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

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Recently, the production and control of fast-flowing plasma are of growing significance for clarifying various MHD phenomena observed in space and fusion plasmas, for developing advanced electric propulsion systems and for 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 ion heating and acceleration in a magnetic nozzle using helium and hydrogen gases in the HITOP device.[1),2)] Ion heating were occurred by ion cyclotron resonance heating and increased thermal energy was converted to flow energy by passing through a diverging magnetic nozzle.

In order to evaluate the produced plasma flow properties, behaviors and its physical mechanism, a Mach numbers is one of the significant parameters. The purpose of this research is to evaluate and control plasma flow Mach number by various magnetic nozzles.

Mach number is defined as a ratio of a flow velocity to a specific propagation velocity in the media. In a magnetized plasma, there are two typical Mach numbers, an ion Mach number M_i and an Alfvén Mach number M_A, which are defined as the following equations,

$$M_i = \frac{U}{C_s} = \frac{U}{\sqrt{(\gamma_e T_e + \gamma_i T_i)/m_i}} , \quad (1)$$

$$M_A = \frac{U}{V_A} = \frac{U}{B/\sqrt{\mu_0 n_i m_i}} , \quad (2)$$

Here, U, C_s, and V_A are a plasma flow velocity, an ion acoustic velocity, an Alfvén velocity.

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. An additional small coil is attached to the MPDA in order to form a Laval-type or diverging magnetic field near the MPDA as shown in Fig.1. Magnetic field strength at the coil position was changed up to 0.3T. The MPDA can generate a supersonic plasma flow with ion Mach number of nearly unity.

In order to evaluate M_A and M_i simultaneously, we have newly developed an Alfvén Mach probe, which is composed of a conventional Mach probe and a magnetic probe. We have measured the Mach numbers in the plasma flow passing through various magnetic nozzles.[5)] The configuration of the typical magnetic field profile, 100mT upstream and 2mT downstream, is shown in Fig.2. As the magnetic field in the downstream region decreased, M_A gradually increased. With the increase of the discharge current and magnetic field B_{zp} at the muzzle of the MPDA, T_i and n_e increased. It resulted in the decrease of M_i and increase of M_A. As is shown in Fig.2, M_A and M_i attained more than unity in the downstream of the magnetic nozzle. Here, an ion Hall parameter was more than unity and ion Larmor radius was smaller than the plasma radius. As M_A and M_i attained more than unity with the magnetic Reynolds number of more than several 10s, the super sonic and super Alfvénic plasma flow was generated.

We have measured various plasma parameters with several noble gas species (He, Ar, Ne, Kr). Effects of magnetic configuration, discharge current, and gas pressure, are also investigated in order to evaluate mass effect of the working gases.

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.

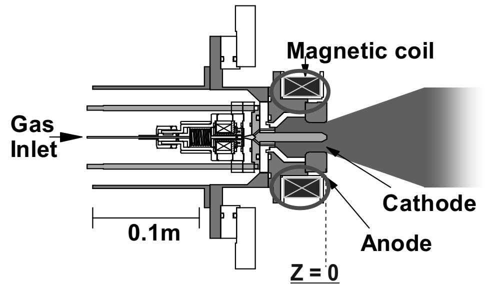

Fig. 1 MPDA with an additional magnetic coil

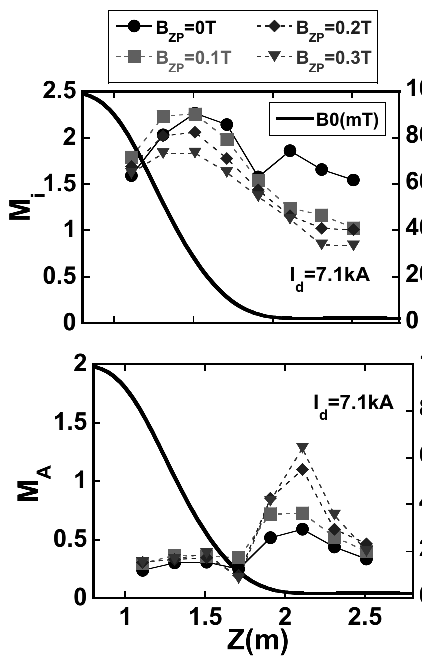

Fig. 2 Axial profiles of M_i and M_A. Discharge current is 7.1kA. He plasma.