2-D effect of ion dynamics on radial profile of ion temperature in the edge of magnetized plasma

Ion dynamics in the edge region of magnetized plasmas have been studied by comparing experimentally obtained radial profiles of ion temperature with analytical ion mean energy profiles based on the ion Larmor motion. Both radial profiles show the tendency that ion temperature increase at the outside of the plasma column with increasing the radial distance from the plasma center. Two-dimensional model considering the radial profile of magnetized plasma indicates the importance of high-energy ions which have large Larmor radius.

1. Introduction

It is important to understand the edge and the divertor plasmas in order to operate high performance plasmas in magnetic confinement fusion devices. The spatial profiles of ion temperature $T_i$, electron temperature $T_e$ and electron density $n_e$ are the key parameters for characterizing the transport in these boundary plasmas. So far, $T_i$ measurements using an Ion Sensitive Probe (ISP) [1] have been done using a linear plasma device, Compact Test Plasma device with Hot Cathode (CTP-HC), in Nagano National College of Technology. The observed results showed the tendency that $T_i$ becomes high with increasing radial position at the outside of the plasma column [2,3]. A simple analysis about the radial profile of $T_i$ also has been done using one-dimensional (1-D) $T_i$ evaluation model based on ion Larmor motion [4]. According to the model, a probe put at far from the plasma column measures high-energy ions selectively. The analysis model showed the results consistent with experimental one.

In this study, in order to check the influence of two-dimensional (2-D) effect for $T_i$ profile we have measured $T_i$ using an ISP in the linear divertor plasma simulator NAGDIS-II in Nagoya University of which plasma diameter is larger than CTP-HC. The experimental results have compared $T_i$ profiles with 1-D and 2-D models.

2. Experimental setup

Figure 1 shows a schematic of the ISP measurement system in NAGDIS-II. Radial position of the probe can be changed with 2mm in space resolution. In this study, Helium is used for plasma discharge.

3. Analysis model

We consider the behavior of ion which is located at $P(r, \theta)$ in a cross section of a cylindrical plasma, where $r$ is the distance from the plasma center and $\theta$ is an azimuthal angle as shown in Fig. 2. Assuming no diffusion process, the ion at $P(r, \theta)$ can reach a probe position $r_c$ moving a Larmor orbit when it has ion energy $E_i(r, \theta)$. The distance between $P$ and $r_c$ is represented by $l$. At the probe position $r_c$, ions with Larmor radius of $l/2$ are collected. $E_i(r, \theta)$ is ion energy to reach probe head calculated by $l$ and is proportional to squared Larmor radius.
This 2-D model indicates ions with large Larmor radius (higher energy) can reach more outside of plasma column. Therefore, \( T_i \) is expected to show high temperature with increasing radial position.

Considering the all position for the origin of ion, mean energy at the probe position \( T_i(r_c) \) is expressed as follows:

\[
T_i(r_c) = \frac{\int \int n(r,\theta)E_i(r,\theta)F(E_i)drd\theta}{\int \int n(r,\theta)F(E_i)drd\theta}
\]  \hspace{1cm} (1)

Where, \( n(r,\theta) \) is plasma density. \( F(E_i) \) is Maxwell distribution assuming a \( T_i \) in the plasma column at \( P(r,\theta) \).

4. Results and discussion

Figure 3 shows the comparison of the experimentally obtained \( T_i \) profile with analytical results using Eq. (1). Both analyses assume the experimental condition of NAGDIS-II for \( n_e \) profile, gas pressure. \( T_i \) in the plasma column is assumed an exponent profile predicted by the experimental result.

As shown in Fig.3, the experimental result shows the tendency that \( T_i \) becomes high with increasing radial position like CTP-HC. Both analytical results of 1-D and 2-D model also show the same tendency. Hence, the analytical results are qualitatively consistent with the experimental result. However, analytical results show higher \( T_i \) profiles than the experimental result. Furthermore, 2-D analytical result shows higher \( T_i \) profiles than 1-D analytical one.

The reason why the difference caused might be due to lack of some assumptions. One possible reason is diffusing low temperature plasma around plasma column. Another one is the charge exchange reaction of ions during Larmor motion. Moreover parallel transport might be taken into account.

The cause of that 2-D analysis show higher \( T_i \) profile than 1-D could be due to considering more ions on the 2-D analysis than the 1-D analysis.

5. Conclusions

In this study, radial profiles of \( T_i \) have been measured using an ISP in NAGDIS-II. The experimental results show the tendency that \( T_i \) becomes high with increasing radial position. The results of 1-D and 2-D analyses based on the ion Larmor motion were compared with the experimental result. Both analytical results were qualitatively consistent with the experimental result, although the both analytical results showed higher profiles than the experimental result. Moreover, the 2-D analytical result showed higher profile than the 1-D analytical result.

References