Characteristics of Side by Side Operation of Hall Thruster

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Abstract: To examine the operational characteristics and the thrust performance of cluster system consisting of Hall thruster heads, the magnetic-layer-type side-by-side (SBS) systems were employed. From the measurements of the discharge current profiles and the thrust, it was found that the influences of the interference between the two heads on the characteristics of the 20 kHz-range discharge current and the thrust performance depend on the discharge voltage.

Nomenclature

A	=	amplitude of 20 kHz-range discharge current oscillation
D_T	=	distance between centerlines of two heads
$F_{opposite}$	=	thrust for applied magnetic fields by two heads in opposite directions
F_{same}	=	thrust for applied magnetic fields by two heads in the same direction
$J_{opposite}$	=	discharge current for applied magnetic fields by two heads in opposite directions
J_{same}	=	discharge current for applied magnetic fields by two heads in the same direction
$\eta_{t,opposite}$	=	thrust efficiency for applied magnetic fields by two heads in opposite directions
$\eta_{t,same}$	=	thrust efficiency for applied magnetic fields by two heads in the same direction

I. Introduction

For manned and robotic explorations of Moon, asteroids, and Mars, high power electric propulsion systems are required. In Japan, a high power cluster system consisting of five Hall thruster heads and a cathode is under development. [1] Variety types of Hall thrusters have been studied by numerous researchers in Japan. [2-15] The project of the high power cluster system was named Robust Anode-layer Intelligent Thruster for Japan's IN-space propulsion system ("RAIJIN"). At Gifu University, to investigate the fundamental characteristics of cluster systems of Hall thruster, side-by-side systems consisting of two heads (named "SBS") have been developed. The fundamental studies on operational characteristics of multi-head systems have been performed.[16] For two types of SBS systems, a magnetic-layer-type system consisting of two GMK-I heads and an anode-layer-type system of two GAK-I heads, measurements have been done.

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In this study, to examine characteristics of the magnetic-layer-type SBS system (see Fig.1), discharge current profiles of the two heads and thrusts were measured for two different combinations of directions of magnetic fields applied by the two heads. To evaluate effects of interference between the two heads of the SBS system on operational instabilities, the discharge current profiles of the two heads were measured for two different combinations of the magnetic fields and at various discharge voltages. The phase relation and the amplitude of 20 kHz-range oscillations of the two discharge currents of the heads were investigated. In addition, to discuss influences of the interference between the heads on the thrust performance, the thrusts were also measured at various discharge voltages.

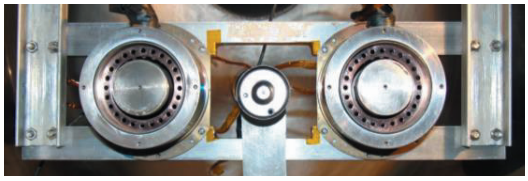


Figure 1. Photograph of magnetic-layer-type SBS system.

II. Experimental Setup

A. Magnetic-Layer-Type SBS System

We perform the cluster operations for both magnetic-layer-type head GMK-I at Gifu University. A cross-sectional view of a GMK-I head is shown in Fig. 2. The propellant flows into the acceleration channel through 24 anode orifices. The thruster head has an almost uniform magnetic layer distribution in the acceleration channel. The SBS system is composed of two GMK-I heads and a hollow cathode. The system employs a HCN-252 hollow cathode. The cathode is located in the center between the heads.

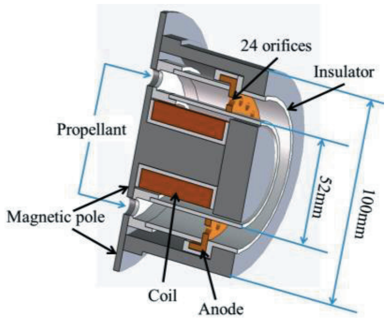


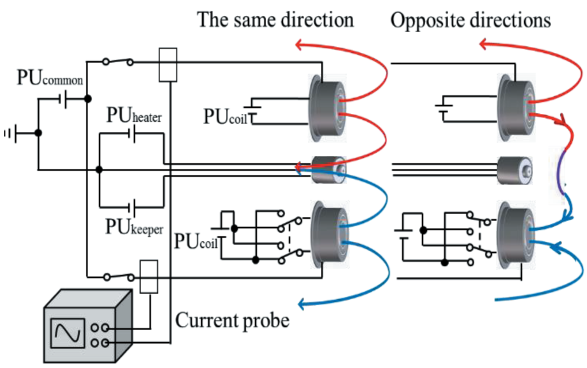
Figure 2. Schematic cross section of magnetic-layer-type head GMK-I.

B. Power Unit System

In this study, a common power unit system for the main discharges of the two heads was employed (see Fig. 3). For coil currents of the two heads, individual power units were employed. For the two different combinations of magnetic field directions of the heads, the measurement of the SBS operations were performed.

C. Measurements

The SBS system was set inside a JAXA vacuum chamber wherein a high vacuum environment was maintained. The discharge currents of the thruster heads were measured by two current probes independently and were recorded on a Tectronix TDS1000B digital oscilloscope. The ion fluxes of the two plumes were measured using a retarding potential analyzer (RPA). In the measurements of the ion flux distributions in the interhead direction, the RPA was used as an ion corrector (see Fig. 4). For the measurements of the thrusts, a pendulum thrust stand was used.



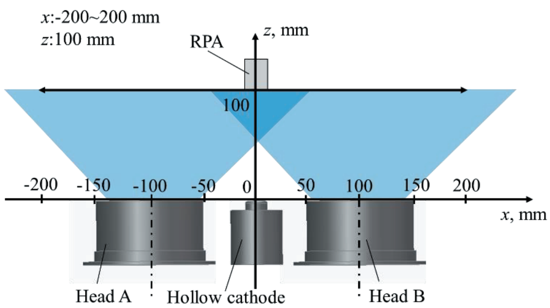


Figure 4. Schematic of ion flux measurement.

III. Results and Discussion

Figure 5 shows a snapshot of the SBS operation. In the present study, xenon was used as the propellant. The mass flow rate was fixed at 12.5 sccm. The discharge current profiles were measured at the discharge voltage of 130-210 V. In the measurements of the current profiles and the ion flux distributions, D_T was fixed at 200 mm. The measurements of the thrust and the discharge currents for the evaluations of the thrust performance were performed at 140-200 V for D_T of 156 mm.

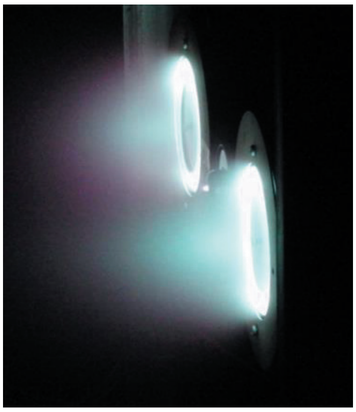
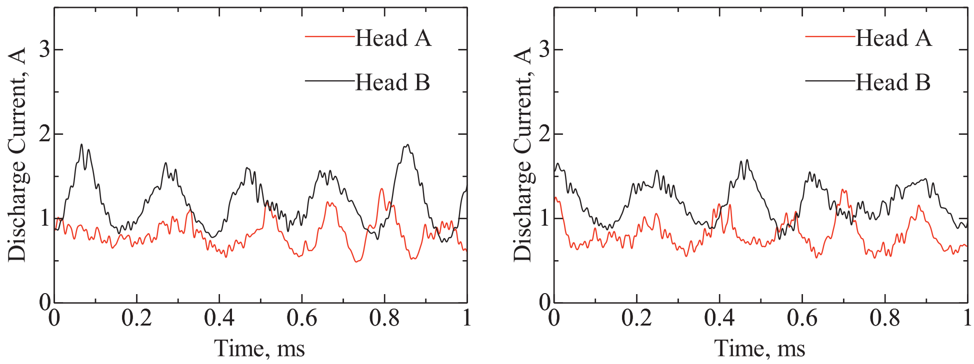


Figure 5. Snapshot of SBS operation.

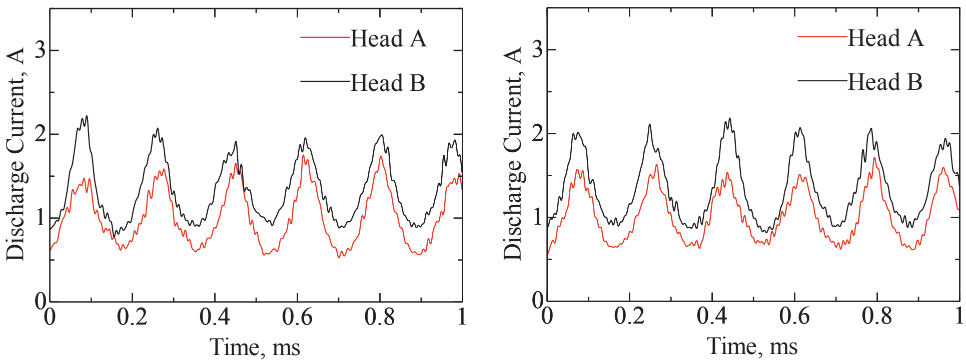
D. 20 kHz Range Discharge Current Oscillations of Two Heads

Figures 6 and 7 show the measured profiles of the discharge currents at 130 and 180 V, respectively. In the figures, the profiles for the two combinations of the magnetic field directions of the two heads were shown. In Fig. 6, there was no clear relation between the profiles of the two 20 kHz-range oscillation for the both combinations. However, in Fig. 7, the oscillations were in coordinate phase. The coordinate phase oscillations were also observed at 150 and 210 V. The coordinate phase phenomena reveal that some interferences between the discharges of the two heads at the higher voltages exist.



(a) The same direction **(b) Opposite directions**

Figure 6. Profiles of discharge currents of two thruster heads for applied fields in the same and opposite directions at 130 V.



(a) The same direction **(b) Opposite directions**

Figure 7. Profiles of discharge currents of two thruster heads for applied fields in the same and opposite directions at 180 V.

The amplitudes A of the 20 kHz-range discharge current oscillations of the two heads at 130-210 V are shown in Fig. 8. In Fig. 8, the amplitudes in the single operation were also plotted. At the lower voltages of 130 and 150 V, the amplitudes for the both combinations of the magnetic fields in the SBS operations were larger than those in the single operations. However, the amplitudes in the SBS operations at 180 and 210 V decreased were smaller than those in the single operations. These results reveal that the interference between the discharges of the two heads also appears. The difference in these characteristics of the amplitude suggests that the interference effect on the amplitude depends on the discharge mode.

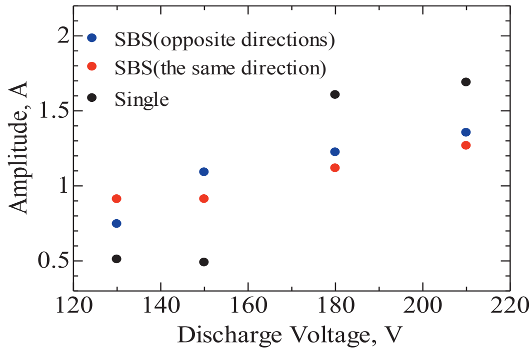


Figure 8. Amplitudes of 20 kHz-range discharge current oscillation as a function of discharge voltage for applied fields in the same and opposite directions.

E. Thrust Performance

Figure 9 shows the thrusts and the discharge currents for the two combinations of the applied magnetic fields in the SBS operations at 140-200 V. The thrust for opposite directions of the applied fields was higher than that for the same direction at every discharge voltage. The calculated magnetic flux density distributions in interference region between the two heads for the two combinations of the applied field directions are shown in Fig. 10. The two distributions were considerably different. The opposite directions of the magnetic fields increased an interhead component of the magnetic flux vector. On the other hand, for the same direction of the magnetic fields increased a downstream component. Thus, these are inferred that the difference in the magnetic field distribution causes the difference in the plume divergence through the profile of the equipotential lines. Figure 11 shows the ion flux distributions along the interhead line 100 mm downstream of the head ends at 130 and 210 V for the two combinations of the applied fields. The ion fluxes for opposite directions in the interference region were clearly lower than those for the same direction. These results confirm the influence between the magnetic field distributions on the thrust through the plume divergence.

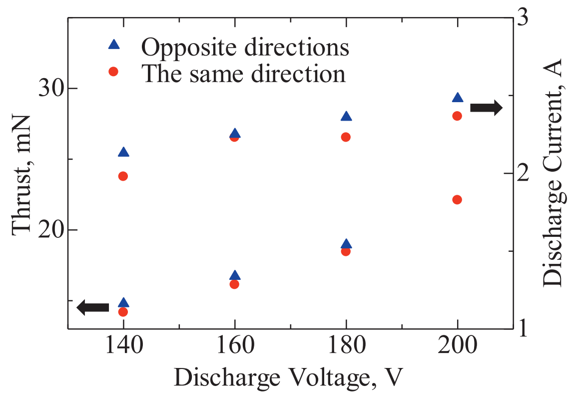
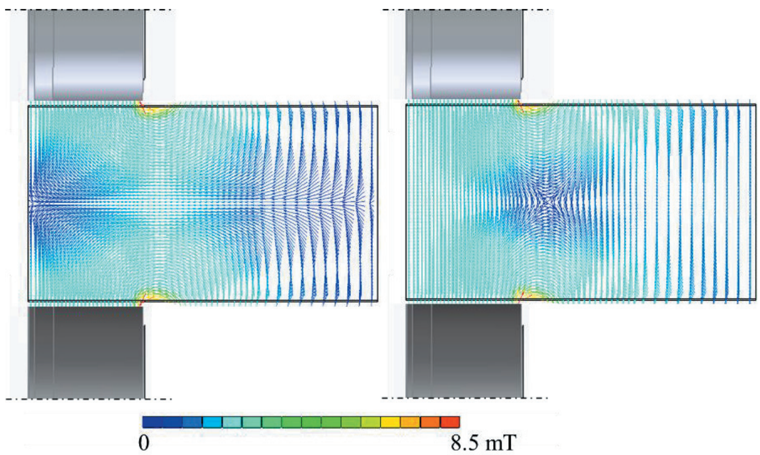


Figure 9. Thrust and discharge currents a function of discharge voltage for applied fields in the same and opposite directions.



(a) The same direction **(b) Opposite directions**

Figure 10. Calculated magnetic flux density distributions in interference region between two thruster heads for magnetic fields applied by two heads in the same and opposite directions.

Figure 12 shows the thrust ratios $F_{opposite}/F_{same}$, the discharge current ratios $J_{opposite}/J_{same}$, and the thrust efficiency ratios $\eta_{t,opposite}/\eta_{t,same}$ at 140-200 V. As observed in Fig. 9, the thrust ratio $F_{opposite}/F_{same}$ was higher than 1 at every voltage. $F_{opposite}/F_{same}$ at 140 V was 1.044. However, as the discharge voltage increased, $F_{opposite}/F_{same}$ became lower. The thrust ratio $F_{opposite}/F_{same}$ at 200 V was only 1.011. The difference in the plume divergence are caused by the difference in the direction of the equipotential lines in the downstream region. Therefore, at higher discharge voltage, the ions are sufficiently accelerated in the acceleration channel. Thus, it is inferred the influence of the magnetic field distributions on the thrust becomes smaller. In Fig. 11, the difference in the ion flux in the interference region at 210 V became lower than that at 130 V. This result confirms the mechanism.

As with the thrust ratio, the discharge current ratio $J_{opposite}/J_{same}$ was higher than 1 at every discharge current. Thus, in the cases of 180 and 200 at which the thrust ratio were low, the thrust efficiency ratios were lower than 1. Therefore, in spite of the highest thrust ratio at 140 V, the thrust efficiency ratio $\eta_{t,opposite}/\eta_{t,same}$ was only 1.012.

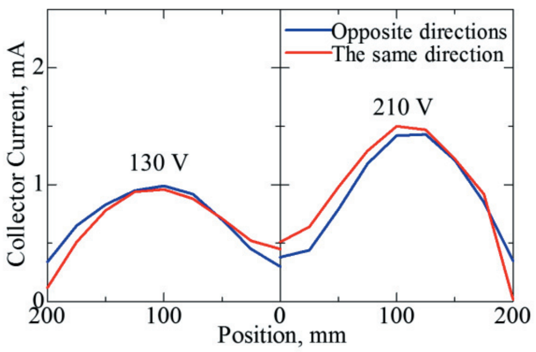


Figure 11. Ion flux distributions along interhead line 100 mm downstream of head ends at 130 and 210 V for applied fields in the same and

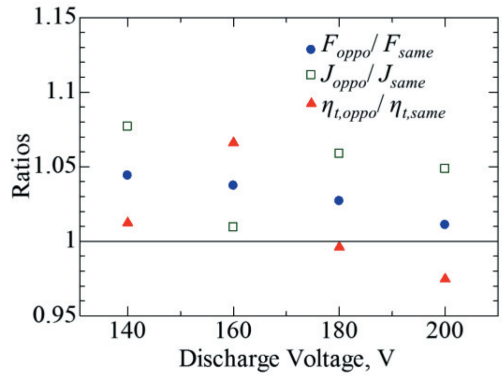


Figure 12. Thrust, discharge current, and thrust efficiency ratios as a function of discharge voltage.

IV. Conclusions

To examine the discharge characteristics and the thrust performance of a cluster system consisting of Hall thruster heads, the discharge currents and the thrust of the magnetic-layer-type SBS system were measured at various discharge voltages. The coordinate phase 20 kHz-range discharge current oscillation were observed at higher voltages. In addition, as compared with the amplitude in the single operation, the amplitude in the SBS operation became higher at lower voltages and became lower at higher voltages. The thrust for opposite directions of magnetic fields applied by the two heads were higher than that for the same direction. However, as the discharge voltage increased, the thrust ratio between the two combinations of the applied field directions became smaller. These results reveal that the interference effects depend on the discharge voltage. Therefore, investigations at further high discharge voltages are required for developments of actual high power systems.

Acknowledgments

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