§3. Measurement of Supersonic Flow Velocity with Directional Langmuir Probe

Okamoto, A. (Univ. Tokyo)
Yoshimura, S., Tanaka, M.Y.

Plasma flow has been one of interesting topics in laboratory plasmas, confined plasmas as well as astrophysical plasmas. Recently, a sharply-peaked electrostatic potential is spontaneously formed in an ECR plasma,[1] generating a supersonic $E \times B$ rotation of the plasma. To investigate the supersonic rotation, development of supersonic flow measurement has been required. We previously proposed a model to obtain flow velocity with directional Langmuir probe (DLP),[2] which is based on the property of symmetry of ion current in a flowing plasma. In this paper, the effect of supersonic flow on the DLP current is presented, and our previously proposed method is extended to the supersonic region.

A directed ion current is collected by the DLP through a small opening (1 mm diam) made on the side wall of the ceramic insulator (3 mm diam). In subsonic flow case, the ion saturation current is modified by the effect of flow velocity, $F_v \propto \cos\theta$, and magnetic field, $F_B \propto \cos 2\theta$, and is expressed as $I_s(\theta) = I_0(1+F_v)(1+F_B)$. Thus the ion flow velocity at a certain angle θ with respect to the reference axis, $v(\theta)$, is obtained by measuring two ion saturation currents, $I_s(\theta)$ and $I_s(\theta+\pi)$, and by using the following relation:

$$\frac{v(\theta)}{C_s} = \frac{1}{\alpha} \frac{I_s(\theta+\pi) - I_s(\theta)}{\left[I_s(\theta+\pi) + I_s(\theta)\right]/2} \qquad (1)$$

where C_s the ion sound speed. The factor α is of the order of unity.

The experiments have been performed in the high-density plasma experiment (HYPER-I) device at the National Institute for Fusion Science. In this experiment, azimuthal rotation of helium plasma is driven by the $E \times B$ drift induced by the sharply-peaked electrostatic potential. We have measured the ion flow velocity at two radial positions: (a) r = 30 mm, supersonic region, and (b) r = 70 mm, subsonic region. Taking the Fourier amplitude of experimentally obtained $\Delta I / \langle I \rangle$ (where $\Delta I = I_s(\theta+\pi) - I_s(\theta)$, and $\langle I \rangle = [\, I_s(\theta+\pi) + I_s(\theta)\,]/2$, respectively) shows that the amplitude of fundamental mode is proportional to the flow velocity in the subsonic flow. The higher modes are negligible compared to the fundamental mode, showing the validity of DLP method.

In the supersonic flow measurement, however, the amplitude of higher odd modes, $m = 3, 5, \cdots$, are not negligible (see Fig. 1). The phase of the higher mode (m=3) has a characteristic feature in the supersonic flow case. It is nearly 180 degrees different from that of fundamental mode (see Fig. 2). This result sharply contrasts with that of the subsonic flow case, where the phase difference between these modes is not clear and the amplitude of m=3 mode is negligibly small. The appearance of $m = 3, 5, \cdots$ modes may be related to the existence of supersonic flow; the probe immersed in a supersonic flow may change the flow field around the probe, because compressibility becomes important.[3] In this situation, the flow effect on ion current, F_v, may have the higher order correction terms. A simple model including the higher modes due to flow field distortion is formulated to evaluate the supersonic flow velocity, extending applicability of the previously proposed DLP method. There is a good agreement between the predicted value and experimental one.

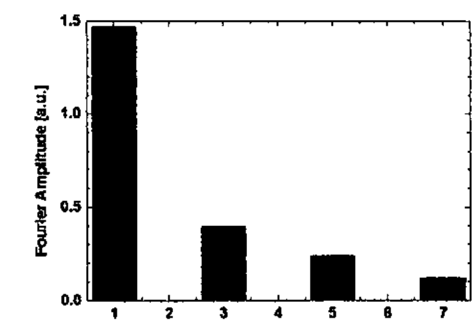

Fig. 1 Fourier amplitude of $\Delta I / \langle I \rangle$ in a supersonic flow.

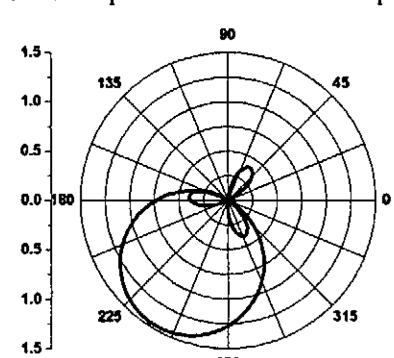

Fig. 2 Polar plot of Fourier components m=1,3

Reference

1) Nagaoka, K. et al. : Phys. Rev. Lett. **89**, (2002) 075001

2) Nagaoka, K. et al. : J. Phys. Soc. Jpn. **70**, (2001) 131

3) Okamoto, A. et al. : J. Plasma Fusion Res. SERIES **6**, (2004) in press