Development of 10 kW Applied-Field MagnetoPlasmaDynamic Thruster for Nuclear Electric Propulsion

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1. Introduction

Nuclear Electric Propulsion (NEP) produces thrust by ionizing and accelerating the propellant using electrical power that are generated by a fission reactor. NEP typically consists of fission reactor, power convertor, heat rejection, and electric propulsion (EP).

NEP is considered one of the most promising candidates for in-space propulsion technology for Mars manned mission scheduled for 2039 [1] because of its high fuel efficiency and relatively large thrust. For the Mars manned mission, a thrust of >10 N and a specific impulse of >2000 s are required, indicating that 1 MW_e class NEP is needed [1].

However, a high-power EP technology for NEP is strictly regulated by several advanced countries in space technology so we must develop our own technology. As part of these efforts, KAERI started to develop 10 kW class Applied-Field MagnetoPlasmaDynamic thruster (AF-MPDT) since last year.

The KAERI MPDT was initially developed for fusion divertor simulator. We chose AF-MPDT to mimic the heat and particle fluxes of fusion divertor regions, because it can produce very high-density plasmas in steady-state. Currently, the developed divertor simulator is also used for studying plasma-surface interactions.

2. KAERI AF-MPD Thruster

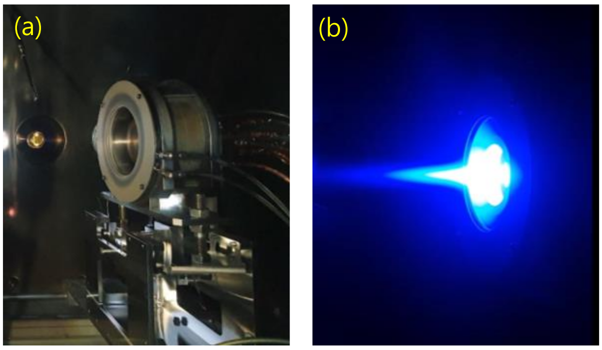

Fig. 1 Photos of (a) KAERI MPDT setup and (b) Ar plasma operating at 6 kW

KAERI AF-MPD thruster consists of copper anode, thoriated tungsten cathode, and alumina ceramic insulators. The details of KAERI MPDT design can be found in Refs. [2. 3]. The outer diameter of the anode is 100 mm and that of the cathode is 12 mm. The applied field (external B-field) is provided by an NdFeB permanent magnet placed outside of the thruster body. The axial magnetic field was measured to be 1700 G at the center of the magnet. It is noted that there is a field null near the anode exit (z = 2 cm from the anode) because we use a permanent magnet. Figure 1(a) is a photo of the KAERI MPDT and Fig. 1(b) shows the Ar plasma operated with an input power of 6 kW.

3. Performance Test

In order to accurately measure the performances of the thruster such as thrust and exhaust speed, it is necessary to have a large vacuum chamber and a high pumping speed. The volume of our vacuum chamber is 2.6 m^3 and the pumping speed is 11,000 L/s for Ar gas. The pumping speed of our vacuum pumps is not fast enough for 10 kW class thruster because the chamber pressure when the MPDT is operating is about 1 mTorr which is 1-2 orders of magnitude higher than other facilities.

We developed a thruster stand that can measure thrust (T) of our MPDT using a load cell. Then, the thruster body and the permanent magnet were installed on the thruster stand and the load cell indicator was calibrated using a pulley and weights. After the calibration was done, we measured the thrust produced by our MPDT with Ar plasmas. The results are shown in Fig. 2. As seen in the figure, KAERI MPDT produces about 300 mN thrust at 8 kW input power. Then, the specific impulse (I_{sp}) was obtained from the relation, $I_{sp} = T/m'g$ where m' is the fuel mass flow rate. The obtained specific impulse is displayed in Fig. 3. Note that the thrust and specific impulse measured here can be overestimated due to high operation pressure.

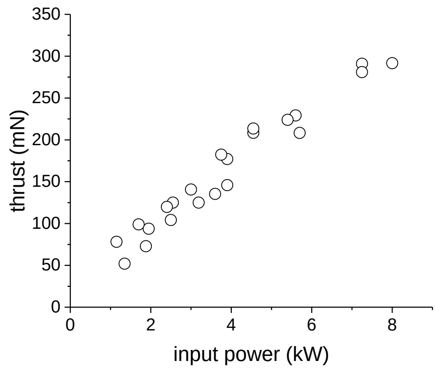

Fig. 2 Measured thrust produced by KAERI MPDT. Thrust is proportional to the input power and the maximum 30 mN thrust is measured at 8 kW input power.

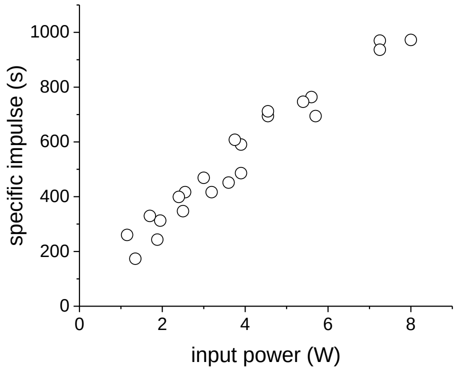

Fig. 3 Measured specific impulse of the KAERI MPDT. The measured specific impulse is 1000 s at 8 kW.

To measure the energy and exhaust speed of ions, we developed a retarding potential analyzer. It consists of 5 grids and 1 faraday cup: first two are the floating grids, third one is the electron repel grid, fourth one is the retarding grid, and fifth one is the secondary electron repelling grid. The faraday cup measures the ion current with sweeping the regarding potential on the retarding grid and the ion energy distribution is obtained by differentiating the measured current signal. The obtained ion energy distributions are shown in Fig. 4. From the measured distribution, we can obtain the exhaust speed of Ar ions as seen in Fig. 5. The exhaust speed is about 12 km/s at 6 kW input power.

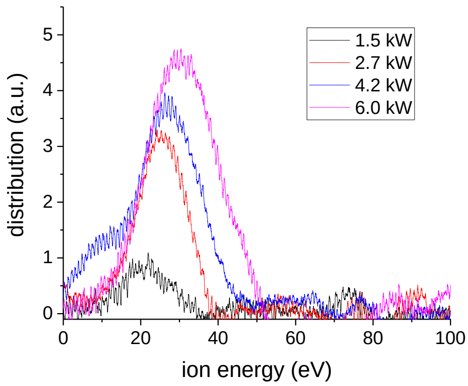

Fig. 4 Ion energy distribution measured by RPA. The ion peak energy is shifted towards the high energy side as the input power increases.

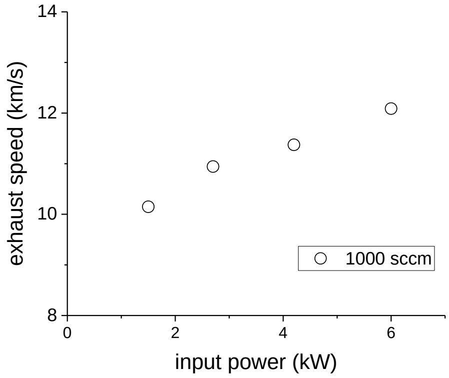

Fig. 5 Ion exhaust speed obtained from the measured ion energy distribution. The maximum exhaust speed was 12 km/s at 6 kW input power.

4. Concluding Remarks

KAERI MPDT has been successfully developed and the performances were measured: thrust of 300 mN and specific impulse of 1000 s were obtained. However, as mentioned above, the volume of our vacuum chamber is small and the pumping speed of our pump system is low for testing the performance of 10 kW class thrusters. Therefore, we are currently planning a new research project for acquiring a large vacuum chamber (>60 m^3) and high pumping speed (>100,000 L/s) at KAERI.

ACKNOWLEDGEMENT

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