§4. Gyro-fluid Simulation of Kinetic Internal Kink Modes

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The collisionless reconnection process of the $m = 1$ (poloidal) and $n = 1$ (toroidal) kinetic internal kink mode is simulated by the three dimensional two field (the electrostatic potential, ϕ, and the component of the vector potential in the direction of toroidal magnetic field, A_z) gyro-fluid code including the effects of the electron inertia and the perturbed electron pressure gradient.

$$\frac{d}{dt}(\nabla_\perp^2 \phi) = -v_A^2 \, \boldsymbol{b}^* \cdot \nabla(\nabla_\perp^2 A_z) , \qquad (1)$$

$$\frac{\partial}{\partial t} A_z = -\boldsymbol{b}^* \cdot \nabla \phi + d_e^2 \frac{d}{dt}(\nabla_\perp^2 A_z) + \rho_s^2 \boldsymbol{b}^* \cdot \nabla(\nabla_\perp^2 \phi), \qquad (2)$$

where $v_A = c\,\omega_{ci}/\omega_{pi}$ (c is the speed of light in vacuum and ω_{ci} and ω_{pi} are the ion cyclotron and plasma angular frequencies, respectively) is the Alfven velocity, $d_e = c/\omega_{pe}$ (ω_{pe} is the electron plasma angular frequency) is the collisionless electron skin depth, $\rho_s = \sqrt{T_e/m_i}/\omega_{ci}$ (m_i is the ion mass, T_e is the electron temperature) is the ion Larmor radius calculated by the electron temperature, $\boldsymbol{b}^*$ is the unit vector of the magnetic field,

$$\boldsymbol{b}^* = \boldsymbol{b} + \frac{\nabla A_z \times \boldsymbol{b}}{B_0} , \qquad (3)$$

and d/dt is the convective derivative defined by

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{\boldsymbol{b} \times \nabla \phi}{B_0} \cdot \nabla . \qquad (4)$$

The external magnetic field is assumed to be $\boldsymbol{B} = B_0 \boldsymbol{b}$ where $\boldsymbol{b}$ is the unit vector.

The computational model is a rectangular system ($L_x \times L_y \times L_z$) which represents a straight tokamak with periodic boundary condition in the z (toroidal) direction. The plasma is surrounded by the perfectly conducting walls in the x and y (poloidal) directions. The measured linear growth rates agree with the theory in which $\gamma \propto d_e$ for $d_e \gg \rho_s$ and $\gamma \propto d_e^{\frac{1}{3}} \rho_s^{\frac{2}{3}}$ for $d_e \ll \rho_s$ (see Fig.1 and Fig.2). Also, results of the gyro-fluid code agree quite well with those of the gyrokinetic particle code (GYR3D) for linear and early nonlinear phase of the instability. The comparison of both codes in the deeply nonlinear phase of the instability is in progress.

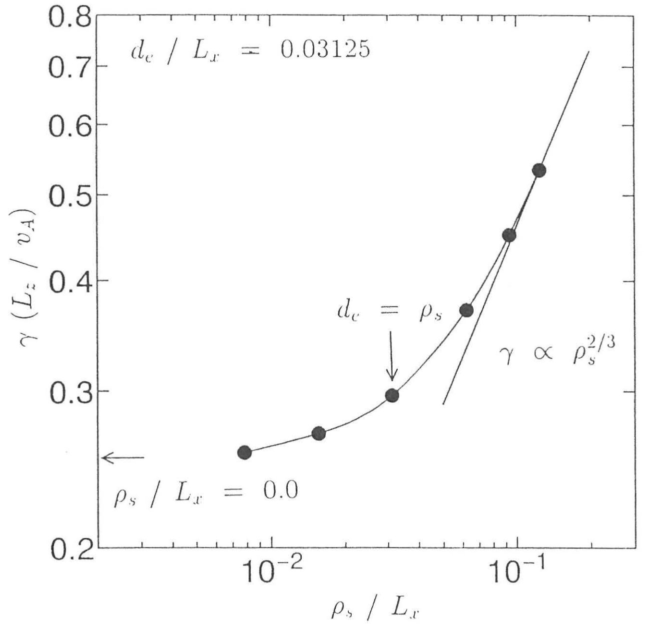

Fig.1. The ρ_s/L_x dependence of the growth rate of the kinetic internal kink mode for $d_e/L_x = 0.03125$.

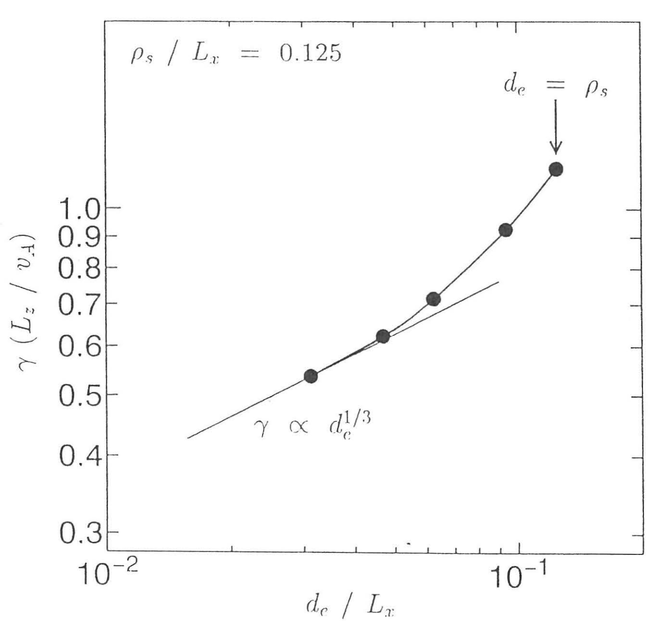

Fig.2. The d_e/L_x dependence of the growth rate of the kinetic internal kink mode for $\rho_s/L_x = 0.125$.