# §16. Measurement of the Non-Parallel Flow Velocity Using a Mach Probe in Divertor-Simulating Weakly Magnetized Plasmas (NIFS04KOAB009)

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Plasma flow patterns are linked to the various kinds of phenomena both in fusion-relevant magnetic confinement devices and laboratory plasmas. The flow usually has components parallel and perpendicular to the magnetic field direction and the both are needed to be known. Although diagnosing techniques of parallel flow have been widely investigated so far, there is still an interest to identify the perpendicular flow which determines various kinds of plasma phenomena.

As a technique to obtain the magnitude and direction of the local flow velocity, Mach probe has been investigated. In a previous paper [1], we have revealed that similar size of ion gyro-radius and probe tip causes the strong dependence of ion collection on probe geometry. In order to compensate for the effect of probe geometry, we derived a practical formula based on the unmagnetized models with eliminating the effect of magnetic field. Theoretically this formula can be applied to the perpendicular flow as well as the parallel flow. However, the experimental confirmation of its applicability is an important task.

In the Mach probe experiment, the ion current angular distribution in unmagnetized plasmas can be expressed as $j(M,\theta) = j_0 \exp(-KM\cos\theta/2)$, where $j_0$ is the unperturbed ion current density, $K$ is a model dependent constant, $M$ is the Mach number defined as $M = v_f/c_s = v_f/[(T_e+T_i)/m_i]^{1/2}$ with $v_f$ being the flow velocity, $c_s$ is the ion sound velocity, $m_i$ is the ion mass, $T_e$ and $T_i$ are the electron and ion temperatures, and θ is the polar angle relative to the direction of flow. In our previous work, the above equation was modified from a practical point of view. The difference of probe geometry can be compensated for by integrating the equation over $\theta \pm \Delta\theta$, were Δθ is the collection angle of the Mach probe. In addition, the equation, which is originally derived without taking the effect of magnetic field into consideration, can be applied to weakly magnetized plasmas by taking the ratio of ion currents $j(M,\theta+\pi)/j(M,\theta)$. This procedure can eliminate the magnetic field effect assuming that the effect is independent of the flow field [2]. A practical formula to determine Mach numbers in weakly magnetized plasmas, then, can be written as

$$\frac{\int_{\theta-\Delta\theta}^{\theta+\Delta\theta} j(M,\theta+\pi)d\theta}{\int_{\theta-\Delta\theta}^{\theta+\Delta\theta} j(M,\theta)d\theta} = \exp\left[K\left(M_{//}\cos\theta + M_{\perp}\sin\theta\right)\cdot\frac{\sin\Delta\theta}{\Delta\theta}\right]$$

where $M_{//}$ and $M_{\perp}$ are the parallel and perpendicular Mach numbers which can be determined as the sine and cosine components of the ion current angular distribution, if $K$ is predicted for a specific condition.

The experiment was performed in a linear divertor-simulator MAP-II [3]. A plasma was generated by a low pressure dc-arc discharge and radially confined by axial magnetic field of about 300 Gauss. A typical plasma parameters measured by a single probe were the electron density of $10^{17}$ $m^{-3}$ and electron temperature of 10 eV for hydrogen plasmas. The plasma potential was measured using an emissive probe with a thoriated tungsten wire 0.2 mm in diameter operated at the emission current of 5.3 A. For the Mach probe measurement, a slit-shaped Mach probe (SP) [1] with the collection angle of Δθ~50 degrees (sinΔθ/Δθ~0.88) was installed and rotated by a stepping motor. The SP consists of an $Al_2O_3$ insulator 4 mm in diameter and a tungsten electrode 5 mm in diameter.

In cylindrical plasmas the azimuthal rotation is induced by the $\mathbf{E}\times\mathbf{B}$ and ion-diamagnetic drifts. The radial profiles of plasma parameters were measured to calculate the drift velocities using the single and emissive probes in the different magnetic field conditions (121 and 205 Gauss). In the MAP-II device, a negative plasma potential is formed as a result of the ambipolar diffusion so that the $\mathbf{E}\times\mathbf{B}$ and ion-diamagnetic drifts have the opposite rotational directions. A comparison of the Mach numbers between the calculation of drift velocities and measurement using the SP is given in figure. In the figure, filled circles show the Mach numbers measured by the Mach probe and open diamonds show that of calculation. Here, a constant ion temperature of $T_i$~1eV was assumed over the whole plasma column and spatial variation of K was neglected. Note that the velocity of ion-diamagnetic drift is small compared to that of $\mathbf{E}\times\mathbf{B}$ so that this assumption does not change the conclusion. In the figure, the Mach numbers obtained by Mach probe with $K = 1.4$ (no magnetic field, $T_i$=0.1$T_e$) [4] shows good agreement with that of calculation even in the case of changing the magnetic field condition.

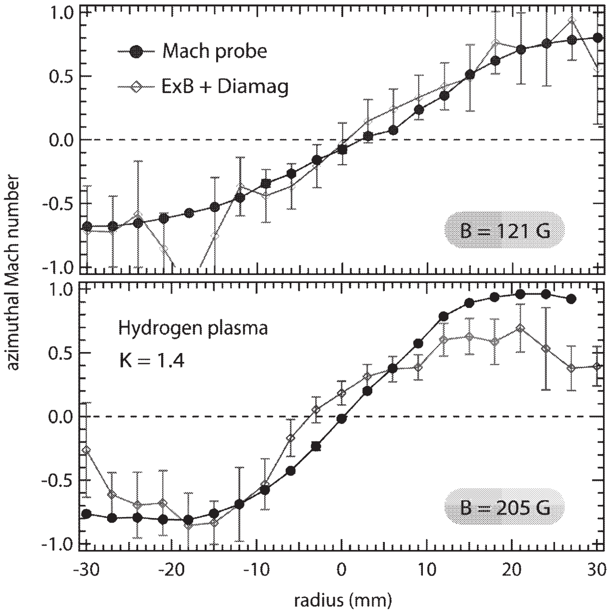

Figure. Radial profile of Mach numbers.

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[4] I.H.Hutchinson, *Plasma Phys. Control. Fusion* **44** (2002) 1953.