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Modeling of Turbulent Transport due to Dissipative Trapped Electron Modes in Tokamak Plasmas

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Turbulent transport is one of the most important subjects in research of toroidal plasmas. The purpose of this study is to quantify turbulent transport. Microscopic plasma instabilities are studied using electromagnetic gyrokinetic simulations. Linear calculations are used to investigate the type of instability. The saturation level of the instability or the turbulent level is determined from nonlinear calculations to obtain the turbulent transport value. The trapped electron mode (TEM) where normalized electron collision frequency is less than unity is called dissipative-TEM (d-TEM) in a high collisional regime. Here, this mode is driven by dissipation from the electron collision and ions do not need to be in the banana regime. This mode is known to be driven unstable in the presence of density and/or temperature gradients. Not many studies of the transport level due to the d-TEM using gyrokinetic simulation have been done so far. Plasma experiments at the PLATO device at the Research Institute for Applied Mechanics, Kyushu University have been started. Transport simulations using integrated code are carried out on the PLATO tokamak to forecast plasma performance and plasma profiles in the PLATO are predicted using an empirical model in the integrated code, the TASK code. In these plasmas, the electron collision frequency is typically less than the electron bounce collision frequency and the ion collision frequency is larger than the ion bounce collision frequency. Therefore, these plasmas are in a high collisional regime and the d-TEM is predicted to be unstable. We focus on the d-TEM and the Ion Temperature Gradient (ITG) mode.

At first, the GKV code [1] is used for local flux tube gyrokinetic simulation, using the Sugama collision model operator [2] or the Lenard-Bernstein collision model operator. The dissipative-TEM, which is excited by the density gradient, is studied. The linear simulation results are compared in the cases of the Sugama and Lenard-Bernstein collision model operators. Using the Sugama collision model operator, the plasma instabilities are found to be excited by the d-TEM and ITG mode at $\rho=0.47$ and $\rho=0.65$ by the linear simulation results, where $\rho=r/a$. On the other hand, only the d-TEM is unstable at $\rho=0.81$. The rapid change from the d-TEM to the ITG mode is classified to occur at $\rho=0.65$ in terms of the real angular frequency in the wavenumber space, respectively. The ITG mode is excited at $\rho=0.47$ and $\rho=0.65$ only by using the Sugama collision operator. The two states before and after the rapid change in the dependence of the angular frequency on the poloidal wavenumber are found. Using the Lenard-Bernstein collision model operator, the only d-TEM is obtained in the parameter regime studied here. The residue level of the zonal flows and the zonal flow decay time using the Sugama collision operator are found to be larger than those using the Lenard-Bernstein collision operator by the simulations of the linear response for the zonal flows. As predicted by the linear simulations results, the amplitude of the zonal flows with the Sugama collision operator model is found to be larger than that with the Lenard-Bernstein collision operator model in the nonlinear simulation results. Therefore, the turbulence level using the Sugama collision operator is mostly smaller than that using the Lenard-Bernstein one, due to the zonal flow effect [3].

Next, the turbulent transport is modeled by the simulation results when the Sugama collision model operator is used. The energy diffusivities and quasilinear transport fluxes for the ITG instabilities in the Large Helical Device were modeled [4]. In the d-TEM/ITG plasmas, the energy and particle diffusivities are modeled by the electrostatic turbulence and zonal flow potential fluctuations. For example, the electron energy diffusivity is modeled by the function $\chi_e/\chi_e^{GB}=C_1T^a/(C_2+Z^b/T)$, where T and Z are the electrostatic turbulent and zonal flow potential fluctuations, respectively. Here, χ_e^{GB} is the electron gyro-Bohm diffusivity. The zonal flow effect is evaluated by the power of Z, b. Zonal flows are more effective on the turbulent transport for lower poloidal wavenumbers. The reduced models for the transport simulation [5] are constructed. These reduced models of the turbulence diffusivities for the d-TEM/ITG plasmas in tokamak plasmas, which are the functions of the linear simulation results, will be shown. Here, the linear simulation results are the mixing length estimate and the zonal flow decay time [4].

References

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