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トカマクプラズマにおける高エネルギー粒子駆動軸外れフィッシュボーン不安定性のシミュレーション研究

Simulation study of energetic-particle driven off-axis fishbone instabilities in tokamak plasmas

李瀚政 [1,2]，藤堂泰 [1,2]，王灝 [2]， Malik Idouakass[2] and 王佳磊 [2]
Hanzheng Li[1,2], Yasushi Todo[1,2], Hao Wang[2], Malik Idouakass[2] and Jialei Wang[2]
東京大学 [1]，核融合研究所 [2]
The University of Tokyo[1], National Institute for Fusion Science[2]

The linear growth and nonlinear evolution of off-axis fishbone mode (OFM) destabilized by trapped energetic ions in tokamak plasmas were investigated using kinetic-magnetohydrodynamic hybrid models.

The spatial profile of OFM is dominated by the $m/n = 2/1$ mode within the $q = 2$ magnetic flux surface, but the $m/n = 3/1$ mode dominates outside the $q = 2$ surface shown in Fig. 1, where m and n denote the poloidal and toroidal mode numbers, respectively, and q denotes the safety factor. On the poloidal plane, the OFM's spatial profile has a strongly shearing form, indicating that the interaction with energetic ions has a nonperturbative effect.

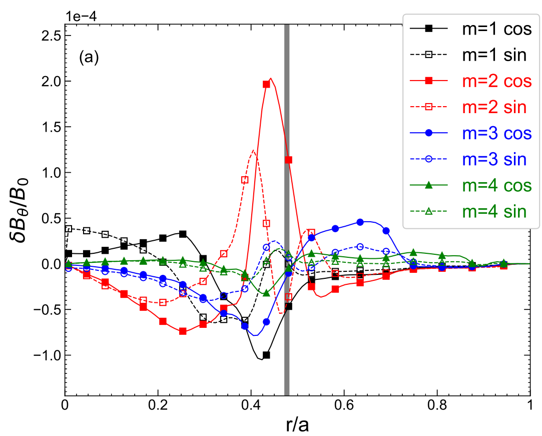

Fig. 1: Radial structures of magnetic field perturbation at the linear growth phase.

In the linear growth phase, the frequency of the OFM is in good accord with the precession drift frequency of trapped energetic ions, but in the nonlinear phase, the frequency chirps down. There are two types of resonance conditions discovered between trapped energetic ions and OFM.

To understand frequency chirping, the resonance frequency of each resonant particle is evaluated. This frequency is defined using the precession drift and bounce frequencies. The resonance frequency of the particles that transfer energy to the OFM chirps down, which corresponds to the OFM frequency chirping down. For the energetic particles involved in wave-particle interactions, the gradient of the distribution function along $E' = const.$ line drives or stabilizes the instability.

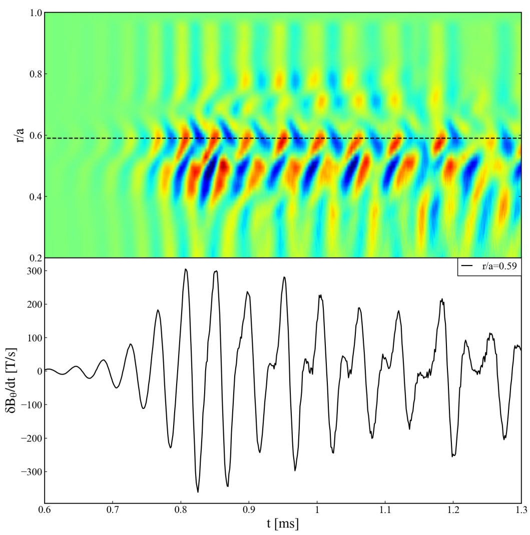

Fig. 2: The mode distortion.

Lastly, we observe the mode distortion of OFM in our simulations, which is previously found in experiments. The shearing profile of the OFM found in this work my affect the waveform distortion observed at a specific location through the spatial profile of the nonlinearly generated modes shown in Fig. 2.