Voltage waveform dependences on thrust performances in a Hall thruster

Tomohiro Ichimaru
Advanced Space Propulsion Lab.

1. Introduction

Space applications such as weather observation systems, telecommunication systems, GPS, are essential for our lives nowadays.[1] Satellites need propulsion devices to control its attitude and orbit. There are candidates of propulsion system, and the Hall thruster is the most expected electric propulsion.[2] The Hall thruster has both high thrust efficiency (more than 50 %) with high specific impulse (1000 - 3000 s), and higher thrust density than ion thrusters because of the existence of electrons in the ion acceleration zone.

In the previous study, the new PPU (Power Processing Unit) concept for Hall thruster operations has been proposed. Generally, a constant voltage is used for the power source of Hall thrusters. While, the proposed PPU, we called harmonized PPU, provides fluctuating voltages in accordance with discharge current oscillation in Hall thrusters. When the harmonized PPU is used, better thrust efficiency and thrust to power ratio are achieved compared to the case of DC power source. This trend results from the considerable reduction of the power consumption.[3]

The reason why the performances are improved using the harmonized PPU has not been clarified. In addition to that, the voltage waveform has not been optimized yet. Therefore, the purpose of this study is to investigate above two subjects.

2. Experimental Setup

The whole experiment system is shown in Fig.1. A 1 kW magnetic layer type Hall thruster developed at Kyushu University (Fig. 2) is used in this experiment. The inner diameter and the outer diameter of the acceleration channel are 48 mm and 72 mm, respectively. Four solenoidal coils set outside, a solenoidal coil set inside, and a magnetic pole made of soft iron make a radial magnetic field. The Hall thruster and the hollow cathode on the thrust stand are in the vacuum chamber whose pressure is about 2.29×10^{-2} Pa when Xe inflow. Inner and outer coil currents are set as 0.6 A and 2.4 A, and mass flow rate to the thruster and cathode are fixed at 10.4 sccm and 2.8 sccm, respectively. Fig. 3 shows the applied voltage waveform. The rectangular wave is generated by a function generator, and it is added to the base voltage which is made by a DC power supply through a power amplifier. Base voltage and amplitude are set to 150 V and 25 V, respectively. In the frequency response analysis, sin wave is applied. Also, base voltage, amplitude, inner coil current, and outer coil current are set to 200 V, 5 V, 0.4 A, and 1.6 A, respectively.

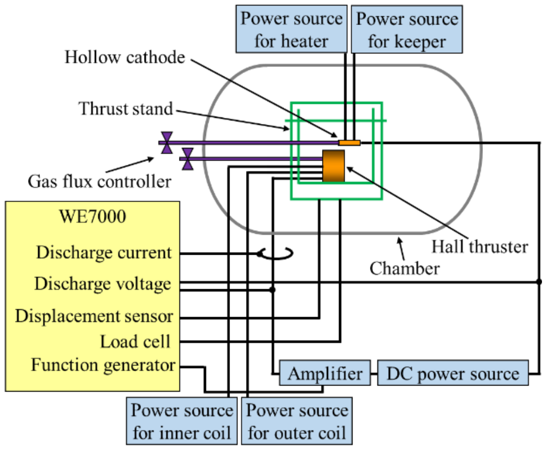

Fig. 1 Experimental system

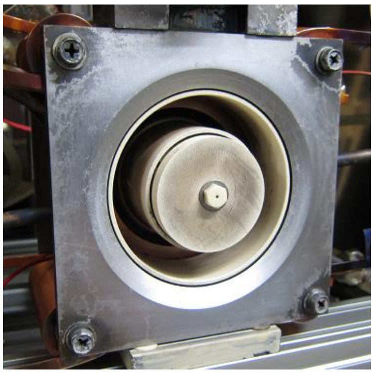

Fig.2 Hall thruster

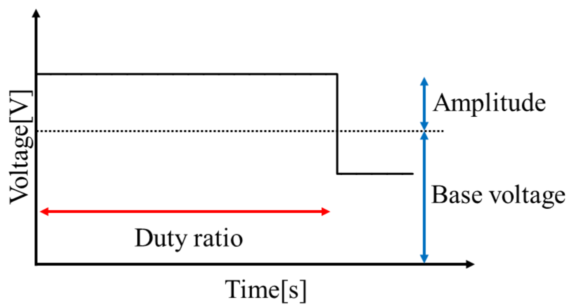

Fig. 3 Applied voltage waveform

3. Results and Discussion

Fig. 4 shows the duty ratio dependence on efficiency in the frequency of 12 kHz. When the duty ratio is less than 0.3, the Hall thruster cannot maintain discharge in this experimental condition. The average voltage becomes high as the duty ratio increases. Then, ions are accelerated efficiently and are generated a lot. As a result, efficiency increases with the increase of duty ratio. At duty ratio of 0.8, efficiency is improved around 35 % in comparison with DC.

Fig. 5 shows the frequency dependence on efficiency in the duty ratio of 0.8. Current phase varies with frequency because Hall thrusters have the characteristic such as a serial resonance circuit. That is clarified by the frequency response analysis shown in Fig. 6. When the current phase lags in an adequate range such as Fig. 7, efficiency become high. The frequency of 12 kHz offers the best efficiency in this experimental condition. It is a little higher than the original frequency of discharge current oscillation, 8.7 kHz. If the current phase is almost same to voltage phase, the power consumption is large, and if the current phase lags too much, the thrust decreases. Owing to the trade-off between two, there is an optimum frequency.

4. Conclusion

Because voltage waveforms vary with frequency in the previous study, the performance improvement factor is not clear. While, it is suggested in this study that current phase lags improves efficiency.

The results contribute to optimizing parameters of the PPU developed in the previous study.

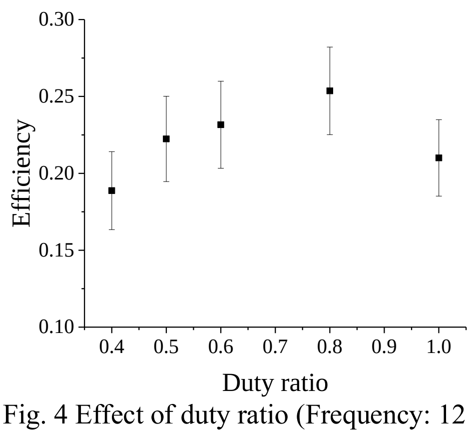

Fig. 4 Effect of duty ratio (Frequency: 12 kHz)

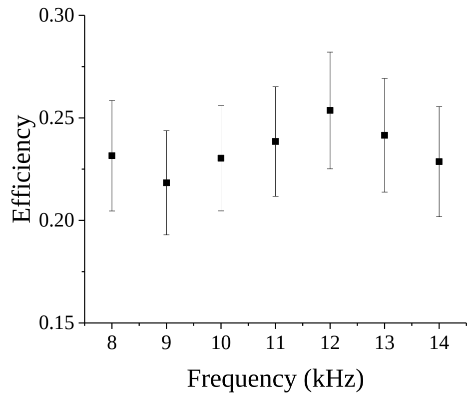

Fig.5 Effect of frequency (Duty ratio: 0.8)

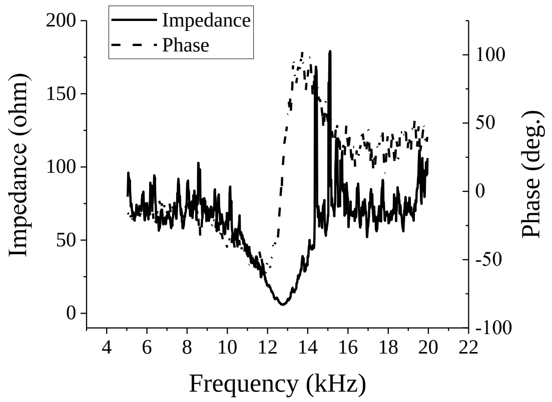

Fig. 6 Frequency response analysis

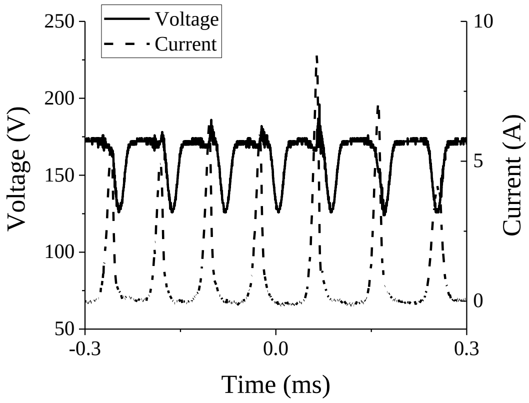

Fig. 7 Voltage and current trace (0.8, 12 kHz)

References

[1] T. Maeda, et al.: Launch Result and Current Status of "KIZUNA, IEIICE Technical Report SANE 2008-19, 2008. (in Japanese)

[2] V. V. Zhurin, et al.: Physics of Closed Drift Thrusters, Plasma Sources Sci. Rechnol. 8, R1-R20, 1999.

[3] N. Yamamoto, et al.: Development of a Novel Power Processing Unit for Hall Thrusters, IEEE Transactions on Plasma Science, Vol.43, No.1, 2015.