Analysis of edge harmonic oscillations observed during operation of the National Spherical Tokamak Experiment

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Edge harmonic oscillations (EHOs) have been observed during operation of the National Spherical Tokamak Experiment (NSTX) in which no edge localized modes have appeared. This paper will utilize beam emission spectroscopy and Mirnov coil diagnostic data to analyze the frequency, mode number, and amplitude of EHOs observed in NSTX. Additionally, charge exchange recombination spectroscopy and multiple point Thomson scattering diagnostics will be used to analyze the plasma pedestal region, while outputs from a magnetohydrodynamics equilibrium fitting code will be used to characterize the global plasma during the occurrence of an EHO. This extensive analysis highlighted several relationships between EHOs and various plasma parameters. Notable data trends included access to higher toroidal mode numbers at lower electron collisionality, lower toroidal rotation speed, and within narrows bands of electron pressure and density pedestal heights and gradients. Additionally, larger amplitude EHOs were preferentially detected within a range of toroidal rotation speed and at larger electron density and pressure pedestal gradients and heights. Finally, correlations between high confinement times and reduced EHO activity as well as reduced frequency gap between adjacent EHOs were also found.

Analysis of Edge Harmonic Oscillations Observed in NSTX

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INTRODUCTION

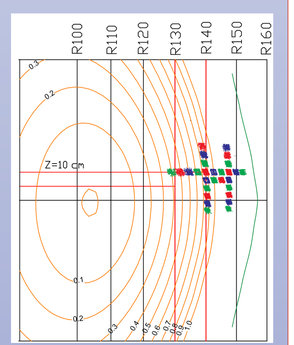
Edge harmonic oscillations (EHOs) have been a topic of recent focus in an attempt to mitigate the harmful effects that edge localized modes (ELMs) can create during the operation of fusion devices. Currently, there is very little understanding of the underlying physics of EHOs, but they have appeared in fusion devices operating in quiescent H (QH) mode.[1] This regime is currently being heavily explored because of the ability to operate devices without ELMs, but instead with EHOs. In some devices, such as DIII-D, EHOs have been seen to saturate at current densities below the threshold for ELMs and thus allowing for ELM-free operation.[2] This is believed to be a result of enhanced particle transport. More recently, EHOs have been observed in ELM-free operation of the National Spherical Tokamak Experiment (NSTX). However, initial studies suggest EHOs do not generate significant particle transport in the NSTX pedestal region.[1] This apparent discrepancy highlights need for a better understanding of the particle transport physics related to EHOs. The goal of this investigation is to uncover relationships correlating EHO characteristics – specifically amplitude, frequency and toroidal mode number – with plasma and pedestal parameters, especially relationships that provide insight into the particle transport of EHOs.

OBJECTIVES

- Create MATLAB functions to gather and manipulate data from a magnetohydrodynamics equilibrium fitting code (EFIT) as well as from beam emission spectroscopy (BES), Mirnov coils, charge exchange recombination spectroscopy (CHERS), and multiple point Thomson scattering (MPTS) diagnostics on NSTX
- Identify and analyze EHOs in NSTX and gather plasma characteristics during EHO occurrences
- Identify trends between EHO characteristics and plasma characteristics

EXPERIMENTAL METHODS

- **BES**
  - Collect Doppler-shifted D_α (n=3➔2) emissions from neutral beam and filter from thermal D_α emissions [3]
  - Poloidal array images from core to scrape-off layer[3]
- **Mirnov Coils**
  - Measures poloidal magnetic field at locations around the torus[4]
  - 10 of 16 channels were used
- **CHERS**
  - Collect ^{12}C (n=8➔7) emission from neutral beam interactions[5]
  - Doppler-shifted emission light used to obtain quantities such as electron density and temperature
- **MPTS**
  - Collect light scattered from laser beam in plasma[4]
  - Maps frequency of scattered light against position of emitted light in plasma[4]
- **EFIT**
  - Reconstructs equilibrium quantities and geometries of plasma
  - Uses magnetic field and Thomson scattering data as inputs



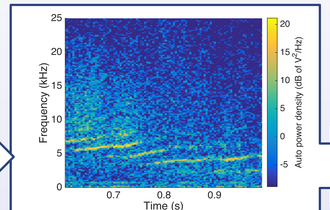
- BES channel layouts for R140 views on the center plane of the neutral beam with typical flux surfaces.[3]

DATA ANALYSIS METHODOLOGY

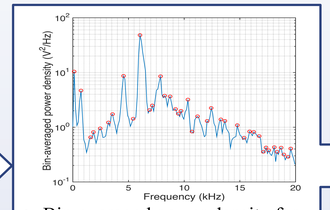
Calculate spectral power from raw BES data

$$P = 2 * \left| \frac{FFT(A) * FFT^{*}(B)}{n} \right|$$

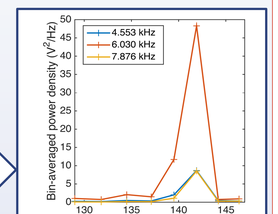
where n is the number of points in the FFT, A and B are BES signals



- Channel 6 Spectrogram for shot #141255
- Horizontal lines of high auto power density are EHOs



- Bin-averaged power density for shot #141255 between 670-750ms.
- Peaks at 4.553, 6.030, and 7.876 kHz correspond to EHOs



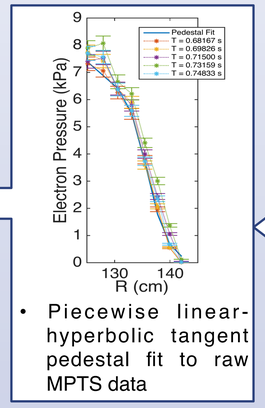
- Radial amplitude profiles for all EHOs identified in NSTX shot #141255 during 670-750ms.

EHO toroidal mode number algorithm from Mirnov Data[6]

$$\mathbf{T}_n = \left(\frac{\mathbf{N}_n \bullet i\boldsymbol{\theta}_p^T}{c} \right) \bullet \mathbf{A}_p^T e^{i\boldsymbol{\Phi}_p^T}$$

$$\boldsymbol{S}_n = \sqrt{\left| 1 - \frac{c * \boldsymbol{T}_n^{\,2}}{\sum_{p=1}^{c} \boldsymbol{A}_p} \right|}$$

where $\mathbf{N_n}$ is a vector of all positive and negative modes, c is number of channels, $\mathbf{A_p}$ is vector of FFT amplitudes, $\mathbf{\Phi_p}$ is vector of FFT phase, and $\mathbf{\theta_p}$ is vector of toroidal measurement angle. Absolute value of the *n*th entry in **N**, where *n* minimizes bin-averaged entry in **S,** is the EHO toroidal mode number



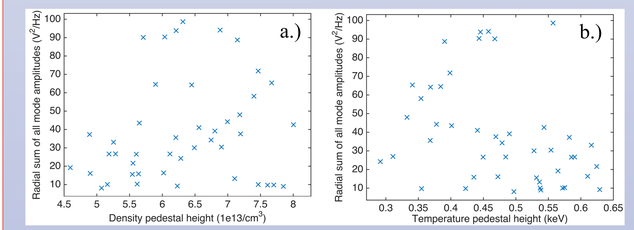
- Piecewise linear-hyperbolic tangent pedestal fit to raw MPTS data

Interpolate CHERS toroidal rotation speed data to the top of the pressure pedestal and average over each time of interest

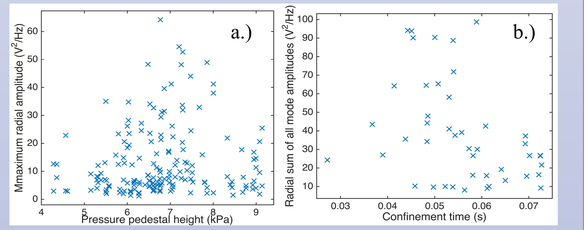
Gather and average EFIT outputs for each time of interest

Create scatterplots relating EHO and plasma properties

EHO AMPLTIUDE RESULTS

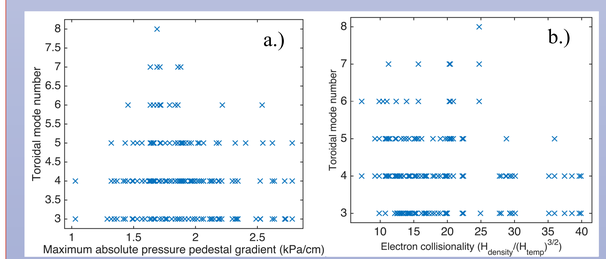


- a.) Higher EHO activity attainable at higher density pedestal heights
- b.) Higher EHO activity attainable at lower temperature pedestal heights

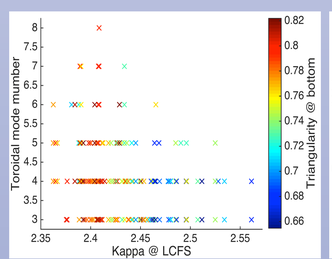


- a.) EHO amplitude steadily reaches higher amplitudes until sudden drop off at large electron pressure pedestal heights
- b.) High confinement time regimes have relatively low amounts of EHO activity

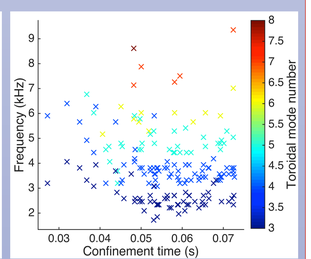
EHO TOROIDAL MODE NUMBER RESULTS



- a.) Higher toroidal mode numbers accessible in optimum range of electron pressure pedestal gradients
- b.) Higher toroidal mode numbers accessible at low electron collisionality

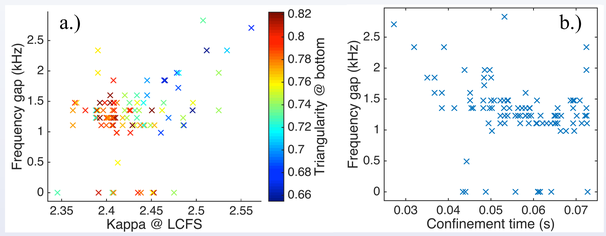


- Higher mode numbers at low plasma elongation (Kappa @ LCFS) and high triangularity at bottom divertor



- Frequency distribution narrows for a given mode number as confinement time increases

EHO FREQUENCY GAP RESULTS



- a.) Large frequency gaps between adjacent EHOs are observed at low plasma elongation (Kappa @ LCFS) and high triangularity at bottom divertor
- b.) Frequency gap tends to decrease as confinement time increases

CONCLUSIONS

- Larger EHO activity is consistent with reduced confinement
  - Potentially due to EHO-induced particle transport
  - Previous NSTX observations did not find evidence for EHO-induced particle transport
- Higher toroidal mode numbers can be attained in optimal regions of plasma and pedestal properties
- EHO seem to have a strong dependence on plasma shaping
- Future work focused on gaining greater understanding of EHO control through various plasma parameters could improve QH mode operation
- Upgraded 2-D BES diagnostic on NSTX-U will allow for more direct analysis of EHO-induced particle transport

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