

FAST PARTICLE DRIVEN MHD ACTIVITY

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1. Introduction

Neutral beam injection (NBI) is the dominant heating system in present day tokamaks and the energetic ion populations that it forms are intimately related with many of the prevalent plasma instabilities. Fishbones, sawteeth, global Alfvén modes such as TAE and ELMs are generally, and for some of these exclusively, only observed during NBI.

2. Experimental Observations

An overview of the NBI heated discharge #10346 in ASDEX Upgrade is shown in Fig. 1, from which one can clearly see sawtooth, fishbone and ELM activity present. Approximately 50 ms after the increase in NBI heating power from 10 MW up to 12.5 MW a sawtooth crash occurs and there is a cessation in MHD activity and a quiescent window during which TAE modes are observed.

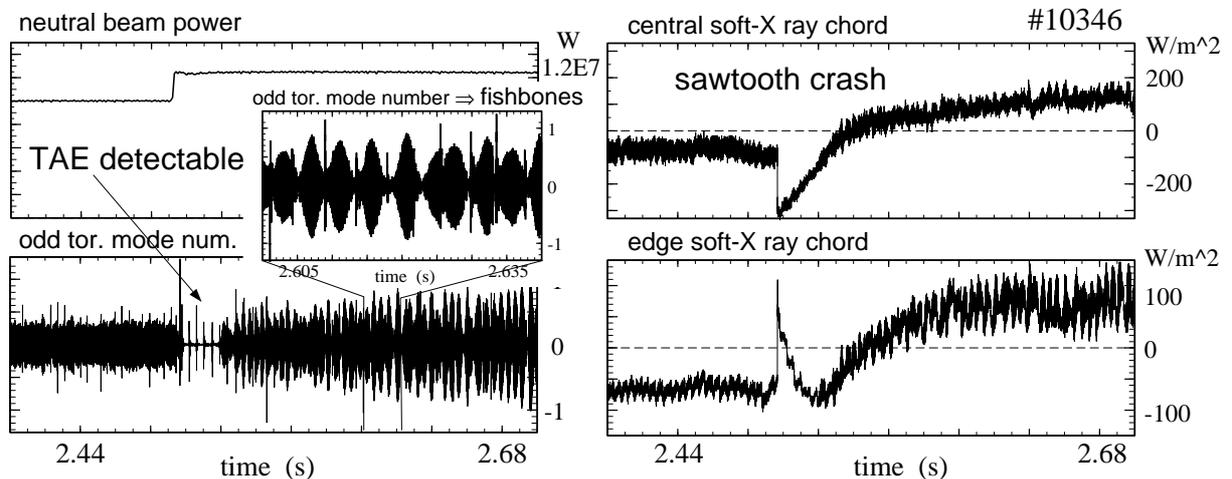


Fig. 1. Overview of activity during #10346 in ASDEX Upgrade.

The frequency and principle mode numbers of the TAE are measured using the ASDEX Upgrade Mirnov coil system with Fig. 2 showing the cross power spectrum. The frequency of the observed TAE, $f \simeq 125$ kHz, is found to match almost exactly an $n = 4$, $m = 3, 4$ TAE found using the CASTOR code [1], $f = 126$ kHz. The presence of neoclassical tearing modes within this shot makes the long term observation of TAE experimentally difficult.

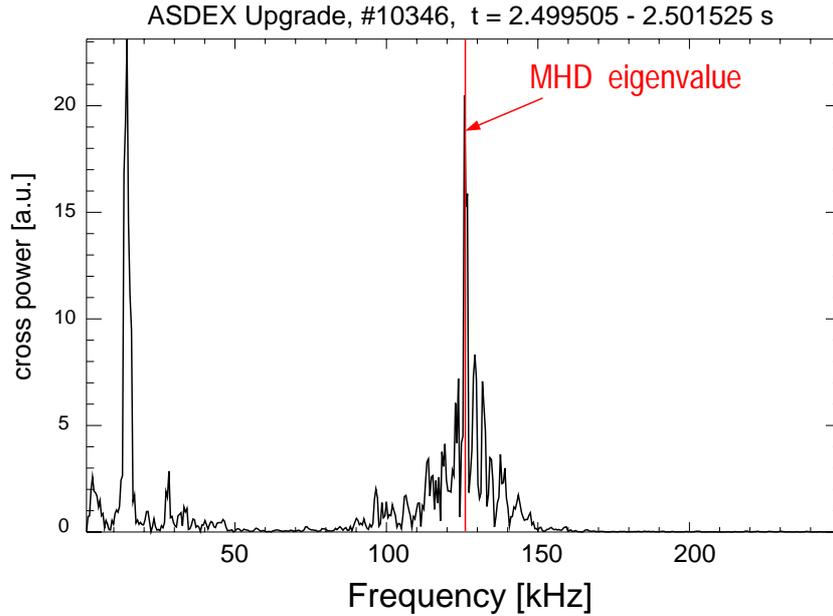


Fig. 2. Cross power spectrum obtained from the Mirnov coil diagnostics for #10346 in ASDEX Upgrade.

Fishbone and sawteeth oscillations are both related to the $n = 1$ internal kink. Analysis with CASTOR reveals that the $n = 1$ kink has a growthrate of $\gamma = 7.27 \times 10^{-2} \tau_A$ whilst the $n = 2$ kink has a comparable growthrate of $\gamma = 5.73 \times 10^{-2} \tau_A$, where τ_A is the on-axis Alfvén time. The structure of both of these modes is primarily located inside the $q = 1$ surface with the (1,1) and (2,2) harmonics dominating the spectrum.

3. Numerical Modelling

The primary equilibrium reconstruction for discharge #10346 was performed using the CLISTE code [2]. This iteratively calls a Grad-Shafranov solver to find the optimum ideal MHD equilibrium least squares fit to a given set of experimental measurements. These measurements included external magnetic data and information about the diameter of the $q = 1$ surface from SXR measurements.

The NBI system in ASDEX Upgrade produces a population of energetic particles with characteristic birth energy of ~ 60 keV and a typical slowing down time of around 75 ms. The system comprises two injectors, each containing four sources, each with different tangency radii. The distribution of these beam particles has been calculated by solving for the bounce averaged fast ion distribution function using the FPP-3D code [3]. FPP-3D is based upon the 3D Fokker Planck theory of ‘banana regime’ neoclassical effects in tokamaks and treats both non-Maxwellian distributions and large trajectory deviations from flux surfaces. Fast particle distributions have also been calculated for the more tangential future NBI configuration in which the beam line tangencies are changed from 0.54 m and 0.93 m to 0.84 m and 0.129 m, assuming that all plasma parameters remain the same.

Studies of the interaction between fast particles and the experimentally observed modes were performed using the HAGIS code [4], a δf code which follows the guiding centres of the beam distribution calculated by the FPP-3D code whilst self-consistently evolving the amplitudes and phases of the linear MHD eigenmodes calculated using the CASTOR code. Fig. 3 shows the evolution of the experimentally observed $n = 4$ TAE driven by the neutral beam.

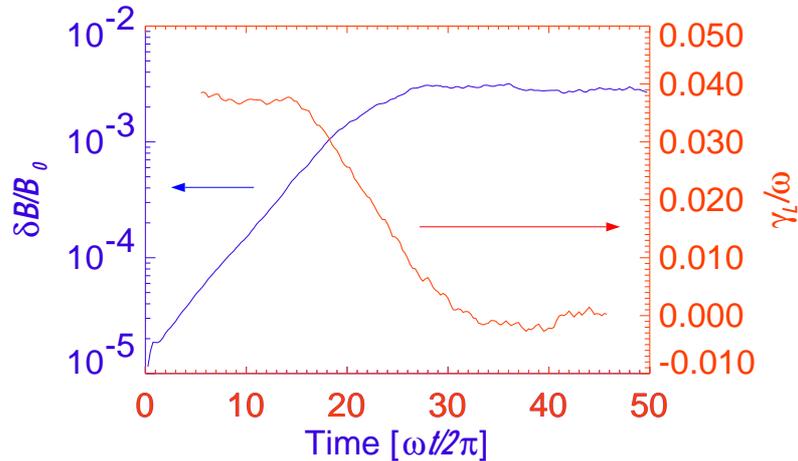


Fig. 3. Evolution of the $n = 4, m = 3, 4$ TAE observed in #10346 in ASDEX Upgrade by the HAGIS code.

The system assumed a beam tangency of 93cm and co-injection of 12.5 MW. The continuum damping rate calculated for this mode by CASTOR is $\gamma_d \simeq 3 \times 10^{-6} \tau_A$, which is negligible in comparison to the drive from the beam particles. Since this mechanism usually constitutes the dominant damping method for these modes, this and other damping mechanisms have been neglected in this analysis. Figs. 4 and 5 show the variation in growthrate of the experimentally

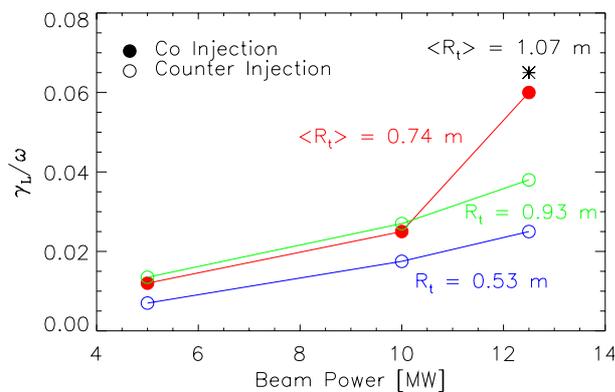


Fig. 4. HAGIS TAE growthrates versus injected neutral beam power.

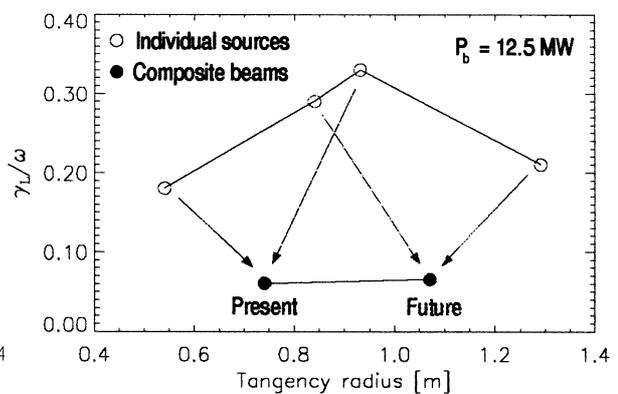


Fig. 5. Variation of TAE growthrate with the tangency radius of NBI beam line.

observed TAE with respect to the NBI heating power and the tangency radius of the beam line.

One sees that the increased anisotropy of the individual beam sources leads to higher growth rates than for the combined sources.

4. Conclusions and Future Work

The simulations presented demonstrate the successful integration of various advanced computational models to simulate the evolution of an NBI driven TAE. The results show the scaling of TAE growth rate with respect to NBI power and also that the growth rate has a maximum with respect to the tangency of the beam line. The growth rate from the composite beam is shown to be lower than for the individual beam sources and predicts that there will be a marginal change in growth rate for the new configuration.

The extension to modelling the interaction of energetic particles with stellarator instabilities is not easy. Using linear MHD eigenmodes calculated for 3-D stellarator geometry with the CAS-3D code [5] and a toroidally averaged 2-D stellarator-like equilibrium, a preliminary analysis with HAGIS similar to that performed for the NBI system on ASDEX Upgrade is planned for the future on Wendelstein VII-AS.

Future work aims to focus upon the fishbone cycle in ASDEX Upgrade and to investigate the role played by the fast particles.

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