Nonlinear Fishbone Dynamics in Spherical Tokamaks with Toroidal Rotation

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Abstract

Fishbone is ubiquitous in tokamak plasmas with fast ions. A numerical study of nonlinear dynamics of fishbone has been carried out in this work. Realistic parameters of NSTX are used to understand linear instability and nonlinear frequency chirping in real tokamak plasmas. First, the effects of shear toroidal rotation are considered for fishbone instability. It is shown that with low q_{min} , toroidal rotation has small effects on the mode; while with high q min , a new unstable region with a strong ballooning feature in mode structure appears. Second, a systematic study of nonlinear frequency chirping and energetic particles' dynamics is carried out. It is found that, linearly, the mode is driven by both trapped particles and passing particles, with resonance condition $\omega_d \simeq \omega$ for trapped particles and $\omega_\phi + \omega_\vartheta \simeq \omega$ for passing particles, where ω_d is trapped particles precession frequency, and ω_ϕ, ω_ϑ are passing particle transit frequency around toroidal and poloidal direction. As the mode grows, resonance particles oscillate and move outward in P_ϕ space, which reduces particles' frequency. We believe that this is the main reason for the mode frequency chirping down. Finally, as the mode frequency chirping down, particles with lower orbit frequencies, which are non-resonant linearly, can turn into resonant particles in the nonlinear regime. This effect can sustain a quasi-steady state mode amplitude observed in the simulation.