§3. Plasma Heating and Flow Control in a Fast-flowing Plasma

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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.

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

The exhausted fast-flowing plasma expands through the magnetic field and deforms it due to the high beta effect. This deformation enables the plasma to detach from the magnetic field. In order to elucidate the magnetic field deformation by the plasma flow, magnetic field and Mach numbers (ion Mach number M_i and Alfvén Mach number M_A) were measured by the Alfvén Mach probes, which is composed of a conventional Mach probe and a magnetic probe.

A fast-flowing plasma with M_i~1 is generated by using a Magneto-Plasma-Dynamic Arcjet (MPDA) 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. The configuration of the typical magnetic field, 100mT upstream and 2mT downstream, is shown as a solid line in Fig.1. When the plasma flows into the diverging magnetic nozzle, M_i increased above unity and attained to 2 as shown in the figure. Plasma flow velocity was 30km/s measured by a time-of-flight method of an ion saturation current. Electron temperature was 2eV and ion temperature was 8eV measured by a retarding energy analyzer. T_i was several times larger than T_e in Ar plasma. Although M_i was over unity, M_A was lower than unity. The decrease of axial magnetic field ΔB_z was observed due to the diamagnetic effect of the plasma. It gradually approached to zero due to the decrease of plasma density.

An additional small coil was attached to 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. With applying the additional magnetic field near the MPDA, plasma density, temperature and flow velocity drastically increased. Figure 2 shows axial profiles of M_i, M_A and ΔB_z observed at B_zp=0.38T with a discharge current I_d=7.1kA. Electron temperature attained to 4eV and flow velocity was 60km/s. M_i was lower than that in Fig.1, since electron and ion temperature increased. Due to the increase of plasma density and velocity, M_A strongly increased and attained to 1.5. Here, the supersonic and super-Alfvénic flow was obtained.[5)] It should be noted that ΔB_z became positive near the position where M_A started to increase. This increase caused by paramagnetic effect of magnetic filed, that is the magnetic field deformation occurred by the plasma flow. This deformation related to the plasma detachment phenomena and further investigation is necessary.

1) A.Ando, *et.al.*, Physics of Plasmas, **13** (2006) 057103.
2) A.Ando, *et.al.*, Transaction of Fusion Science and Technology, **51** (2007) 72.
3) H. Tobari, *et al.*, Physics of plasmas, **14** (2007) 093507.
4) M. Inutake, *et.al.*, Plasma Phys. Cont. Fusion, **49** (2007) A121.
5) R.Aramaki, *et al.*, Proc. of APFA2009, (Aomori), **1** (2009) 103.

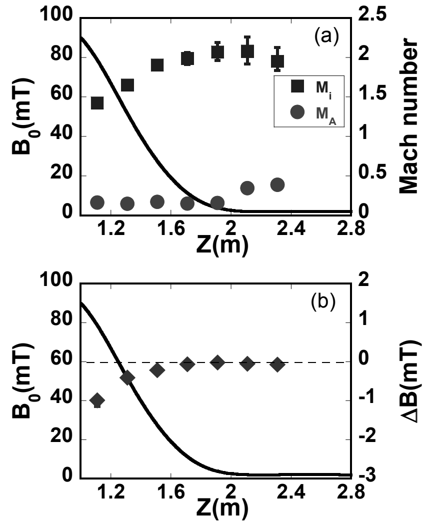

Fig. 1 Axial profiles of (a) M_i , M_A and (b) ΔB_z with the magnetic field strength (solid lines). Discharge current I_d=5.3kA, additional field B_zp=0, Ar plasma.

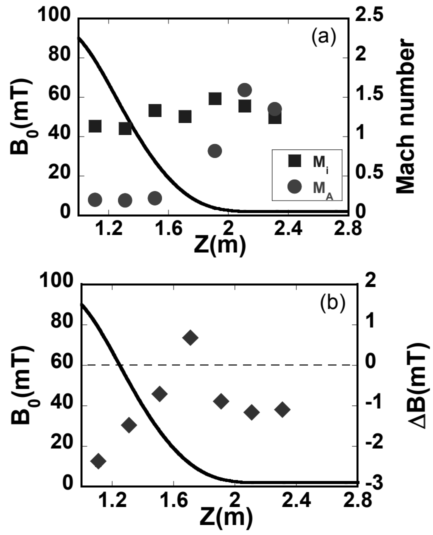

Fig. 2 Axial profiles of (a) M_i , M_A and (b) ΔB_z with the magnetic field strength (solid lines). Discharge current I_d=7.1kA, additional field B_zp=0.38T, Ar plasma.