§18. Simulation Study of Zonal Flow in Non-circular Tokamaks by Collisionless Kinetic-fluid Model

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ExB zonal flows, which are tangential to flux surfaces and oscillatory in the radial direction, play an important role in determining the anomalous transport level by regulating the turbulence. This means that the zonal flows should be treated accurately by the simulation model in order to make reliable predictions of the turbulent transport. Fluid model needs much smaller computational resources than the kinetic model, which is a great advantage of the fluid simulation. The zonal flow is actually observed in the relatively simple, classical fluid model such as the Hasegawa-Wakatani model [1]. However, kinetic effects of collisionless high-temperature toroidal plasmas cannot be treated with a high accuracy in such classical fluid models. The damping process of the so-called geodesic acoustic mode (GAM), which is the transient response of the zonal flow in the short time, is introduced by Hammett-Perkins model [2], and more systematic gyrofluid models have been developed [3]. However, it was pointed that these gyrofluid models do not reproduce the same residual zonal flow level as predicted by the gyrokinetic theory [4].

A new fluid model for describing the zonal flows has been recently developed which has a closure model based on the collisionless gyrokinetics [5]. In order to accurately treat the residual zonal flow level in the tokamaks, this model is derived from using the analytical solution of the zonal-flow part of the gyrokinetic equation, and it explicitly contains the geometrical factor associated with the neoclassical polarization due to the trapped particles. In this work, we use this model for the simulation studies of the linear damping of the zonal flow, and the residual level in tokamaks with arbitrary shapes of the magnetic surfaces for which magnetohydrodynamics (MHD) equilibria are obtained numerically by the VMEC code [6].

The effects of the plasma elongation and triangularity on the residual zonal flow level are shown in Fig.1. Here the simulation results as well as results by theories of R-H[4], X-C [7] and Z-Y [8], are shown. The residual zonal flow increases with the elongation, while the triangularity dependence is weak. This tendency is common for the simulation and theories. There exist small gaps between the simulation results and results by X-C and Z-Y. One of the reason for this is the difference between the numerically calculated equilibrium and the equilibrium models which are used in deriving the analytical theories.

Next we consider efficiency of the nonlinear generation of zonal flow by the microinstabilities. To see this, ExB nonlinear sources for the fluid variables are evaluated by using linear gyrokinetic solutions calculated by goblin code [9]. ITG modes and TEMs are considered, and the result is shown in Fig.2. The zonal flow potential generated by the density source from the ITG modes reaches a higher level than the one generated by the TEM density source (open marks), except for the region near marginal stability. It is interesting that the difference between the ZF levels shown by the ITG and TEM sources becomes larger by including the parallel flow sources (closed marks), which is due to a effect of the finite initial parallel flow.

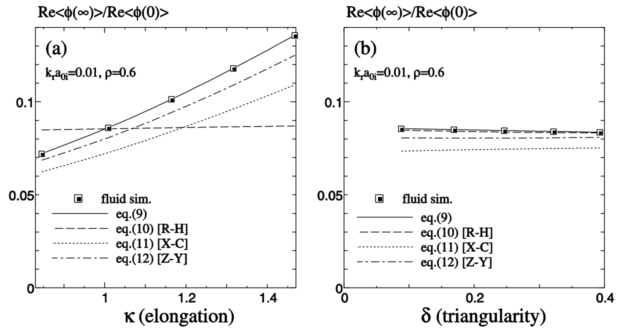

Figure 1: Residual zonal flow as functions of elongation (left) and triangularity (right)

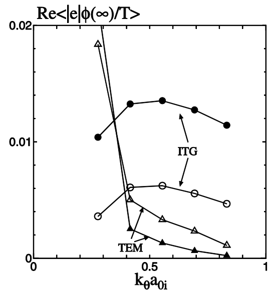

Figure 2: Residual zonal flow as a function of $k_\theta \rho_i$, which are generated by ITG modes and TEMs.

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