§20. Electromagnetic ITG Modes in Helical Systems

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The ion temperature gradient (ITG) mode is considered to cause the anomalous ion thermal transport in high temperature core regions of tokamak plasmas. Recently, helical systems such as the Large Helical Device (LHD) have succeeded in producing high ion temperature plasmas. In addition, experiments to produce higher β plasmas in helical systems are in progress, and therefore it is important to clarify electromagnetic effects on the ITG mode. In this work, linear properties of the electromagnetic ITG mode in finite-β helical systems with the large aspect-ratio magnetic configuration $B/B_0 = 1 - \epsilon_t \cos\theta - \epsilon_h(L\theta - M\zeta)$ are studied, and compared with those in the electrostatic case and in the tokamak case[1].

The temporal dependence of the perturbation terms $\tilde{\phi}$ (the electrostatic potential) and $\tilde{A}_{\parallel}$ (the parallel component of the vector potential), is assumed to be given by $\tilde{\phi}, \tilde{A}_{\parallel} \propto \exp(-i\omega t)$ with a complex frequency $\omega = \omega_r + i\gamma$ and time t. The perturbation part is given by $\delta f = -(q_c\tilde{\phi}/T)nF_M + \tilde{h}\exp(-i\boldsymbol{k}_\perp \cdot \boldsymbol{\rho})$, where $\boldsymbol{\rho} \equiv (\boldsymbol{B}/B) \times (\boldsymbol{v}/\Omega_B)$ is the gyroradius vector, $\Omega_B = q_c B/(mc)$ is the gyrofrequency, $\boldsymbol{k}_\perp$ is the wavenumber vector given by the ballooning representation, q_c is the charge ($q_c = e$ for ions, $-e$ for electrons), n is the equilibrium density, and c is the light speed. The nonadiabatic part of the distribution function $\tilde{h}$, is determined by the collisionless linear electromagnetic gyrokinetic equation,

$$\left[i\frac{v_{\parallel}}{Rq}\frac{\partial}{\partial\theta} + (\omega - \omega_D)\right]\tilde{h} = (\omega - \omega_{*T})J_0\left(\frac{k_\perp v_\perp}{\Omega_B}\right)F_M\frac{q_c n}{T}\left(\tilde{\phi} - \frac{v_{\parallel}}{c}\tilde{A}_{\parallel}\right), \tag{1}$$

where $\omega_D = \boldsymbol{k}_\perp \cdot \boldsymbol{v}_D$, $\boldsymbol{v}_D = \Omega_B^{-1}(v_{\parallel}^2 + v_\perp^2/2)B^{-2}\boldsymbol{B} \times \nabla B$, $\omega_{*T} = \omega_*[\{1 + \eta(v/v_T) - 3/2\}]$, $\omega_* = ck_\theta T/q_c BL_n$, $\eta \equiv L_n/L_T$, $L_n = -(d/dr)\ln n$, and $L_T = -(d/dr)\ln T$. In order to derive the eigenmode equations, the quasineutrality condition $\tilde{n}_i = \tilde{n}_e$ and the Ampère's law $\nabla_\perp^2 \tilde{A}_{\parallel} = -(4\pi/c)(\tilde{j}_{i\parallel} + \tilde{j}_{e\parallel})$ are used. The number density perturbation $\tilde{n} = \int d^3v\, \delta f$ and the current density perturbation $\tilde{j}_{\parallel} = q_c \int d^3v\, v_{\parallel}\, \delta f$ are rewritten in terms of $\tilde{\phi}$ and $\tilde{A}_{\parallel}$ by integrating Eq.(1). Here, we neglect effects of trapped particles and take the lowest-order solution of Eq.(1) in the massless-electron approximation. Derived parameter dependence of the dispersion relation is written as

$$\frac{\omega}{\omega_{*e}} = F(q, \hat{s}, \theta_k, \alpha, k_\theta, \eta_i, T_e/T_i, \epsilon_n, \beta_i, \tau_e, \epsilon_h/\epsilon_t, L, M), \tag{2}$$

with the dimensionless function F, the safety factor q, the magnetic shear parameter $\hat{s} = (r/q)(dq/dr)$, the ballooning angle θ_k, the field line label α, the poloidal wavenumber k_θ, $\epsilon_n = L_n/R_0$ and $\beta_i = 8\pi nT_i/B^2$. We use the parameters $q = 2$, $\hat{s} = -1$ (negative shear), $\theta_k = 0$, $\alpha = 0$, $k_\theta \rho_{Ti} = 0.65$ $\eta_i = \eta_e = 3$, $\epsilon_n = 0.3$, $T_e/T_i = 1$, $\epsilon_h/\epsilon_t = 1$, $L = 2$, $M = 10$. For the tokamak case, $\epsilon_h/\epsilon_t = 0$.

Figure 1 shows the β_i dependence of the real frequency and the growth rate of the ITG mode. For $\beta_i = 0.001\%$ and 0.5%, the real and imaginary parts of the eigenfunctions $\tilde{\phi}$ and $\tilde{A}_{\parallel}$ are plotted in Fig. 2 for the helical system. In the low β_i case ($\beta_i = 0.001\%$), The real frequency, the growth rate, and the potential eigenfunction are in good agreement with those in the electrostatic case[2], and the amplitude of $\tilde{A}_{\parallel}$ is negligibly small as shown in Fig. 2.

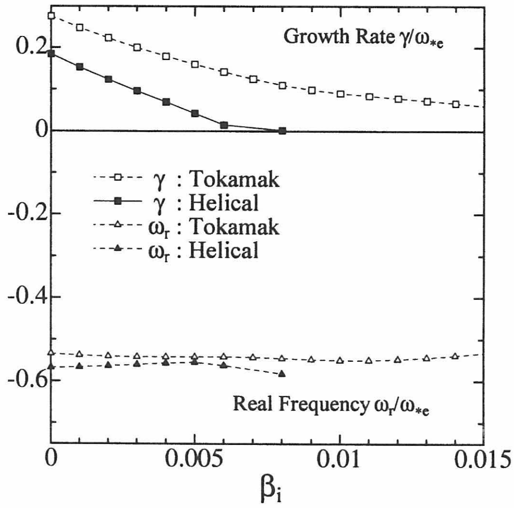

Figure 1: Normalized real frequency ω_r/ω_{*e} and growth rate.

In the case of $\beta_i = 0.5\%$, higher β increases magnetic fluctuations and gives more oscillatory profiles of eingenfunctions, which results from the multiplier effect of the helical magnetic ripples and the coupling to electromagnetic shear Alfvèn waves.

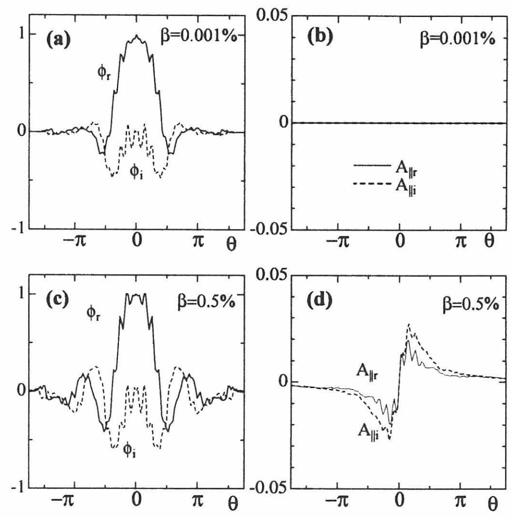

Figure 2: Normalized eigenfunctions $(e/T_e)\tilde{\phi}$ and $(ev_{Ti}/cT_e)\tilde{A}_{\parallel}$ in the helical system

Thus, the growth rate of the ITG mode for the helical system decreases with increasing β_i, and keeps smaller values than for the tokamak case.

Reference

[1] J. Q. Dong, *et al.*: Nucl. Fusion **39** (1999) 1041.

[2] T. Kuroda, *et al.*: J. Phys. Soc. Jpn. **69** (2000) 2485.

[3] T.Kuroda, H.Sugama, to be published in JPFR SERIES **5**.