DESTABILIZATION OF TAE MODES BY FAST IONS WITH FINITE WIDTH OF PITCH DISTRIBUTION

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Toroidicity-induced Alfvèn eigenmodes (TAE) are often observed in tokamaks and stellarators. They are typically destabilized by the pressure gradient (∇p_α) of fast-ions produced by neutral beam injection (NBI) and /or acceleration during ion cyclotron resonance heating (ICRH). Because the radial profile of fast ions is normally decreasing $(\nabla p_\alpha < 0)$, TAEs driven by ∇p_α usually propagate in the direction of plasma current, i.e. they are co-propagating TAE, co-TAE. In the exceptional case of beam ions with inverse radial profile $(\nabla p_\alpha > 0)$, TAEs driven by the spatial inhomogeneity of fast ions are counter propagating, ctr-TAE.

However, the pressure gradient of fast ions is not always the dominant destabilizing factor in TAE instabilities. The velocity anisotropy of fast ions is another factor affecting the plasma stability. Moreover, TAEs can be destabilized in the absence of a non-Maxwellian population of fast ions, in Ohmic discharges.

Despite the fact that ctr-TAEs are not typical, they occurred in various devices. In particular, in NSTX-U experiments [1] and earlier in TFTR [2], JT-60U [3]. They were observed also in the absence of fast ions in Ohmic discharges in SUNIST [4].

Various mechanisms of TAE instabilities, with a special attention to finding conditions leading to ctr-TAEs, were considered in a recent work of the authors [5]. In addition to a general analysis, a specific example was considered in Ref. [5]: an experiment with NBI on the spherical tokamak NSTX-U where co- and ctr-TAEs were observed simultaneously [1] was considered. It was concluded that both types of TAEs occurred because their destabilization was caused by the velocity anisotropy of beam ions, which overrode effects of spatial inhomogeneity, although $\nabla p_\alpha > 0$ could contribute to the instability drive.

It was assumed in Ref. [5] that the pitch distribution of fast ions is approximated by the Dirac δ-function, $F_\alpha \sim \delta(\chi - \chi_0)$, where $\chi = \mathrm{v}_{\parallel}/\mathrm{v}$, v is the particle velocity, $\mathrm{v}_{\parallel}$ is the velocity along the magnetic field. This approximation was justified by the fact that the dependence of the fast ion distribution on χ was not known. At the same time, it remained open a question whether finite width of distribution over χ does not stabilize the instability.

In order to clarify this issue, the relations used in Ref. [5], which describe the instability growth rate, $\gamma(\chi)$, were extended by taking into account the presence of fast ions with various pitches, $\Delta\chi \neq 0$. The numerical code calculating the growth rate was changed correspondingly. Calculations for both ctr-TAEs and co-TAEs were carried out for the cases when the fast ion density, $n_\alpha(r)$, has a plateau or a weak maximum, as shown in Fig. 4 of Ref. [5]. It was found that the instability can persist for both types of $n_\alpha(r)$ even when $\Delta\chi$ is rather large, e.g. $\Delta\chi = 0.2$. A reservation to this statement, however, is required: When $n_\alpha(r)$ has a plateau, the ctr-TAE mode with lower frequency remains unstable provided the plateau region is slightly extended, as was predicted in Ref. [5].

The results of calculations for ctr-TAE are shown on Fig. 1. We observe that finite $\Delta\chi$ decreases the growth rate, and can even completely suppress the instability (Fig. 1, left panel; when $\Delta\chi = 0.2$, low mode is stable at $x_{\max} = 0.35$ but unstable for $n_\alpha(x)$ with an extended plateau, $x_{\max} = 0.4$). On the other hand, it is a bit surprising that in some cases, when $\Delta\chi \neq 0$, fast ions with pitches which are stabilizing for $F_\alpha \sim \delta(\chi - \chi_0)$ can become destabilizing (Fig. 1, left panel; the stable region of high mode at $\chi_0 > 0.75$ becomes unstable). This is explained by the fact that the positive derivative $\partial F_\alpha / \partial \chi > 0$ shifts to smaller χ due to $\Delta\chi \neq 0$.

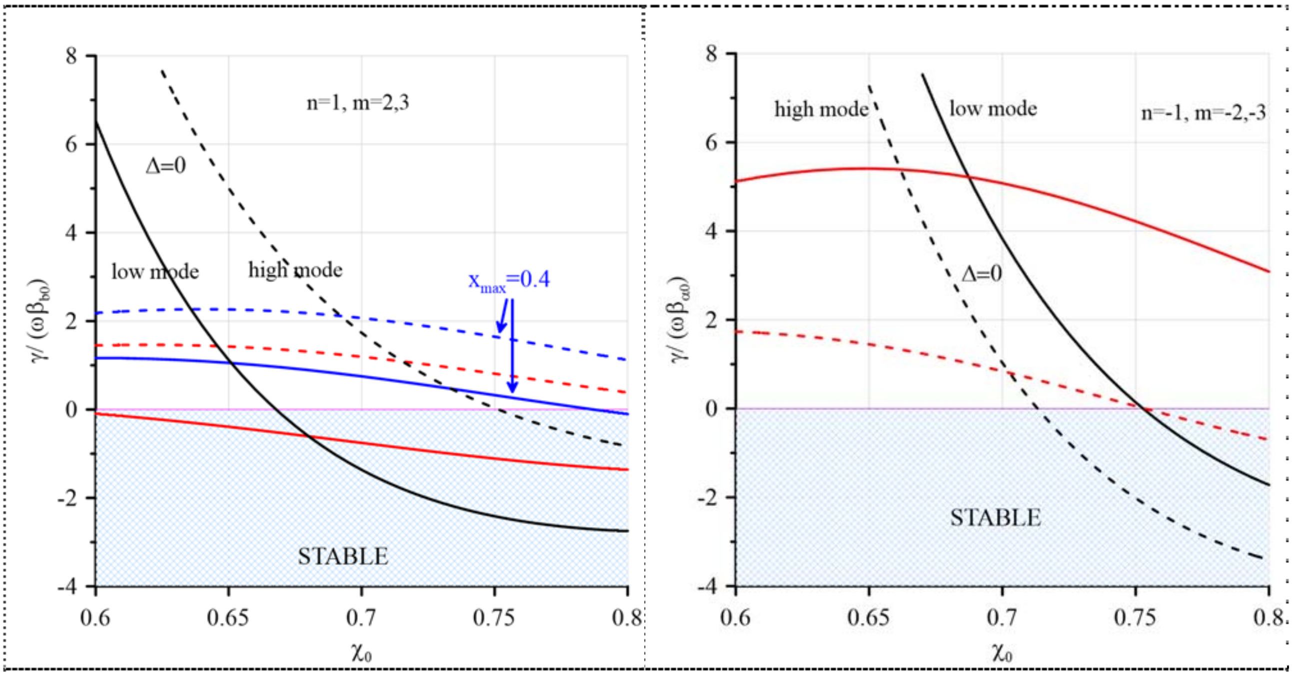

Fig. 1. γ versus χ_0 for ctr-TAE in the NSTX-U discharge #205072 when $F_\alpha = n_\alpha(x)(\mathrm{v}^3 + \mathrm{v}_c^3)^{-1}\exp[-(\chi-\chi_0)^2/(\Delta\chi)^2]$, with x=r/a: Left panel, $n_\alpha(x)$ with a plateau in the region [0, $x_{\max}$], $x_{\max} = 0.35$ except where noted $x_{\max} = 0.4$. Right panel, $n_\alpha(x)$ with a maximum at $x_{\max-} = 0.35$, c.f. Fig. 5 of Ref. [5]. The low mode and high mode are TAEs with lower and higher frequency, respectively; mode numbers are $m = 2$ and 3, $n = 1$.

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