§12. Simulation Studies on Neoclassical Toroidal Viscosity in Tokamaks with Small Magnetic Perturbations and E × B Rotation

Satake, S., Sugama, H., Kanno, R.,
Park, J.-K. (PPPL)

Recent studies have shown that the non-axisymmetry in tokamaks as small as $\delta B/B_0 \sim 10^{-3}$, which is assumed in RMP experimetns, can induce significant damping in toroidal rotation by the neoclassical toroidal viscosity (NTV). To give a precise prediction of the toroidal rotation damping by small perturbation, we have developed a simulation code, FORTEC-3D, to evaluate NTV is developed using the δf Monte Carlo method.[1] The advantage of this method is that we can calculate NTV without relying on the conventional approximations used in analytic theories such as zero-orbit-width limit, mono-energy treatment with pitch-angle scattering operator, etc.

We have benchmarked FORTEC-3D simulation with the combined analytic formula devised by Park[3] in 2010-2011. In the zero-$\mathbf{E}\times\mathbf{B}$ limit, it has been demonstrated that the two calculations agrees well in the wide range of collisionality, $10^{-4} < \nu_* < 10$.[2] Following this results, we carried out further benchmarks in the finite-$\mathbf{E}\times\mathbf{B}$ rotation cases.

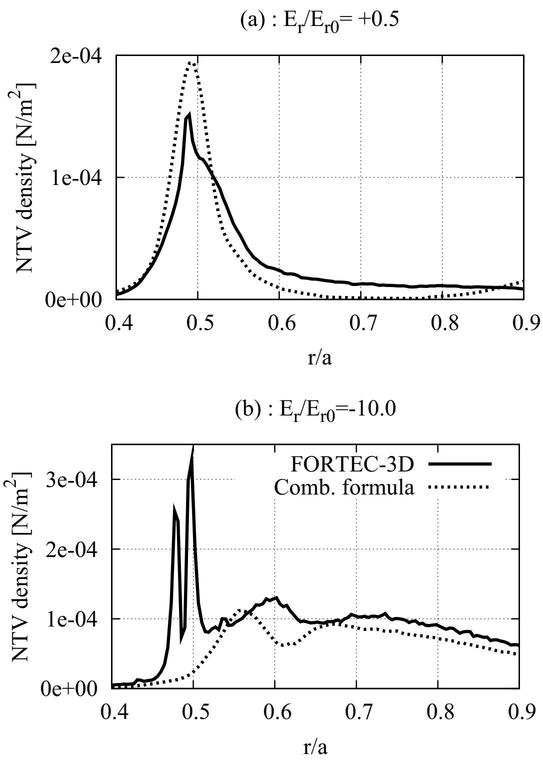

Fig. 1: Radial profiles of NTV from FORTEC-3D and the combined formula in two cases of E_r/E_{r0}.

To investigate the effects of finite $\mathbf{E}\times\mathbf{B}$ rotation, we set the reference radial electric field from the force balance relation, $E_{r0} = (T_i/e)d\ln n_i/dr$, where $dT_i/dr = 0$ and zero initial toroidal rotation are assumed for simplicity. Collisionality is $\nu_* \simeq 0.05$. If the force balance is completely satisfied in the $\delta B/B_0 \to 0$ limit, NTV becomes zero. The E_r profile in each simulation is given by $E_r(r) = E_{r0}(r) \times$ (numerical factor). In the benchmarks, two distinctive features are found in the δf simulation.

First, the peak of NTV at the resonant flux surface, which can be seen when $|E_r/E_{r0}|$ is small as in Fig. 1, shrinks in the both calculations as $|E_r|$ becomes larger. It is because the large $E \times B$ rotation can decorrelate the drift motions which otherwise resonate with RMP field. However, as $|E_r/E_{r0}|$ increases, there appear other twin peaks of NTV on the both sides of the resonant rational surface only in the δf simulation. There has been no theoretical prediction of this phenomenon. It is anticipated that the higher-order effects associated with finite-orbit-width effect in the δf simulation can make a new contribution to NTV. Second, as the magnitude of E_r increases, the amplitude of the total toroidal torque, which is the volume integral of NTV, also increases as shown in Fig. 2. Though the tendency is similar, the torque from the combined formula is much larger than that from FORTEC-3D when $E_r/E_{r0} \gg 1$.

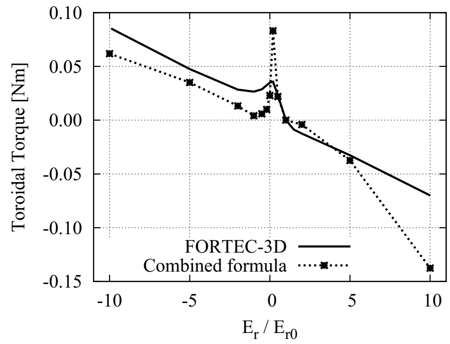

Fig. 2: Comparison of the total toroidal viscosity torque obtained from FORTEC-3D and the combined formula.

Since the E_r profile in real tokamak experiments varies according to the toroidal rotation profile, it is important to understand the dependence of NTV on E_r in detail. We will continue to investigate the reason why the δf simulation results deviates from analytic estimation and establish a method of evaluating the NTV with high accuracy.

1) Satake, S. *et al.*, Plasma Phys. Control. Fusion **53** (2011) 054018.

2) Satake, S. *et al.*., Phys. Rev. Lett. 107 (2011) 055001.

3) Park, J.-K. *et al.*., Phys. Rev. Lett. **102** (2009) 065002.