§7. Turbulent Transport Simulations of a High Ion Temperature LHD Plasma

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Turbulent transport of the Large Helical Device (LHD) plasmas are investigated by means of nonlinear gyrokinetic simulations of ion temperature gradient (ITG) turbulence. In the present studies, the simulations with full geometrical effects of the LHD configuration are carried out, in which the transport levels comparable to the experimental results are reproduced and reasonable agreements are also found in the wavenumber spectra of the density fluctuations. Numerical analysis of the turbulence spectra on the two-dimensional perpendicular wavenumber space clarifies the spectral transfer into a high radial wavenumber region through the interaction with zonal flows, which correlates with the turbulent transport reduction. It is now widely recognized that the ITG turbulent transport is determined by the competitive interaction between turbulence and zonal flows. The resultant transport levels are expressed in terms of a simple linear relation between the transport coefficient and the ratio of the squared turbulent potential fluctuation to the averaged zonal flow amplitude.

In linear gyrokinetic simulations[1] in the LHD high ion temperature discharge #88343[2], it was found that the density fluctuations measured by phase contrast imaging (PCI) in the experiment have large amplitudes for the radial positions and the poloidal wavenumbers which correspond to ITG modes having large growth rates. Applying the gyrokinetic Vlasov flux-tube code GKV-X[3], the nonlinear ITG turbulent transport simulations with adiabatic electrons are performed and the saturation levels of the turbulent fluctuations, zonal flows, and ion heat transport in the LHD discharge are evaluated. The radial profile of the electron density is so flattened in the discharge that the trapped electron mode is considered to be stabilized. A snapshot of the electrostatic potential fluctuations obtained from the simulations is shown in Fig.1, and a comparison of the ion heat fluxes $P_{\rm i}$ obtained from the simulations and the LHD experiment is performed as in Fig.2. The simulation results agree well with the anomalous part of experimental $P_{\rm i}$, such that the observed differences are less than 10% for $\rho = 0.46, 0.65$, and about 30 % for $\rho = 0.83$. The ITG turbulence simulations also have shown the poloidal wavenumber spectrum of the potential fluctuation which is similar to that of the density fluctuation given by the PCI measurements within experimental ambiguities in low wavenumber regions[4].

Self consistent interaction between turbulence and zonal flows causes the resultant transport level. In the spectral analyses of the squared potential fluctuations in the two-dimensional perpendicular wavenumber space, spectra for the experimental case in outer radial region and the optimized LHD configuration case (inward-shifted case) spread broader in the high radial wavenumber region which is caused by the spectral transfer from the low- to the high-radial wavenumber space through the interaction between zonal flows and turbulence[5]. The higher wavenumber modes in the spreading spectrum make less contribution to the transport while they still contribute to the integrated power spectrum. Indeed, larger zonal flows causing the spectrum spreading are generated for the experimental case in outer radial region and inward-shifted case. Correlations of the resultant transport level on the turbulence and the zonal flows are also found that any simulation results including the inward-shifted case are well represented by the relation, $\chi_{\rm i}/\chi_{\rm i}^{\rm GB} \propto \mathcal{T}/\mathcal{Z}^{1/2}$, where the squared turbulent potential $\mathcal{T} = (1/2)\sum_{k_x,k_y\neq0}\langle|e\phi_{k_x,k_y}R_0/T_{\rm i}\rho_{\rm ti}|^2\rangle$ and the zonal flow potential $\mathcal{Z} = (1/2)\sum_{k_x}\langle|e\phi_{k_x,0}R_0/T_{\rm i}\rho_{\rm ti}|^2\rangle$. This relation is useful for modeling of the turbulent ion heat diffusivity applicable to the transport code analyses by estimating $\mathcal{T}$ and $\mathcal{Z}$ including effects of equilibrium profiles and magnetic configurations.

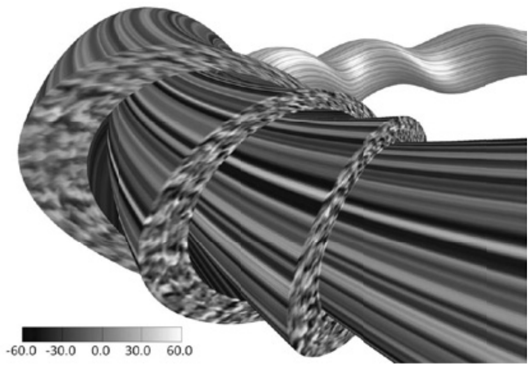

Fig. 1: Snapshot of the perturbed electrostatic potentials obtained from GKV-X simulations in the LHD high-$T_{\rm i}$ discharge.

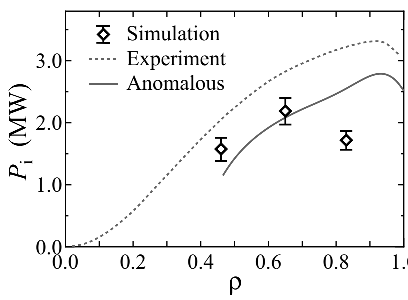

Fig. 2: Radial profiles of ion heat flux obtained from the experiment (dotted curve) and the GKV-X simulations (symbols). The solid curve represents the anomalous part of the experimental result.

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2) K. Tanaka *et al.*, Plasma Fusion Res. **5** (2010) S2053.
3) M. Nunami *et al.*, Plasma Fusion Res. **5** (2010) 016.
4) M. Nunami *et al.*, Phys. Plasmas. **19** (2012) 042504.
5) M. Nakata *et al.*, Phys. Plasmas. **19** (2012) 022303.