Investigation of Side by Side Hall Thruster System

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Abstract: The integrated system termed a "side-by-side (SBS) system" and represents two aligned heads on either side of the cathode was constructed for the present study. To examine the fundamental operational characteristics of the cluster, magnetic layer thruster heads were employed. From the measurements, it was inferred that the 20 kHz-range discharge current oscillation between the two thruster heads were in antiphase only when using a common main power unit system with a small inter-head distance.

Nomenclature

B	=	magnetic flux density
D_C	=	axial distance between thruster head and cathode surfaces
D_T	=	distance between centers of thruster heads
$\dot{m}$	=	mass flow rate
V_d	=	discharge voltage

I. Introduction

In Japan, for development of high-power electric propulsion systems for the proposed missions, a Robust Anode-layer Intelligent Thruster for Japan's IN-space propulsion system (named "RAIJIN") has been initiated as a collaborative research and development project.[1)] Variety types of Hall thrusters have been studied by numerous researchers in Japan.[4-15)] To avoid an increase in system mass due to heat measures in high-power operations of a mono Hall thruster, RAIJIN is a 25 kW class cluster system consisting of five 5 kW class thruster heads and a high-current cathode (see Fig. 1).

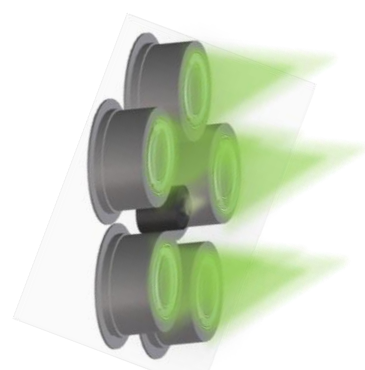

Figure 1. Concept illustration of a cluster system consisting of five thruster heads and a cathode.

At Nagoya University and Gifu University, magnetic layer thrusters with uniform magnetic fields have been developed and been investigated.[11-15)] While thrusters operating with a uniform magnetic field reduces the plume divergence, the thruster also increases the amplitude of the discharge current oscillation in the 20 kHz-range. This oscillation has the largest amplitude of the various oscillations measured for Hall thruster operations and represents a significant detriment to operational stability. In past studies, the characteristics of the 20 kH-range oscillation were found to depend on the inflow condition of the propellant and proposed methods for reduction of its amplitude were suggested. On the basis of the knowledge obtained from these studies, interference among the plumes in a

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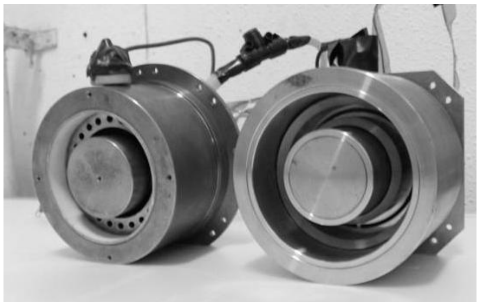
cluster system consisting of magnetic layer thrusters have been investigated. A cluster system consisting of two thruster heads and a hollow cathode was constructed for the present study. The integrated system is termed a “side-by-side (SBS) system” and represents two aligned heads on either side of the cathode. To examine the fundamental operational characteristics of the cluster, the minimum configuration was employed in this study. In this study, we report on the results of the measurements conducted on the SBS system.

II. Experimental Setup

A. The SBS System

We perform cluster operations for both magnetic-layer-type head named GMK-I and anode-layer-type thruster named GAK-I developed at Gifu University. Figure 2 show pictures of GMK-I and GAK-I heads. A cross-sectional view of a GMK-I head is shown in Fig. 3. The propellant flows into the acceleration channel through 24 anode orifices. The thruster head has a uniform magnetic layer distribution in the acceleration channel. Figure 4 shows a schematic picture of the SBS system developed at Gifu University. The SBS system is composed of two GHK-I heads and a hollow cathode. To examine interference effects between the two heads, the distance between the heads D_T is a variant of the SBS system that forms the subject matter of this report. The system employs a HCN-252 hollow cathode. The cathode is located in the center between the heads and the axial distance between the heads and the cathode D_C is also allowed to vary.



(a) GMK-1 (b) GAK-I

Figure 2. Pictures of magnetic-layer-type thruster GMK-I and anode-layer-type thruster named GAK-I.

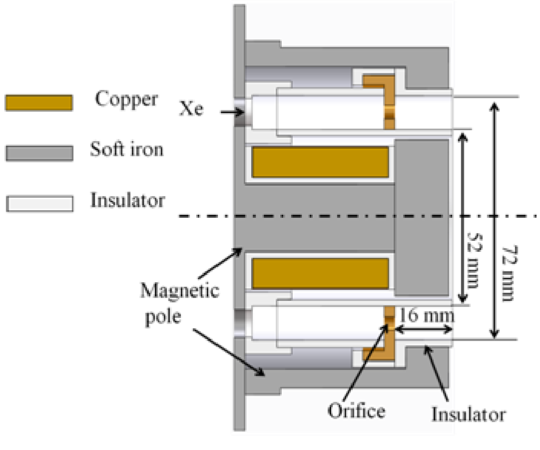


Figure 3. Cross-sectional view of GMK-I head.

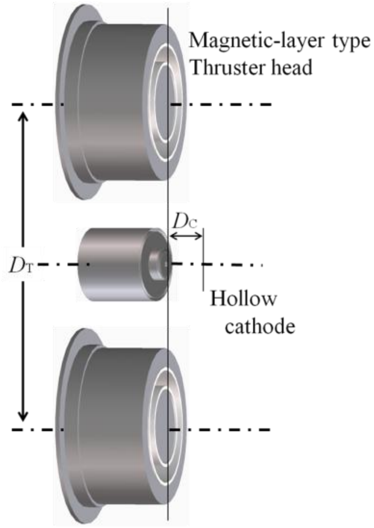


Figure 4. Concept illustration of side by side (SBS) cluster system consisting of five thruster heads and a cathode.

B. Common and Independent Power Unit System

In this study, both common and independent power unit systems for the main discharge were employed in the SBS measurements. In the common power unit (C-PU) system, each discharge current of the head is supplied by a common power source. In the independent power unit (I-PU) system, two main power units supply the heads, independently.

C. Discharge Current Measurements

The SBS system was set inside a vacuum chamber 1 m in diameter and 1.8 m long wherein a high vacuum environment was maintained by a diffusion pump. The discharge currents of the thruster heads were measured by two current probes independently and were recorded on a Tectronix TDS1000B digital oscilloscope. The total discharge current of the SBS system was obtained from the sum of the two currents.

III. Results and discussion

In the present study, xenon was used as the propellant. In the measurements, the discharge voltage V_d and the mass flow rate $\dot{m}$ were fixed at 170 V and 17 sccm, respectively. The developed SBS system was successfully operated using both the magnetic-layer-type thruster GMK-I heads and the anode-layer-type GAK-I heads. Figure 5 shows a photograph of the SBS system in operation for the GMK-I heads. In this paper, we report on the results of the measurements conducted on the SBS system using the GMK-I heads.

The discharge current profiles were measured for different distances between the two thruster heads D_T, different axial positions of the hollow cathode D_C and for the different power unit systems employed. In addition, to evaluate the influences of interference phenomena of the combination of applied magnetic field directions of the two heads, measurements were also performed for magnetic fields applied by the two thruster heads in both the same and in opposite directions. Figure 6 show the calculated magnetic flux density B distributions in the interference region between the two thruster heads for magnetic field directions applied in the same direction and in opposite directions. From Fig. 6, differences in directions of magnetic flux between the two cases were evident in the interference region.

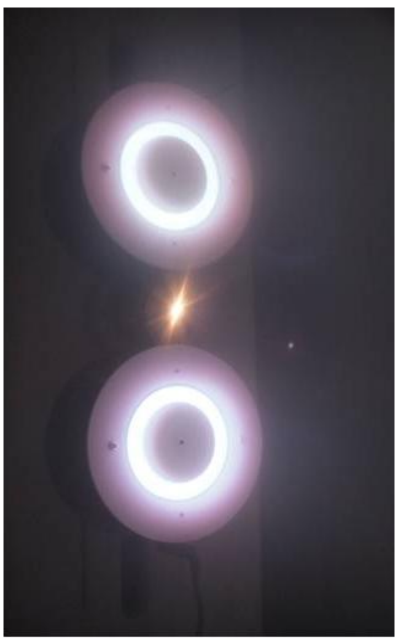


Figure 5. Photograph of SBS system in operation for GMK-I heads.

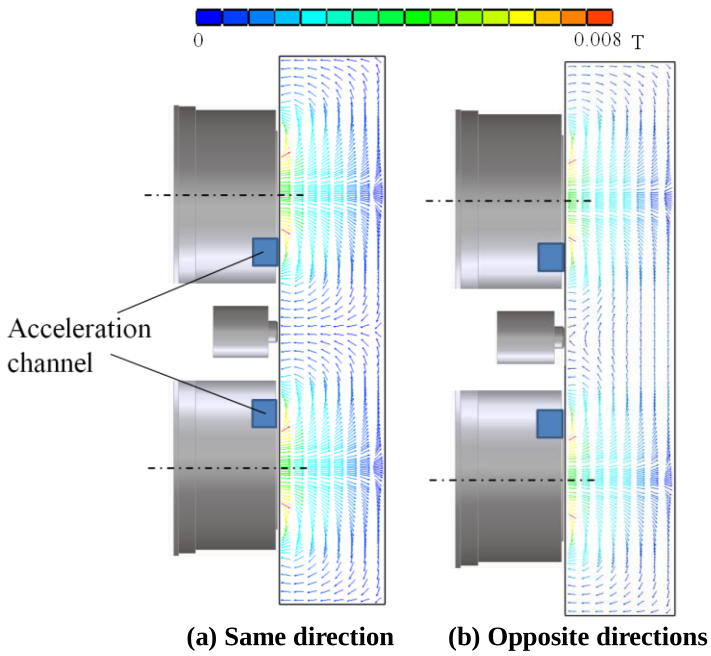


Figure 6. Calculated magnetic flux density distributions in interference region between two thruster heads for magnetic field directions applied in same direction and in opposite directions.

A. Phases of 20 kHz Range Discharge Current Oscillations of Two Heads

Figures 7 and 8 show the measured profiles of the discharge currents of the two thruster heads and the total current profile for the SBS cluster system using the C-PU for two different thruster head distances D_T of 156 and 298 mm, respectively. In the figures, the magnetic fields applied by the two heads were in opposite directions (see Fig. 6(b)). The axial distance between the heads and the cathode D_C was set to 0 mm. In the figures, the 20 kHz-range oscillation profiles were observed. For a short D_T of 156 mm, the 20 kHz-range discharge current oscillation of the two heads were in antiphase. The observed antiphase profiles reduced the amplitude of the total current oscillation. For a long D_T of 298 mm, no clear correlation the two phases were observed. These results suggest that some conditions of interference in the cluster operation result in antiphase phenomena between the two heads in the 20 kHz-range discharge current oscillation. The antiphase phenomenon was also observed in the study of cluster operations using the D-55 anode layer cluster by Semenkin et al.[16] The results revealed in the present study indicate that antiphase phenomena of the 20 kHz-range discharge current oscillation is a specific characteristic in the cluster operation.

Figure 9 shows the discharge current profiles under the same conditions as Fig. 7 except the combination of the magnetic field directions. In Fig. 9, the magnetic fields were applied in the same direction (see Fig. 6(a)). As shown in Fig. 6, the magnetic field applied by the heads in the opposite direction has a considerably different distribution compared to that found for that applied in the same direction. However, under the present conditions, the combination of the magnetic field directions made no measurable difference in the current profiles. The current oscillations of the two heads in Fig. 9 were also in antiphase.

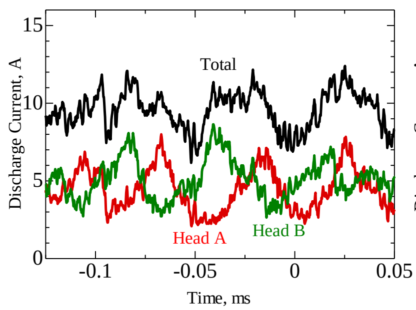


Figure 7. Profiles of discharge currents using C-PU for head distance of 156 mm, axial distance between heads and cathode of 0 mm, and opposite magnetic field directions.

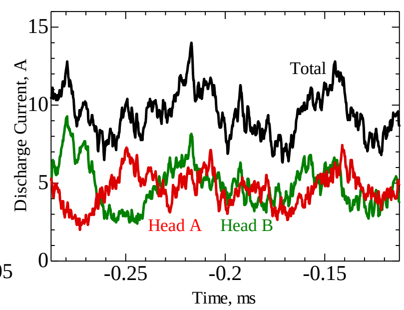


Figure 8. Profiles of discharge currents using C-PU for head distances of 298 mm, axial distance between heads and cathode of 0 mm, and opposite magnetic field directions.

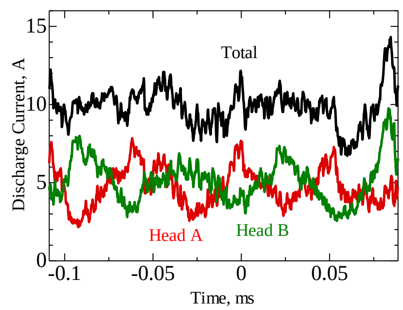


Figure 9. Profiles of discharge currents using C-PU for head distance of 156 mm, axial distance between heads and cathode of 0 mm, and the same magnetic field direction.

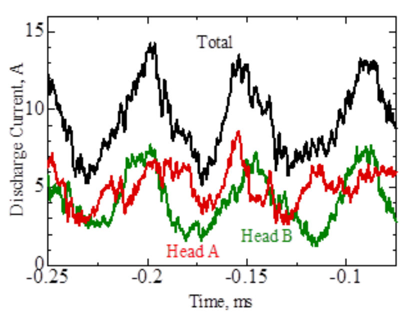


Figure 10. Profiles of discharge currents using I-PU for head distance of 156 mm, axial distance between heads and cathode of 0 mm, and opposite magnetic field directions.

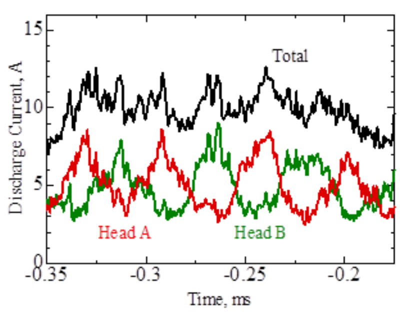


Figure 11. Profiles of discharge currents using C-PU for head distance of 156 mm, axial distance between heads and cathode of 25 mm, and opposite magnetic field directions.

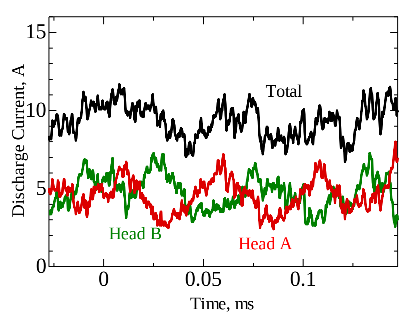


Figure 12. Profiles of discharge currents using C-PU for head distance of 156 mm, axial distance between heads and cathode of 25 mm, and the same magnetic field direction.

Figure 10 shows the discharge current profiles using the I-PU. The other conditions were the same as Fig. 7. As is the case in Fig. 8, antiphase characteristics were not observed even when D_T was small.

Figures 11 and 12 show the discharge current profiles using the C-PU for the small D_T of 156 mm, D_C of 25 mm, and for the heads operated in opposite and the same magnetic field directions, respectively. The both results in Figs. 11 and 12 show also the antiphase as with those in Figs. 7 and 9 and no significant difference in the phase correlation of the profiles between the two different combinations of the magnetic field line directions.

B. Amplitude and Frequency of Discharge Current Oscillations

The frequencies and the amplitudes of the 20 kHz-range discharge current oscillation for the various conditions described above are shown in Figs. 13-16. In the figures, the frequencies and the amplitudes are nondimensionalized by the values in the respective solo operations. As mentioned above, the phase characteristics of the oscillation depend on the conditions. However, in Figs. 13-16, no clear difference in both the frequency and the amplitude is observed among the various conditions, and the values are, in fact, very similar to those observed for solo operation.

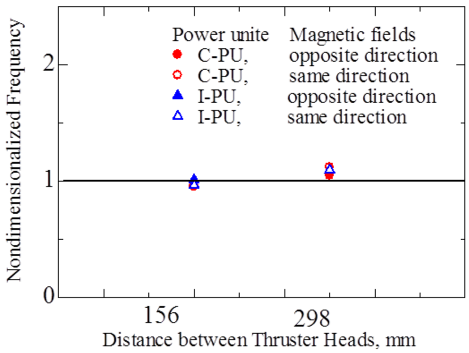


Figure 13. Nondimensionalized frequencies for axial distance between heads and cathode of 0 mm.

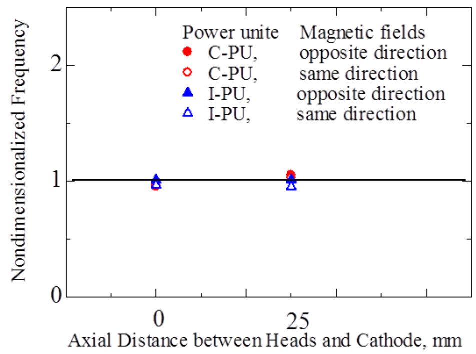


Figure 14. Nondimensionalized frequencies for head distance of 156 mm.

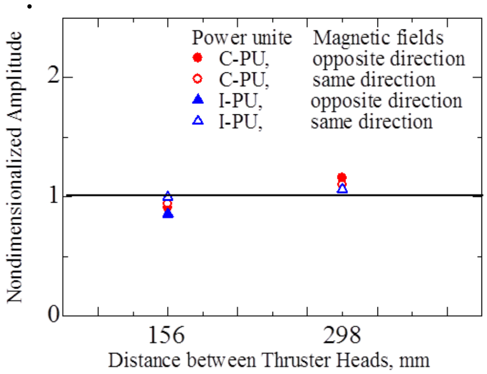


Figure 15. Nondimensionalized amplitudes for axial distance between heads and cathode of 0 mm.

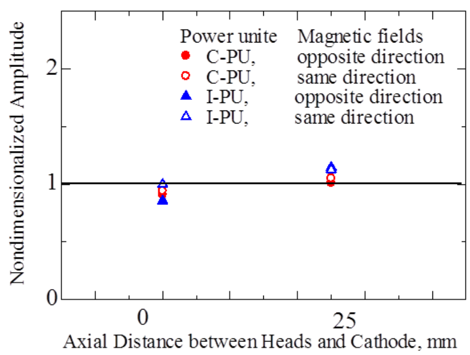


Figure 16. Nondimensionalized amplitudes for head distance of 156 mm.

IV. Conclusions

To examine the fundamental operational characteristics of a Hall thruster cluster system, a SBS system in which a hollow cathode is sandwiched between two magnetic layer thruster heads was developed at Gifu University. The discharge current measurements were performed for different distances between the thruster heads, axial positions of the hollow cathode, combinations of magnetic field directions applied by the heads, and different main power unit systems.

The results showed that it was inferred that the 20 kHz-range discharge current oscillation between the two thruster heads were in antiphase only when using a common main power unit system with a small inter-head distance. This reveals that antiphase phenomena are caused by interference between the thruster heads in cluster operations. This antiphase characteristic indicates the possibility of power load reduction and a possible advantage of a cluster system for development of high-power systems.

However, the differences in the amplitude and the frequency of the 20 kHz-range discharge current oscillation were marginal. At Gifu University, measurements over a much wider range of conditions using both magnetic layer and anode later thrusters has begun for cluster system unification. To examine the characteristics of the 20 kH such as the frequency and the amplitude, to investigate them under much stronger interaction conditions of the magnetic fields is required.

Acknowledgments

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