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Self-consistent measurement of shear viscosity and flow veocity by using conventional Mach probes in tokamak edge plasmasCharacterization of a Large Area ICP

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Without the knowledge of the normalized viscosity, conventional Mach probes with two electric probes may be just directional probes. By using the analytic solutions[1] of the bounded and free presheaths, there is a way to deduce the flow velocity along with the normalized viscosity. From measured Mach probe data of KT-1 tokamak and previous TEXT-U tokamak, we deduced the Mach number and the normalized viscosity.
[1]Kyu-Sun Chung, Phys. Plasmas 1, 2864 (1994).

Ⅰ. INTRODUCTION

While flow velocity is a key parameter in analyzing edge plasma, it is a difficult problem to accurately measure plasma flows in the edge because of the complexity of theoretical analysis for electric probe measurements, or small Doppler shifts with high spatial resolution needed for spectroscopic techniques. The usual technique for measuring plasma flows is the Mach probe, two directional Langmuir probes which measure the ion saturation currents collected parallel (upstream) and antiparallel (downstream) to the magnetic field. A flux tube(presheath) extends from the Debye sheath surrounding the probe along a flux tube in the direction of the magnetic field.

The transport process of ions filling the flux tube depends not only on the flow velocity but also upon the viscosity of the ions. The ratio of upstream to downstream current densities in a Mach probe is then a function of the flow velocity, usually expressed as the Mach number(M_0), and the normalized shear viscosity (α).

Once α is given, M_0 can be deduced from the measured ratio of current densities from the Mach probe[1-2]. Mach probes have been used to measure the flow velocity in the scrape-off layer of several tokamaks[3-5], and these measurements raise questions regarding the applicability of probe models for data interpretations. Among many models for deducing flow velocity from the Mach probe measurements[6-9], Chung's analytic theory for the free and bounded presheaths is used for the present analysis[9]. While viscosity and flow velocity were measured simultaneously by using a four-pin Visco-Mach probe in the TEXT-U tokamak[10], we present the first simultaneous measurements of shear viscosity and flow velocity using a conventional Mach probe in the TEXT-U and KT-1 edge plasmas[11].

Ⅱ. EXPERIMENTS

TEXT-U is a tokamak with a major radius R_0=1.05m and minor plasma radius a=0.27m defined by three point limiters at a single toroidal location. The plasma was in a rectangular vessel with closest wall at d=0.325m. For the results presented here, the tokamak was operated with a circular plasma with Ohmic heating only and deuterium fueling. Here, the toroidal magnetic field B_t=2.0T, plasma current I_p=170kA with a line averaged density $n_{e0}=4\times10^{19}m^{-3}$. Measured edge parameters for these plasma conditions at the limiter are T_e=30eV, $n_e=2\times10^{18}m^{-3}$ and T_e/T_i=1 are assumed. The probe was mounted on the top of the tokamak, displaced 2.7m toroidally from the limiters in the plasma current direction. KT-1 is a tokamak first operated in Korea, with a R_0 =27cm, a=5cm defined by a closed poloidal limit. Motor driven probe was installed at the side of the tokamak. Present data are analyzed at the condition of the toroidal magnetic field B_t=1.0T and plasma current I_p=5kA. Measured edge parameters at the limiter are T_e =10-30eV, $n_e=10^{11}$-$10^{12}cm^{-3}$. Figure 1 shows the schematic diagram of the probe positions of the TEXT-U and KT-1 tokamaks. In TEXT-U, data was measured by the larger Mach probe of the Visco-Mach probe which is made of two Mach probe arrays where the smaller Mach probe array is located in the presheath of the larger Mach probe array.

In KT-1, a simple Mach probe was used to measure the ratios of ion saturation currents.

Ⅲ. MEASUREMENT AND ANALYSIS

In order to reduce these measured current ratios ($R=J_{up}/J_{down}$) to estimates of M_0, and α, an iteration procedure must be followed by using the theoretical values of $R(M_0,\alpha)$ and $M_0(\alpha)$, which are determined by the specific edge conditions and specific location of a Mach probe along the bounded presheath formed by two limiters. From Chungs analytic theory, the ratio of up-to down stream sheath current density is derived as

$$R(M_\infty)=\left(\frac{(\beta+1)+\beta M_\infty}{(\beta+1)-\beta M_\infty}\right)^{\delta}\times\exp\left[\frac{\alpha M_\infty}{\sqrt{q}}\left(\tan^{-1}\frac{\beta(2-M_\infty)}{\sqrt{q}}+\tan^{-1}\frac{\beta(2+M_\infty)}{\sqrt{q}}\right)\right]$$

where $\beta=1+\alpha$, and these results are shown in Fig. 2 for the free presheaths in both up- and down-stream directions. Along the bounded presheath, the analytic relation between the flow velocity and the here position is given by

$$y(M)=\int_1^{M_0}\frac{(1-M^2)n_m e^H}{G(G^{\delta}-n_m e^H)}dM$$

where $G\equiv1-\beta M_0M+\beta M^2$ and

$$H\equiv\frac{\alpha M_0}{\sqrt{q}}\left\{\tan^{-1}\left[\frac{\beta(2M-M_0)}{\sqrt{q}}\right]-\tan^{-1}\left[\frac{\beta M_0}{\sqrt{q}}\right]\right\}$$

So if one can choose the maximum density(n_m) of a bounded presheath, then the relation between the velocity at a probe position (M_0) and α, i.e., $M_0(\alpha)$ is to be obtained. Figure 3 shows calculated values of $M_0(\alpha)$ for TEXT-U (probe position =460cm from one limiter) and KT-1 (probe position =3.3cm). In order to obtain this figure, the choice of n_m is very important. By changing n_m, we equate the connection length of the scrape-off layer(L_c) to the length of the bounded presheath(L_b) formed by two limiters. The normalized position of the Mach probes for each device is 0.3485 for TEXT-U and 0.0389 for KT-1, respectively. As for TEXT-U, at r=29.5 cm, R_m=1.273±0.027 and as for KT-1, at r=3.3 cm, R_m=7.7±0.82. Deduced values of α and $M_0(\alpha)$ by iteration of $R(M_0, \alpha)$ and $M_0(\alpha)$ are 1.016±0.242 and 0.140±0.001, respectively, while 1.0±0.032 and 0.141±0.040 by the Visco-Mach probe Mmeasurement[10]. As for KT-1 case, the measured value(R_m = 7.7) is so large that calculated value of the Mach number may exceed the maximum value of $M_0(\alpha)$ due to small difference in M_0 for the wide range of α. This may be solved by generating either $R(\alpha, M_0)$ for bounded(downstream)- and free(upstream) -presheaths or $M_0(\alpha)$ with different n_m depending upon the radial position of the probe, and this will be discussed later

Ⅳ. CONCLUSIONS

A new method to measure the flow Mach number and the normalized viscosity is developed for the dege plasmas of the limiter tokamaks, without directly using the Visco-Mach probe. If one knows the ratio of current densities ($R(\alpha, M_0)$) by a Mach probe and flow velocity at the probe position ($M_0(\alpha)$) along the bounded presheath, α and $M_0(\alpha)$ can be deduced by an iteration method. Although this new method shows a possible way to deduce α and $M_0(\alpha)$ simultaneously, the results show the preference of direct use of the Visco-Mach probe for simultaneous measurements of viscosity flow velocity due to small difference in M_0 for the wide range of α.

ACKNOWLEDGMENTS

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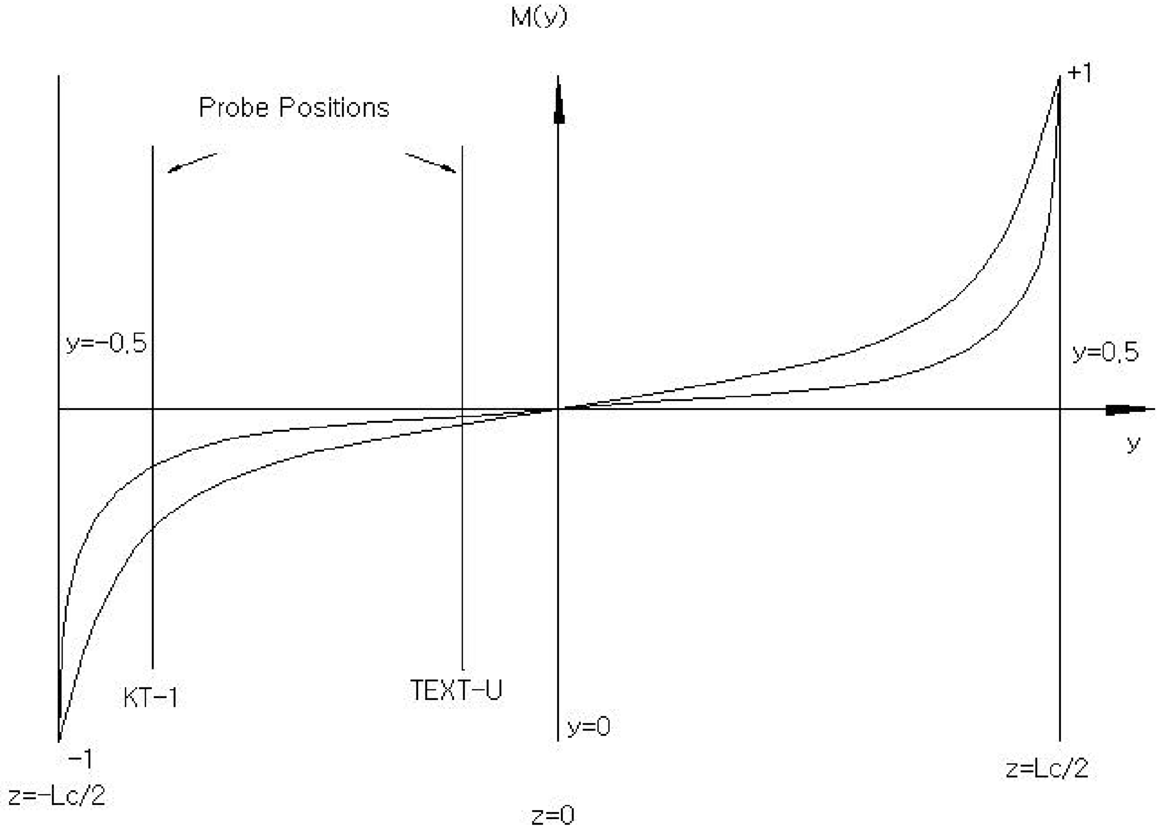

Fig. 1 Profiles of the flow velocity along the bounded presheaths of the TEXT-U and KT-1 tokamaks, Lc(TEXT-U)=1320cm, Lc(KT-1)=84.8cm. probe position of TEXT-U=460cm, probe position of KT-1=3.3cm

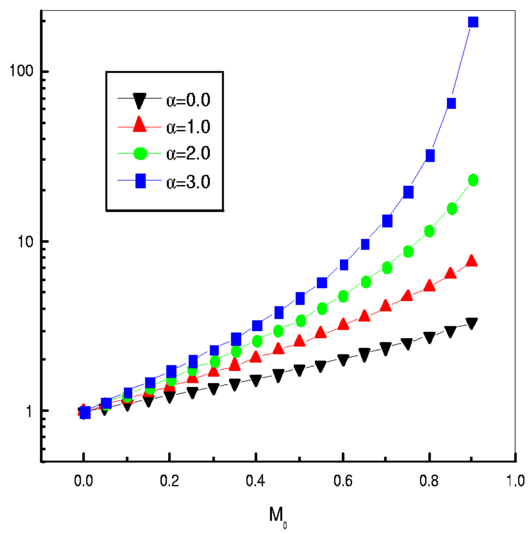

Fig.2 Ratio of current densities in terms of α for $-1<M_0<+1$

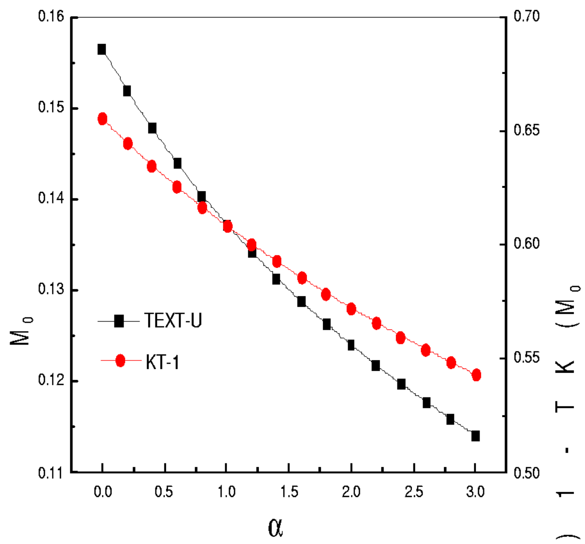

Fig. 3 Flow velocities at the probe position along the bounded presheath in terms of α for TEXT-U and KT-1 tokamaks.