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Research of turbulent transport by gyrokinetic analyses in collisional plasmas for tokamak devices

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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 in toroidal plasmas. Microscopic plasma instabilities are studied using electromagnetic gyrokinetic simulations. Linear calculations are used to investigate the type of instability and to evaluate the conditions for instability excitation. The saturation level of the instability or the turbulent level is determined from nonlinear calculations. The trapped electron mode (TEM) where the normalized electron collision frequency is less than the unity [1,2] is called the dissipative-TEM, where the ions do not need to be in the banana regime. This mode is known to be driven unstable in the presence of density [3] and/or temperature gradients. In previous studies of the ion temperature gradient (ITG) and TEM plasmas, the TEM is mainly excited by the density and/or temperature gradients in the collisionless plasmas. The plasma experiments at the PLATO device at the Research Institute for Applied Mechanics, Kyushu University have been started. The plasma profiles in the PLATO are predicted using the integrated code, the TASK code [4]. The electron collision frequency is typically less than the electron bounce collision frequency and the ion collision frequency is larger than the unity in these plasmas, therefore, the dissipative TEM is predicted to be unstable. Not many studies of the dissipative-TEM using the gyrokinetic simulation have been done so far.

A local gyrokinetic simulation by the GKV code [5] using the model collision operators, such as the Sugama (*S*) [6] and Lenard-Bernstein (*LB*) collision model operators, is performed in this study. In this article, the instabilities are predicted to be driven by the dissipative-TEM and the ion temperature gradient (ITG) mode in the predicted parameter regions for the PLATO. First, the dominant mode and the condition under which the instability occurs are studied by the linear gyrokinetic simulations. Next, the nonlinear simulation demonstrates the time evolution of the electrostatic potential fluctuations. By the nonlinear simulation results, the turbulent levels of the fluxes and diffusivities are quantified. The *S* collision operator was used for the residue level of zonal flows with the collisional effect. In these analyses, the residue level of zonal flows using the *S* collision operator is found to be close to the analytically predicted one. On the other hand, the linear response of zonal flows using *LB* collision operator shows over-damping [7]. Therefore, in this study, the *S* collision operator is used for the local gyrokinetic simulation.

The gyrokinetic simulation is performed for the tokamak plasmas in the collisional regime. The dissipative-TEM, which is excited by the density gradient in this article, is studied. The linear simulation results are compared in the cases of the *S* and *LB* collision model operators. Using the *S* collision model operator, the plasma instabilities are found to be excited by the TEM and ITG mode at $\rho=0.47$ and $\rho=0.61$ by the linear simulation results. On the other hand, only the TEM is unstable at $\rho=0.81$. The ITG mode is excited for $0.026<k_e\rho_e<0.052$ at $\rho=0.47$ and for $0.030<k_e\rho_e<0.060$ at $\rho=0.65$ only by using the *S* collision operator. The mode changes from the TEM to the ITG mode when the poloidal wave number increases, where the electrons form the banana orbit and the ions do not. Using the *LB* collision model operator, the only TEM is obtained. The residue level of zonal flows and the zonal flow decay time [8] using the *S* collision operator are found to be larger than those using the *LB* collision operator. The turbulent transport is evaluated by the nonlinear gyrokinetic simulation results. The effects of zonal flows using two kinds of the collision operators are studied in the nonlinear simulation results. In the previous studies, the reduced models are constructed [9] for the ITG turbulence in helical plasmas. These reduced models, which are constructed by the linear simulation results, quickly reproduce the nonlinear simulation results for the turbulent transport, thus, these reduced models enable us to simulate the integrated transport simulation in helical plasma [10]. The simulation results for the TEM and ITG mode plasmas in this study are the basis when the reduced models for the TEM and ITG mode turbulence in tokamaks will be constructed.

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