§4. Neoclassical Transport Simulation for the Radial Electric Field and the Bootstrap Current in LHD Plasmas with Transport Barrier

Matsuoka, S. (Res. Org. for Inform. Sci. and Tech.)

Improved confinement called CERC (Core Electron-Root Confinement) plasmas have been successfully achieved in recent LHD experiments. The transport barrier of steep electron temperature (T_e) gradient at the core region of CERC plasmas are formed following the formation of the large positive radial electric field (electron root). To clarify the mechanism of the transport barrier in CERC plasmas is one of the key issue to understand the relation between the radial electric field (E_r) and the improved confinement in LHD high T_e plasmas.

The neoclassical transport is an irreducible minimum for the plasma transport process. It also determines the ambipolar radial electric field through the ambipolar condition of the neoclassical particle flux in helical magnetic configurations. We have developed FORTEC-3D code, which is a particle code based on the two-weigth δf Monte Carlo method, for this purpose. FORTEC-3D code has a desirable feature for neoclassical transport analyses in high-temperature plasmas since it can treat the finite orbit width effect, which is caused by the radial drift of the plasma particle and becomes more influential in higher temperature plasmas.

The purpose of this study is; (1) neoclassical transport and radidal elctric field analysis as a basis to clarify the transport properties in a CERC plasma, (2) improving the numerical scheme of Monte Carlo method to evaluate transport observables more accurately by FORTEC-3D with less numerical noise.

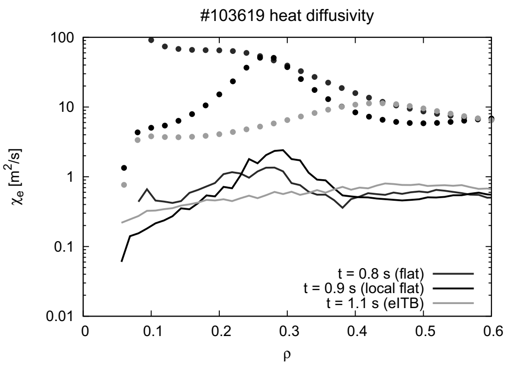

Fig. 1: Radial profiles of the thermal diffusiivities in a CERC plasma at $t = 0.8$, 0.9, 1.1 s. Lines represent the neoclassical ones, and circles are the experimental ones.

Neoclassical transport analysis of CERC plasma

FORTEC-3D has been applied to a LHD CERC plasma discharge, #103619. The electron thermal diffusivity and the formation process of the ambipolar E_r have been investigated. The radial profiles of the electron thermal diffusivities χ_e are shown in Fig. 1. As shown in the figure, the neoclassical χ_e at the core $\rho < 0.4$ remain almost the similar level during the discharge, while T_e there increases from $T_e \simeq 2$ keV at $t = 0.8$ s up to 8 keV at 1.1 s. At the same time, the ambipolar E_r gradually increases and the large electron-root E_r is formed. This indicates that the build up of the large electron-root E_r compensates the increase in the neoclassical transport expected by its $1/\nu$-dependence. On the other hand, the experimental (total) thermal transport decreases since the anomalous transport decreases. This makes a whole transport level rather small in the higher temperature plasma at $t = 1.1$ s compared to the lower one at $t = 0.8$ s.

Development of a new variance reduction technique for Monte Carlo simulation

To improve the two-weigth δf Monte Carlo method, which leads to a large numerical noise in a longer time simulation due to the so-called weight spreading, a new improvd control-variate technique has been applied to a new local neoclassical transport code based on FORTEC-3D. The new technique was first proposed by Kleiber, *et al.*, and applied to a simple one-dimensional diffusion model [1]. The effectiveness of the technique to reduce the numerical noise in a more practical transport problem in a multi-dimensional plasma has been investigated.

The time evolution of the energy flux, Q, is shown in Fig. 2. In the figure, Q obtained by using the control-variate technique is shown in a red line. A black dashed line represents that without using the technique. As shown in the figure, burst-like behaviors occationally appearing in the energy flux has been successfully eliminated. It has been demonstrated that smoothed time evolution can have been successfully obtained using the new technique.

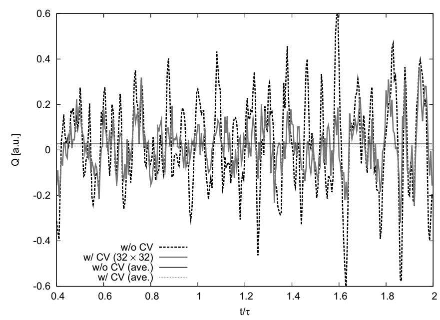

Fig. 2: Time evolution of the energy flux.

1) R. Kleiber, *et al.*, "An improved control-variate scheme for particle-in-cell simulations with collisions", Comp. Phys. Comm., **182**, 1005 (2011).