§22. Modeling of Transport Diffusivity using Gyro-kinetic Analysis

Toda, S.

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. 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 and $\tilde{\tau}_{ZF}$ is the normalized decay time of zonal flows. 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 such as TASK3D, because the transport analysis of helical plasmas demands a high radial resolution so as to accurately evaluate the radial electric field and the field configuration. 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 linear gyrokinetic analysis at each time step of the transport simulation. The field configuration is fixed at the initial state in the transport simulation. We have developed the formula for $\mathcal{L}$ in terms of L_{T_i}. The computational cost to obtain the value of the turbulent ion heat diffusivity by this modeling at each time step of the transport simulation is much smaller than that of the linear gyrokinetic simulation. The simulation results for the high-T_i discharge of the shot number 88343 have been shown. In this study, the modeling of the mixing length estimate term and the zonal flow decay time is done for the high-T_i discharge of #109081. The value of the density gradient scale length in the case of #109081 is different from that in the case of #88343. This additional modeling is applied to the transport code and enables us to study the simulation results with the experimental results in LHD.

Firstly, the linear analysis is done using the GKV-X code for the additional modeling of the turbulent ion heat diffusivity. The analysis of the plasma dynamics using TASK3D was done for #109081 in LHD. A reduced model for the ITG turbulent heat diffusivity in terms of the functions $\mathcal{L}\left(\equiv \int(\tilde{\gamma}_{\tilde{k}_y}/\tilde{k}_y^2)d\tilde{k}_y\right)$ and $\tilde{\tau}_{ZF}(= \tau_{ZF}/(R/v_{ti}))$ was obtained as $\chi_i/\chi_i^{GB} = A_1\mathcal{L}^\alpha/(A_2 + \tilde{\tau}_{ZF}/\mathcal{L}^{1/2})$, where χ_i^{GB} is the gyro-Bohm diffusivity, $\tilde{\gamma} = \gamma/(v_{ti}/R)$ and $\tilde{k}_y = k_y\rho_{ti}$. As the function of L_{T_i}, the parameter $\mathcal{L}$ is modeled by

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

where L_{T_c} is the normalized critical ion temperature gradient for the ITG instability. To examine 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. When we use the modeling for the mixing length estimate and the zonal flow decay time at $t = 4.2$s for #109081 in LHD, the fitting polynomials of (a) the normalized ion temperature gradient R/L_{T_c} and (b) $a(\rho)$ are obtained as $R/L_{T_c} = 4.712 - 38.644\rho + 512.56\rho^2 - 2481\rho^3 + 5991.3\rho^4 - 6810.3\rho^5 + 2911.3\rho^6$ and $a(\rho) = 0.13049 + 6.3631\rho - 45.33\rho^2 + 134.8\rho^3 - 177.95\rho^4 + 90.153\rho^5 - 4.6622\rho^6$ in figure 1. The fitting function for $\tilde{\tau}_{ZF}$: $\tilde{\tau}_{ZF}(fit) = 0.34823 + 6.817\rho - 15.452\rho^2 + 15.972\rho^3 - 6.4126\rho^4$ is shown for the case of #109081 in LHD.

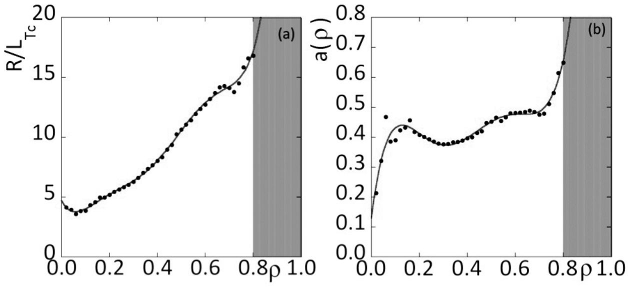

Fig. 1: The radial dependence of (a) R/L_{T_c} and (b) $a(\rho)$ is shown with filled circles for #109081 in LHD.

The transport dynamics is examined using the modeled turbulent ion heat diffusivity, when the TASK3D is performed. The radial profiles of the density and the electron temperature are fixed. The dynamics of the radial $T_{\rm i}$ profile is simulated by solving the diffusion equation. The profile of the radial electric field E_r is derived from the ambipolar condition at the initial plasma state. In #109081, one negative radial electric field is shown from the ambipolar condition and is dynamically fixed. At the initial state, the ITG mode is stable in the region $0.0 \le \rho \le 0.8$. The simulation results using the diffusion equation for the ion temperature shows the higher value than the experimental results in the core region. At the plasma center, the value of T_i of the simulation result is 4.2keV, which is higher than the value of T_i: 3.2keV for the experimental results in LHD. The ITG mode becomes unstable in the region $0.18 \le \rho \le 0.42$ at the stationary state of the simulation results. However, the neoclassical transport is dominant compared with the turbulent transport driven by the ITG instability. In the case of #109081, the value of L_n becomes much smaller than the case in #88343. At $\rho = 0.5$, the values of $\eta_i(= L_n/L_{T_i})$ are -12.0 and 1.37 for #88343 and #109081 in LHD, respectively. In this study, we perform the gyrokinetic simulation with the adiabatic electrons. It is not enough for showing the T_i profile close to the experimental one only by the ITG stability analysis using the adiabatic electrons, especially for #109081 case. The gyrokinetic simulation with the kinetic electrons shows the larger ion heat flux than that by solving the gyrokinetic equation with the adiabatic electrons.