§5. Plasma Acceleration in a Diverging Magnetic Field

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Plasma flow plays an important role in laboratory and astrophysical phenomena, and also important in the development of efficient space propulsion system. Usually “magnetic nozzle effect” is considered to produce a fast ion flow, however, it is still uncertain whether electromagnetic acceleration is effective for ion acceleration, because there always presents an electrostatic field in inhomogeneous plasmas and we may expect the electrostatic acceleration. To clarify the ion acceleration mechanism in an inhomogeneous plasma, we are carrying out ion flow measurement using the HYPER-I device.

The ion flow velocity along the magnetic field has been measured with a directional Langmuir probe (DLP)$^{1)}$. It is found that the ions are accelerated up to M=1 and the velocity saturates, where M is ion Mach number. In the saturation region, the ions start rotating around the plasma axis. The initiation of azimuthal rotation corresponds to breaking of ion magnetization, in which the electrons are still magnetized. This result suggests that the ion rotation is driven by the radial electric field, which is induced from the charge separation generated by the difference of stream lines of the ions and electrons. The axial electric field measurement shows that the ion acceleration is attributable to the axial electric field$^{2)}$.

Plasma is produced by electron cyclotron resonance (ECR) heating with a microwave (frequency 2.45 GHz) injected from an open end of the cylindrical vacuum chamber. Argon gas is used in the present experiments, and its pressure is 0.1-0.4 mTorr. The ion flow velocity is measured at 4 positions located between z=1.17m to 1.82m from the microwave launching point (open end of the chamber). At each position, axial and azimuthal velocities are measured with a DLP. An axial DLP is introduced from another end of the device, and the axial flow velocity profile and the plasma potential have been measured.

Figure 1 shows the axial dependence of ion saturation current and axial flow velocity normalized by ion sound velocity. The electron temperature is almost constant along the magnetic field, thus Fig.1(a) shows the axial profile of plasma density. The magnetic field intensity weakly decreases in the region z < 1.6 m, and then exhibits a substantial change along the axis. The plasma density monotonically decreases along the axial direction, but the flow velocity clearly indicates acceleration and saturation as flowing from upstream region to downstream region. The velocity saturation roughly agrees with that the substantial change in field intensity takes place (z = 1.6 m).

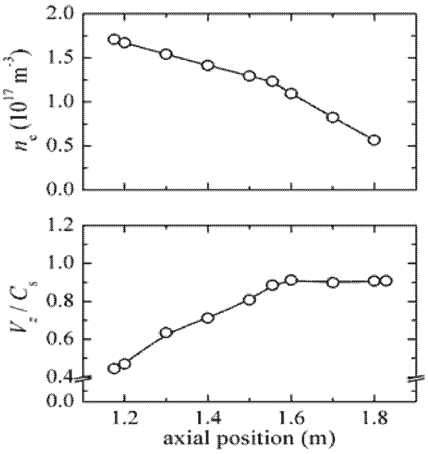

Fig.1 (a): axial profile of ion density, (b): normalized axial flow velocity

The azimuthal velocity profiles measured at 4 different axial-positions are shown in Fig.2. Far upstream region, the plasma doesn’t rotate (z=1.2 m). As we go from the upstream region to the downstream region, plasma rotation becomes fast and there is also a substantial change in rotation velocity at z =1.6 m. The flow vector field measurement revealed that the ion stream line deviates from the field line and tends to flow straight in the region z > 1.6 m, while the electrons are magnetized to move along the field line and radially diffuse faster than the ions. Accordingly, plasma potential becomes a positive hill, producing a radial electric field. The plasma rotation in the downstream region is attributable to the ExB drift of this electric field.

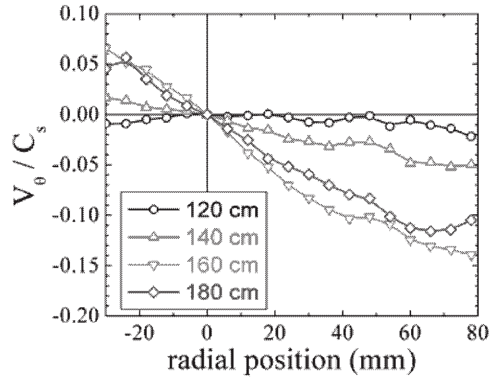

Fig.2 Azimuthal rotation velocity profile measured at 4-different axial positions.

1) Nagaoka K. *et. al.*, J. Phys. Soc. Jpn 70 (2001) 131
2) Terasaka K *et. al.*, Plasma Fusion Res. Series (2009) in press .