Simulation of multi-modes in ASDEX-Upgrade

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Recently, a series of experiments demonstrated the coexistence of Alfvén eigenmode (AE), energetic particle driven geodesic acoustic mode (EGAM), and energetic particle driven mode (EPM) in ASDEX-Upgrade tokamak[1-3]. A hybrid simulation is conducted with the code MEGA to investigate the mode properties and the resonant particles. The simulation is based on realistic experimental parameters with slowing-down energetic particle distribution.

In the simulation, AE, EGAM, and EPM, are reproduced in the same run. The mode numbers m/n are 2/-1 and 3/-1 for AE, m/n = 0/0 for EGAM, and m/n = 2/-1 for EPM. AE and EGAM are located around r/a = 0.5$\sim$0.6, while EPM is located in core region around r/a = 0.1. The frequencies of AE, EGAM, and EPM are 103 kHz, 42 kHz, and 145 kHz, respectively. In nonlinear saturated stage, the frequency of AE chirps down, and the frequency of EPM chirps up. By contrast, the frequency of EGAM keeps constant.

The resonant condition of AE is $\omega_{AE} = n\omega_\phi + L\omega_\theta$, where ω_ϕ and ω_θ are particle toroidal and poloidal frequencies, respectively, n is toroidal mode number, and L is an arbitrary integer. In the present simulation, it is found that L is 1 for the above resonant condition. The resonant condition of EGAM is $\omega_{EGAM} = L\omega_\theta$. In the present simulation, the resonant particles with L = 1 are dominant, and also, some particles resonate with L = 2. In addition, fractional resonance (L = 1.5) also exists.

The resonant particles are analyzed in both (ω_ϕ, ω_θ) space and (Λ, E) space where Λ is pitch angle and E is energy. In linear growth stage, resonant particles of EGAM are located in low frequency and low energy region, by contrast, resonant particles of AE are located in high frequency and high energy region. There is an obvious gap between this 2 kind of particles. In nonlinear saturated stage, with time evolving, more and more particles fill into the gap and the gap becomes difficult to identify.

References

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