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Investigation of mode transition induced by fast particle transport in phase space on EAST

Wei Shen[1], Liqing Xu[1], G. Y. Fu[2], Zhenzhen Ren[3], Feng Wang[4],
Liqun Hu[1], Nong Xiang[1], Dingzong Zhang[5] and the EAST team
[1] Institute of Plasma Physics, Chinese Academy of Science
[2] Institute for Fusion Theory and Simulation, Zhejiang University
[3] School of Physics and optoelectronic engineering, Anhui University
[4] School of Physics, Dalian University of Technology
[5] College of Physics and Electronic Engineering, Hengyang Normal University
e-mail (speaker): shenwei@ipp.ac.cn

Numerical investigation of mode transition induced by fast particle transport in phase space on the EAST tokamak has been carried out by the global kinetic-magnetohydrodynamic (MHD) code M3D-K[1,2]. Firstly, based on the fishbone instabilities observed on EAST, linear simulations show that the fishbone instability is excited at experimental value of beam ion pressure. The mode is mainly driven by low energy beam ions via precessional resonance. When the beam ion pressure is increased to exceed a critical value, the low frequency fishbone transits to a beta-induced Alfvén eigenmode (BAE) with much higher frequency. This BAE is driven by higher energy beam ions. Nonlinear simulations show that the frequency of the low frequency fishbone chirps up and down with corresponding hole-clump structures in phase space, consistent with the Berk–Breizman theory. In addition to the low frequency mode, the high frequency BAE is excited during the nonlinear evolution due to the fast particle redistribution in phase space. As BAEs are more efficient to heat thermal ions, this work finds a potential new way to transfer the energy of fast particles to thermal ions through waves.

Secondly, Alfvén eigenmodes (AEs) and Energetic Particle Modes (EPMs) have been observed in EAST neutral beam injection (NBI) plasma with the presence of heavy Tungsten impurity in the core region. The AEs are identified as Toroidal Alfvén eigenmodes (TAEs) with roughly constant frequency f_{TAE}~100 kHz and a special set of AEs with frequency chirping up from frequency f_{AE}~70 kHz to f_{AE} ~100 kHz. The frequency of EPMs is around f_{EPM}~60 kHz, exhibiting with frequency chirping down feature. A transition from EPMs to AEs is found, and the location and mode numbers are measured by experimental diagnostics. Hybrid simulations with the global kinetic-MHD code M3D-K have been carried out to investigate the observed AEs and EPMs, and linear simulations find the EPM with toroidal mode number n=2 and poloidal mode number m=3. Nonlinear simulations show that the EPM frequency chirps down nonlinearly, and then two modes emerge with frequencies around 72.7 kHz and 88.0 kHz, the mode with higher frequency is a TAE, and the other mode is an EPM. Afterwards, the TAE disappears quickly with the frequency almost unchanged, and the EPM with lower frequency chirps down continuously. The frequency chirping and jumping correspond to the distribution change of fast ion in phase space, and the mode frequencies and locations of the simulated EPM and TAE, as well as the chirping down feature of the EPM frequency, are consistent with the experimental measurements. The transition from EPM to TAE is found to be a self-consistent dynamic of nonlinear evolution with the expel of energetic ions due to EPM.

Thirdly, fishbone instabilities with both m/n=1/1,2/2 mode numbers have been observed on EAST. Numerical simulations show that the m/n=2/2 high frequency fishbone branch is linearly stable, but nonlinearly grows due to the coupling with the m.n=1/1 low frequency fishbone branch. The frequency of the m/n=2/2 fishbone is almost twice of the m/n=1/1 fishbone, and they chirps down together. In addtion, BAE is excited during the nonlinear evolution of the m/n=2/2 fishbone due to the beam ion transport in phase space. All these results show the mode transition induced by fast particle transport in phase space on EAST.

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