## §12. Plasma Flow Control in a Magnetic Nozzle

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Recently, the production and control of a fast-flowing plasma are of growing significance not only for clarifying various MHD phenomena observed in space and fusion plasmas but for developing advanced electric propulsion systems and applying in various industrial researches.

Magnetic nozzle acceleration in a fast-flowing plasma attracts much attention as a new control method of flow energy in various applications. We have investigated control of supersonic and super-Alfvénic flow by using a magnetic nozzle in the HITOP device.[1),2)]

A fast-flowing plasma with $M_i$~1 is generated by using a Magneto-Plasma-Dynamic Arcjet (MPDA) shown in Fig.1, which is attached at the HITOP device. [3),4)] Various profiles of an axial magnetic field up to 0.1T can be generated by external coils in the HITOP. An additional small coil was attached on the MPDA in order to form an expanding magnetic nozzle field near the MPDA. Additional magnetic field strength at the coil position $B_{zp}$ was changed up to 0.5T. The configurations of magnetic field at the MPDA are shown in Fig.2.

In plasmas there are azimuthal current $I_\theta$ caused by a diamagnetic current and a hall current. Axial force appears $I_\theta$ x $B_r$, where $B_r$ is in a divergent magnetic nozzle. We have investigated the effect of the magnetic nozzle to plasma acceleration.

Figure 3(a) and (b) show electron density and plasma flow velocity measured at 1.3m downstream from the MPDA. The electron density $n_e$ increased with the discharge current $I_d$. The flow velocity $U$ also increased slightly with $I_d$. In case (a), where the nozzle position was located at upstream from the muzzle, $n_e$ and $U$ increased by adding the magnetic nozzle. Whereas, they decreased in case (c), where the nozzle position was located at downstream.

The exhausted plasma flow was measured by a pendulum type thrust target. It measured impulse bit of plasma flow with pulse duration of 1ms. Thrust $F$ and specific impulse $I_{sp}$ were derived by using the target. They are shown as a function of $I_d$ in Fig.3(c). $F$ and $I_{sp}$ increased by adding the magnetic nozzle, especially in case(a). These dependences correspond well to those of $n_e$ and $U$. These data show that plasma flow can be controlled by magnetic nozzle as well as discharge current of the MPDA.

1) A.Ando, *et.al.*, A. Ando, et al., Trans. JSASS Space Tech Japan, **7** (2009) Pb_35.
2) M. Inutake, *et.al.*, Plasma Phys. Cont. Fusion, **49** (2007) A121.
3) A.Ando, *et.al.*, Transaction of Fusion Science and Technology, **51** (2007) 72.
4) H. Tobari, *et al.*, Physics of plasmas, **14** (2007) 093507.

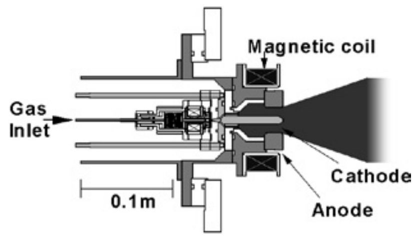


Fig. 1 Schematic of an MPD arcjet

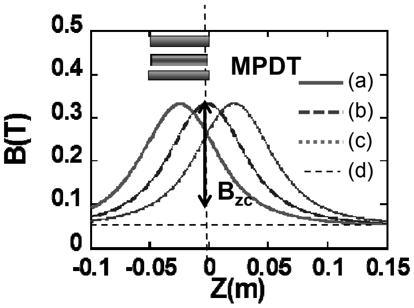


Fig. 2 Magnetic field profiles applied to the MPD outlet.

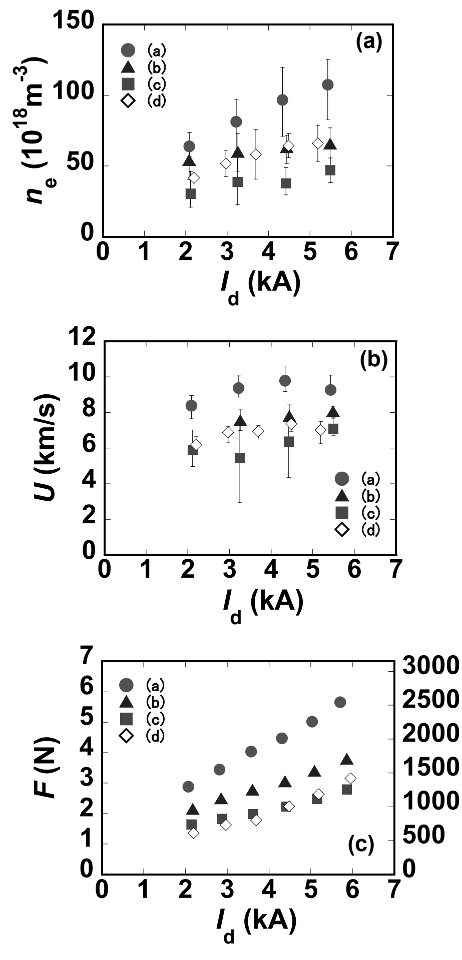


Fig. 3 Dependences of (a)$n_e$ , (b)$U$, (c)$F$ and $I_{sp}$ on discharge current $I_d$.