§9. Non-local Neoclassical Transport Simulation in LHD

Satake, S., Okamoto, M., Nakajima, N., Sugama, H., Yokoyama, M.

Because of the recent progress in super computers, direct simulation study of neoclassical transport including the non-local nature appearing from the finite-orbit-width (FOW) effect is becoming possible. The non-local treatment of neoclassical transport is important to evaluate accurately the transport level and the self-consistent radial electric field profile in a plasma.

As concerns neoclassical transport in LHD, analytical approaches that is based on the ripple-averaged (or bounce-averaged) drift kinetic equation has been the most popular one. However, these analytical studies lack in the preciseness as follows: 1) approximation in the collision operator 2) simplified model used in order to describe magnetic field configuration and particle motion 3) the FOW effect 4) short time-scale behavior of electric field evolution such as geodesic acoustic mode (GAM) oscillation.

In order to simulate the transport phenomena with considering the points as mentioned above, we have develop a numerical simulation code FORTEC-3D, which is applicable to 3-dimensional configurations like LHD plasma. FORTEC-3D is based on the δf Monte Carlo method, which directly solves the time evolution of plasma distribution function according to the drift-kinetic equation. In FORTEC-3D, the collision operator is implemented by the random scatterings in the velocity space. It also retains the basic properties of the Fokker-Planck collision operator. The FOW effect is essentially included in the δf method, in which the exact guiding center motion is traced.

In adopting the δf method to 3D transport simulation, the most difficult problem is the large amount of consumption of both calculation time and resources. Therefore, FORTEC-3D has been developed with High Performance Fortran so that the code can be executed on the vector-parallel supercomputer SX-7 in NIFS with the good calculation efficiency.

As concerns the FOW effect, it is effective only for ions. Calculating both ion and electron transport by the δf method is heavy for the computers available now, therefore we have invented a hybrid simulation model. In FORTEC-3D, only the ion transport is solved with the δf method, while electron transport is obtained from a numerical solver for a ripple-averaged kinetic equation (GSRAKE[1]), which is used to make a table of electron particle flux in a form $\Gamma_e(r, E_r)$. Then the time evolution of radial electric field $dE_r/dt \propto -(\Gamma_i - \Gamma_e)$ is solved in FORTEC-3D, which is finally converges into an ambipolar state. If both Γ_i and Γ_e from are used, the result corresponds to the conventional SOW limit. Then one can easily compare the transport between with and without the FOW effect.

As far as we know, FORTEC-3D is the first application in the world of the δf neoclassical simulation which can calculate the time evolution of plasma in the whole plasma region at once, including the FOW effect. Its primal results were reported in IAEA conference[2]. Some examples of the results of simulations in LHD are shown below. In Fig.1, the ambipolar-E_r profile is compared between the result from FORTEC-3D and the SOW limit. We found that the difference of the ambipolar field becomes smaller as the magnetic axis is shifted inward. Therefore, the difference is considered to be the result of the FOW effect on ion transport, since the contribution of transit particles, which has a large orbit width, is suppressed in inwardly shifted configuration. In Fig. 2, the time evolution of E_r on 3 radial points are shown. The rapid oscillation is GAM, and the oscillation frequency in the simulation agrees with the analytical value. On the other hand, the damping rate of GAM seems much faster than that expected from previous analysis[3] in the SOW limit. By comparing the recent simulations of gyrokinetic GAM oscillation[4], we expect that the rapid damping of GAM found in our simulation is also because of the FOW effect. We continue to investigate the details of the GAM damping both by analytical way and by simulations.

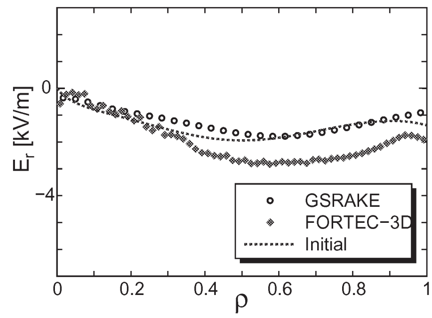
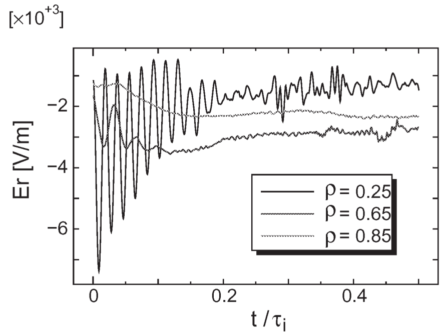


Fig.1 : The ambipolar E_r profile from FORTEC-3D and an expectation in the SOW limit (open circles).



Fig, 2: Time evolution of E_r on each flux surface.

Reference

1) Beidler C. D. and Maassberg H., Plasma Phys. Control. Fusion **43**, 1131 (2001).
2) Satake S. *et al*, Proc. of 20th IAEA Fusion Energy Conf., TH/P2-18 (2004)
3) Novakovskii S. V. *et al*, Phys. Plasmas 4,4272 (1997)
4) Sugama H. And Watanabe T.-H., to appear in Proc. of ICNSP&APPTC 2005, A6-2.