Synopsis CATEGORY TH-W

Linear and Nonlinear Hybrid Simulations of Beam-driven TAEs and Fishbone Instability in NSTX

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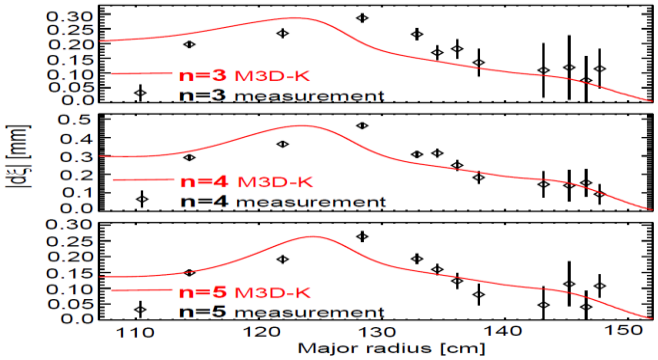
Energetic particle modes and Alfvénic modes driven by super-Alfvénic beam ions are routinely observed in neutral beam heated plasmas on the National Spherical Torus Experiment (NSTX). These modes can significantly impact beam-ion transport, thus causing beam-ion redistribution or losses. In this paper we report on recent new self-consistent simulations of Toroidicity-induced Alfvén Eigenmodes (TAEs) as well as fishbone instabilities in NSTX plasmas using the kinetic/MHD hybrid code M3D-K. The simulation results of TAEs show mode radial structure consistent with the reflectometer measurements of electron density fluctuations. Nonlinear simulation of TAEs shows mode saturation and frequency chirping. The results of fishbone simulation show nonlinear saturation with strong frequency chirping as well as a nonlinearly-driven m=2/n=1 magnetic island.

A. TAE For the purpose of validating the M3D-K code, linear simulations of beam-driven TAEs have been carried out for a NSTX plasma. Results show that unstable TAEs with n=2-5 can be excited by fast beam ions. The calculated mode frequency, structure and phase shift are consistent with experimental measurements from a multi-channel reflectometer diagnostic [N. Crocker et al, PPCF 2011]. In particular, the reflectometer response to the simulated TAEs, modeled with a synthetic diagnostic, is in reasonable agreement with the reflectometer measurement as shown in the following figure, which shows the effective displacement resulting from the density perturbations.



A sensitivity study on plasma rotation, q profile and equilibrium beam-ion distribution is performed. It is found that rotation has a significant destabilizing effect on the modes at the level of rotation in the experiment. The growth rate is also sensitive to the q_{min} position and beam-ion distribution. But mode structure and peak position have weak dependence on these factors. The TAE simulations have been extended to the nonlinear regime and the results show mode saturation with significant frequency chirping.

B. Fishbone Extensive linear and nonlinear M3D-K simulations have been carried out to investigate energetic particle effects on the non-resonant kink mode and excitation of fishbones for NSTX-like plasmas with weakly reversed q profile and q_{min} value just above unity. Numerical results show that beam ions have a strong stabilizing effect on the non-resonant kink (NRK) mode at low values of q_{min} and beam beta. However, at a higher beam ion beta, a fishbone-like mode is excited. The results show that the fishbone is preferentially excited at higher q_{min} values as shown in the figure below, consistent with the observed appearance of fishbones before the "long-lived mode" in NSTX and MAST experiments [I. Chapman et al, Nucl. Fusion 2010]. Nonlinear simulations show that the fishbone saturates nonlinearly with strong downward frequency chirping and beam ion distribution flattening. An m/n=2/1 magnetic island is induced nonlinearly, which could provide a trigger for the 2/1 neoclassical tearing mode sometimes observed after the fishbone instability in NSTX [S. Gerhardt et al, Nucl. Fusion 2009]. These results have important implications for future burning plasma such as ITER with respect to alpha particle confinement and NTMs.