Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2026

Experimental Investigation of Magnetic Field Geometry Effects on Magnetoplasmadynamic Thruster Performance

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***Keywords : plasma, AF-MPD thruster, electric propulsion, magnetic field geometry**

1. Introduction

Magnetoplasmadynamic (MPD) thrusters are considered promising candidates for high-power electric propulsion due to their high thrust density and scalability over a wide power range. With recent advancements in space nuclear fission power and nuclear electric propulsion (NEP) systems, interest in applied-field MPD (AF-MPD) thrusters has increased for deep-space missions. In AF-MPD thrusters, plasma acceleration is governed by the interaction between current and an externally applied magnetic field. Therefore, both the strength and geometry of the magnetic field significantly influence AF-MPD thruster performance. Electromagnets provide controllability of magnetic field strength but require additional power, whereas permanent magnets offer structural simplicity without external power consumption. Differences in magnetic field topology between the two magnet types, such as the presence of magnetic null points, may result in variations in thruster performance. In this study, the influence of magnetic field geometry on AF-MPD thruster performance is experimentally investigated by comparing electromagnet and permanent magnet configurations [1].

2. AF-MPD Thruster Performance under Different Magnetic Field Geometries and Operating Conditions

In this section, the experimental setup and performance results under various magnetic field geometries and operating conditions are presented.

2.1. Experimental Setup

The present experiments were performed using a 10 kW-class AF-MPD thruster to investigate the influence of magnetic field geometry on thruster performance [2]. The thruster consisted of a thoriated tungsten (2%) cathode, a water-cooled copper anode, and alumina insulators, as shown in Fig. 1(a). Argon was supplied through the cathode as the propellant. External magnetic fields were generated using either an electromagnet or an axially magnetized ring-type permanent magnet. The axial magnetic field distributions for the two configurations are compared in Fig. 1(b). The permanent magnet produced a peak axial magnetic flux density of 0.175 T at the cathode tip, while the electromagnet field strength varied with coil current from 10 A to 40 A. As illustrated in Fig. 1(c), the electromagnet configuration provided a predominantly axial magnetic field, whereas the permanent magnet configuration introduced a magnetic null point and enhanced radial field components within the discharge channel.

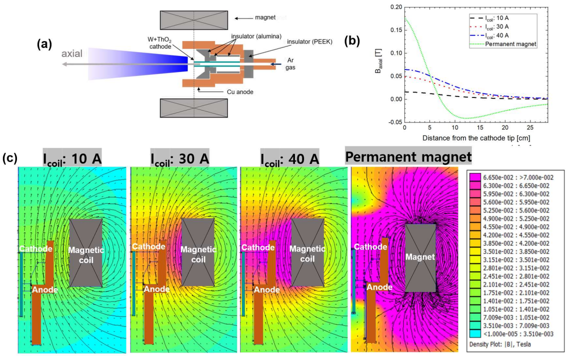

Fig. 1. (a) Structure of the AF-MPD thruster, (b) axial magnetic flux density along the channel, and (c) magnetic field distributions.

2.1. Experimental Results

Thruster performance was evaluated for both electromagnet and permanent magnet configurations over comparable operating ranges. As shown in Fig. 2, thrust was analyzed as a function of the product of discharge current and applied magnetic field strength (IB_A), following established AF-MPD scaling relationships. In both configurations, thrust increased approximately linearly with IB_A. In the electromagnet case (Fig. 2(a)), thrust increased with discharge current under all conditions. Notably, at a higher coil current of 40 A, thrust exhibited a more pronounced increase at the lower argon flow rate (500 sccm), and exceeded the higher flow rate case at elevated discharge currents. For the permanent magnet configuration (Fig. 2(b)), higher argon flow rates resulted in greater thrust at a given IB_A.

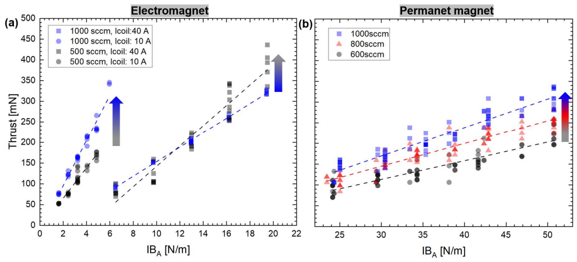

Fig. 2. Thrust as a function of the product of magnetic field strength and discharge current (IB_A) for (a) the electromagnet and (b) the permanent magnet configurations.

Thrust and specific impulse were also evaluated as functions of input power, as presented in Fig. 3. In both configurations, thrust increased with increasing power, and higher argon flow rates generally produced higher thrust. The electromagnet configuration achieved a maximum thrust of 436 mN and a specific impulse of 2935 s at an input power of 15 kW and 500 sccm. Under comparable operating conditions, the permanent magnet configuration showed lower thrust and specific impulse values.

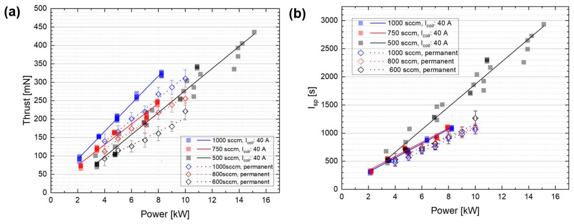

Fig. 3. (a) Thrust and (b) specific impulse (I_{sp}) as a function of input power for both electromagnet and permanent magnet configurations.

3. Summary and Conclusions

The performance of an AF-MPD thruster was evaluated for the electromagnet and the permanent magnet configurations under comparable operating conditions. Thrust increased approximately linearly with the product of discharge current and applied magnetic field strength (IB_A). Although the permanent magnet provided a stronger applied magnetic field, the electromagnet configuration achieved higher thrust and specific impulse under similar conditions. The electromagnet case reached a maximum thrust of 436 mN and a specific impulse of 2935 s at 15 kW. The reduced performance of the permanent magnet configuration may be associated with the presence of a magnetic null point, which shortens the effective magnetic field region and can limit plasma acceleration. These results indicate that magnetic field geometry, in addition to magnetic field strength, plays an important role in determining AF-MPD thruster performance and should be carefully considered in thruster design.

REFERENCES

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