§3. Calculation of the Electron Neoclassical Transport with Finite Orbit Width Effect and the Radial Electric Field

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Recent LHD experiments have achieved high electron temperature (T_e) reaching 20 keV at the plasma core, and such high T_e plasmas are called CERC (Core Electron-Root Confinement) plasmas[1]. A CERC plasma is characterized by its high T_e with the steep T_e gradient of the electron internal transport barrier (eITB) and the large positive (electron-root) radial electric field (E_r). The neoclassical transport (NC) is still important in helical devices, since it increases due to the helically-trapped particles in the low collisionality plasmas. The NC particle flux plays a key role to determine the ambipolar E_r in helical devices. Although the ion finite orbit width (FOW) effect on ion NC transport calculations has attracted much attention in recent studies, electron NC transport has been so far evaluated without FOW effect due to the small mass of electrons. In CERC plasmas, however, the electron neoclassical transport needs to be evaluated with electron FOW effect because the FOW effect of the helically-trapped electron increases in proportion to $T_\mathrm{e}^{7/2}$. For this purpose, we have extended a numerical NC transport calculation code, FORTEC-3D (F3D)[2], to be applicable to the electron. F3D solves the drift kinetic equation based on δf Monte-Carlo method. In F3D, particle orbits including the radial drift are traced, and the NC transport thus obtained involves the FOW effect.

Benchmark calculation of electron FORTEC-3D

We have carried out benchmark calculations among F3D, DCOM/NNW (DCN), and GSRAKE codes. The latter two numerical codes are widely used for the NC transport analysis based on the local NC transport calculation which neglects the FOW effect. It has been confirmed that results of F3D agree well with those obtained by DCN and GSRAKE for the low T_e and high collisionality plasma. Numerical results for a high T_e (5 keV at the core) and low collisionality plasma are shown in Fig.1[3]. As shown in this figure, while the particle flux rapidly increases at around $E_\mathrm{r} = 0$ for both DCN and GSRAKE, the F3D result shows similar but slight increase at the positive E_r. This indicates that the FOW effect involves two different physical mechanisms; (1) the poloidal resonance not at $E_\mathrm{r} = 0$ but at the finite E_r, and (2) the collisionless detrapping which leads to the reduction of the particle flux at the poloidal resonance.

Transport analysis of LHD high T_e plasma

We have implemented the transport analysis for a CERC plasma including electron FOW effect for the first time by using F3D[4]. The time evolution of E_r is solved simultaneously with calculating the electron NC transport by F3D and referring to the ion particle flux data base obtained by DCN. Results of F3D is compared to experimental observations and DCN results in Fig.2. It is shown that E_r at the core of approximately $\rho < 0.2$, where the CERC plasma has its characteristic T_e gradient and the electron-root E_r, has a similar radial profile observed in the LHD experiment. The NC fluxes there also show larger differences from those of DCN at the core compared to the values approximately at $0.3 < \rho < 0.6$. This suggests that the electron FOW effect affects the ambipolar E_r for CERC plasmas. On the other hand, E_r of F3D at the edge shows the ion-root (weak, negative) value and it does not agree with the experimental observations of the electron-root one. More detailed analyses on the NC transport and E_r for CERC plasmas are being performed. The reason why the difference between E_r of F3D and the experiment arises at the edge will be investigated.

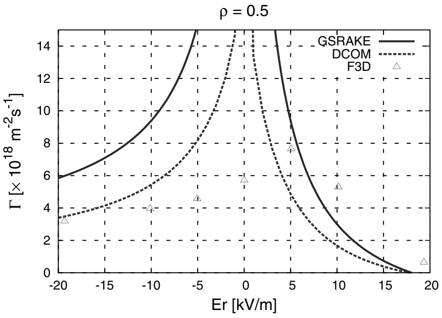

Fig. 1: The E_r dependence of the particle flux at $\rho = 0.5$ calculated by F3D, DCN, and GSRAKE.

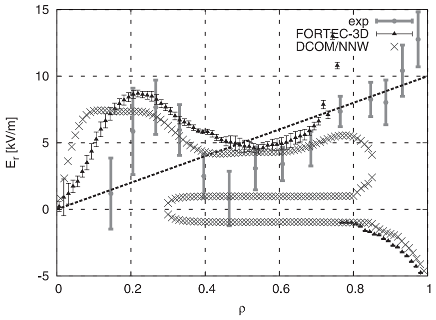

Fig. 2: The radial profile of E_r obtained by F3D and DCN. Experimental observations are also plotted.

1) e.g., Yokoyama, M., *et al.,* Fus. Sci. Tech., **50** (2006) 327

2) Satake, S., *et al.,* Plasma Fus. Res., **1** (2006) 002

3) Matsuoka, M., *et al.,* Phys. Plasmas, **18** (2011) 032511

4) Matsuoka, M., *et al.,* Plasma Fus. Res., **6** (2011) 1203016