§8. Formation of Electric Field in a Fast-flowing Plasma with Diverging Magnetic Nozzle

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Formations of electric field and plasma flow in non-uniform magnetic field has been a vigorous research topic associated with the structural formation and suppression of the plasma fluctuations in fusion researches. Some of the insights obtained in the fusion researches are also useful for plasma flow control for the electric propulsion in space and industrial applications. Especially, the electromagnetic plasma acceleration has attracted much attention as a new approach to development of the high power and efficient electric propulsion devices[1,2].

In this study, the plasma dynamics in a magnetic nozzle is investigated, where a fast-flowing plasma is generated by a magnetoplasmadynamic (MPD) plasma source. Measurements of the electromagnetic force exerted to the plasma flow and an electric field in the plasma will give us important information to clarify the detailed plasma dynamics.

In this year, the magnetic Laval nozzle, which has a convergent-divergent magnetic field lines, is applied to the MPD plasma source in addition to the simple divergent magnetic field.

The experiments are performed in HITOP machine of Tohoku University, which consists of a 0.8 m diameter and 3.3 m long vacuum chamber and magnetic solenoids.

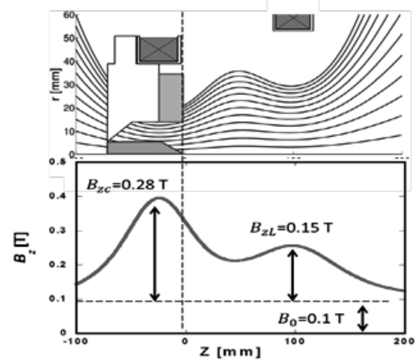

Fig.1: Magnetic field lines and strength of the magnetic Laval nozzle, together with the MPD arcjet configuration.

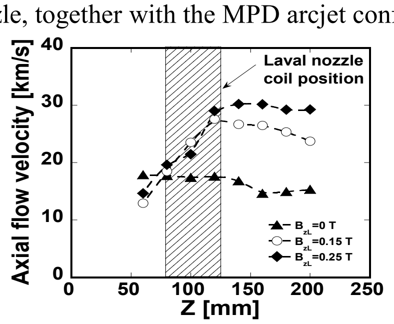

Fig.2: Measured axial flow velocity along the axis for three different magnetic field configurations, where the discharge current is chosen as 4 kA.

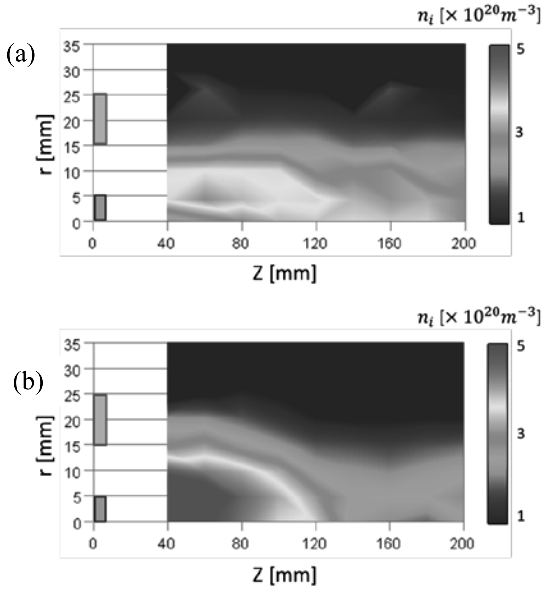

Fig.3: Two dimensional profiles of the plasma density for (a) B_{zL} = 0 T and (b) B_{zL} = 0.25 T, where the discharge current is maintained at I_d = 4 kA..

The solenoids can provide a uniform magnetic field of about 0.1 T as a background magnetic field. The MPD arcjet plasma source having a two small solenoids is attached to one end of the HITOP. The field line generated by the two solenoids is shown in Fig.1. By pulsing the electric current supplied to the small solenoids, the divergent and magnetic Laval nozzles can be formed. The magnetic field strength at the plasma source (B_{zc}) and at the Laval nozzle throat (B_{zL}) are changeable by using the two pulsed circuit. In this experiments, the working gas is chosen as helium and the mass flow rate is maintained at 38 mg/s.

Figure 2 shows the axial profiles of the axial plasma flow velocity for three different magnetic field configurations, where the flow velocity is estimated by the Mach probe calibrated by the Doppler shift of the optical emission. It is clearly observed that the axial flow velocity increases when applying the magnetic Laval nozzle, compared with that in the simple divergent magnetic nozzle (B_{zL}= 0 case). Two-dimensional profiles of the plasma density is taken for the typical two magnetic field configurations of B_{zL}= 0 and 0.25 T cases, respectively, as shown in Fig. 3. The strong density gradient near the throat and the high plasma density near the thruster exit are observed only for the case of B_{zL} = 0.25 T, i.e., the Laval nozzle configuration. The fast plasma flow induced by the magnetic Laval nozzle seems to be due to the presence of the pressure gradient near the nozzle throat [3].

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[3]Y. Kobayashi *et. al.*, The 34th International Electric Propulsion Conference, IEPC-2015-168 (2015).