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On the Radial Electric Field in High Electron Temperature CERC Plasmas in LHD
LHD高電子温度CERCプラズマにおける両極性径電場について

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The neoclassical transport analyses are carried out for LHD CERC (Core Electron-Root Confinement) plasmas. The CERC plasmas are characterized by their high electron temperature (T_e), its steep gradient, and the strong positive (electron-root) radial electric field (E_r) at the core region. The poloidal rotation, which is related to the ambipolar E_r through the radial force balance, is also investigated. The poloidal rotation of the CERC plasma increases in the negative direction with the formation of the electron-root E_r at the core region, where the flat T_e profile still exists.

1. Introduction

To investigate the neoclassical (NC) transport and the radial electric field (E_r) is still an important issue in helical devices such as LHD with the three-dimensional magnetic configuration. This is due to the so-called $1/\nu$ nature of the NC transport, which increases in the high temperature, or low collisional plasma, where ν is the collision frequency. The radial electric field, which is determined by the ambipolar condition of the electron and ion NC particle flux in helical devices, also plays a key role since it affects not only the NC transport but also the anomalous transport arising from the turbulence through the E_r shear.

In recent LHD experiments, high electron temperature (T_e) plasmas called CERC (Core Electron-Root Confinement) [1,2] are intensively explored with the ECH heating. The characters of CERC are; high T_e and its steep gradient of the electron internal transport barrier (eITB) in the core region, and the electron-root, or strong positive E_r with the strong shear in the core region. The eITB in a CERC plasma in LHD is formed by introducing the ECH heating [2]. As the T_e at the core region increases, the foot point of the eITB moves outward. The region where the flat T_e profile is observed becomes narrower. Finally, the flattening of T_e disappears and peaked, or steep T_e gradient, or eITB is formed, which is followed by the formation of the electron-root E_r with the strong shear there.

The poloidal and toroidal rotations of plasma are strongly related to the Er formation as driving terms in the radial force balance equation [3]. Especially, in the ITB formation, the close relationship between the poloidal rotation and E_r has been pointed out from the experimental observations in JET [4]. (In [4], a significant discrepancy between experimental E_r and NC one has also reported.)

However, the radial force balance of the poloidal rotation and E_r in LHD CERC (eITB) plasmas has not been fully investigated yet. It is required to understand the underlying mechanism of the transport barrier from the viewpoint of the radial force balance in LHD. Thus, in this study we focus on the behavior of the local flattening region of T_e and the formation of the NC ambipolar E_r and the poloidal rotation there in this work. Also the particle orbit near the local flattening region and its effect on E_r and rotation is investigated.

2. NC transport analysis by FORTEC-3D

We apply a numerical NC drift kinetic equation solver, FORTEC-3D [5,6] to CERC plasmas. FORTEC-3D follows the orbit of the huge number of particles and determines the NC transport flux based on δf Monte-Carlo method. The advantage of the code is that it involves the dynamics of many particles including the finite orbit width (FOW) effect, which comes to affect the NC transport and E_r in a low collisional plasma [4]. Since T_e of the CERC plasma is high and its gradient is steep, it is appropriate to investigate the ambipolar E_r with the electron FOW effect.

In FORTEC-3D, the electron particle flux, Γ_e is determined from the solution of the drift kinetic equation, δf_e. At the same time, the poloidal and toroidal rotations are obtained. The radial electric field is now obtained by two ways; one is from the balance equation, and the other is from the ambipolar condition in which E_r satisfies $\Gamma_e = \Gamma_i$ as usually done in the transport analyses in helical devices.

3. Calculation results

FORTEC-3D is applied to LHD high T_e plasmas. As an example, calculation results for two cases are shown in Fig. 1. One is the typical CERC plasma with eITB at the core region but has the local flattening region at $0.2 < \rho < 0.4$. The other is that without eITB and has the broad local flattening region at $\rho < 0.4$. The magnetic axis is 3.53 m and the magnetic field strength is 2.70 T.

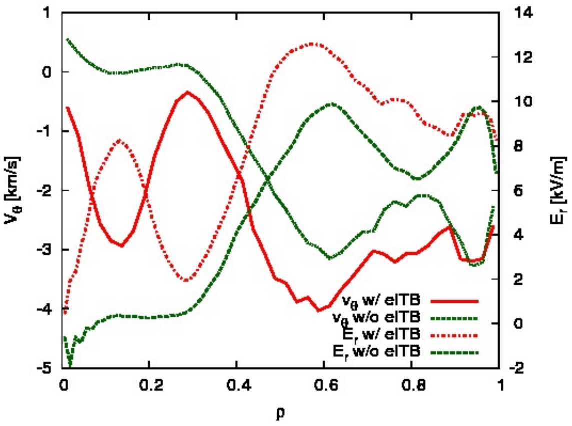

Fig.1. Radial profiles of the poloidal rotation V_θ and E_r. Plasmas with and w/o eITB are shown respectively.

It is clearly shown in Fig. 1 that the CERC plasma with eITB has the strong electron-root E_r (up to 8 kV/m) at the core region and the poloidal flow increases in the poloidal negative direction. It should be pointed out that the finite E_r and thus the finite V_θ are observed at $0.2 < \rho < 0.4$ except near $\rho = 0.3$, although the local flattening of T_e does exist there. On the other hand, the ambipolar Er of the plasma w/o eITB is approximately zero at the core region where the local flattening of T_e exists and does not rotate poloidally there. These results suggest that the formation of E_r and the spin-up of V_θ precede the resolution of the local flattening.

In the presentation, we will show more calculation results of LHD CERC plasmas. The radial force balance of E_r and the poloidal and toroidal flows is discussed in more detail. The particle orbit in the local flattening region is also discussed.

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