Simulations of fishbones with reversed safety factor profile and Energetic Particle Modes in the EAST tokamak

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Hybrid simulations of fishbone instabilities with reversed safety factor profile and Energetic Particle Modes (EPMs) in the EAST tokamak have been carried out by the global kinetic-magnetohydrodynamic (MHD) code M3D-K[1,2]. Firstly, linear stability and non-linear dynamics of the fishbone instabilities with reversed safety factor profile have been investigated by the hybrid code M3D-K. For the consideration of the fishbone instability with a reversed q profile, there are two different types of the fishbone instability: dual resonant fishbone (DRF) with double q=1 surfaces and non-resonant fishbone (NRF) with the minimum value of safety factor $q_{\min}$ a little larger than unity. Based on EAST-like parameters, linear simulations show that the DRF is excited by the trapped beam ions when the fast ion pressure exceeds a critical value, and the mode structure of DRF exhibits splitting radial structure due to double q=1 surfaces. When $q_{\min}$ increases from below unity to above unity, the fishbone instability transits from the DRF to the NRF, and the mode frequency of the NRF is higher than the DRF as the NRF is resonant with fast ions with larger precessional frequency. Nonlinear simulations show that the saturation of the DRF is due to MHD non-linearity with a large n=0 component. However, the saturation of the NRF is mainly due to the non-linearity of fast ions, and the frequency of the NRF chirps down nonlinearly. The fast ions are redistributed and become flattened due to the DRF or the NRF, and the transport level of the fast ions due to the NRF is weaker with more centrally radial redistribution region in comparison with that of the DRF.

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.

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References

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