Observation of edge harmonic oscillation in NSTX and theoretical study of its active control using HHFW antenna at audio frequencies*

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Edge localized modes (ELMs) can generate unacceptable heat loads to plasma facing components in a reactor scale tokamak or spherical torus, and therefore ELM control is a critical issue in ITER. One promising concept is the application of steady non-axisymmetric (3D) fields to maintain the pedestal pressure below the edge stability boundary, as well as to provide sufficient particle transport without ELMs. However 3D coil requirements are demanding in cost and engineering, and thus it is also valuable to minimize the coil requirements and/or to find an alternative means of ELM control, such as the operation in the quiescent H (QH) mode. The QH mode uses naturally arising 3D fields in the edge, called edge harmonic oscillations (EHOs), instead of externally driven 3D fields. However, the QH mode requires strong rotational shear, and thus the operational window is possibly limited or external 3D field coils may be required again to control the rotational shear. These requirements may be mitigated if internal and external drive of 3D fields can be constructively combined. This paper presents two important topics for this vision: Experimental observations of edge harmonic oscillations in NSTX (not necessarily the same as those observed in DIII-D QH modes), and theoretical study of its audio-frequency active control using the existing NSTX high harmonic fast wave (HHFW) antenna as 3D field coils, to amplify the internally arising harmonic oscillations, in order to provide externally adjustable particle transport and ELM control.

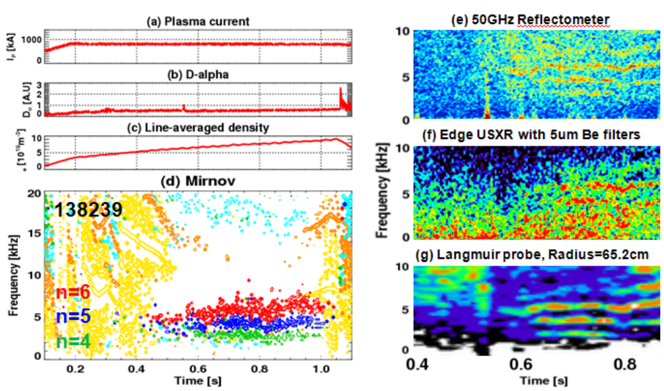

Figure 1. An NSTX time trace shows n=4-6 edge oscillating modes by (d) Minov, (e) Reflectometer, (f) USXR, (g) Langmuir probe.

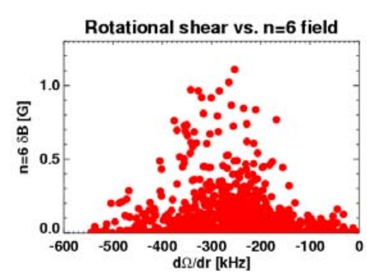

Figure 2. Correlations showing that n=6 modes have favored rotational shear.

In ELM-free operation in NSTX associated with strong lithium deposition, clear edge harmonic oscillations are reproducibly observed during operation at ~ 4MW of beam power, ~ 800kA plasma current, and B_T ~ 4.5kG. They are observed on Mirnov coils, by reflectometry, on ultra-soft x-rays (USXR), and on Langmuir probes in the far scrape-off-layer. Figure 1 shows an example of observations where one can see clearly separated harmonic oscillations, with 2-8kHz and toroidal harmonics n=4-6, in long ELM-free periods with low core n=1 modes. Reflectometer measurements especially indicate the edge localized (The increase of oscillations towards the edge as shown in Figure 4) and coherent nature of the modes. However, these oscillations, which share some characteristics with the n=1 dominated modes observed in small-ELM regimes in NSTX [1], do not provide any clear particle and impurity control, as can be seen in the density rise in Figure 1 (c), differently from the EHOs in DIII-D QH modes. The EHOs on DIII-D are understood as peeling modes destabilized by strong rotational shear and non-linearly saturated by regulating the rotation shear. Statistical analysis correlating the rotational shear and the n=6 mode amplitudes, Figure 2, shows that there may be a favored level of rotational shear and thus perhaps the rotational shear plays a role to activate these modes as well as to determine the operational window similarly to EHOs in DIII-D.

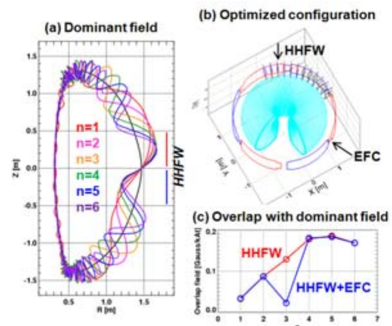

Figure 3. n=1-6 dominant external field, optimized HHFW configuration to maximize n=4-6 overlap. EFC can be used to correct n=3.

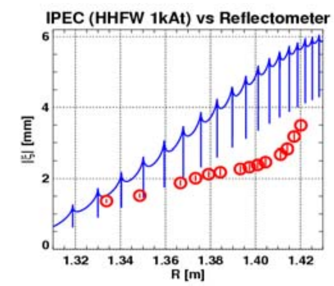

Figure 4. Comparison between reflectometer measurement (Red) and IPEC prediction (Blue) for n=6 displacements by 1kAt HHFW.

The NSTX edge harmonic oscillations could potentially be used for particle and ELM control if the modes could be amplified by external means such as 3D field coils, directly rather than indirectly such as by the control of the rotational shear. The HHFW antenna has been proposed in NSTX to couple external 3D fields to the internal modes using audio-frequency currents in the antenna straps [2]. The HHFW antenna locations are localized within 90 toroidal sectors and so can effectively drive high n modes in the edge. The 24 antenna straps in total also give high flexibility to optimize the configuration. In optimization, the dominant external field for plasma is identified using the Ideal Perturbed Equilibrium Code (IPEC), and the best configuration is chosen to produce the dominant external field for n=4-6 as closely as possible while minimizing n=1-3 fields. Figure 3 shows (a) the dominant external field for n=1-6, (b) the optimized configuration, and (c) the overlap with the dominant field for each n when optimized. Even error field correction coils in principle can be combined to minimize low n modes if driving frequencies are sufficiently low. Quantitative IPEC calculations of driven radial displacement are compared with the quantitative reflectometer measurements in Figure 4. 1kA current in the HHFW straps can drive twice larger displacements than the NSTX edge harmonic oscillations. This current is within the normal range of RF frequency currents in NSTX. The possibility of implementing a drive system will be examined in NSTX-U first, and successful application may provide a pathway in the future to AC drive of peeling-ballooning modes for edge particle and ELM control in future devices, including ITER.

[1] A. C. Sontag, J. M. Canik, R. Maingi et al., Nucl. Fusion 51, 103022 (2011)
[2] J.-K. Park, R. J. Goldston, Presented at the 16th MHD Mode Control Workshop (2011)
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