power deposition region is generated by choosing the plasma parameters properly, which would direct the way for current profile control with LHCD in establishing stationary RS operation.

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3. 2 Instability Driven by Anisotropy Ion Temperature Gradient in Toroidal Plasmas[1)]

DONG Jiaqi

Key words: Ion temperature gradient, Instability, Anisotropy

Stimulated by ion cyclotron resonance frequency (ICRF) heating and neutral beam injection (NBI) heating which can generate anisotropy in temperature and temperature gradient of ions in tokamak experiments, Migliuolo first investigated effects of ion temperature anisotropy on ion temperature gradient (ITG) driven modes in a shearless slab configuration[1]. He found that the anisotropy in the direction of $T_{\perp}>T_{/\!/}$ gives an overall stabilizing effect. Later, Mathey and Sen investigated effect of an anisotropy in ion temperature gradient on ITG driven instability in same geometry to explain the experiments on the Columbia Linear

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Machine (CLM)[2]. Using the local kinetic theory, they showed that a finite gradient in the parallel temperature is necessary for the instability, and a gradient in the perpendicular temperature can either enhance or diminish the instability. In particular, it was shown that a large perpendicular temperature gradient could introduce a significant increase of the threshold value of the parallel temperature gradient, suggesting a stabilization of this mode. Recently, the subject was generalized to a shearless toroidal system by Kim et al. with a local kinetic theory[3]. It was concluded that the effect of the anisotropy in the temperature gradient on ITG modes is significantly different between the slab and toroidal modes. For the slab mode, a large gradient in the perpendicular temperature can give a significant stabilizing effect, while for the toroidal mode, the perpendicular temperature gradient contributes to only the destabilization like the parallel temperature gradient. In addition, it is also pointed out[3] that while the local approximation is useful to obtain quantitative physics trend of the anisotropy effect, the non-local consideration, with magnetic shear effects included, is needed to obtain more complete conclusions.

The significant progress in auxiliary heating power such as ICRF and NBI may generate more anisotropy in temperature and temperature gradient of ions in future tokamak experiments. Thus it is important to consider effects of the anisotropy on the drift wave instabilities responsible for anomalous transport more in detail.

The ITG driven micro-instabilities are studied, using fluid and kinetic theories, for plasmas with ion temperature and temperature gradient anisotropy in sheared slab geometry by Dong et al[4]. The effects of a parallel velocity shear (PVS) and a perpendicular velocity shear ($v'_{0//}$ and v'_E) on the modes were also investigated [4].

The ITG driven micro-instabilities in toroidal plasmas with ion temperature gradient anisotropy are studied in present work with integral eigenvalue equation.

The integral dispersion equation in toroidal plasma with ion temperature gradient anisotropy is derived from the quasi-neutrality condition in ballooning representation as[5]:

$$[1+\tau_{\mathrm{i}}]\hat{\phi}(k)=\int_{-\infty}^{+\infty}\frac{\mathrm{d}k'}{\sqrt{2\pi}}K(k,\ k')\hat{\phi}(k') \tag{1}$$

where $\hat{\phi}(k)$ is the extended Fourier components (in ballooning space) of $\tilde{\phi}(r)$ and

$$K(k,\ k')=-\mathrm{i}\int_{-\infty}^{0}\omega_{*\mathrm{e}}\mathrm{d}\tau\sqrt{2}\exp(-\mathrm{i}\omega\tau)$$

$$\left[\frac{\exp\left[-\dfrac{(k'-k)^2}{4\lambda}\right]}{\sqrt{\alpha}(1+\alpha)\sqrt{\lambda}}\times\left\{\frac{\omega}{\omega_{*\mathrm{e}}}\tau_{\mathrm{i}}+1-\frac{1}{2}\eta_{//}-\eta_{\perp}+\frac{2\eta_{\perp}}{(1+\alpha)}\times\right.\right. \tag{2}$$

$$\left.\left.\left[1-\frac{k_{\perp}^2+k_{\perp}'^2}{2(1+\alpha)\tau_{\mathrm{i}}}+\frac{k_{\perp}k_{\perp}'}{(1+\alpha)\tau_{\mathrm{i}}}\frac{I_1}{I_0}\right]+\frac{\eta_{//}(k-k')^2}{4\alpha\lambda}\right\}\right]\Gamma_0(k_{\perp},k_{\perp}')$$

with

$$\lambda=\frac{\tau^2\omega_{*\mathrm{e}}^2}{\tau_{\mathrm{i}}\alpha}\left(\frac{\hat{s}}{\hat{q}}\in_n\right)^2$$

$$\alpha=1+\frac{\mathrm{i}2\in_n}{\tau_{\mathrm{i}}}\omega_{*\mathrm{e}}\tau\frac{g(\theta,\theta')}{(\theta-\theta')}$$

$$g(\theta,\theta')=(\hat{s}+1)(\sin\theta-\sin\theta')-\hat{s}(\theta\cos\theta-\theta'\cos\theta')$$

$$k=k_{\theta}\hat{s}\theta,\ \ k'=k_{\theta}\hat{s}\theta'$$

$$\Gamma_0=I_0\left[\frac{k_{\perp}k_{\perp}'}{(1+\alpha)\tau_{\mathrm{i}}}\right]\exp[-(k_{\perp}^2+k_{\perp}'^2)/2\tau_{\mathrm{i}}(1+\alpha)]$$

$$k_{\perp}^2=k_{\theta}^2[1+(\hat{s}\theta)^2],\quad k_{\perp}'^2=k_{\theta}^2[1+(\hat{s}\theta')^2]$$

$$\in_n=\frac{L_n}{R_0},\ \ \eta_{\perp}=\frac{L_n}{L_{\mathrm{Ti}\perp}},\ \ \eta_{//}=\frac{L_n}{L_{\mathrm{Ti}//}},\ \ \tau_{\mathrm{i}}=\frac{T_{\mathrm{e}}}{T_{\mathrm{i}}}$$

The quantities k, k' and k_θ are normalized to $\rho_{\mathrm{s}}^{-1}=eB/c\sqrt{2T_{\mathrm{e}}m_{\mathrm{i}}}$, x is normalized to ρ_{s}, and I_j(j=0, 1) is the modified Bessel
function of order j. In addition, all the symbols have their usual meanings such as the L_{n} is the density gradient scale length, L_{T} are the temperature scale lengths, q is the safety factor, $\hat{s}=r\mathrm{d}q/q\mathrm{d}r$ is the magnetic shear, m and T are the mass and temperature, respectively, $\omega_{*\mathrm{e}}=ck_{\theta}T_{\mathrm{e}}/q_sBL_{\mathrm{n}}$ is the electron diamagnetic drift frequency.

Eq. (1) has been solved numerically with a well developed code and the main results are presented in Fig. 1 [5].

Shown in Fig. 1 are the normalized growth rate (a) and real frequency (b) versus $\eta_{\perp}(\eta_{/\!/})$ in a torus with magnetic shear. The lines with open circles and diamonds are for $\eta_{/\!/}$= 2.5 with q= 2 and 4, respectively. The lines with closed circles are for $\eta_{\perp}$=2.5, q=2 and varying $\eta_{/\!/}$. The other parameters are $\in_n$=0.2, τ_i=1, $k_\theta \rho_i$=0.6 and $\hat{s}$=1.6. The growth rate of the modes keeps increasing with $\eta_{\perp}$ as well as with $\eta_{/\!/}$ up to very high η_i values (≈12). No stabilization from either $\eta_{\perp}$ nor $\eta_{/\!/}$, is observed and the results from shearless toroidal model are confirmed with the sheared torus model. In addition, it is clearly illustrated in Fig. 1 that the growth rate of the modes increases with $\eta_{/\!/}$, for a fixed $\eta_{\perp}$(= 2.5) much faster than it does with $\eta_{\perp}$ for a fixed $\eta_{/\!/}$(=2.5). As the magnitude of the real frequency is concerned, it is the opposite.

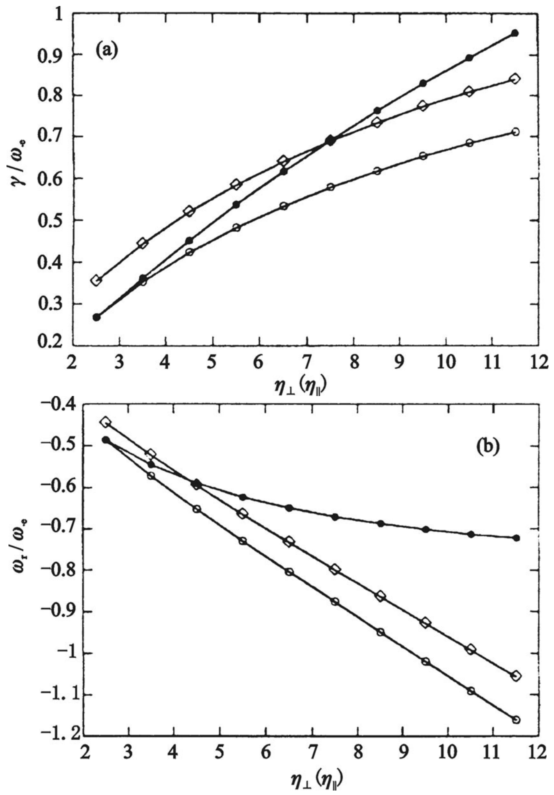

Fig. 1 The normalized growth rate (a) and real frequency (b) versus $\eta_{\perp}$ ($\eta_{/\!/}$) in a torus with magnetic shear

The lines with open circles and diamonds are for $\eta_{/\!/}$= 2.5 with q = 2 and 4, respectively. The lines with closed circles are for $\eta_{\perp}$= 2.5, q = 2 and varying. The other parameters are $\in_n$ = 0. 2, τ_i =1, $k_\theta \rho_i$ =0.6 and $\hat{s}$ =1.6.

As significant progress in auxiliary heating power such as ICRF and NBI is made, more anisotropy in temperature and temperature gradient of ions is possible in future tokamak experiments. Thus, it is important to consider effect of the anisotropy on the drift wave instabilities and anomalous transport in a torus with a finite magnetic shear. Such studies are performed and the results for a shear-less torus[3] are confirmed for a torus with magnetic shear in this work. No stabilization from either $\eta_{\perp}$ nor $\eta_{/\!/}$ is observed. In addition, it is demonstrated that the growth rate of the modes increases with $\eta_{/\!/}$ for fixed $\eta_{\perp}$ much faster than it does with $\eta_{\perp}$ for a fixed $\eta_{/\!/}$.

As is pointed out in Ref. [5] that the local magnetic shear effects are poorly represented with the ballooning formalism which emphasize the exact treatment of ballooning structure of eigenfunctions and toroidal curvature and magnetic gradient drifts, i. e., the ballooning effects. The magnetic effects in a torus are studied with the quasi-toroidal model[5], which has a better representation for local magnetic shear and mode structure in radial direction in order to examine the role of the ballooning formalism in such studies. The results are very close to what are given in Fig. 1. The growth rate of the modes keeps growing with the increase of $\eta_{\perp}$ even for nonrealistic values ($\eta_{\perp}\approx 40$).

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