Topic: THW

Numerical Simulations of NBI-driven GAE modes in L-mode and H-mode Discharges in NSTX *

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Experimental observations from NSTX suggest that many modes in a sub-cyclotron frequency range are excited during neutral beam injection (NBI). As was shown recently, these modes can induce strong anomalous electron transport [1], and it is suggested that these modes can cause a redistribution of fast ions [2,3]. These modes were identified as Compressional Alfven Eigenmodes (CAEs) and Global Alfven Eigenmodes (GAEs), driven unstable through the Doppler shifted cyclotron resonance with the super Alfvenic NBI ions. These modes can be excited in ITER due to super Alfvenic velocities and strong anisotropy of the beam ions. In addition, the high frequency modes can also be excited by alpha particles near the outer edge of ITER plasma due to anisotropies in alpha particle distribution, and could be used as a diagnostic for ITER alphas. Hybrid 3D code HYM [4] has been used to investigate properties of beam ion driven GAE modes in NSTX. The HYM code is a nonlinear, global stability code in toroidal geometry, which includes fully kinetic ion description. A generalized form of the Grad-Shafranov equation solver has been developed, which includes, non-perturbatively, the effects of the beam ions with anisotropic distribution [5]. Excitation of GAE modes have been studied for L-mode and H-mode NSTX discharges. Equilibrium profiles and plasma parameters have been chosen to match several of the NSTX discharge numbers profiles, using the TRANSP and EFIT codes.

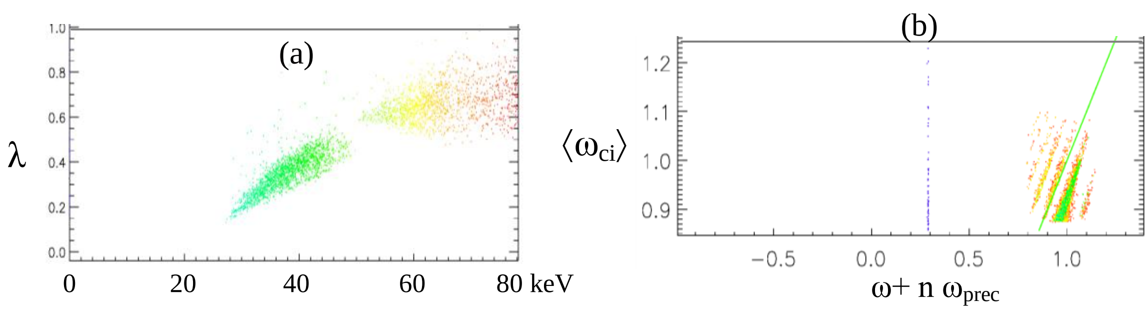

Figure 1. *(a) Location of resonant particles in phase space, $\lambda=\mu B_0/\varepsilon$ vs energy, (b) resonant particles shown with orbit-averaged cyclotron and precession frequencies, both normalized to the ion cyclotron frequency at the axis, ω_{ci0}. From HYM simulations for NSTX shot #135419, $\omega=0.29\omega_{ci0}$, $\gamma=0.01\omega_{ci0}$, (n=9, m=-1). Particle color corresponds to different energies: from E=0 (purple) to E=80keV (red).*

HYM simulations comparison with experimental results for NSTX L-mode shot#135419 [3], show good agreement in terms of the most unstable toroidal mode numbers, mode frequency, and mode structure. For the n=9 mode, in particular, mode frequency f =1.02MHz, amplitude $\delta n/n\approx 0.15\%$, and $\gamma/\omega=3.4\%$ compare with measured mode frequency f≈950 kHz, amplitude $\delta n/n\approx 0.1\%$, and estimated growth rate [3]. The magnetic perturbations have shear Alfven wave polarization in the core, however the compressional component dominates at the edge, also in agreement with magnetic measurements. Linearized and nonlinear simulations have been performed in order to study in detail resonant wave-particle interaction (Fig. 1). The resonant particles are shown to satisfy Doppler-shifted cyclotron resonant conditions, and multiple resonances are found for each toroidal mode number (Fig. 1b). It has been shown that most resonant particles have stagnant orbits, and there is relatively small variation of the background magnetic field along the orbit, and poloidal structure of the unstable mode is relatively coincident with location of the resonant orbits, allowing a strong resonant interaction. Nonlinear simulations show that GAE instabilities saturate at low amplitudes due to particle trapping.

Figure 1a show location of the resonant particles in the λ-ε space, there two distinct groups of resonant particles can be seen, but with similar $v_{\|}$. Figure 1b show that resonant particles satisfy condition: $\omega - \langle\omega_{ci}\rangle + n\omega_{prec} + k\omega_{transit} = 0$, where n=9, and k=0,±1,±2,… Transit frequency is small compared to other terms in the resonant condition, with $\omega_{transit}$=0.06-0.08 ω_{ci0}, resulting in the fine splitting of resonances in Fig. 1b, where the solid line corresponds to condition $\langle\omega_{ci}\rangle = \omega + n\,\omega_{prec}$. The spread in $\omega_{transit}$ is comparable to the mode growth rate, γ=0.01 ω_{ci0}.

Numerical simulations have been performed for H-mode, NSTX shot #132800 (with I_p = 1.0 MA, B_T = 4.5 kG, E_B = 90 keV), where a robust GAE activity and related High-Energy Feature (HEF) have been observed [2]. Figure 2 shows comparison between EFIT and HYM equilibrium poloidal flux contours and toroidal magnetic field contours, and mode structure for n=7 GAE mode. It has been found that self-consistent equilibrium with anisotropic fast ion distribution has larger magnetic axis radius compared to the MHD equilibrium solution (Fig. 2a). Simulations show unstable GAE for n ~ 6 – 9, consistent with Mirnov coil data. The n=7, m=-1 GAE mode exhibits the largest growth rate with γ=0.02ω_{ci0} and ω=0.21ω_{ci0} (f=600kHz), the n=6 and n=8 are also unstable with smaller growth rates.

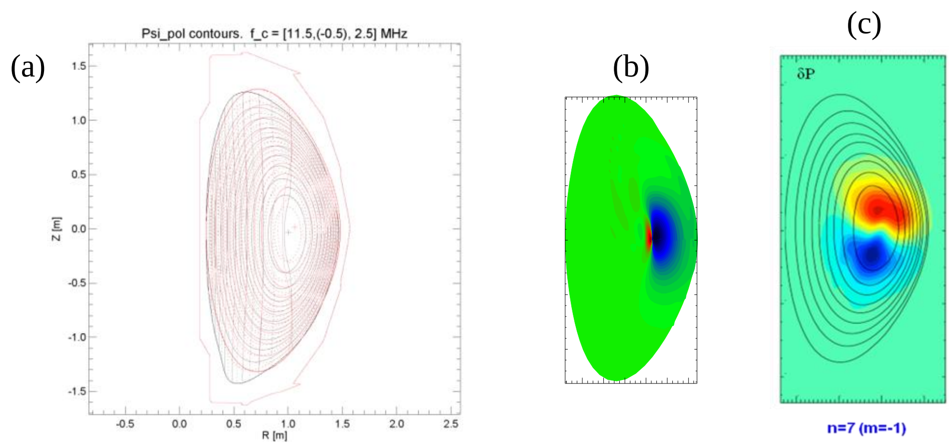

Figure 2. *(a) Comparison between EFIT and HYM equilibrium poloidal flux contours and toroidal magnetic field contours; (b) contour plot of normal component of perturbed magnetic field, and (c) pressure perturbation for n=7 GAE mode.*

Recent experimental observations from NSTX suggest that modes in a sub-cyclotron frequency range (GAE and CAE) can induce strong anomalous electron transport in STs[1]. In order to study the effects of these modes on the electron transport, a kinetic description for the electrons has been implemented in the HYM code, where the electrons are described as delta-f drift-kinetic particles. The effects of GAE and CAE modes on the electron transport will be studied using both test particle and self-consistent simulations.

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