Impact of localized ECRH on Alfven Eigenmodes in the ASDEX Upgrade tokamak

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Introduction

Future burning plasma experiments such as ITER may be subject to the excitation of Alfven eigenmode (AE) instabilities by 3.5MeV fusion born alpha particles as well as fast-ions created by auxiliary heating systems. If allowed to grow unabated, these instabilities have the potential to cause fast-ion redistribution and loss leading to a degradation of the performance, heating and current drive efficiencies as well as to possible serious damage of first wall components. Of special importance to magnetically confined fusion plasmas are toroidal Alfven eigenmodes (TAEs) and reverse shear Alfven eigenmodes (RSAEs) because of their potential to eject fast-ions before their thermalization.

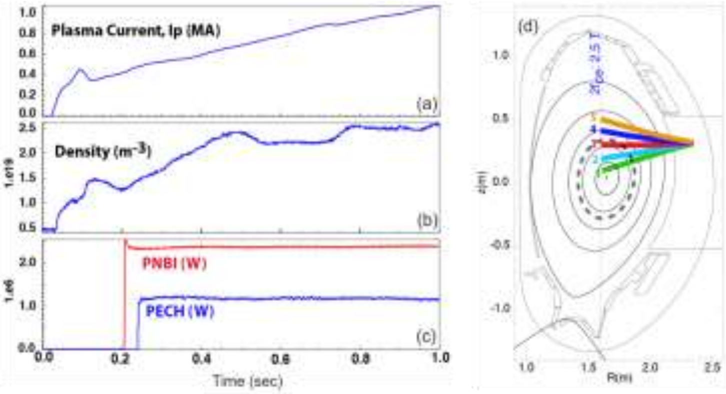

Fig.1. Overview of the main plasma and heating parameters in AUG discharges for NBI driven AE mitigation. Temporal evolution of (a) plasma current, (b) core line integrated density and (c) external heating. (d) ECRH deposition volumes.

External actuators are commonly used to mitigate or even suppress magnetohydrodynamic (MHD) fluctuations of diverse nature. Among others, externally applied resonant magnetic perturbations (RMPs) and localised Electron Cyclotron Resonant Heating (ECRH) are the most extended methods to mitigate some of the most deleterious MHD perturbations in present tokamaks, i.e. Edge Localised Modes (ELMs) and Neoclassical Tearing Modes

(NTMs) respectively. The successful mitigation of ELMs and NTMs though RMPs and localised ECRH has, however, a limited operational window and sometimes important side effects on some plasma parameters that can affect the resulting plasma confinement, e.g. density pump-out and fast-ion losses caused by RMPs in ELM mitigated discharges [1]. A throughout understanding of the physics mechanism underlying the effect that external actuators have on plasma stability and eventually on additional transport is thus mandatory.

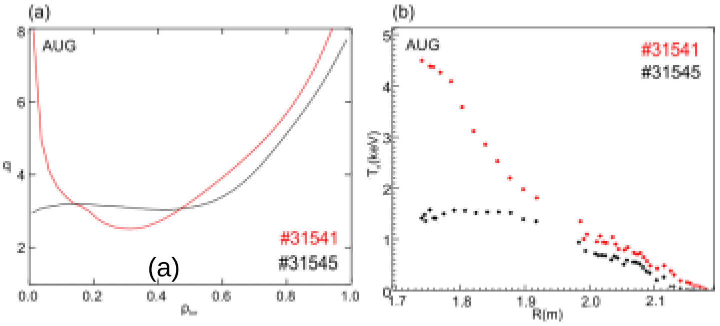

Fig.2. q and T_e profiles of discharges with mitigated (black) and non-mitigated (red) AEs at t=0.4 sec.

Experiments in DIII-D have shown the dramatic effect that localized ECRH can have on neutral beam driven Alfvén Eigenmode (AEs) activity in reversed magnetic shear plasmas [2]. The most commonly observed effect is a shift in the dominant observed modes from a mix of reversed shear Alfvén eigenmodes (RSAEs) and toroidicity induced Alfvén eigenmodes (TAEs) to a spectrum of weaker TAEs when ECRH is deposited near the shear reversal point (q_{min}). ECRH deposition near the magnetic axis typically increases the unstable mode amplitudes and resultant fast ion transport. It is found that for many of the intervals with minimal RSAE activity, or RSAEs with a much reduced frequency sweep range, that the geodesic acoustic mode (GAM) frequency at q_{min} is very near or above the nominal TAE frequency - suggesting the so-called beta suppression mechanism [3] might explain some of the experimental observations. Although it has been observed that localised ECRH has a clear impact on AE activity not only in tokamaks but also in stellerators, a robust explanation of the experimental findings is still missing.

The ASDEX Upgrade (AUG) tokamak is especially well suited to test the validity of this AE mitigation method due to its powerful and versatile heating mechanisms as well as internal fluctuation and fast-ion diagnostics. Recent experiments have been carried out to study the impact that localised ECRH has on AEs driven by fast-ions of Neutral Beam Injection (NBI) and Ion Cyclotron Resonant Heating (ICRH) origin. RSAEs driven by sub-alfvenic NBI ions have been successfully mitigated applying localised ECRH near q_{min} (RSAE location) though almost no effect is observed on AEs driven unstable by supra-alfvenic ICRH ions.

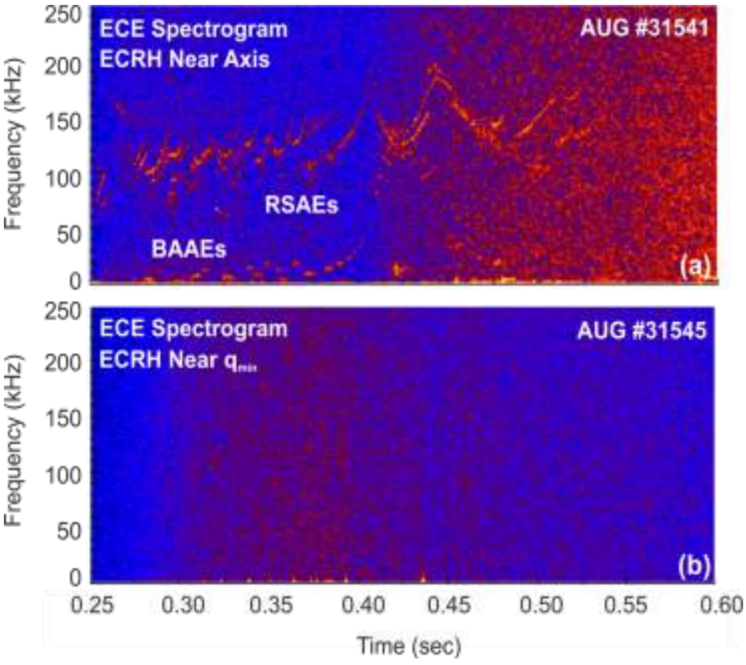

Fig.3. ECE spectrograms showing AE activity near q_{min} in (a) #31541 and (b) 31545 AUG discharges.

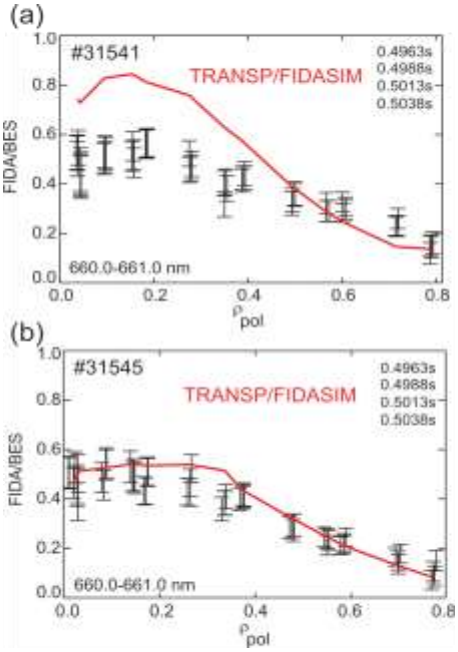

Fig.4. FIDA profiles measured in (a) a discharge with Alfvenic activity, #31541, and (b) without Alfvenic activity #31545.

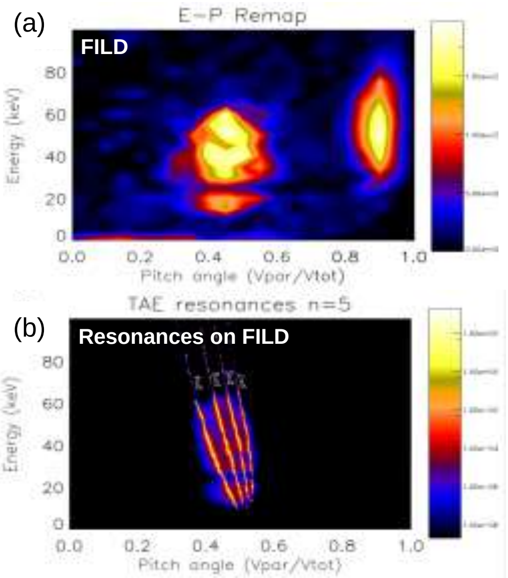

Fig.5. Velocity-space of fast-ion losses measured with FILD in a discharge with NBI driven AEs. (a) Remapped scintillator plate on orthogonal energy – pitch-angle coordinates. (b) Calculated resonances between escaping ions and n=5 TAE.

ECRH impact on NBI driven AEs.

NBI driven Alfvén Eigenmodes (AEs) are routinely obtained in the ASDEX Upgrade (AUG) tokamak during the current ramp-up phase with early NBI heating (starting at around 0.2 sec) and reversed q-profile. ECRH is typically applied tens of ms after the starting of the NB to maintain a reversed q-profile as long as possible and affect the observed AE activity. Fig.1-(a) shows the most relevant plasma and heating parameters in a typical NBI driven AE mitigation discharge. The ECRH deposition location is scanned in a shot-to-shot basis as shown in Fig.1-(b). Most commonly observed AEs comprise Reversed Shear Alfven Eigenmodes (RSAEs) and Toroidal Alfven Eigenmodes (TAEs). The q- and T_e-profiles of the studied AE discharges are presented in Fig.2. Fig.3-(a) shows an ECE spectrogram with the observed RSAE activity near q_{min}. At low frequencies, Beta Induced Alfven-Acoustic Eigenmodes (BAAEs) are also observed.For ECRH injection near q_{min}, (RSAEs location) the overall mode activity is significantly reduced. While in DIII-D, the unstable modes shift from strong RSAEs to weaker global TAEs and reminiscent RSAEs are visible only at their highest frequencies during their transition to TAEs [1], in AUG, almost all mode activity disappears with ECRH injection near q_{min}, see Fig.3-(b). With reduced or no mode activity, the fast-ion confinement is significantly improved, in fact, the fast-ion profile measured with Fast-Ion D-Alpha (FIDA) spectroscopy matches classical TRANSP predictions. Fig.4 shows the fast-ion profiles measured in a discharge with AE activity, Fig.4-(a) and in a discharge without AE activity Fig.4-(b). In agreement with this observation, and with classical fast-ion profiles, e.g. discharge #31545, no fast-ion losses induced by AEs are observed by the Fast-Ion Loss Detectors (FILD) systems. In contrast to this, clear convective losses are measured in discharges with NBI driven AE activity.

Fig.5-(a) shows the velocity-space of the escaping ions measured during the AE activity in a typical AUG discharge. Orit simulations show that only the lost ions with pitch angles between 0.3 and 0.6 can fulfil the AE resonance conditions, Fig.5-(b) show the possible resonances for a n=5 TAE.

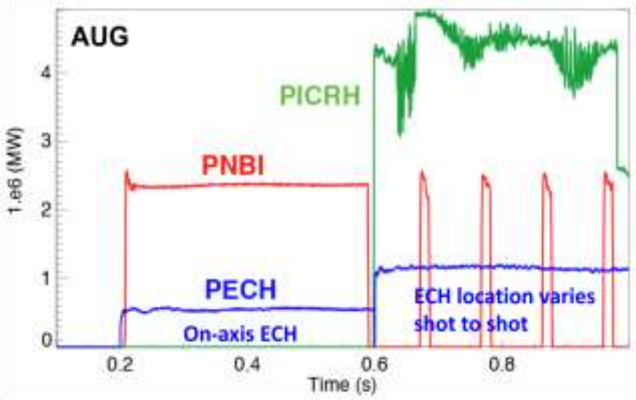

Fig.6. Heating timing / power in AUG discharges for ICRH driven AE mitigation.

ECRH impact on ICRH driven AEs. Similar experiments have been carried out to study the ECRH impact on AEs driven unstable by supra-alfvenic ICRH ions. Early on-axis ECRH and NBI is applied to obtain a high and reversed q-profile. ICRH heating is applied at ~0.6 sec with some NBI blips for diagnostics purposes and an ECRH deposition location scan in a shot-to-shot basis. Fig.6. shows the heating timing and power used in these discharges. ICRH driven AEs do not exhibit the same reduction in RSAE activity with ECRH near q_{min}. In contrast to this, no RSAEs are observed with ECRH on-axis while in discharges with ECRH applied near q_{min} a rich pattern of RSAEs and TAEs driven by ICRH ions is clearly visible. Fig.7 shows the AE activity observed near q_{min} in ECE fluctuations with ECRH near magnetic axis Fig.7-(a) and ECRH deposition near q_{min}, Fig.7-(b) and –(c). In all cases clear convective losses due to AEs are observed by the FILD systems. Future sensitivity experiments and modelling will focus on understanding this difference and the overall impact that the slightly ECRH modified q-profile, T_e and fast-ion pressure may have on the observed AE activity as well as other possible mitigation mechanisms.

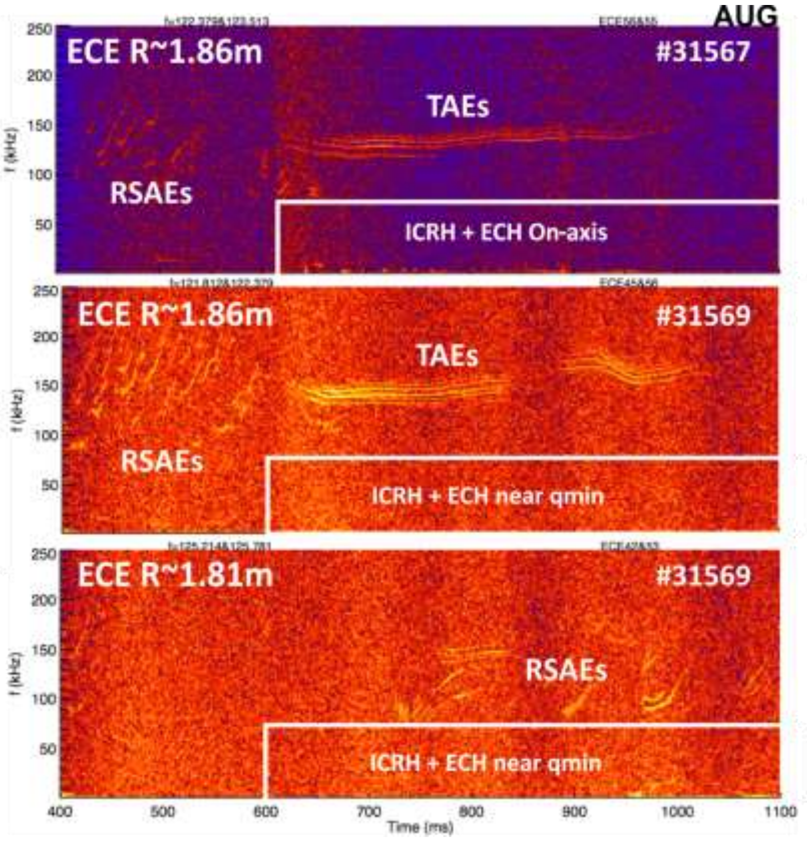

Fig.7. ECE spectrograms showing the ICRH driven AE activity with ECRH on-axis (a), and near q_{min} (b) and (c).

References

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