§12. Mach Number and Wavenumber Dependences of Zonal Flow Response in LHD Configurations

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

Turbulent ion heat transport in magnetically-confined toroidal plasmas is regulated by self-generated poloidal shear flows, that is, the zonal flows (ZFs). ZFs generated in the ion temperature gradient (ITG) turbulence lead to the transport reduction and the up-shift of critical gradient of ion temperature. For finding further reduction of the turbulent transport, thus, it is meaningful to investigate what kind of structure of the confinement field is preferable for effective generation of ZFs, which was first considered by Rosenbluth and Hinton for a tokamak plasma. Their pioneering work has been extended to helical configurations[1), 2)] where a high-level zonal flow is sustained for a longer time by reducing bounce-averaged radial drift velocity of helical-ripple-trapped particles. Correspondingly, gyrokinetic simulations of the ITG turbulent transport by means of the GKV code have manifested the stronger ZF generation and lower ion heat transport in the neoclassically-optimized LHD (Large Helical Device) configuration with the inward-shifted magnetic axis position[3)].

Recent gyrokinetic theory for a helical plasma with an equilibrium-scale radial electric field (E_r) also suggests further enhancement of the ZF response[4), 5)] where E_r drives the poloidal rotation of helical-ripple-trapped particles with reduced radial displacements of drift orbits. By means of the newly extended GKV code, we have performed gyrokinetic simulations of the zonal flow response in helical systems with E_r. The new GKV simulation results of zonal flow response with E_r support the theoretical prediction[4),5)]. It also means that under the same conditions, use of ions with a heavier mass leads to a higher zonal-flow response.

Utilizing the Plasma Simulator installed in 2009 at NIFS, we have thoroughly investigated the Mach number and wavenumber dependences of ZF response in the single-helicity and the inward-shifted model LHD configurations. The radial wavenumber (k_r) dependence of the residual zonal flow potential amplitude for the single-helicity case with the poloidal Mach numbers of $M_p = 0$ (square) and 0.3 (solid circle) are shown in Fig.1 where the ZF potential is time-averaged from t = 15 to 30 R_0/v_{ti}. The same results but for the inward-shifted model case are summarized in Fig.2.The residual ZF level for the single helicity case increases as k_r while the poloidal flow enhances the residual ZF levels. In contrast, disappearance of the k_r dependence of the residual potential is confirmed by simulations for the inward-shifted model case shown in Fig.2, where one finds significant amplification of the ZF response in a low k_r regime.

Poloidal Mach number dependence of the residual ZF is summarized in Fig.3 for the inward-shifted model case. The parameter study for sensitivity of the residual potential to M_p shows that the ZF response rapidly grows in a range of $M_p \sim 0.1$- 0.2. The parameter range surveyed is relevant to the LHD experimental conditions. Here, it should be reminded that, for the same T_i and E_r, the M_p-dependence is regarded as the isotope effect on the ZF response. Since the response function for $M_p = 0.15$ is about 2.7 time higher than that for $M_p = 0.1$, the ZF is expected to be enhanced by the isotope effect for the fixed E_r and T_i under the experimentally relevant conditions.

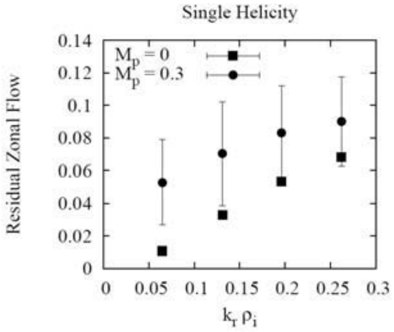

Fig.1. Residual zonal flow potential for single-helicity case.

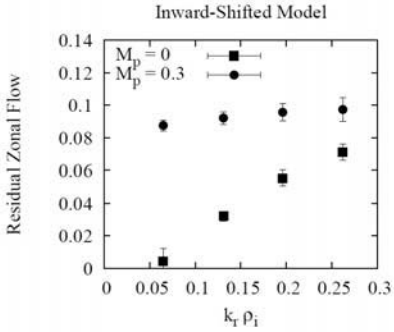

Fig.2. Residual zonal flow potential for inward-shifted model case.

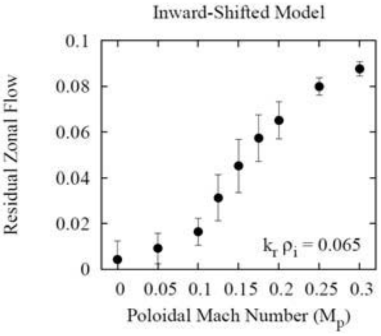

Fig.3. Poloidal Mach number dependence of residual zonal flow potential for inward-shifted model case.

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