§15. Long-Time Zonal Flow Response and ITG Turbulence Simulation in Helical Systems with Radial Electric Field

Watanabe, T.-H., Sugama, H., Nunami, M.

Gyrokinetic theory for helical plasma with an equilibrium-scale radial electric field (E_{r0}) predicts enhancement of the zonal flow (ZF) response, where E_{r0} drives the poloidal rotation of helical-ripple-trapped particles with reduced radial displacements of drift orbits. The poloidal ExB rotation due to E_{r0} is introduced in the gyrokinetic equation in terms of the poloidal Mach number (M_p). If the ion mass is changed with the ion temperature and the radial electric field fixed, the E_{r0} dependence of the ZF response is translated into an isotope effect through M_p. Indeed, a neoclassical transport analysis for the the Large Helical Device (LHD) confirms that magnitude of the equilibrium radial electric field estimated for the deuterium discharge is almost identical to that in the hydrogen plasma, if other parameters are the same. The isotope effect on ZF response is, thus, expected to appear through E_{r0} generated by the neoclassical transport, and would play a favorable role in reducing the turbulent transport because the turbulent transport regulation by the stronger zonal flows is anticipated.

The gyrokinetic simulation of the ZF enhancement by E_{r0} in helical systems was carried out by means of the gkv code, and shows effective amplification of the ZF response for M_p=0.2-0.3 which is relevant to LHD experiments. The isotope effect on ZF response, thus, appears through E_{r0} generated by the neoclassical transport, and is expected to play a favorable role in reducing the turbulent transport.

In the present study, long-time behaviors of the ZF response are investigated where an extended version of gkv code is applied. The ITG turbulence simulation in case with the equilibrium-scale radial electric field in helical systems is also investigated. While the uniform and constant E_{r0} leads to the Doppler shift of the ITG mode frequency, the linear instability growth rate is unaffected. Nevertheless, the nonlinear gkv simulation presents reduction of a turbulent fluctuation level and transport flux in case with E_{r0}[1)].

Zonal flow amplitudes presented in the previous study have shown good agreement with the theoretical estimate in the long wavelength limit. According to the theoretical analysis, after many poloidal rotations, radial drift motion of trapped particles causes finer velocity-space structures of the perturbed distribution function with the higher k_r. In contrast, the previous simulations were carried out only one poloidal rotation which is much shorter than the time scale for development of the fine velocity-space structures. Therefore, we have investigated a long time behavior of zonal flow response. In the long time simulation run for the single helicity case [Fig. 1 (a)], for

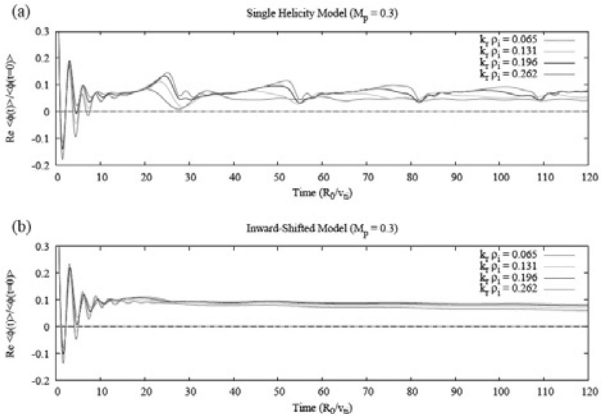

Fig1: Long-time zonal flow response for (a) single-helicity and (b) inward-shifted cases.

all wavenumbers considered here, one finds oscillatory behaviors of the ZF response due to the ExB rotation of the helical ripple trapped particles. In the single-helicity case with no transition particles, E_{r0} effectively drives the poloidal rotation of helical ripple trapped particles. The measured oscillation period is close to that of the poloidal rotation. In the inward-shifted model case, the ZF amplitudes quite slowly decreases in time [see Fig. 1 (b)]. One finds that the relative amplitude among different wavenumber modes varies in time, where the smaller k_r modes decay faster. This is clearly found by plotting relative potential amplitudes (normalized by that of the lowest wavenumber component) which continue to grow in time.

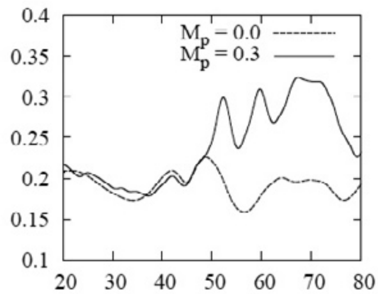

Fig2: Zonal flow potential amplitudes normalized by the turbulent fluctuations

Fig.2 shows a resultt of the nonlinear gkv simulation for the ITG turbulence in helical systems with E_{r0}, where ratio of the ZF amplitude, Z, and the turbulent fluctuations, T, is plotted as a measure for effectiveness of the zonal flow generation by turbulence. In the case with M_p = 0.3, the ZF amplitude normalized by the turbulent fluctuations (Z/T) increases after the saturation of the instability growth at t=40 L_n/v_{ti}, even though almost the same values of T are observed before the saturation. The obtained results suggest that the ZF response enhancement due to the equilibrium-scale radial electric field plays a positive role in the turbulence suppression and the transport reduction.

1) Watanabe, T.-H., Sugama, H., Nunami, M.: Proceedings of the 23^{rd} IAEA Fusion Energy Conference.