Pedestal Characterization and Stability of Small-ELM Regimes in NSTX

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In order to avoid excessive erosion of the first wall in ITER, the stored energy released by a single ELM event must remain below 0.4-0.5 MJ/m^2, which translates to a stored energy drop of < 0.3% [1]. First wall integrity in ITER therefore depends on identifying ELM-free and/or small-ELM regimes that can be reliably accessed. The work that will be reported here is focused on understanding an MHD phenomenon in NSTX with characteristics similar to the Edge Harmonic Oscillation (EHO) observed during Quiescent H-modes, which is coincident with a transition to a small-ELM regime. The quiescent H-mode first observed in DIII-D [2] is an attractive ELM-free regime. It has been postulated that an EHO observed during QH-mode provides sufficient particle transport near the plasma edge to avoid the peeling-ballooning modes thought to be responsible for ELMs, while maintaining good core confinement. The EHO was hypothesized to be a saturated low-n kink that is destabilized by rotational shear and is accessed at low density and high rotational shear at the plasma edge [3,4]. The goal of this study is to determine extrapolability of the NSTX small-ELM regime to ITER.

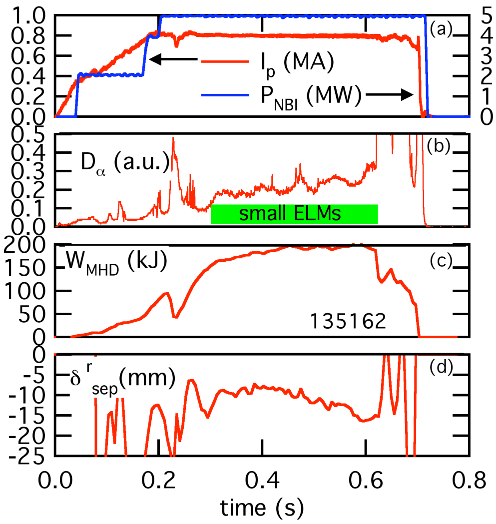

Figure 1: Time evolution of shot 135162

The time evolution of a small-ELM NSTX discharge with this MHD phenomenon is shown in Figure 1. In this discharge, the transition to small-ELMs occurs at 0.29 s as shown in the D_α trace in panel (b). These ELMs decrease the plasma stored energy by << 1%, i.e. well below the statistical uncertainty in equilibrium reconstructions. Transition to this regime is associated with a downward biased plasma as evidenced by δ_r^{sep} < -5 mm, consistent with previous the dependence of type V ELMs [5] (δ_r^{sep} is the radial separation of the two separatraces at the outer midplane).

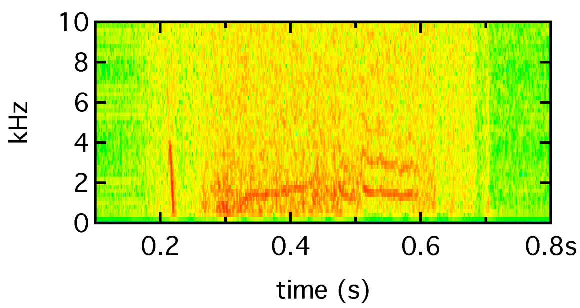

Figure 2: Spectral content of USXR channel 12 in shot 135162. X-ray emission is viewed through 10 µm Be filters.

The edge mode coincident with the transition to small ELMs is observed in the B-dot coils as well as in Ultrasoft X-ray (USXR) emission, as shown in Figure 2. The channels of the diode array have lines of sight at a single toroidal location that extend from the magnetic axis (channel 1) into the scrapeoff layer (channel 13). The mode is observed as low frequency oscillations that grow in two channels near the plasma edge (channels 11 & 12) starting at approximately 0.29s (coincident with the transition to small-ELMs). These oscillations are coherent with a frequency of 1-3 kHz. This rotation speed is the same as the measured toroidal rotation at the pedestal, indicating an n=1 instability. These oscillations persist throughout the small-ELM period. After 0.5 s, multiple harmonics can be observed with frequencies corresponding to integer multipliers of the lowest frequency mode, which is similar to observations of the EHO in QH-mode. Reflectometer measurements in the pedestal show a sharp increase in the density fluctuation level a few milliseconds before the transition to small-ELMs and a subsequent decrease a few milliseconds before the plasma leaves the small-ELM regime.

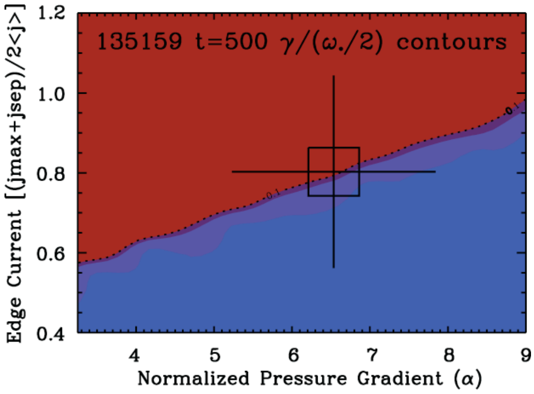

Figure 3: ELITE analysis of the peeling-ballooning stability of shot 135159.

Ideal MHD stability analysis during the small-ELM phase has been performed using both the ELITE [6] and PEST [7] stability codes. Figure 3 shows the results from the ELITE analysis indicating that the plasma is on the peeling side of the stability limit, with n=3 being the most unstable mode. Similar calculations for DIII-D show that discharges with the EHO lie near the peeling stability boundary [3]. PEST calculations also indicate n=3 is the most unstable mode with the mode eigenfunctions peaking near the plasma edge. Note that these analyses do not take into account the plasma rotation, which previous calculations have indicated could cause the most unstable mode to shift towards lower-n [3], i.e. closer to observations of a dominant n=1.

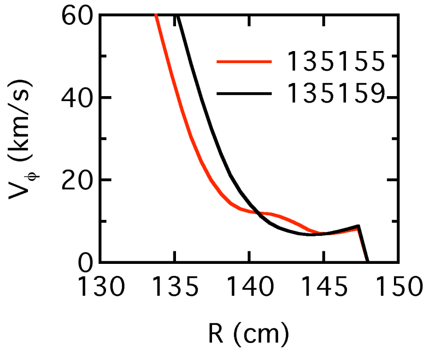

Figure 4: Rotation profiles for shot 135155 (type-I) and shot 135159 (small-ELM).

A comparison of the edge rotation profiles for two shots, one with large type-I ELMs (135155) and one with small-ELMs (135159), is shown in Figure 4. Other than a programmed variation in the lower plasma triangularity, these shots have similar time evolutions in all global parameters. The two discharges have similar H-mode pedestal pressure, but there is more rotational shear at the location of the observed low-frequency mode (~140 cm) in the small ELM shot. These observations and analysis are consistent with rotational destabilization of low-n kink modes near the plasma edge.

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