§19. Theoretical Study on the Interplay between Magnetic Configuration Property and Zonal Flow, GAM Oscillations and Fluctuations in LHD

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It has been pointed out in the ion-temperature-gradient (ITG) turbulence study in tokamaks that the zonal flow (with poloidal and toroidal mode numbers of 0, having the velocity shear in the radial direction) effectively suppresses the turbulent fluctuations and induced transport. In a toroidal geometry, the zonal flow is coupled with geodesic acoustic mode (GAM) with poloidal mode of 1. The theoretical investigation of the zonal flow and GAM oscillations has been carried out by employing the linear analysis based on the initial value problem.

The solution obtained from the above approach provides the characteristic lifetime of the zonal flow, and it is important for understanding the basic feature of the zonal flow and GAM oscillations. It has been pointed out, by Rosenbluth-Hinton, in a tokamak geometry that the residual zonal flow is maintained after the collisionless Landau damping of the GAM oscillation in the presence of trapped particles. This formulation has been extended to helical systems.

The theoretical and numerical investigation has been performed by Sugama-Watanabe for a model helical configuration with a single helicity of the magnetic field. It has revealed that the zonal flow can be maintained for a longer timescale in a configuration having smaller radial drift velocity of helically-trapped particles (that is, having lower ripple transport in a low collisional regime). Based on this finding, more realistic equilibrium (utilizing information from VMEC calculation) for the Large Helical Device (LHD) has been investigated. The slower damping of the zonal flow is found in an inward-shifted configuration (R_{ax}=3.60m) rather than in a configuration with R_{ax}=3.75m, which can be understood from the above mentioned basic finding.

The effects of the three-dimensionality of magnetic configurations on the reduction of the turbulence transport in the presence of the zonal flow will be investigated, for example, by utilizing the nonlinear gyro-kinetic simulation of ITG turbulence.

The density fluctuation has been measured in LHD by the 2 dimensional phase-contrast imaging method. The fluctuations with a radial wave number of 0.1-0.15 mm^{-1}, thus, $k_\perp \rho_i$=0.1-1 (anticipated range for ITG/TEM (trapped electron mode)) can be measured with the spatial resolution of 1/3 to 1/5 of the minor radius.

The fluctuations have been measured with $k_\perp$~0.2 at ρ<0.8 and $k_\perp$~0.8 at ρ>0.8. It is also found that the phase velocity is spatially changing from the electron diamagnetic direction to ion diamagnetic direction in the peripheral region. The velocity shear in this region is close to the shear of the $\boldsymbol{E}\times\boldsymbol{B}$ velocity measured by the charge exchange recombination spectroscopy. The fluctuation propagating in the ion diamagnetic direction becomes larger as the particle diffusion coefficient becomes larger. However, the comparison of the linear growth rate of ITG/TEM modes in different configurations has shown that the inward-shifted configuration (with smaller particle diffusion, fluctuation level and magnetic ripple) has a larger growth rate than that in an outward-shifted configuration (with larger particle diffusion, fluctuation level and magnetic ripple). This comparison may indicate that the linearly-growing fluctuations in an inward-shifted configuration might be suppressed such as by the $\boldsymbol{E}\times\boldsymbol{B}$ velocity shear and the zonal flow.

Linkage of such theoretical and experimental investigations on fluctuation/turbulence will be pursued.