§ 2. Vorticity Distribution of an Anti-$E \times B$ Tripolar Vortex in a Charge-Exchange Dominated Plasma

Okamoto, A., Nakano, H., Hara, K. (Nagoya Univ.)
Kono, M. (Chuo Univ.)
Vranješ, J. (K.U. Leuven)
Nagaoka, K., Yoshimura, S., Tanaka, M.Y.

Recently, vortex formation has been attracting much attention in connection with researches on structure formation, transport phenomena, and turbulent flow in plasmas, and accordingly there is an increasing demand for a way to measure the vorticity distribution experimentally.

Perpendicular flow velocity of a plasma with an external magnetic field is usually given by the $\boldsymbol{E} \times \boldsymbol{B}$ drift and the diamagnetic drift. The vorticity distribution is then determined by measuring both the potential and density profiles or by directly measuring the flow velocity vectors in order to utilize $\nabla \times \boldsymbol{v}$. In a charge-exchange dominated plasma, however, the vorticity distribution of the ion flow field can be determined from the neutral density profile. An experimental example is given here.

We have observed that a tripolar vortex occurs in an argon plasma, and more interestingly the ion flow direction is opposite to that of the $\boldsymbol{E} \times \boldsymbol{B}$ drift.[1] This result indicates the existence of an effective force acting on the ions other than the radial electric force. To explain the mechanism of anti-$\boldsymbol{E} \times \boldsymbol{B}$ vortical motion, we consider the equation of motion for ions under charge-exchange dominant conditions. The perpendicular flow velocity for ions is then given by

$$v_\perp = \frac{1}{\omega_{ci}^2 + v_{in}^2}\Big[\frac{e}{M}(\omega_{ci}\boldsymbol{e}_z \times \nabla_\perp \phi - v_{in}\nabla_\perp \phi) + v_{Ti}^2(\omega_{ci}\boldsymbol{e}_z \times \nabla_\perp \log n_i - v_{in}\nabla_\perp \log n_i) + (\omega_{ci} v_{in} D_{eff}\boldsymbol{e}_z \times \nabla_\perp \log n_n - v_{in}^2 D_{eff}\nabla_\perp \log n_n)\Big], \quad (1)$$

where v_{in} is the charge exchange collision frequency, and D_{eff} is the effective diffusion coefficient. The term $\omega_{ci} v_{in} D_{eff}\boldsymbol{e}_z \times \nabla_\perp \log n_n$ represents the $\boldsymbol{F} \times \boldsymbol{B}$ drift motion due to the effective force, which originates from the rate of change of momentum during the charge exchange process per unit volume. Taking the *curl* of the above equation and taking our experimental conditions into account, the z-component of vorticity is determined only by the neutral density profile:[2]

$$\omega_z \propto \nabla_\perp^2 \log n_n . \quad (2)$$

It is emphasized that the quantity $\log n_n$ becomes the stream function of the ion flow field in this case.

We have measured the perpendicular velocity and the neutral density profile, and compared the z-component of $\nabla \times \boldsymbol{v}$ with $\nabla_\perp^2 \log n_n$. Figure 1(a) shows the z-component of vorticity distribution determined by the flow velocity field. In the figure, the positive vorticity is localized in the central region, while the negative one in both sides of the center vortex, forming a tripolar structure: a three aligned vortices with alternate signs of polarity of rotation.

Figure 1(b) shows the contour map of $\nabla_\perp^2 \log n_n$. The neutral density profile n_n was determined by the ratio of the ArI (425.9 nm) intensity to the square root of ArII (488.0 nm) intensity. The second-order derivative of neutral density profile $\nabla_\perp^2 \log n_n$ was obtained by using the Fast Fourier Transform, in which the short wavelength modes (noises) were removed. The contour map shown in Fig. 1(b) also exhibits a tripolar structure fairly similar to that shown in Fig. 1(a), indicating that the effective force due to neutrals in fact dominates the radial electric field.

The importance of our experimental results lies in the fact that the effective force generated by the neutral density profile may overcome the ambipolar electric field in a charge exchange-dominated plasma. In such a circumstance, the logarithm of the neutral density profile acts as the stream function, which makes it possible to obtain the vorticity distribution without laborious measurements of the flow velocity field.

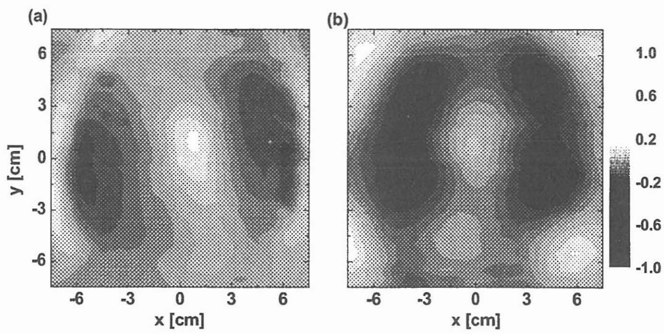

Fig.1 (a): Vorticity distribution obtained by $\nabla \times \boldsymbol{v}$;
(b): Contour map of $\nabla_\perp^2 \log n_n$.

Reference

1) Okamoto, A. et al. : Phys. Plasmas **10**, (2003) 2211
2) Okamoto, A. et al.: J. Plasma Fusion Res. **78**, (2002) 1143