§7. Development of Neoclassical Transport Code and its Applications

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Neolclassical(NC) transport analysis and determination of the ambipolar radial electric field are one of the key issue to study the plasma confinement property of LHD plasmas. It is known that LHD plasma has a wide flexibility for optimizing the NC transport level by shifting the magnetic axis position and by changing the ambipolar condition. The radial electric field, which autonomously develops so that the $E \times B$ rotation suppresses the ion and electron radial fluxes to match the ambipolar condition $\Gamma_i = \Gamma_e$, is important to understand the neoclassical transport level in experiments. Since detailed and accurate treatment to solve the drift-kinetic equation (DKE) is difficult in helical plasmas, many assumptions and approximations has usually been used in analytic formulae or numerical solvers of NC transport in 3-D geometry. To include the finite-orbit-width (FOW) effect, behavior of trapped particles in realistic helical magnetic ripples, and linearized Fokker-Planck collision operator which has conservation property and both pitch-angle and energy diffusion terms, are considered to be important factors to calculate NC transport with quantitative reliability. To include these effect, we have developed FORTEC-3D code[1)], which solves the DKE and the time evolution of radial electric field in helical plasmas by the δf Monte-Carlo method. Last year we have reported the numerical accuracy of FORTEC-3D has improved drastically by adopting new numerical schemes. Following the improvement, this year we have proceed to some applications for transport analysis and further improvement of FORTEC-3D code as followings:

Neoclassical transport analysis in high-T_i plasmas In LHD experiments, high-T_i plasmas ($T_i > 5keV$) are achieved, where the FOW effect for ions is considered important. The applicability of FORTEC-3D code in such a high-T_i case is benchmarked. Figure 1 shows a simulation result of ambipolar radial electric field. In FORTEC-3D, only Γ_i is solved by the δf method, while Γ_e is obtained from a zero-orbit-width (ZOW) approximation, reduced DKE solver GSRAKE[2)]. For comparison, estimations of ambipolar-E_r only by GSRAKE are also shown. Here, neglect of $\partial B/\partial r$-term in GSRAKE means the neglect of poloidal and toroidal components of ∇B- and curvature drifts. The E_r profile obtained by FORTEC-3D is more similar to the GSRAKE one with $\partial B/\partial r$-term, which acts to shift the peak of $\Gamma_i(E_r)$ in the negative-E_r direction. We found that the discrepancy of ion-root E_r between FORTEC-3D and conventional ZOW-limit analysis like GSRAKE is larger as the ion temperature becomes hider. It suggests not only the FOW effect but also the ∇B- and curvature drifts of ions, both of which have been neglected in conventional NC calculation, are effective for high-T_i LHD plasmas. More detailed investigation is going on.

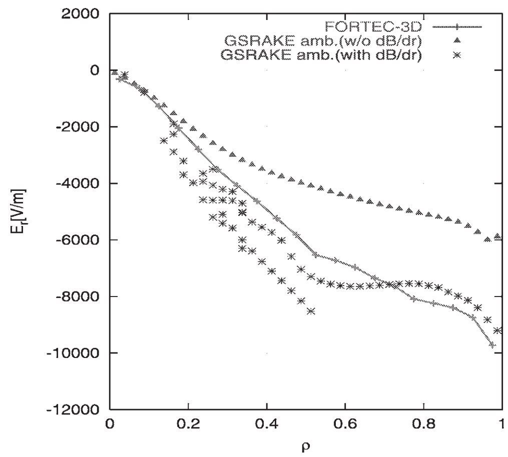

Fig. 1: Radial electric field profile for T_{i0} =4.0, T_{e0} =3.0 keV LHD model profile. Red line is FORTEC-3D result, while blue and gray marks represent GSRAKE result with or without the $\partial B/\partial r$ term.

Development of the ZOW-limit code As mentioned above, FORTEC-3D depends on GSRAKE code for Γ_e which is used to determine the ambipolar condition. However, because of the formalism it adopted, GSRAKE cannot treat the toroidal mode $n \geq 2$ magnetic field spectra. The LHD magnetic field is known to have $n \geq 2$ modes in a inward-shifted configuration in which NC transport is reduced. Therefore, we have started to develop a ZOW-limit, simplified version of FORTEC-3D code to replace Γ_e calculation with GSRAKE. The simple version neglect the FOW effect but higher-n toroidal magnetic field ripples are retained. It has first benchmarked for a simple tokamak geometry case by comparing thermal diffusivity χ_i, and good agreement both with analytic estimation and previous FORTEC-3D result with including the FOW effect is shown[3)]. It will be benchmarked for helical plasmas in the near future, and by integrating the FOW calculation of ion transport, it is expected that more accurate NC transport calculation is available for inward-shifted configurations.

1) Satake, S., Kanno, R., and Sugama, H., Plasma and Fusion Research 3 (2008) S1062.

2) Beidler, C. D. *et al.*, Plasma Phys. Control. Fusion 43 (2001) 1131.

3) Satake, S., *et al.*, *64th JPS annual meeting*, 27pXE-11, Mar. 27 (2009) Rikkyo Univ, Tokyo.