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

G. Y. Fu[1*], D.Y. Liu[2], F. Wang[3],J. A. Breslau[1], N. A. Crocker[4] , E. D. Fredrickson[1], S. Kubota[4], J.Y. Liu[3], M. Podesta[1],

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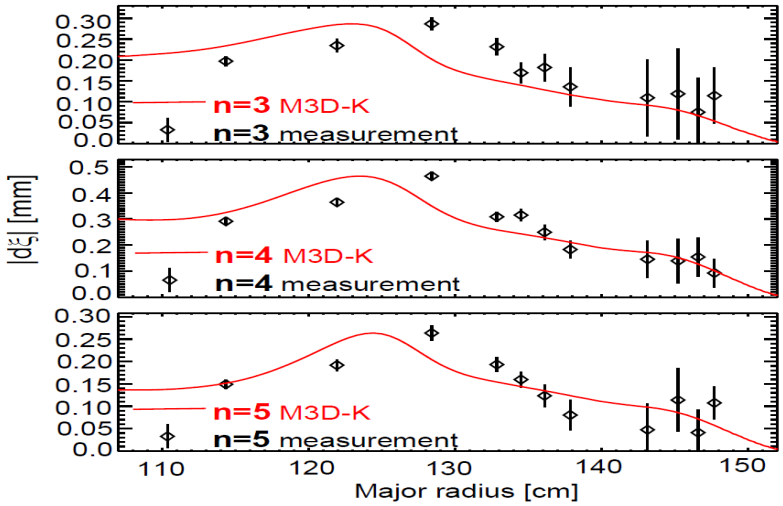
[1]*Princeton Plasma Physics Laboratory, USA*
[2]*University of California, Irvine, USA*
[3]*Dalian University of Technology, Dalian 116024, China*
[4]*University of California, Los Angles, USA*
**Email:fu@pppl.gov*

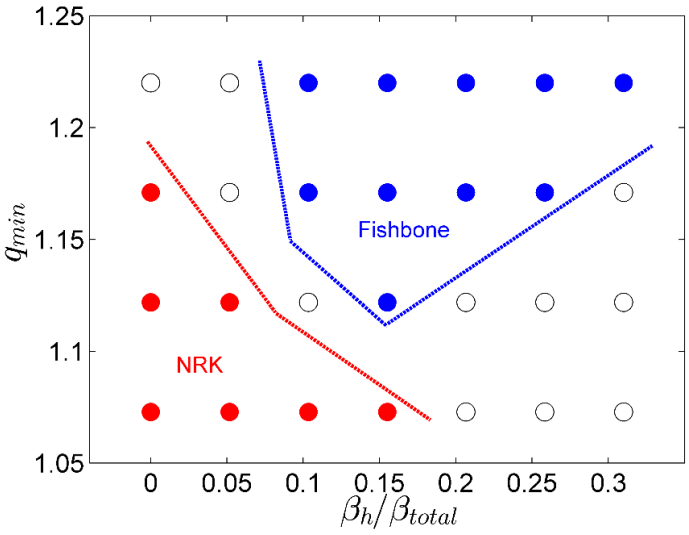
Energetic particle modes and Alfvénic modes driven by super-Alfvénic beam ions are routinely observed in neutral beam heated plasmas on theNational Spherical Torus Experiment (NSTX). These modes can significantly impact beam-ion transport, thus cause beam-ion redistribution or loss. In this paper we 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 measurement of electron density fluctuation. Nonlinear simulation of TAE shows mode saturation and frequency chirping. The results of fishbone show nonlinear saturation with strong frequency chirping as well as nonlinearly-driven m=2/n=1 magnetic island.

A. TAE For the purpose of validating the M3D-K code, linear simulations of beam-driven TAE have been carried out for a NSTX plasma. Result 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. In particular, the simulated TAE radial displacement profiles are in reasonable agreement with the reflectometer measurement as shown in the following figure.



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 mode stability at experimental level. The growth rate is also sensitive to 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 nonlinear regime and results show mode saturation with significant frequency chirping. However, the mode structure changes little during the nonlinear saturation.

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 fishbone 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 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 fishbone before "long-lived mode" in NSTX and MAST experiments [1]. Nonlinear simulations show that the fishbone saturates nonlinearly with strong downward frequency chirping, and beam distribution flattened. An m/n=2/1 magnetic island is induced nonlinearly, which could providea trigger for the 2/1 Neoclassical tearing mode sometime observed after fishbone instability in NSTX [2]. There results have important implications for future burning plasma such as ITER with respect to alpha particle confinement and NTM.



[1] I. Chapman, M.-D. Hua, S. Pinches et al., Nuclear Fusion 50,045007 (2010).

[2] S. Gerhardt, D. Brennan, R. Buttery et al.,Nuclear Fusion 49, 032003 (2009).