Internal amplitude and structure of high frequency compressional and global Alfvén eigenmode density perturbations in NSTX

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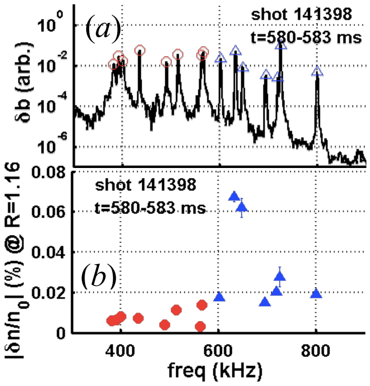
Fast-ions (e.g. fusion alphas and neutral beam ions) will excite a wide range of instabilities in ITER or a Fusion Nuclear Science Facility device. Among the possible instabilities are compressional (CAE) and global (GAE) Alfvén eigenmodes excited through Doppler-shifted cyclotron resonance with beam ions [1]. High frequency AEs cause fast-ion transport [2,3,4], correlate with electron thermal transport [5] and are postulated to contribute to ion heating [6]. The effect on plasma performance of high frequency AEs is investigated in NSTX. Detailed measurements of high frequency AE amplitude and eigenmode structure were previously obtained with an array of 16 fixed-frequency quadrature reflectometers [7,8] in a high power (6 MW), beam-heated H-mode plasma (shot 141398) very similar to those discussed in Ref. [5]. New analysis of the reflectometer measurements is presented yielding density perturbation (δn) amplitude and structure, which are used in modeling the effects of the modes on electron thermal transport and ion heating. The resulting δn are also compared to mode structure from simulations using the hybrid kinetic and MHD code, HYM [9], as part of an ongoing effort to validate the physics model of HYM. The comparison reveals similarities and difference in experimental and simulation mode structure that will aid in future development of the physics model of HYM.

Analysis of reflectometry measurements in a high power beam heated H-mode plasma shows that the CAEs observed tend to have δn with larger amplitude in the plasma core than in the edge, while the opposite tends to be true for the GAEs (Fig. 1). Figure 1a shows the spectrum of edge magnetic fluctuations, including 15 modes found [7,8] to be predominantly GAEs for $f < 600$ kHz and CAEs for $f > 600$ kHz. The structure and amplitude of these modes were probed [7,8] using a 16 channel array of reflectometers with frequencies spread over 30 – 75 GHz, operating with ordinary-mode polarization, leading to cutoff densities of 1.1 – 6.9 x 10^{13} cm^{-3} [7]. Results are presented here of inverting the measurements for each mode to obtain δn vs. R. Using a synthetic diagnostic code to model the reflectometer response, δn was constructed for each mode from basis functions in order to best fit the measurements. Figure 1b shows $|\delta n|$ at $R = 1.16$ m, normalized by equilibrium density (n_0) at the magnetic axis. Figure 1c shows $|\delta n|$ vs. R for each mode normalized using $|\delta n|$ at $R = 1.16$ m to facilitate comparison of mode structures. (The magnetic axis is $R_0 = 1.05$ m and the plasma edge is $R = 1.5$ m). The temporal phase of δn (not shown) varies significantly from core to edge (as much as π) for most modes. The modes with $f >$ 600 kHz tend to feature distinct $|\delta n|$ peaks in both the core and edge of the plasma, with the latter



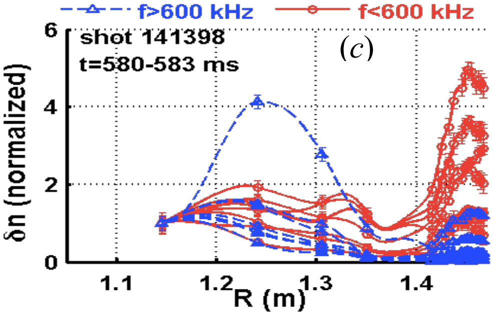
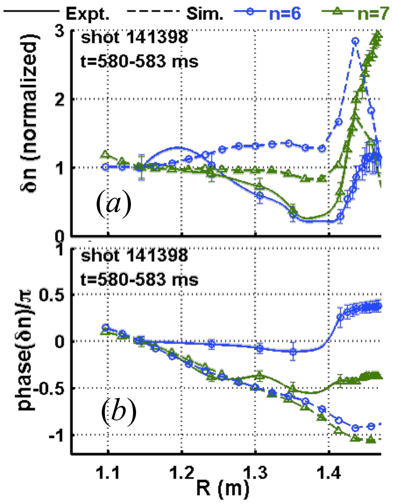


Figure 1: *(a) δb spectrum with modes marked; (b)* $|\delta n|/n_0$ *of modes at R=1.16 m; and (c)* $|\delta n|$ *vs. R, normalized by* $|\delta n|$ *at R=1.16 m. Symbols indicate reflectometer cutoffs. Dashed or solid lines are for modes with f > or < 600 kHz, respectively. In all panels, symbols ∆ or o used for modes with f > or < 600 kHz, respectively. Statistical uncertainties shown in (b) and (c).*

Figure 2: δn from experiment (solid) and simulation (dashed) for n = 6 (o) and n = 7 (Δ) GAEs: (a) |δn| vs. R, normalized by |δn| at R=1.16 m. (b) temporal phase of |δn|. Symbols mark reflectometer cutoffs for experiment and grid points for simulation. Statistical uncertainties shown for experiment.



being much lower amplitude. In contrast, the modes with $f <$ 600 kHz tend to have low amplitude, relatively flat core |*δn*| profiles with large amplitude peaks in the edge. The edge peaks for all modes occur in the pedestal, likely resulting from the structure of the equilibrium density profile (not shown; see Ref. [7]), which is monotonic, with a shallow core gradient and a steep gradient in the pedestal region ($R \approx 1.41$ m – 1.5 m). Even a small radial plasma displacement in the pedestal could cause a large density perturbation there.

As part of an effort to validate the HYM code, which models a fully kinetic fast-ion population coupled to an MHD plasma, HYM has been used to investigate the linear stability and structure of CAEs and GAEs in the plasma where the measurements of Fig. 1 were obtained [10]. The simulation showed unstable CAEs and GAEs with frequencies and mode numbers comparable to the experiment. Fig. 2 compares two modes in particular, counter-beam-propagating $n = 6$ and $n = 7$ GAEs, which are observed in both experiment and simulation. The modes shown from the simulation were those found to be most unstable at those particular *n*. The experimental measurements indicated only a single $n = 6$ GAE, but several $n = 7$ GAEs. The $n = 7$ GAE shown in Fig. 2 is closest in frequency to that from the simulation. Specifically, the frequencies of the GAEs in simulation are $\omega/\omega_{ci} = 0.19$ ($n = 6$) and 0.15 ($n = 7$), where $\omega_{ci}/2\pi = 2.48$ MHz. The simulation did not include toroidal rotation, so for comparison these frequencies are "corrected" by addition of a Doppler shift using the measured central rotation frequency, ~ 20 kHz (in the co-beam direction) [7,8], giving 591 and 512 kHz, respectively. The experimental frequencies were very similar, at 563 and 515 kHz, respectively.

Figure 2 reveals significant similarities and differences between the measured and simulated structures. For instance, as can be seen in Fig. 2a, which shows |*δn*| profiles, both simulation and experiment show large edge peaks and relatively flat central profiles for |*δn*|. On the other hand, the central profiles are notably flatter in the simulation. Also, as can be seen in Fig. 2b, which shows profiles of *δn* temporal phase, there is significant phase variation from core to edge in both simulation and experiment. However, it is notably greater in the simulation. The similarities between experiment and simulation show promise for the development of HYM as a tool for predicting CAE and GAE activity, while the differences offer clues that will help prioritize future development of the physics model of HYM.

Work supported by U.S. DOE Contracts DE-FG02-99ER54527 and DE-AC02-09CH11466.

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