§10. Simulation Study of Neoclassical Transport and GAM Oscillation

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

To study the Neoclassical transport and time evolution of radial electric field, especially in Large Helical Device (LHD), we have developed a Monte-Carlo transport simulation code "FORTEC-3D"[1,2], using the δf method. In this method, the distribution function of plasma is separated into $f = f_M + \delta f$, where f_M is a local Maxwellian and δf is considered as a small perturbation from f_M. We solve the linearized drift-kinetic equation for δf as follows

$$\left(\frac{\partial}{\partial t} + (\mathbf{v}_{\parallel} + \mathbf{v}_d)\cdot\nabla + e\mathbf{v}_d\cdot\mathbf{E_r}\frac{\partial}{\partial \mathcal{K}} - C(\ ,f_M)\right)\delta f = -\mathbf{v}_d\cdot\left(\nabla - \frac{e\mathbf{E_r}}{T}\right) f_M + C(f_M,\delta f), \quad (1)$$

where $\mathcal{K} = mv^2/2$. $C(\delta f, f_M)$ is the test-particle collision term implemented by random kicks in the velocity space, and $C(f_M, \delta f)$ is the field-particle collision term defined so that the collision operator satisfies the conservation properties. In eq. (1), the term $\mathbf{v}_d\cdot\nabla\delta f$ brings the finite-orbit-width (FOW) effect and non-local nature of neoclassical transport, which is neglected in standard formulation. The radial electric field develops according to

$$\epsilon_0\left(1 + \frac{c^2}{v_A^2}\right)\frac{\partial E_r(r,t)}{\partial t} = -Z_i e\langle\Gamma_i(r,E_r,t) - \Gamma_e(r,E_r,t)\rangle. \quad (2)$$

In FORTEC-3D, only the ion particle flux Γ_i is calculated, and Γ_e is obtained from GSRAKE code[3], which solves a bounce-averaged kinetic equation. The adoption of GSRAKE is to reduce the calculation time.

In the time evolution of E_r, a rapid oscillation called geodesic acoustic mode (GAM) occurs. It is known that GAM shows a collisionless damping. Recently, analytic estimation of the GAM damping rate has been shown[4]. It is expected that the collisionless damping rate in helical system depends on the relative magnitude of Fourier spectrum of magnetic field evaluated in Boozer coordinates. To investigate the dependence of the GAM damping rate on magnetic configuration in LHD, we compare the simulation results of LHD changing the magnetic axis position $R_a x = 3.7$m and 3.6m. We also compare the simulation result which used only the major 3 modes of magnetic field spectrum ($B_{0,0}$, $B_{1,0}$, and $B_{2,10}$ where $B_{m,n}$ is the Fourier component of the magnetic field expressed as $B(\rho,\theta,\zeta) = \sum_{m,n} B_{m,n}(\rho)\cos(m\theta - n\zeta)$) and the one in which as much as 12 modes are used. Figure 1 shows the time evolution of radial electric field in those simulations. As it can be seen from Fig.1, the damping of GAM oscillation is slightly rapider in the $R_{ax} = 3.7$ case, and 12-modes calculation shows rapider damping compared with the simulation using only 3 modes. We confirmed that these tendencies agree with the expectation from the analysis in [4]. This suggests that the the behavior of GAM in LHD can be controlled by shifting the magnetic axis.

We have also investigated the FOW effect on the damping rate. Using a simple tokamak geometry and changing the magnetic field strength, we compared the GAM damping rate γ as shown in Figure 2. It is shown that the damping rate is higher as typical banana width $\propto 1/B$ becomes larger (magnetic field weaker). In helical systems, however, we find that the FOW effect is not significant.

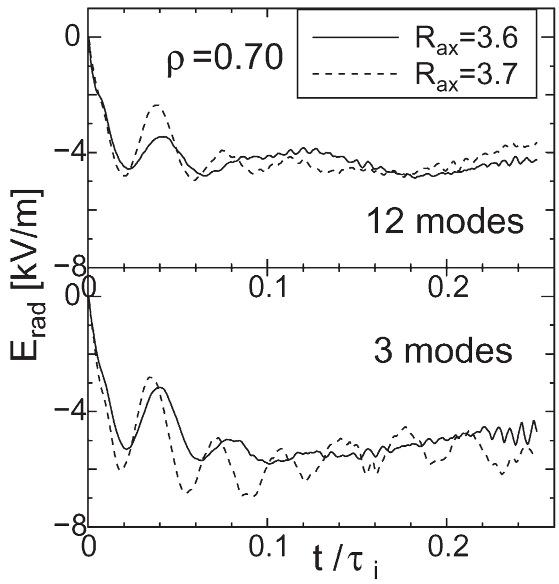

Fig. 1 : Simulation of GAM oscillation in LHD with finite number of magnetic field spectrum

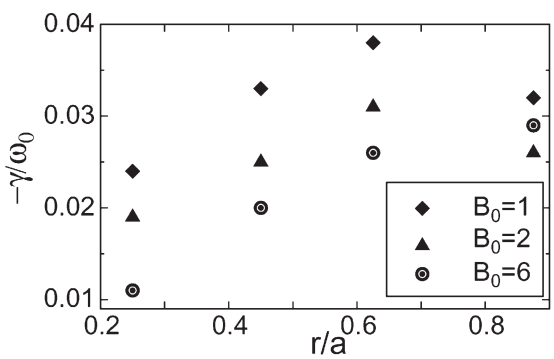

Fig. 2 : Comparison of the GAM damping rate γ (normalized by the real frequency ω_0).

1) Satake, S. et al.: Nucl. Fusion **45** (2005) 1362.
2) Satake, S. et al.: Plasma and Fusion Res. **1** (2006) 002.
3) Beidler, C. D. et al.: Plasma Phys. Control. Fusion **37** (1995) 463.
4) Sugama, H. and Watanabe, T.-H.: Phys. Plasmas **13** (2006) 012501.