

Performance Characteristics of Very Low Power Cylindrical Hall Thrusters

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Abstract: Development of Hall thrusters for small and low-power satellites below 100W is expected. In lowering Hall thruster power, the cylindrical-type Hall thruster is more advantage than conventional coaxial-type Hall thrusters. In this study, a very low-power cylindrical Hall thruster was designed, and the thruster performance was measured. As a result, a stable operation was achieved even with 10W. The specific impulse and the thrust efficiency are 1570sec and 18.1%, respectively, with 66W.

I. Introduction

THE Hall thruster is a promising propulsion device for small satellites because of its high efficiency and thrust density. However, reducing Hall thruster dimension and input power results in significant decline of thrust performance. Accordingly, special design is required for low power Hall thruster. Raitses proposed a cylindrical Hall thruster that has circular cross-sectional ceramic discharge chamber.¹ Because of large volume-to-surface ratio of the thruster, it suppresses an increase in ion flux to the wall accompanied by downsizing Hall thruster, and it prevents from overheating and erosion of thruster parts. Therefore, it will be preferable configuration as low power Hall thrusters. Smirnov designed and investigated miniature cylindrical Hall thruster, and their thruster achieved thrust efficiency of 15-32% in the power range of 50-300W.^{2,3}

Detailed effects of magnetic field configuration in cylindrical Hall thrusters is unknown, although it is much important to improve thrust performance. Hence, we investigated the effects with the cylindrical Hall thrusters named TCHT series in Osaka Institute of Technology. The discharge chamber consists of only a circular cross-sectional part with no coaxial parts. Although cylindrical Hall thrusters made by Raitses and Smirnov have short coaxial part, the coaxial part was excluded from TCHT-series. By applying strong radial magnetic field at the downstream region, Hall thruster TCHT-3B achieved higher thrust performance than TCHT-3A did at low power level because of a decrease in wall losses.⁴⁻⁶ However, when the position applied strong magnetic field was far downstream, the thrust efficiency was declined because of a decrease in ionization utilization. The result indicates that the thrust efficiency is optimized by adjusting the region applied large magnetic field. The optimized TCHT-3B had a high efficiency of 18-39% in the power range of 35-140W.

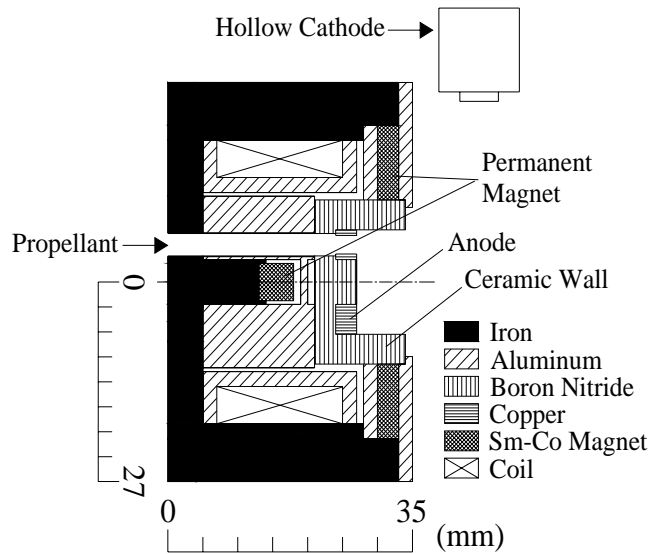
In this study, we developed a lower-power and smaller-size cylindrical Hall thruster named TCHT-4 for small satellites around 50W power. The performance characteristics are measured.

II. Experimental Apparatus

Figure 1 shows the cross-sectional view of a very low power Hall thruster named TCHT-4. The anode located at the upstream end of the circular cross-sectional part is made of copper. The length and radius of the discharge chamber are 7mm and 7mm, respectively. The wall materials of the discharge chamber are Boron Nitride (BN). The thruster has a permanent magnet on the central axis and a ring-like permanent magnet which is located at the downstream end of iron cylinder. Sm-Co permanent magnets were employed because the degradation of magnetic

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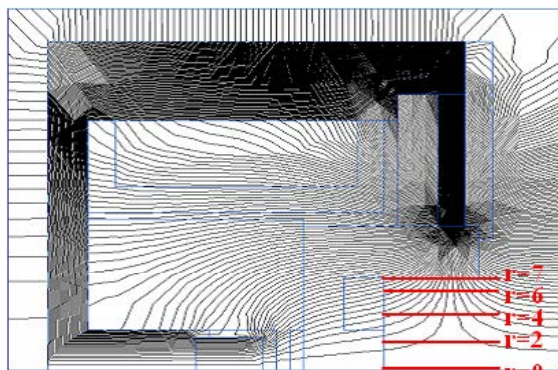
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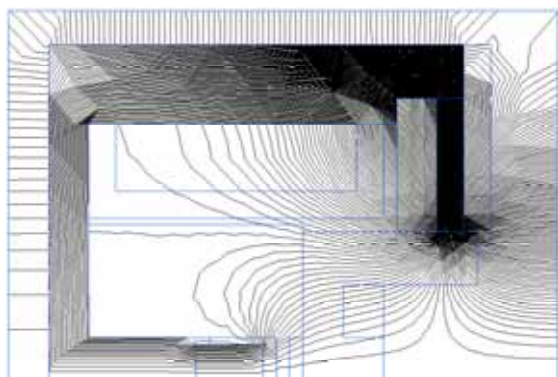
(a) Cross-sectional view.

(b) Photo.

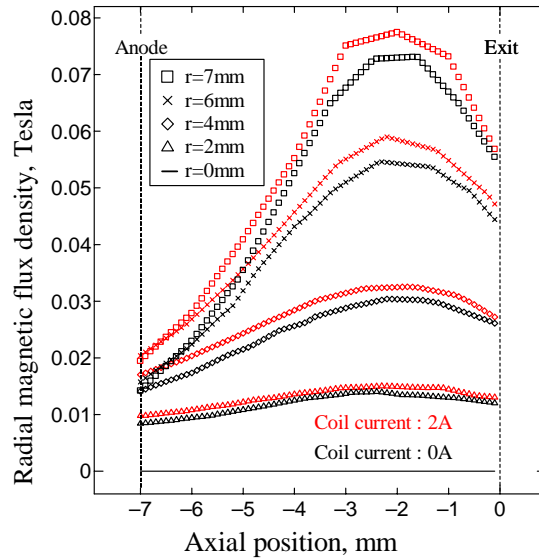
Figure 1. Configuration of very low power cylindrical Hall Thruster TCHT-4.



(a) Solenoidal coil current: 2.0 A.



(b) Solenoidal coil current: 0 A.



(c) Strengths of radial magnetic field.

Figure 2. Shape and strength of magnetic field for TCHT-4 Hall thruster.

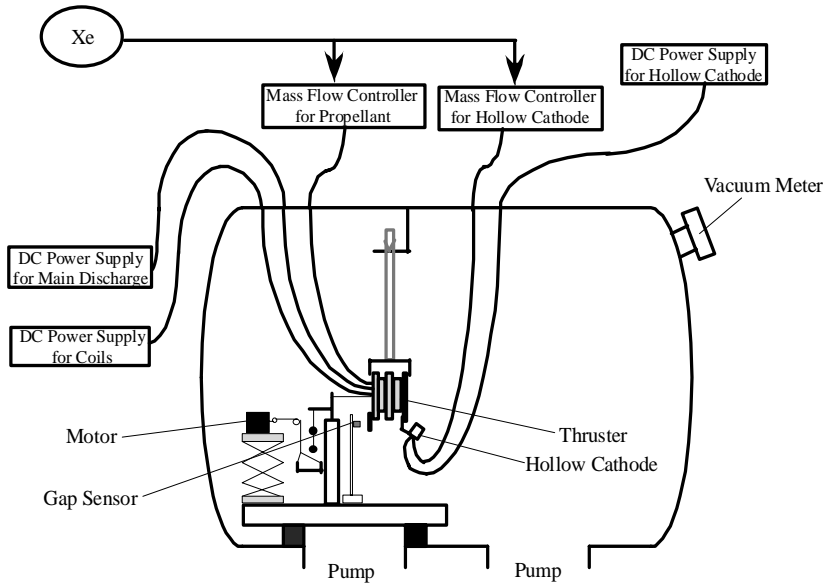


Figure 3. Experimental system for Hall Thruster.

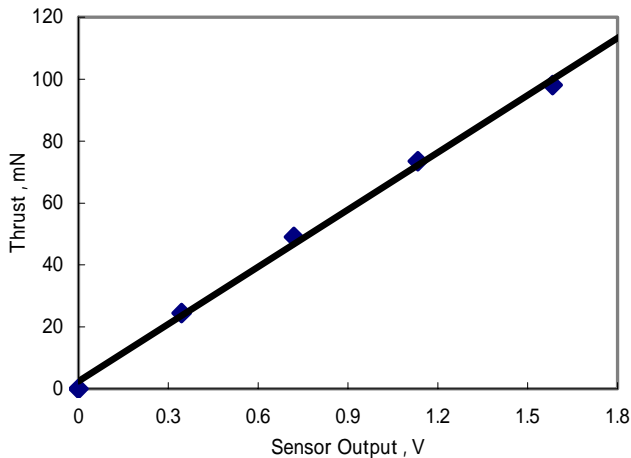


Figure 4. Typical thrust calibration line.

linearity. Thrust calibration is conducted with a weight and knife-edge arrangement which can apply a known force to the thruster under vacuum condition.

III. Experimental Results and Discussion

Figure 5 shows typical photographs of plasma plume for TCHT-4. The stable and azimuthally-uniform plume is slightly expanded radially compared with that with conventional SPT-type Hall thrusters. This is expected because there exists an axial component of magnetic field as shown in Fig.2.

Figure 6 shows the discharge current vs discharge voltage characteristics at xenon mass flow rates of 0.1, 0.2 and 0.3 g/s with and without a solenoidal coil current of 2.0 A. The discharge currents increase with increasing discharge voltage with all operational conditions. At a constant discharge voltage, an increase in mass flow rate increases discharge current. The discharge current without the solenoidal coil is lower than that with the solenoidal coil. This is expected because the magnetic field with both the solenoidal coil and the magnet is not optimized with this thruster.

As shown in Fig.7, both the thrust and the specific impulse almost linearly increase with the discharge voltage with all operational conditions. At a mass flow rate of 0.2 mg/s, the thrust and the specific impulse without the

property by heating is relatively small. TCHT-4 also has a solenoidal coil on the inner surface of the outer cylinder. Figure 2 shows the calculated magnetic field shape and strength for TCHT-4. The magnetic field has an axial component, and the strength is the highest near the anode located at the upstream region. The maximum magnetic flux density is 770 Gauss (0.077 Tesla).

The hollow cathode (Iontech HCN-252) is employed as the electron emission source. Propellant gas is injected into the discharge chamber through four lines behind the anode. Xenon is used as the propellant and the working gas of the cathode.

The experimental facility is shown in Fig.3. The thruster is operated in a water-cooled stainless steel vacuum chamber with 1.2 m in diameter and 2.25 m in length. The chamber is equipped with two compound turbo molecular pumps that have a pumping speed of 10000 l/s on xenon, several DC power supplies, and a thrust measurement system. The vacuum chamber pressure is kept about 3.0×10^{-2} Pa under operation. A clean and high vacuum environment can be created by using the oil-free turbo molecular pump system.

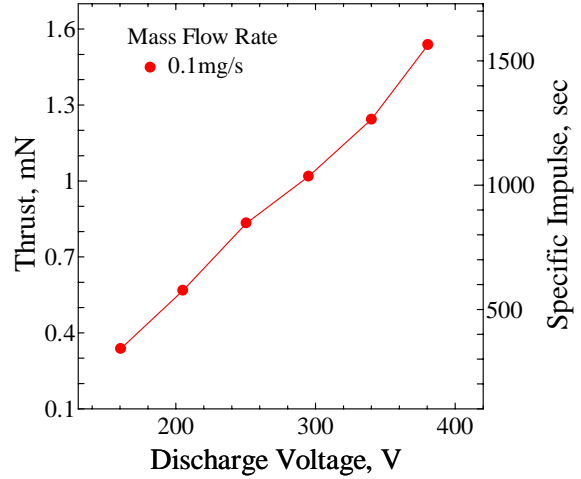
Thrusts are measured by a pendulum method. The thruster is mounted on a thrust stand suspended with an aluminum bar, and the position of thruster is detected by an eddy-current-type gap sensor (non-contacting micro-displacement meter). As shown in Fig.4, it has a high sensitivity and good



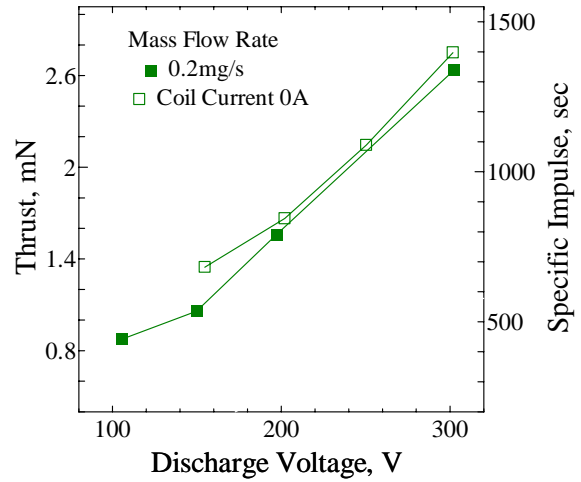
(a) Side view.



(b) Front view.



(a) Mass flow rate: 0.1 mg/s.



(b) Mass flow rate: 0.2 mg/s.

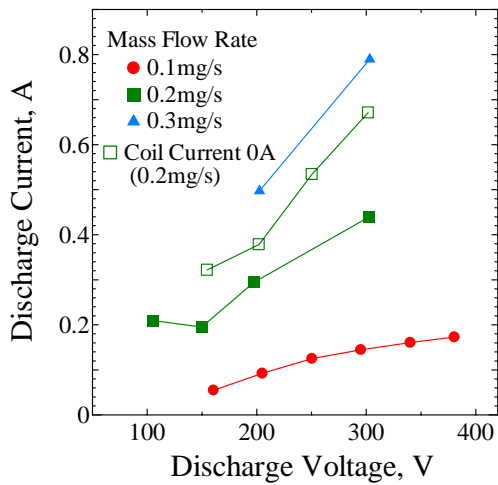
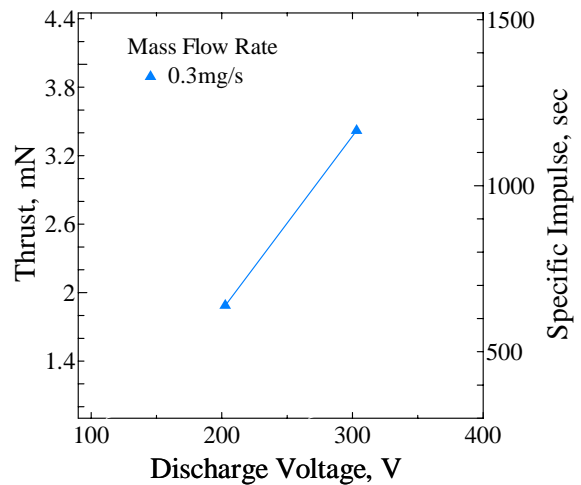


Figure 6. Discharge current vs discharge voltage.



(c) Mass flow rate: 0.3 mg/s.

Figure 7. Thrust and specific impulse vs discharge voltage.

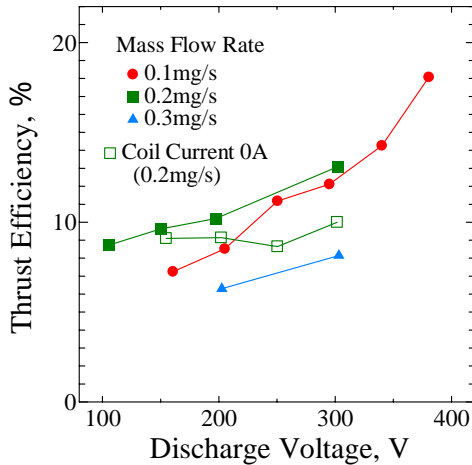


Figure 8. Thrust efficiency vs discharge voltage.

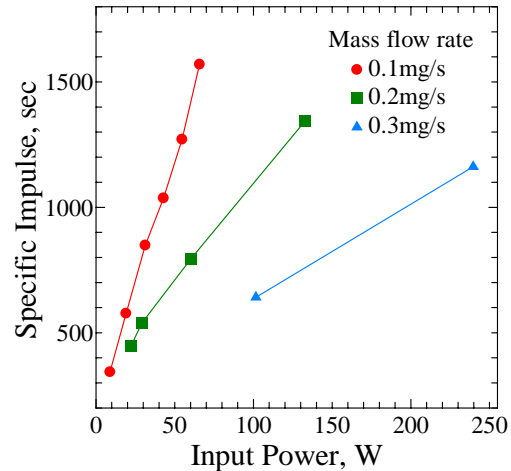


Figure 9. Specific impulse vs input power.

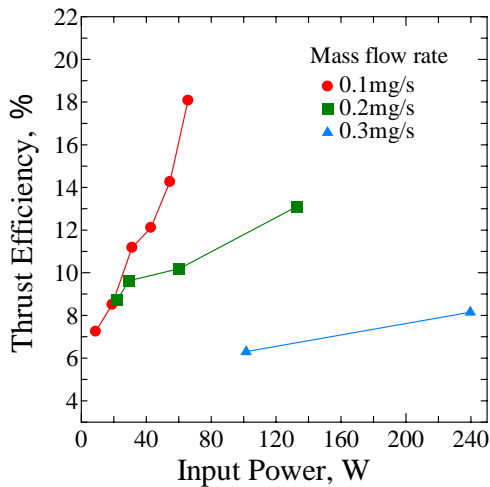


Figure 10. Thrust efficiency vs input power.

solinooidal coil are almost equal to those with the solenooidal coil. The thrust ranges from 0.3 to 3.5 mN and the specific impulse from 400 to 1400 s.

Figure 8 shows the thrust efficiency vs discharge voltage characteristics. The thrust efficiency slightly increases or is constant with increasing discharge voltage. It is around 10 %, and the maximum is about 18 % with a discharge voltage of 400 V.

Figures 9 and 10 shows the characteristics of the specific impulse and the thrust efficiency, respectively, as a fuction of input power. Both the specific impulse and the thrust efficiency almost linearly increase with the input power. They ranges from 350 s and 7 % at 10 W to 1600 s and 18.1 % at 66 W with 0.1 mg/s; from 450 s and 9 % at 20 W to 1350 s and 13 % at 130 W with 0.2 mg/s and from 600 s and 6 % at 100 W to

1200 s and 8 % at 240 W with 0.3 mg/s. The thruster operated stably even with very low powers.

IV. Conclusion

The laboratory-model very low-power cylindrical Hall thruster TCHT-4 was developed, and the thruster performance was measured. Both the thrust and the specific impulse almost linearly increased with the discharge voltage with all operational conditions. The thrust, the specific impulse and the thrust efficiency almost linearly increased with the the discharge voltage and input power. The thrust ranged from 0.3 to 3.5 mN and the specific impulse from 400 to 1400 s. The thrust efficiency ranged from 7 % at 350 s and 10 W to 18.1 % at 1600 s and 66 W with 0.1 mg/s; from 9 % at 450 s and 20 W to 13 % at 1350 s and 130 W with 0.2 mg/s and from 6 % at 600 s and 100 W to 8 % at 1200 s and 240 W with 0.3 mg/s. The thruster operated stably even with very low powers.

References

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