§9. Formations of a High-speed Plasma Flow in a Divergent Magnetic Field and an Electrostatic Potential Structure

Ando, A., Izawa, Y., Suzuki, K., Takahashi, K. (Dept. Electrical Eng. Tohoku Univ.),
Nagoka, K.

Recently, formations of electric field and plasma structures and suppression of a plasma fluctuation are found to be associated with plasma flow dynamics and vigorously investigated; hence, the formations and applications of the high speed plasma flow are recently important research topic to guide the plasma physics and fusion technology. The plasma flow generation using a magnetic nozzle has been investigated for a long time. More recently, much attention is focused on combination of the magnetic nozzle plasma acceleration and the ion cyclotron resonance heating for development of an electric propulsion device [1].

This work is aimed to clarify the detailed plasma flow dynamics and the resultant formation of the structural electric/magnetic field and electric current in magnetic nozzle field. This will contribute to identify the major mechanisms of the plasma flow acceleration, e.g., hall acceleration and swirl acceleration. Further the experimental observation of the plasma detachment from the applied magnetic field also contribute to develop the high power electric propulsion device, which can be efficiently performed by using the control and analytic technique for fusion plasmas. Here the work is focused on the acceleration of the magnetoplasmadynamic (MPD) arc-jet plasma flow under the divergent magnetic nozzle. The present work clearly demonstrates the efficient plasma acceleration by adding a Laval-nozzle-like magnetic nozzle.

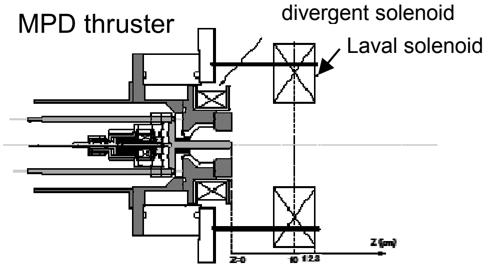

Fig. 1 Schematic diagram of the AF-MPD attached to HITOP device.

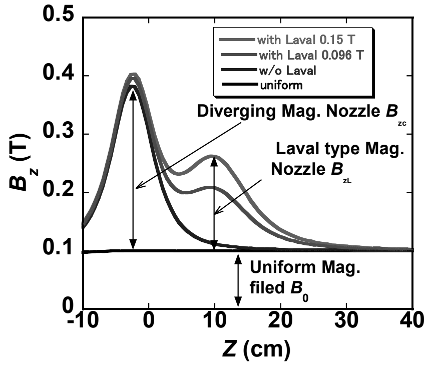

Fig.2 Magnetic field profiles on axis.

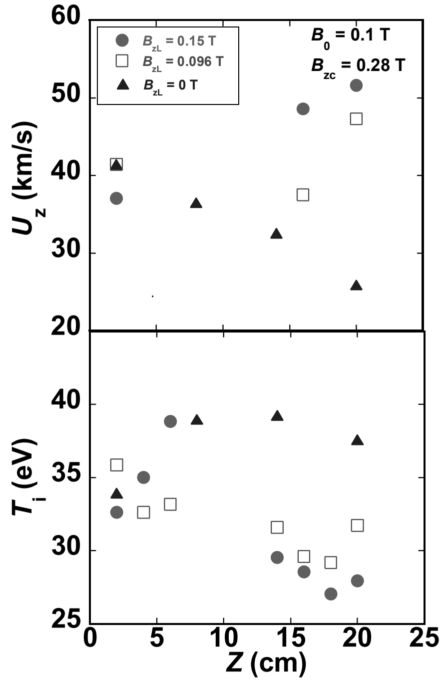

Fig. 3 Axial profile of the plasma flow velocity U_z and ion temperature T_i.

The MPD arc-jet, shown in Fig. 1, is contiguously attached to the HITOP machine of Tohoku University. A uniform magnetic field of ~1kGauss is applied by solenoids surrounding the vacuum tank; further the divergent magnetic nozzle and the Laval magnetic nozzle are applied by additional solenoids located near the thruster head and downstream of the thruster exit. The calculated magnetic fields tested in the present experiment are plotted in Fig. 2. The plasma flow velocity and the ion temperature are measured by optical diagnoses for the various magnetic field structures.

Figure 3 shows the axial velocity U_z of the plasma flow and the ion temperature T_i on axis for the magnetic field profiles shown in Fig. 2, where 7.7 cm < Z < 12.3 cm corresponds to the axial location of the Laval nozzle and the measurement could not be done. The results for the simple divergent magnetic nozzle (B_{zL} = 0 T) show a decreasing flow velocity and increasing ion temperature on axis, which indicate the plasma flow energy is thermalized. By adding the Laval nozzles (B_{zL} = 0.096 and 0.15 T), the plasma flow velocity is successfully increased; then the ion temperature is maintained less than 30 eV. This demonstrates that the thermal energy is re-converted into the plasma flow energy by the presence of the Laval nozzle. Simultaneously the thrust measured by a pendulum target force balance increases (not shown here) and the effect of the Laval nozzle on propulsion performance is demonstrated [2].

(1) A. Ando, et al., Trans. JSASS Space Tech Japan, **7**, Pb_35 (2009).
(2) Y. Izawa, et al., JPS Conf. Proc., **1**, 015046 (2014) .