§34. Stabilization of Kinetic Internal Kink Mode by Electron Diamagnetic Effect

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To understand the kinetic modification of MHD modes in present day and future high temperature large tokamaks, it is inevitable to develop simulation codes based on extended MHD models. We have developed gyrokinetic particle code (GYR3D)[1,2], gyro-reduced-MHD code (GRM3D-2F)[3,4], and Hybrid code[5] to study kinetic modification of MHD modes in a tokamak. These codes have been coded for the rectangular mesh and fast fourier transformation technique is used. The linear and nonlinear development of the $m = 1$(poloidal mode number) and $n = 1$(toroidal mode number) kinetic internal kink mode are simulated successfully. However it has been felt that the cylindrical model with mode expansions in toroidal and poloidal angles would be more powerful to simulate realistic plasmas. The mesh accumulation technique in the radial direction can be used for the cylindrical code. For example, in order to simulate a $m = 1$ and $n = 1$ kinetic internal kink mode, we must resolve the collisionless electron skin depth, $d_e = c/\omega_{pe}$ (c is the speed of light in vacuum and ω_{pe} is the electron plasma angular frequency), around the $q = 1$ (q is the safety factor) surface. For the parameters of present day large tokamaks, d_e/a (a is a minor radius of a plasma) is less than 10^{-3}. By accumulating radial meshes around the $q = 1$ surface, we can simulate the physics including the thin inertial layer by using the moderate number of meshes. As the first step to build the series of cylindrical codes, we developed linear version of the GRM3F-CY code which is based on the three field gyro-reduced-MHD model.

We assume a uniform (toroidal) magnetic field, $\boldsymbol{B} = B_0\boldsymbol{b}$, where $\boldsymbol{b}$ is the unit vector in the z direction. The three field gyro-reduced MHD model was derived by moment equations of the gyro-kinetic equations:

$$\begin{aligned}\frac{\partial}{\partial t}(\nabla_\perp^2\phi) &= -\frac{\boldsymbol{b}\times\nabla\phi}{B_0}\cdot\nabla(\nabla_\perp^2\phi) \\ &- v_A^2\boldsymbol{b}^*\cdot\nabla(\nabla_\perp^2 A_z)\,, \qquad (1)\\ \frac{\partial}{\partial t}A_z &= -\boldsymbol{b}^*\cdot\nabla\phi + d_e^2\frac{d}{dt}(\nabla_\perp^2 A_z) \\ &+ \frac{T_e}{n_{e0}e}\boldsymbol{b}^*\cdot\nabla n_e\,, \qquad (2)\\ \frac{\partial}{\partial t}n_e &= -\frac{\boldsymbol{b}\times\nabla\phi}{B_0}\cdot\nabla n_e \\ &- \frac{1}{e\mu_0}\boldsymbol{b}^*\cdot\nabla(\nabla_\perp^2 A_z)\,, \qquad (3)\end{aligned}$$

where ϕ is the electrostatic potential, A_z is the z component of the vector potential, n_e is the electron density, v_A is the Alfvén velocity, T_e is the electron temperature, n_{e0} is the average electron density, e is the electron charge, μ_0 is the permeability in vacuum, $\boldsymbol{b}^*$ is the unit vector of the magnetic field, $\boldsymbol{b}^* = \boldsymbol{b} + (\nabla A_z \times \boldsymbol{b})/B_0$, and d/dt is the convective derivative defined by $d/dt = \partial/\partial t + [(\boldsymbol{b}\times\nabla\phi)/B_0]\cdot\nabla$. Eq.(1) represents the vortex equation while generalized Ohm's law in the direction parallel to the magnetic field is described by Eq.(2). Eq.(3) represents continuous equation of the electron density.

Without any stabilization effects, the full neconnection followed by the second phase reforming the configuration of $q_0 < 1$ have been observed by the numerical simulations. To study the partial reconnection process, it is important to include some stabilization effects. The stabilization of kinetic internal kink mode by the sheared poloidal flow was studied by H. Naitou et al.[4]. Here, the effects of density gradients on the $m = 1$ (poloidal mode number) and $n = 1$ (toroidal mode number) kinetic internal kink mode are studied numerically by the linearized version of GRM3F-CY code. We have selected $d_e = 5.315 \times 10^{-4}$ and $\rho_s = 2.891 \times 10^{-3}$. Although very small instability remains for $\omega_{*e} > 2\gamma_0$, the ω_{*e} stabilizing effect following the simple theory is observed for $\omega_{*e} \leq 2\gamma_0$.

One explanation of the ω_{*e} stabilization is that, for the Ohm's law along the magnetic field, there is no direct effects of density gradients at the $q = 1$ rational surface because $k_\parallel = 0$. Hence, for the negative and positive current layer at the $q = 1$ surface, there appeares a effective strong shear flow inside the current layer which can destroy the current layer profile characteristic to the unstable kinetic internal kink mode. The another explanation of the ω_{*e} stabilazation is the energy extraction from the unstable region by the drift wave. The stabilizatin is, hence, effective only if there is a sufficient space around the $q = 1$ rational surface so that the drift wave can propagate in the radial directions. Although ion Landau damping was not included in this study, it may be possible that the inclusion of ion Landau damping may increase the stabilizing effects of the drift wave propagating outside of the $q = 1$ surface.

It will be interesting to study nonlinear behavior of the residual instability, since this instability has both characteristics, electrostatic drift wave and internal kink mode. Thus the development of the nonlinear vergion of GRM3F-CY code is our project in the near future.

Reference

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