§20. Modeling of Transport Diffusivity Using Gyro-kinetic Analysis

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Turbulent transport is one of the most critical issues for plasma confinement in magnetic fusion devices. The GKV-X code solving the gyro-kinetic equation has been used to examine the ITG mode and zonal flows in the LHD for studying the turbulent transport in helical plasmas. The reduced model of $\chi_i \sim \rho_{ti}^2 v_{ti} f(\mathcal{L}, \tilde{\tau}_{ZF})/R$ is taken using the GKV-X code for the high-T_i LHD discharge of the shot number 88343, where f is a function of $\mathcal{L}$ and $\tilde{\tau}_{ZF}$. Here, $\mathcal{L}$ is the mixing length estimate $\tilde{\gamma}_{\tilde{k}_y}/\tilde{k}_y^2$ integrated over the $\tilde{k}_y$ space, where $\tilde{\gamma}_{\tilde{k}_y}$ is the normalized linear growth rate of the ITG mode for the normalized poloidal wavenumber $\tilde{k}_y$ and $\tilde{\tau}_{ZF}$ is the normalized decay time of zonal flows. The nonlinear gyrokinetic simulation results are quantitatively reproduced by the reduced model calculations. However, it is costly to carry out linear calculations of the growth rate by the gyrokinetic simulation at each time step of the dynamical transport code. In this study, how to apply the reduced model of the turbulent heat diffusivity for the ITG mode derived from the gyrokinetic simulation to the transport code is shown with a low computational cost. Modeling of the term $\mathcal{L}$ in the reduced model for the ITG mode is necessary to be involved with a parameter dependence of the plasma instability in the dynamical transport code. The ion temperature gradient scale length $L_{T_i}(= -T_i/(\partial T_i/\partial r))$ is chosen for the parameter to apply $\mathcal{L}$ to avoid the calculations of the linear growth rate by the gyrokinetic code. The field configuration is fixed at the initial state in the transport simulation. The linear gyrokinetic analysis is performed using the GKV-X code at this magnetic field configuration. The decay time of zonal flows depends on the magnetic field configuration and is independent of the the density and temperature profiles. The formula of the zonal flow decay time is needed to be calculated only at the initial state in the transport simulation. This additional modeling for the turbulent ion heat diffusivity is applied to the transport code and enables us to study the simulation results with the experimental results in LHD.

The linear analysis is done using the GKV-X code for the additional modeling of the turbulent ion heat diffusivity. The ITG instability is examined in the high-T_i LHD discharge #88343. The value of the turbulent ion heat diffusivity $\chi_i^{(1)}/\chi_i^{GB}$ was fitted only by the function $\mathcal{L}\left(\equiv \int (\tilde{\gamma}_{\tilde{k}_y}/\tilde{k}_y^2) d\tilde{k}_y\right)$ as $\chi_i^{(1)}/\chi_i^{GB} = C_0 (C_T \mathcal{L})^\delta$, where χ_i^{GB} is the gyroBohm diffusivity, $\chi_i^{GB} = \rho_{ti}^2 v_{ti}/R$, $\tilde{\gamma} = \gamma/(v_{ti}/R)$ and $\tilde{k}_y = k_y \rho_{ti}$ with $C_0 = 0.11$, $C_T = 9.8 \times 10$ and $\delta = 0.83$. A reduced model for the ITG turbulent heat diffusivity in terms of the functions $\mathcal{L}$ and $\tilde{\tau}_{ZF}(= \tau_{ZF}/(R/v_{ti}))$ was obtained as $\chi_i^{(2)}/\chi_i^{GB} = A_1 \mathcal{L}^\alpha/(A_2 + \tilde{\tau}_{ZF}/\mathcal{L}^{1/2})$. The numerical coefficients are given by $A_1 = C_1 C_T^{\alpha+1/2} C_Z^{-1}$ and $A_2 = C_2 C_T^{1/2} C_Z^{-1}$, where $\alpha = 0.38$, $C_Z = 0.202$, $C_1 = 6.3 \times 10^{-2}$ and $C_2 = 1.1 \times 10^{-2}$. As the function of the ion temperature gradient scale length L_{T_i}, the parameter $\mathcal{L}$ is modeled by

$$\mathcal{L} = a(\rho)\left(\frac{R}{L_{T_i}} - \frac{R}{L_{T_c}}\right), \tag{1}$$

where L_{T_c} is the normalized critical ion temperature gradient for the ITG instability. To find the critical ion temperature gradient for the ITG mode, the dependence of $\mathcal{L}$ on R/L_{T_i} is examined with all plasma parameters fixed except the ion temperature gradient in the radial region $0.00 \le \rho \le 0.88$. The T_e profile is set as $T_e = T_i$ in a gyrokinetic simulation. We calculate the linear fitting function eq. (1) at each radial point and obtain the critical values of R/L_{T_i}, R/L_{T_c}, where $\mathcal{L}$ becomes zero. The critical ion temperature gradient for the ITG mode, R/L_{T_c} and the slope $a(\rho)$ in terms of R/L_{T_i} are obtained. When we calculate the value of the ion heat diffusivity in the integrated transport code, the fitting polynomials of R/L_{T_c} and $a(\rho)$ are used as $R/L_{T_c} = 4.0929 - 3.7681\rho + 19.712\rho^2 + 11.087\rho^3 - 14.272\rho^4$ and $a(\rho) = 0.38661 - 0.070919\rho + 0.2571\rho^2 + 0.95949\rho^3 - 0.92978\rho^4$. Figure 1 shows the comparison between the right hand side $(a(\rho)\,(R/L_{T_i} - R/L_{T_c}))$ and the left hand side $(\mathcal{L})$ in eq. (1) with the root mean square of $((a(\rho)\,(R/L_{T_i} - R/L_{T_c}))/\mathcal{L} - 1)$ given by $\sigma = 0.13$. The zonal flow decay time $\tilde{\tau}_{ZF}$, which only depends on the magnetic field structure, is examined in the radial region $0.02 \le \rho \le 0.88$. The fitting function for the zonal flow decay time: $\tilde{\tau}_{ZF}(fit) = 0.98565 - 0.65943\rho + 2.4471\rho^2 + 3.2337\rho^3 - 2.8382\rho^4$ is used throughout the transport simulation, because the field configuration is dynamically fixed. The transport dynamics is examined using the modeled turbulent ion heat diffusivity, when the integrated transport code is performed.

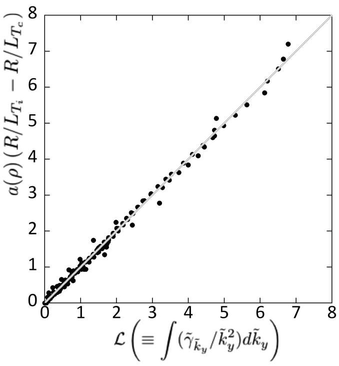

Fig. 1: Comparison between the modeled function in terms of L_{T_i} and the integral of the mixing length estimate over the $\tilde{k}_y$ space.