Potential profile measurement with heavy ion beam probe on the Large Helical Device

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The radial profile of potential in the core region of the Large Helical Device (LHD) plasma was measured with a Heavy Ion Beam Probe (HIBP). The radial profiles of $E_r$ were estimated from differentiation of the experimental data of HIBP. In relatively low temperature (~0.8keV) and medium density plasmas (~0.5 $\times$ 10^{19} m^{-3}), which is heated by neutral beam injection, the small negative radial electric field was observed. In high electron temperature (~2 keV) and low density plasmas (~0.2 $\times$ 10^{19} m^{-3}), which is heated by NBI and electron cyclotron heating, the positive radial electric field was observed. These $E_r$ profiles were compared with the calculation result from neoclassical theory, and the theoretical prediction almost coincided with the experimental data of $E_r$ in the core region of LHD plasmas.

1. Introduction

The radial electric field $E_r$ is a very important parameter to study plasma confinement in magnetized toroidal plasmas. For example, in improved confinement discharge in tokamaks, the shear flow suppresses the turbulence in plasma and high performance of plasma is realized. In helical configuration, of which magnetic configuration is not axisymmetric, trapped particles in helical ripples enhance diffusion loss in low collision regime, so called in 1/$\nu$ regime (diffusion coefficient is proportional to 1/$\nu$). This helical ripple induced loss is intrinsically non-ambipolar, therefore $E_r$ is formed to satisfy ambipolar condition. This $E_r$ reduces the helical ripple diffusion loss, so the formation of $E_r$ in helical device is important.

In order to study physics of the formation of $E_r$ in LHD, heavy ion beam probe (HIBP) was installed and has been developed [1-3]. We measured the profile of potential in wide plasma parameter space such as high ion temperature plasmas and high electron temperature plasmas.

2. Experimental setup

LHD is a helical device, magnetic configuration of which is characterized by the major radius of magnetic axis $R_{\text{ax}}$, the pitch parameter $\gamma$, and the quadrupole field component $B_q$. On experimental results shown here, $\gamma$ and $B_q$ are fixed to standard ones, namely 1.254 and 100%, respectively. By changing the major radius magnetic axis, $R_{\text{ax}}$, the amount of helical ripple can be changed.

HIBP system has been developed in many years. By using tandem accelerator, the gold ion (Au$^+$), maximum energy of which is 6MeV, is generated and is injected to plasma as primary beam. The secondary beam (Au$^{2+}$) is produced by the collision with plasma, of which energy is analyzed by the tandem energy analyzer. The three dimensional orbit of probe beam is controlled by two 8-pole electrostatic deflectors. The radial profile of potential is obtained by sweeping the beam in 10 Hz. The spatial resolution (the scale of sample volume) is about a few cm [2]. The primary and secondary beam current intensity is about a few $\mu$A and a few nA respectively. In order to detect this level of secondary beam current, the very sensitive current detector, micro channel plate (MCP), is used.

3. Experimental result

Density evolution of a typical shot is shown in Fig.1, when the radial profile of plasma potential with HIBP was measured. The magnetic field strength, $B_t$ was 1.5 T, and the major radius of
magnetic axis, $R_{ax}$ was 3.75 m. The line averaged density gradually increased from $0.2 \times 10^{19} \text{ m}^{-3}$ to $0.5 \times 10^{19} \text{ m}^{-3}$ by gas puff control. The central electron temperature was about 2.5 keV at the line averaged density of $0.19 \times 10^{19} \text{ m}^{-3}$ and ~1.0 keV at the line averaged density $> 0.30 \times 10^{19} \text{ m}^{-3}$. In each period marked by alphabets A~E, the potential profile was measured with HIBP as shown in Fig.2. As the density increased, the potential decreased in the core region. In low density and high electron temperature case, the potential at the center tends to be positive. In high density and low electron temperature case, the potential at the center tends to be negative or nearly zero.

By using a polynomial function of $\rho$ as a fitting function, radial electric field profile was obtained from the experimental data. Obtained radial electric field profiles are compared with those estimated by GSRAKE code [4-5]. In Fig.3 (a) and (b), the comparison in period A and C are shown respectively. In the period A ($\bar{n}_e = 0.19 \times 10^{19} \text{ m}^{-3}$), from the theory the positive radial electric field, so called electron root, is predicted. And this prediction roughly coincides with the experimental results. In the period C ($\bar{n}_e = 0.30 \times 10^{19} \text{ m}^{-3}$), the negative radial electric field, so called ion root, in the core region is predicted. And in this case, in the region $\rho > 0.26$, both roots of electron and ion roots are expected. In the core region, the ion root calculated by the neoclassical theory coincides with the experimental result. In the outer region where $\rho \sim 0.6$, the electron root of theoretical prediction coincides with the experimental result.

4. Summary

The radial potential profile was measured with HIBP in LHD. The radial electric field, $E_r$, was obtained from measured radial potential profile. Based on the condition of neoclassical ambiporarity, $E_r$ is estimated theoretically and compared with experimental results. Theoretical predictions roughly coincide with the experimental results. Thus, we clarified that physics of neoclassical context is almost dominant in $E_r$ formation. The results will provide a physical basis to consider further improved confinement scenarios utilizing $E_r$ in helical plasmas.

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