25G06

Measurement of Plasma Flow Velocity in a Fast-flowing Plasma
高速プラズマ流でのプラズマ流速測定

Kohei Okawa, Naohiro Takahashi, Yuko Hashima, Hiroshi Watanabe, Yuki Izawa,
Nozomi Tanaka and Akira Ando
大川　耕平，高橋　直大，橋間　裕子，渡部　博，伊澤　裕紀，田中のぞみ，安藤　晃

Department of Electrical Engineering, Graduate School of Engineering, Tohoku University
6-6-05, Aoba-yama, Aoba, Sendai 980-8579, Japan
東北大学工学研究科　〒980-8579　仙台市青葉区荒巻字青葉6-6-05

The plasma flow velocity is one of the important parameters to understand the plasma flow characteristics and evaluation of thrust performance in electric propulsion. In this research, we measured the plasma flow velocity by the time of flight (TOF) method using Langmuir probes and Mach probes. Ion saturation currents were measured simultaneously by two probes set at separated positions. The plasma flow velocity was evaluated by time difference between the two signals. Effect of the distance between the two probes was examined.

1. Introduction

We have investigated fast-flowing plasma with various magnetic nozzle configurations [1-3]. Mach number was measured directly by Mach probes in the plasma and large increase of Mach number was observed in an expanding magnetic nozzle configuration. The thermal energy of the plasma flow is expected to convert into kinetic energy by passing through the divergent magnetic nozzle. Although plasma flow velocity can be estimated by the measurement of Mach number and temperature, direct measurement of plasma flow velocity is important for the researches of the fast-flowing plasma.

An electric propulsion system is suitable for long-term mission in space with its higher specific impulse [4]. Magneto-Plasma-Dynamic (MPD) thruster is one of the promising candidates for the high power thruster utilizing electric propulsion system. In order to evaluate the thrust performance, measurement of plasma parameters such as flow velocity is important. With a divergent magnetic field applied on a MPD thruster, the flow velocity is expected to increase by additional acceleration forces [5].

We have measured ion saturation currents at different axial positions shot by shot and averaged axial flow velocity was evaluated by the time delay of initial phase of the discharge [6]. In this research, the time of flight (TOF) method was utilized using two probes separated 5-20 cm apart to each other. The estimation method and comparison with the previous method are presented.

2. Experimental procedure

Experiments were performed by the HITOP device in Tohoku University (see Fig. 1). The MPD thruster was attached on an end port of HITOP device, and operated with a variety of gases. Figure 2 shows the schematic of the MPD thruster. A magnetic coil is set near the exit of the MPD thruster to generate an additional magnetic field. Uniform magnetic field of 50 mT and additional field were applied in the experiments as shown in Fig.3, which forms a divergent magnetic nozzle.

A fixed Langmuir probe and a movable Mach probe are set separately with a short distance on the axis of the plasma flow. We can evaluate the plasma flow velocity by the time of flight (TOF) method from the time lag of two ion saturation current

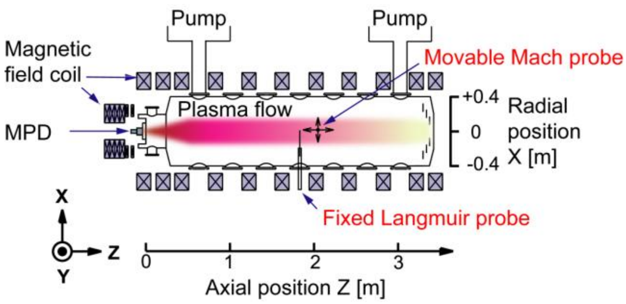

Fig.1. Schematic of the HITOP device

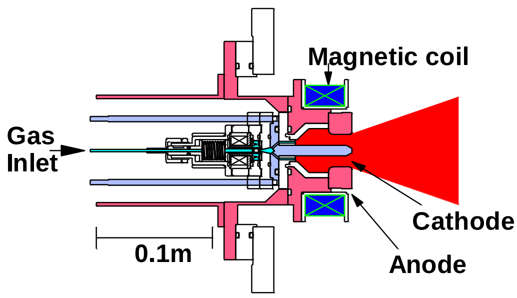

Fig.2. Schematic of the MPD thruster

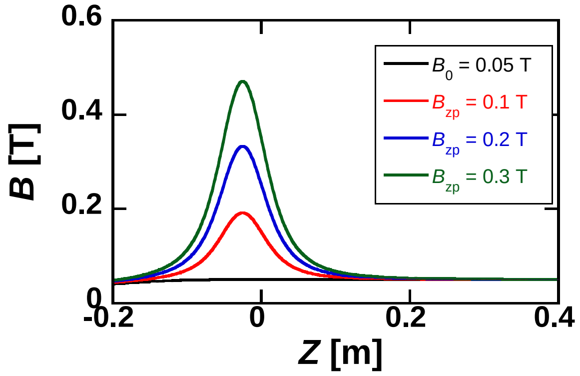

Fig.3. A uniformed magnetic field B_0 and an additional magnetic field B_{zp} by the small coil

signals measured by the two probes. The time lag can be estimated using the cross-correlation function,

$$\phi_{12}(\tau)=\int g_1(x)g_2(x-\tau)dx \quad , \qquad (1)$$

where g_1, g_2 are the ion saturation currents. The time lag equals to τ where the cross-correlation function becomes maximum. The velocity is calculated from the time lag and probe separation distance.

3. Results and discussions

Figure 4 shows the dependence of a plasma flow velocity U on the discharge current I_d. Here the distance of two probes dZ was changed. We have evaluated the plasma flow velocity previously from the initial delay of the discharge measured at several axial positions [6]. The results from Eq. (1) were slightly smaller than the previous results. Previous estimation of plasma flow velocity is probably affected by relatively fast particles in the discharge. Fast particles attain to probes faster than bulk particles and contribute to an initial rise of ion saturation currents. The measured results in this study were slightly scattered but the flow velocity can be estimated within +-3km/s. The error can be reduced by sampling more number of data points in a shot.

Figure 5 shows the dependence of U on I_d in various divergent magnetic configurations in Ar plasma. U increased as the increase of I_d and B_{zp}. This was caused by the increase of Lorentz force which drives the plasma flow axially. When the divergent magnetic nozzle was not applied, the plasma flow velocity increased and limited to about 8.7 km/s, that is the Alfvén critical velocity [7]. With an applied magnetic field the plasma flow velocity increased beyond the critical velocity. The plasma flow velocity increased with the divergent

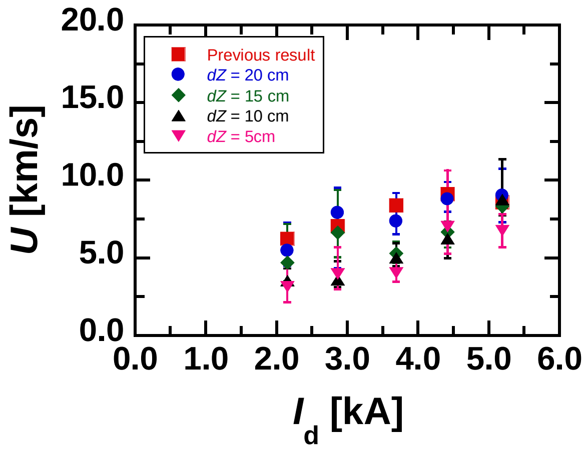

Fig.4. The plasma flow velocity U as a function of the discharge current I_d. dZ is the distance between two probes.

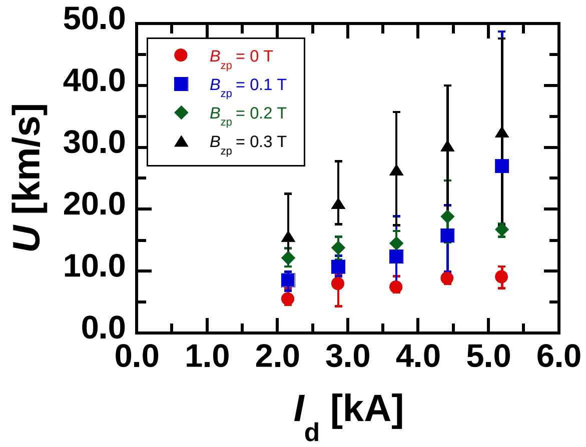

Fig.5. The dependence of U on I_d in various additional magnetic fields in Fig.3. Ar plasma.

magnetic nozzle intensity.

4. Conclusion

The plasma flow velocity in a MPD thruster was evaluated by the TOF method using a cross-correlation function. The plasma flow velocity was evaluated in several separation distances between two probes. The plasma flow velocity increased with the increase of discharge current and the divergent magnetic nozzle intensity.

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