§7. Modeling of Heat Diffusivity for Ion Temperature Gradient Turbulence in Helical Plasmas

Toda, S., Nunami, M., Ishizawa, A., Sugama, H., Watanabe, T.-H. (Nagoya Univ.)

Turbulent transport is one of the most critical issues for plasma confinement in magnetic fusion devices. Further study of the plasma turbulence and the transport is necessary for the improvement of the plasma performance. In the integrated transport analysis suite, TASK3D, which is the one-dimensional (the radial) transport code, the gyro-Bohm scaling on the heat turbulent diffusivities is used in LHD. In the case of ITG turbulence, the form $\chi_i = \rho_{ti}^2 v_{ti} f(\gamma, \hat{s}, \tau_{ZF})/R$ is taken for the ion heat diffusivity, where f is some function of γ, $\hat{s}$ and τ_{ZF}. Here, γ is the growth rate of the mode energy, $\hat{s}$ is the magnetic shear parameter and τ_{ZF} is the decay time of zonal flows. We need to study that which modes are destabilized to determine which models should be chosen for the turbulent diffusivities in transport codes. The GKV-X code solves the gyro-kinetic equation to examine Ion Temperature Gradient (ITG) modes and zonal flows in Large Helical Device (LHD) for the turbulent transport in helical plasmas. For the first step, we perform the linear gyro-kinetic analysis by using GKV-X codes for ITG modes in the LHD high-T_i discharge case of the shot number 88343. This is because the simulation cost of the linear analysis is extremely smaller than that of the nonlinear simulation. The calculation of the growth rate by use of the gyro-kinetic codes at each time step in the dynamical transport codes takes a high cost. Modeling of the ion heat diffusivity is necessary in terms of the significant parameter for the plasma instability. In this study, the significant parameter for the ITG instability is considered to be $L_{T_i}(= -T_i/T_i')$. The dependence of the zonal flow decay time τ_{ZF} on the function f is neglected in modeling χ_i. The form for the ion heat diffusivity χ_i is derived. This form is used in the transport code to compare the simulation results with the radial profile for the ion temperature in LHD experimental results.

Firstly, the simulation of the linear analysis is done using GKV-X codes. The ITG instability is examined in the LHD high-T_i discharge case of the shot number 88343. We set $T_e = T_i$. The value of the ion heat diffusivity χ_i is evaluated as $\chi_i/\chi_{GB} = \Sigma_{k_y}\gamma/k_y^2$, where $\chi_{GB}(= \rho_{ti}^2 v_{ti}/R)$ is the gyro-Bohm diffusivity and k_y is the poloidal wavenumber. To find the critical ion temperature gradient for the ITG mode, the dependence of χ_i/χ_{GB} on the normalized ion temperature gradient is examined at fifty radial points. We model χ_i/χ_{GB} as $\chi_i/\chi_{GB} = a(\rho)(R/L_{T_i} - R/L_{T_c})$, where L_{T_c} is the normalized critical ion temperature gradient for the ITG instability and $\rho = r/a$. The slope depends on the values of the normalized density gradient and the safety factor, which change due to the radial positions. The critical ion temperature gradient for the ITG mode, R/L_{T_c} (a) and the slope $a(\rho)$ (b) in terms of R/L_{T_i} are shown in Fig. 1.

Secondly, the transport dynamics is examined using the modeled ion turbulent diffusivity above, when the transport code is performed. The neoclassical diffusion coefficient is derived from DGN/LHD database in the case of low-β limit. The three solutions of the ambipolar radial electric field are found in the radial region $0.25 < \rho < 0.80$. The positive radial electric field is chosen from three solutions of the ambipolar conditions in the region $0.25 < \rho < 0.80$. The plasma radial profiles except the ion temperature, such as the density, the electron temperature, the radial electric field and the safety factor are set to temporally be constant. The experimental result in the shot number 88343 at $t = 2.230$s of LHD is used for the radial profiles of the density, the electron temperature, and the safety factor. The dynamics of the T_i radial profile is simulated, by use of the transport code. The T_i profile of the experimental results is used as an initial state for the dynamical transport simulation. We obtain the simulation results for the stationary ion temperature profile. The simulation results for the radial T_i profile can show the good agreement with one experimental result in the shot number 88343 at $t = 2.230$s of LHD. The stationary radial profiles of the turbulent and neoclassical diffusivities are also obtained. The ITG mode is stabilized in two radial regions $0.0 < \rho < 0.25$ and $0.8 < \rho < 0.92$. The turbulent transport is dominant compared with the neoclassical transport in the radial region where the positive electric field is chosen.

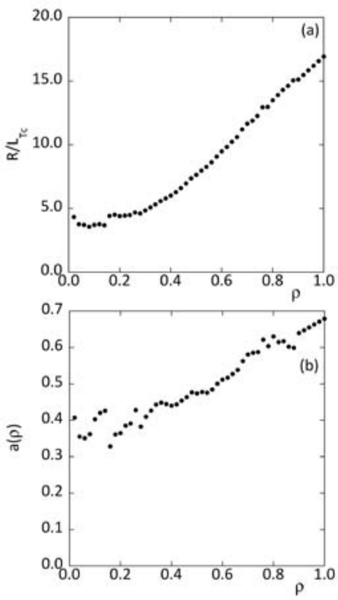

Fig. 1: The radial dependence of (a) the critical ion temperature gradient R/L_{T_c} and (b) the slope $a(\rho)$ in modeled ion diffusivity