§8. Ion Heat Transport Modeling Based on Gyrokinetic Simulations of Turbulence and Zonal Flows in Helical Plasmas

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Based on nonlinear gyrokinetic simulations, a model for ion heat transport in helical plasmas is investigated, taking account of effects of ion temperature gradient (ITG) turbulence and zonal flows. Local gyrokinetic simulations for helical field configurations are carried out by using the GKV-X code[1] with various input parameters such as the density and temperature gradients and local shears. In general, the turbulent transport level is determined through the interactions of turbulent fluctuations and zonal flows[2]. In order to quantitatively clarify the effects of turbulence and zonal flows on the transport level in helical plasmas, we use two nonlinear quantities, the squared turbulent potential fluctuation $\mathcal{T} = (1/2)\sum_{k_x,k_y\neq 0}\langle|e\phi_{k_x,k_y}R_0/T_i\rho_{ti}|^2\rangle$, and the squared amplitude of zonal flow potential $\mathcal{Z} = (1/2)\sum_{k_x}\langle|e\phi_{k_x,0}R_0/T_i\rho_{ti}|^2\rangle$. Here, ρ_{ti} is the ion thermal gyro radius, R_0 is the major radius of the field, the flux-surface average is denoted by $\langle\cdots\rangle$, and (k_x, k_y) represent wavenumbers in radial and poloidal directions, respectively. Figure 1 shows the simulation results obtained in LHD plasmas[3] for time evolutions of $\mathcal{T}, \mathcal{Z}$ and the ion heat transport coefficient in the gyro-Bohm unit χ_i/χ_i^{GB} for two field configurations of LHD with $R_0 = 3.75$ m and 3.6 m, where $\chi_i^{GB} = \rho_{ti}^2 v_{ti}/R_0$. While the squared turbulent fluctuations $\mathcal{T}$ for the two cases are comparable, the squared zonal flow amplitude $\mathcal{Z}$ for $R_0 = 3.6$ m is greater than that for $R_0 = 3.75$ m. Consequently, the transport level cannot be determined only the turbulent fluctuations, and it is reduced by the enhanced zonal flow generation for $R_0 = 3.6$ m.

From twenty and more nonlinear ITG turbulent transport simulations for helical plasmas with changing values of various parameters such as the temperature gradient, radial location, and safety factor, the dependence of χ_i on $(\mathcal{T}, \mathcal{Z})$ is found with the following the function,

$$\frac{\chi_i}{\chi_i^{GB}} = \frac{C_1\,\mathcal{T}^\alpha}{C_2 + \mathcal{Z}^{1/2}/\mathcal{T}} \equiv \mathcal{F}(\mathcal{T}, \mathcal{Z}), \qquad (1)$$

for the simulation data at a wide range of the parameters[4]. Here, $\alpha = 0.36$, $C_1 = 0.067$ and $C_2 = 0.0082$, In the definition of $\mathcal{F}(\mathcal{T}, \mathcal{Z})$, the numerator $C_1\,\mathcal{T}^\alpha$ indicates the enhancement of χ_i with increasing the turbulent fluctuations while $\mathcal{Z}^{1/2}$ in the denominator represents the regulation of χ_i due to zonal flows. Comparisons of χ_i/χ_i^{GB} obtained from the GKV-X simulations with the model function are shown in Fig.2(b), where $\mathcal{F}(\mathcal{T}, \mathcal{Z})$ agrees with the simulation results better than another function $\mathcal{G}(\mathcal{T})$ defined without the zonal flow effects as $\mathcal{G}(\mathcal{T}) \equiv C_0\mathcal{T}^\delta$ with $C_0 = 0.11$ and $\delta = 0.83$. The function in Eq. (1) will contribute to constructing a reduced model for the ITG turbulent transport in helical plasmas. Of course, we should perform more nonlinear simulations and investigate the dependencies on other parameters.

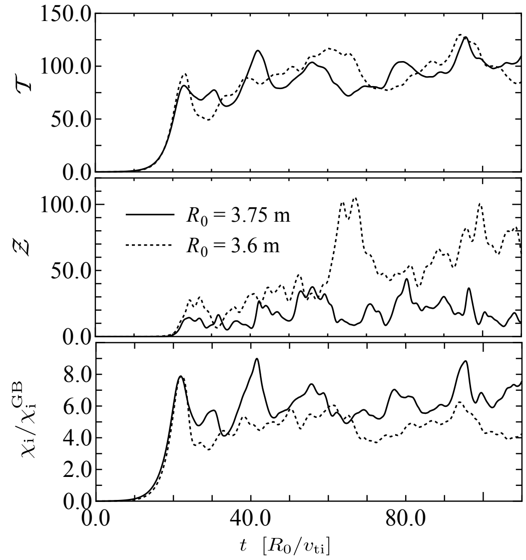

Fig. 1: Time evolutions of $\mathcal{T}, \mathcal{Z}$ and χ_i/χ_i^{GB} resulting from the gyrokinetic simulations. Solid curves correspond to the case for $R_0 = 3.75$ m, and dotted curves for the vacuum magnetic configuration with $R_0 = 3.6$ m.

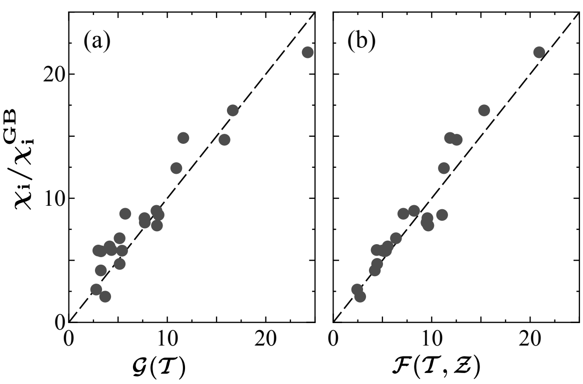

Fig. 2: Comparisons of χ_i/χ_i^{GB} obtained from the simulations and the functions $\mathcal{G}(\mathcal{T})$ and $\mathcal{F}(\mathcal{T}, \mathcal{Z})$. Here, the relative errors are given by $\sigma_\mathcal{G} = 0.271$ and $\sigma_\mathcal{F} = 0.158$, where σ's are defined as the root mean square of $[\chi_i/\chi_i^{Model} - 1]$ with $\chi_i^{Model}/\chi_i^{GB} = \mathcal{G}$ and $\mathcal{F}$.

1) M. Nunami *et al.*, Plasma Fusion Res. **5** (2010) 016.

2) P. Diamond *et al.*, Plasma Phys. Control. Fusion **47** (2005) R35.

3) M. Nunami *et al.*, Phys. Plasmas. **19** (2012) 042504.

4) M. Nunami *et al.*, Plasma Fusion Res. **8** (2013) 1203019.