§3. Anti-E×B Vortex Observed in the HYPER-I Device

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Researches on vortex in plasmas have been developed with drift wave study[1], and have been vigorously carried out in terms of electrostatic instabilities. This has been a natural consequence of treating plasma vortex as *E*×*B* rotation induced by the electrostatic instabilities. We have observed, however, anti-*E*×*B* rotating vortex in the HYPER-I device.[2,3]

When a plasma is produced at a pressure 3×10^{-2} Torr (Argon), tripolar vortex structure is observed. Two-dimensional vector field of ion flow has been measured with a pair of directional Langmuir probes and is shown in Fig. 1, where the ion density contour is superimposed. Two clockwise vortices are situated at the density humps, while a counterclockwise vortex at the center density dip. The rotation directions of all the vortices are opposite to the *E*×*B* drift, which is revealed by potential profile measurement; it is the most remarkable feature of the tripolar vortex observed here. The radial profile of the electrostatic potential measured along the horizontal chord (y = 0cm) is shown in Fig. 2. Around the counterclockwise vortex (x ~ 0cm) the electric field is radially inward with respect to the center of the vortex, and around the clockwise vortex (x ~ 5cm) vice versa. The *E*×*B* rotation directions are determined by the direction of the magnetic field indicated in the upper right of the Fig. 2, and are apparently opposed to the experimental result. Since the directions of rotation are reversed by the inversion of polarity of the magnetic field, this unusual result implies that the vortices rotate to $F\times B$ direction due to a certain force F and that the force is opposed to and larger than the electric force. It should be noted that anti-*E*×*B* vortices are situated within hollow structure of neutral density and surrounded by steep density gradient of neutral particles as indicated in Fig. 2. Neutral particles tend to flow against the gradient due to diffusion process. Then the velocity of neutral particles is given as $\mathbf{v}_\mathrm{n} = -D\nabla\log n_\mathrm{n}$, where D denotes the diffusion coefficient. Anti-*E*×*B* vortices are emerged under relatively high pressure condition, so that ion-neutral charge-exchange interaction frequently occurs and consequently momenta of ion and neutral particle exchange each other. This momentum exchange acts on ions as an effective force due to density gradient of neutral particles. Then the ion velocity perpendicular to the magnetic field is represented as

$$\frac{\mathbf{v}_{\mathrm{i}\perp}}{C_\mathrm{s}} = \frac{\omega_\mathrm{ci}^2}{\omega_\mathrm{ci}^2+\nu^2}\frac{C_\mathrm{s}}{\omega_\mathrm{ci}}\left[\mathbf{e}_z\times\nabla\frac{e}{T_\mathrm{e}}\phi + \frac{\nu D}{C_\mathrm{s}^2}\mathbf{e}_z\times\nabla\log n_\mathrm{n}\right],$$

where ω_ci and ν are ion cyclotron frequency and collision frequency of ion to neutral particles, respectively. The second term in the square bracket of the right hand side represents *F*×*B* drift due to neutral density gradient, while the first term usual *E*×*B* drift. Above equation qualitatively explains the measured velocity profile.

Up to now, interaction between plasma and neutral particles has been neglected in plasma dynamics, however, the interaction can change plasma dynamics in the case of high neutral density.

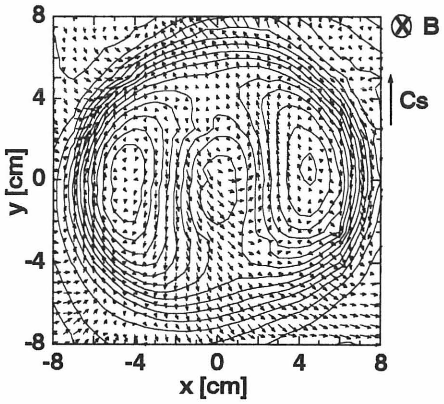

Fig. 1 Velocity vector field and plasma density contour of tripolar vortex

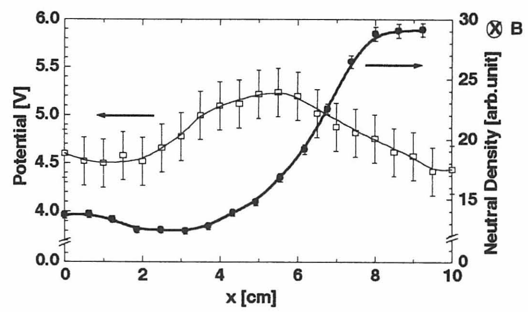

Fig. 2 Potential (□) and neutral density (●) profile of tripolar vortex

Reference

1) Hasegawa, A. and Mima, K.: Phys. Rev. Lett. 39 (1977) 205

2) Okamoto, A. et al.: J. Plasma Fusion Res. SERIES, 4 (2001) 363

3) Okamoto, A. et al. : Phys. Plasmas, to be submitted