Low-frequency fishbone driven by passing fast ions in Tokamak plasmas

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The internal kink modes with dominant poloidal and toroidal wave number $m = 1$ and $n = 1$ can be strongly destabilized by both the perpendicular and tangential neutral-beam injection [1, 2]. With perpendicular injection, the driven modes can be considered as either an energetic particle mode (EPM) with mode frequency comparable to the toroidal precession frequency of the trapped energetic ion [3] or a "gap" mode with mode frequency close to the thermal ion diamagnetic frequency [4]. With tangential injection, both the high-frequency mode and the low-frequency mode have been observed [2]. For the high-frequency branch, the mode was considered as an EPM with frequency determined by energetic particle toroidal circulation frequency [5, 6]. For the low-frequency branch, the mode was modeled as a "gap" mode with the thermal ion diamagnetic frequency [7]. In this work, within the framework of the theory of EPM, the low-frequency mode driven by a resonant interaction between the passing beam ions and the wave with $\omega = \omega_\phi - \omega_\theta$ is studied, where ω_ϕ and ω_θ are respectively the circulation frequency in toroidal and poloidal direction of passing fast ions. With the effect of finite orbit width (FOW) of fast ions, the instability can be excited by passing fast ions. It is found that magnetic shear at the q=1 radius plays an important role in the instability whereas the effect of the background plasma beta is weak. In particular, there exists a critical magnetic shear below which the beam ion beta threshold for EPM excitation is very small. For moderate or higher magnetic shear the beam ion beta threshold is about a few percent. These results are consistent with experimental observation of the low-frequency fishbone in the HL-2A tokamak [8].

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