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Study of fishbone instabilities induced by energetic particles in tokamak plasmas

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Abstract
Fishbone instabilities, driven by trapped and barely passing energetic particles (EPs), including electrons and ions (EEs or EIs), are numerically studied with the spatial distribution of EPs taken into account. The dispersion relations of the modes are derived for slowing-down and Maxwellian models of EP energy distribution. It is found that the modes with frequency comparable to the toroidal precession frequency ω_d of EPs are resonantly excited. Electron and ion fishbone modes share the same growth rates and real frequencies but rotate in opposite directions. The frequency of the modes is found to be higher in the case of near-axis heating than that of off-axis heating. The fishbone instabilities can only be excited by barely trapped or barely passing and deeply trapped particles in positive and negative spatial density gradient regions, respectively. In addition, the most interesting feature of the fishbone modes induced by barely passing particles is that there exists a second stable regime in the higher β_h (pressure of EPs/toroidal magnetic pressure) region, and the modes exist in the range of $\beta_{th1} < \beta_h < \beta_{th2}$ (β_{th} is threshold or critical beta of EPs) only. The results are well confirmed with Nyquist technology. The possible physical mechanism for the existence of the second stable regime is discussed.

(Some figures in this article are in colour only in the electronic version)