–74 W. The discharge current in this operating range was maintained nearly constant as 0.26 A. No change in magnetic field intensity was observed after the thruster operation in this power range.

Figure 4(a) shows the results of thrust measurement in the power range 42–74 W. The measured thrust linearly increased with anode voltage in the range 2.2–3.3 mN, demonstrating 2.6 mN at 52 W. As shown in Fig. 4(b), the anode efficiency and specific impulse at 52 W are 20% and 817 s, respectively. The anode efficiencies are 17–23% in this power range.

![Figure 3](image1.png)

**Figure 3.** (a) Discharge current and (b) anode power versus anode voltage, obtained at 0.32 mg/s Xe mass flow rate

![Figure 4](image2.png)

**Figure 4.** (a) Measured thrust and (b) anode efficiency versus anode power, obtained at 0.32 mg/s Xe mass flow rate

Ion current density was measured by the rotating Faraday probe, and the current efficiency (\(U_c = I/I_d\)) and propellant efficiency (\(U_p = I_m/I_m\)) were obtained, as depicted in Fig. 5. The raw ion current data were calibrated considering secondary electron emission by particle collisions at the collector surface, which takes 5–8% of the raw ion current in this experiment. As plotted in the figure, the current and propellant efficiencies, which increased with anode power, are in the range 0.59–0.65 and 0.55–0.63, respectively. These results are 20–30% lower than those of kW-class Hall thrusters, where the current and propellant efficiencies are in 0.8–0.9. This implies that the ionization or electron confinement inside the channel still needs to be improved.
When the thruster was operated at over 0.37 mg/s, a significant change in plasma plume was observed as the anode voltage increased. The plume plasma became more axially-extended with a more focused and brighter core structure, as depicted in Fig. 6. Approximately 17% and 18% decrease in the plume angle and discharge current were measured, respectively, when the anode voltage was raised from 160 V to 240 V. Ion and electron currents decreased by 5% and 30%, respectively, indicating more significant reduction in electron current. This trend of reduction results in a distinct improvement in current efficiency as well as overall thrust performance. An in-depth study of this mode change is underway.

IV. Summary

A 50 W-class Hall thruster was developed and initial tests were conducted, including thrust and ion current density measurements. The developed thruster showed stable operation in the 50 W-class power range; however, further optimization is required to improve thruster performance and stability at over 80 W of anode power. The measured thrust, specific impulse, and anode efficiency are 2.6 mN, 817 s, and 20%, respectively at 52 W anode power. Under these conditions, the current and propellant efficiencies are 0.62 and 0.58, respectively. Research aimed at improving the design and performance of the developed 50 W-class Hall thruster is ongoing.
Acknowledgments

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