Destabilisation of TAE modes using ICRH in ASDEX Upgrade

D. Borba[1], G.D.Conway[2], S. Günter[2], G.T.A.Huysmans[3], S. Klose[2], M. Maraschek[2], A. Mück[2], I. Nunes[1], S. D. Pinches[2], F. Serra[1]
and the ASDEX Upgrade Team

[1]*Associacão EURATOM/IST, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*
[2]*MPI für plasmaphysik, EURATOM-Association, D-85748 Garching, Germany*
[3]*Association EURATOM-CEA, CEA Cadarache, 13108, St Paul lez Durance, France*

Introduction

In a tokamak fusion reactor, the heating will be provided by the supra-Alfvénic population of charged fusion products (alpha particles), where the birth velocity v_α=1.3x10^{7}ms^{-1} exceeds the Alfvén speed $v_A=B/\sqrt{\rho}\approx10^7$ms^{-1}. Alfvén Eigenmodes (AE) destabilised by supra-Alfvénic ions can cause the redistribution/loss of fast particles, leading to a reduction of heating efficiency and ejected particles can damage first wall components [1]. In present tokamak experiments, the destabilisation of AE can be studied using supra-Alfvénic ions generated by auxiliary heating systems such as NBI and ICRH. Under these conditions, unstable AE have been observed and analysed in tokamaks such as TFTR, DIII-D, JT-60U and JET [2, 3, 4, 5]. The destabilisation and characterisation of Toroidicity induced Alfvén Eigenmodes (TAE) in ASDEX Upgrade [6] is reported in this paper, in the presence of Ion Cyclotron Resonant Heating (ICRH), focussing on the identification of the toroidal and poloidal mode structure. In ASDEX Upgrade, TAE are observed in the magnetic probes, soft x-ray emission and microwave reflectometer, when the ICRH power exceeds P_{ICRH} > 3 MW in conventional scenarios and P_{ICRH} > 2 MW in advanced scenarios, at low density n_e=3-5x10^{19}m^{-3}.

TAE instability in ASDEX-upgrade

In a tokamak, an instability can be characterised by the amplitude, frequency and mode structure as given by $\xi = \zeta(r,\theta)\ e^{i(\omega t+n\phi)}$, where $\zeta(r,\theta)$ is the 2-dimensional plasma displacement, ω the frequency, n the toroidal mode number. In ASDEX-Upgrade, TAE are observed in the frequency range of $f_{TAE}\approx$150-200khz, consistent with the Alfvén frequency for the magnetic field of Bt=2T, electron density of n_e=4-5x10^{19}m^{-3} and major radius of R_0=1.65m. Most unstable TAEs have toroidal mode numbers (n=3,4,5,6) and experiments with reversed current (I_P) and magnetic field (B_T) showed that the TAE propagate in the current direction, i.e. the ion diamagnetic drift direction, confirming that these modes are destabilised by the ICRH produced energetic ions. The differences between the frequency of two adjacent toroidal mode numbers $\Delta f_{TAE=}(f_{TAE\ (n)}+f_{TAE\ (n-1)})$ cannot be explained solely by toroidal plasma rotation, which is less than 2 kHz (<20 km/s) for ICRH only heated plasmas. Experiments performed with no plasma rotation at q=1, shows TAE frequency differences of around Δf_{TAE} =8-12 kHz. The frequency difference of TAE with different toroidal mode numbers can be caused by the TAE being located at different radial positions, kinetic and diamagnetic effects or abnormal rotation profiles in the presence of ICRH.

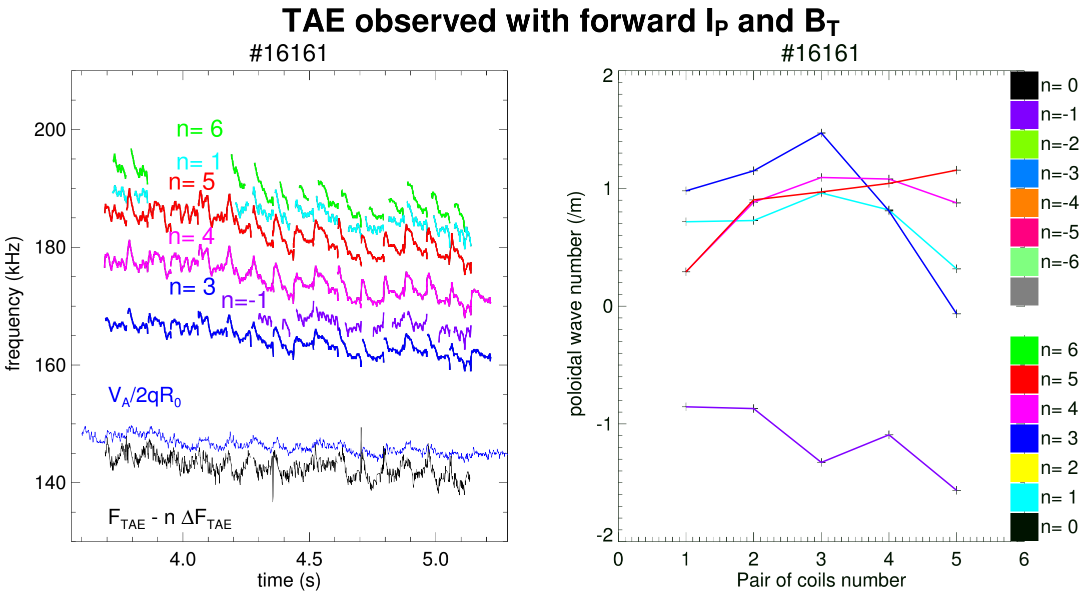


Figure 1 Frequency of the TAE modes observed with different toroidal mode numbers as a function of time, compared with $f_0=f_{TAE}-n\ (f_{(n)}+f_{(n-1)})$ and the Alfvén frequency at q=1.5. Figure 2 Poloidal wave numbers measured at the edge by the poloidal array of magnetic probes.

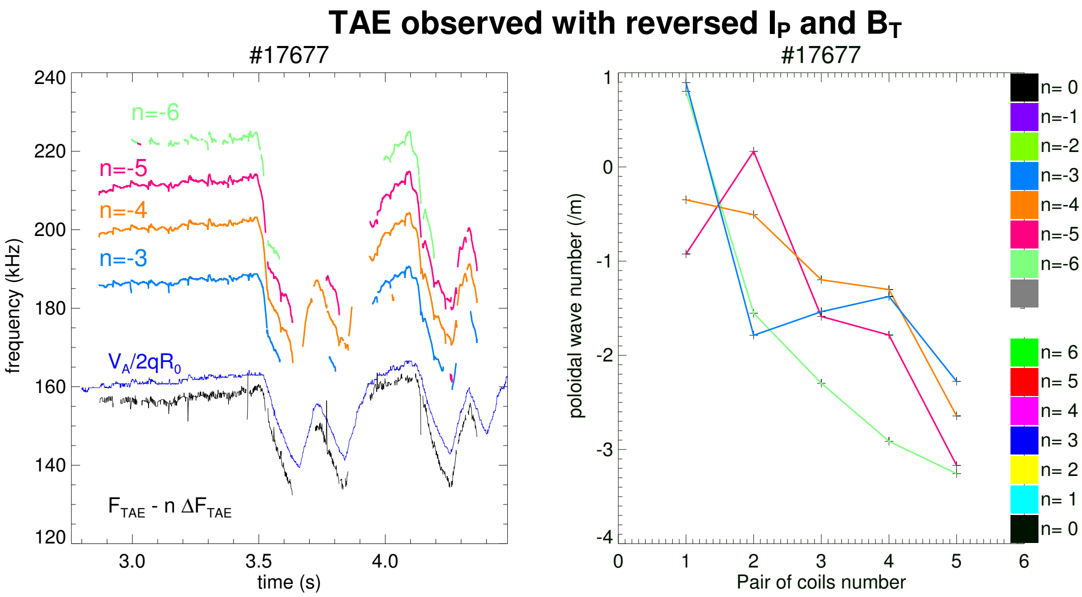
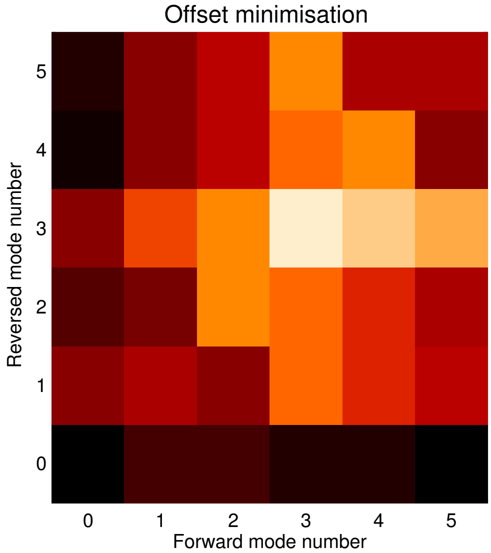


Figure 3 Frequency of the TAE modes observed with different toroidal mode numbers as a function of time, compared with $f_0=f_{TAE}-n\ (f_{(n)}+f_{(n-1)})$ and the Alfvén frequency at q=1.5. Figure 4 Poloidal wave numbers measured at the edge by the poloidal array of magnetic probes.

Toroidal mode number analysis

The analysis of the toroidal mode number (n) is particularly important, since the TAE destabilisation is linked to the breaking of toroidal symmetry by the wave fields in the interaction with the energetic ions. The most unstable toroidal mode numbers are given by the balance between the instability drive proportional to n, which saturates for large n due to finite orbit widths effects, and the various damping mechanisms [7,8]. Due to toroidal symmetry of the tokamak plasma and weak non-linear coupling between different toroidal harmonics, the TAE have well defined toroidal mode numbers. After an appropriate calibration around the TAE frequency, the toroidal mode numbers of the TAE are obtained using the toroidal array of magnetic probes. Considering that there are m – coils; k-modes, the measured phase difference between a pair of magnetic probes is given by $\delta_{km}=\phi_m+ n_k\alpha_m+ 2\pi p$, where ϕ_m is the phase offset between pair of coils-m, n_k the toroidal mode number of mode-k and α_m the toroidal angle between pair of coils-m. In this case, 4 TAE are observed in both forward and reversed current and magnetic field (K=1..8) and in ASDEX-Upgrade there are 5 coils available (m=1..5). The numbers of equations (40) exceed the number of variables (18), $mk > 2m+k$. Therefore, ϕ_m, n_k and α_m can be obtained from the measurement of δ_{km} using a minimisation algorithm.



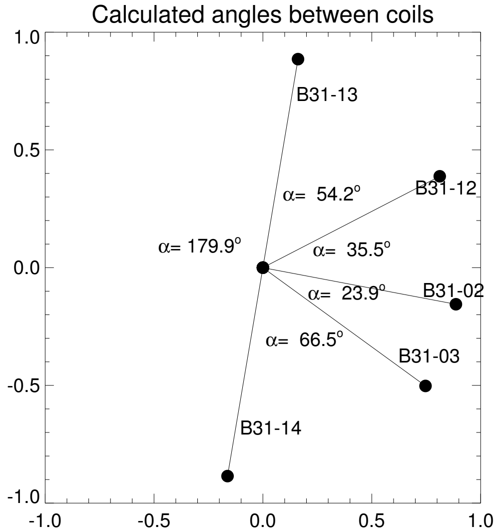


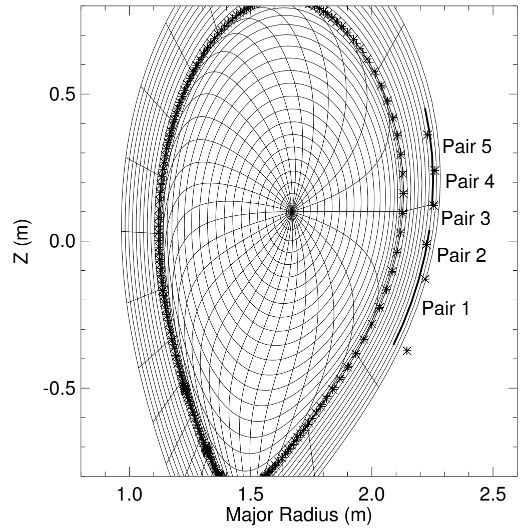
Figure 5 Representation of the minimisation function for different values of the lowest absolute toroidal mode number for each of the two opposite propagating directions. Figure 6 Position of the coils inferred from the propagation of the TAE, confirming the accuracy of the toroidal mode number calculations.

Poloidal mode number analysis

The poloidal mode structure of the TAE is more complex, because the TAE are created by toroidal coupling of 2 adjacent poloidal harmonics [9]. In addition, toroidal coupling across the plasma radius generates higher harmonics towards the plasma edge resulting, in a rather different poloidal structure compared with the structure at the rational surface where the mode is generated. Analysis of the phase difference between consecutive magnetic probe pairs of the poloidal array (1,2,3,4,5 shown in figures 7 and 8), located at the outer mid plane (low field side), shows that the poloidal wave number measured is largely independent of the toroidal mode number. However, the propagation changes direction when the current and field are reversed, as shown in figures 2 and 4. Modelling of the poloidal mode structure has been carried out using the HELENA (MHD equilibrium) and MISHKA (ideal MHD stability) codes [10,11]. The plasma equilibrium for shot #16161 has been reconstructed with HELENA code using the information from the CLISTE equilibrium reconstruction [12]. The calculated poloidal wave number of the TAE vacuum magnetic field perturbation, in the region of the array of poloidal magnetic probes, is given in Table 1. The calculated wave numbers are in the range 1-3 m^{-1} and show also a weak dependence on the toroidal mode number, consistent with the experimental observations. At other poloidal angles, the MHD model predicts much shorter wavelengths, but no reliable measurements are available for comparison.

Table 1 Poloidal wave numbers (low field side midplane) calculated by the MISHKA ideal MHD code

Toroidal mode	n=1	n=2	n=3	n=4	n=5	n=6
Poloidal wave	1.30 m^{-1}	1.20 m^{-1}	1.75 m^{-1}	1.38 m^{-1}	2.47 m^{-1}	2.13 m^{-1}



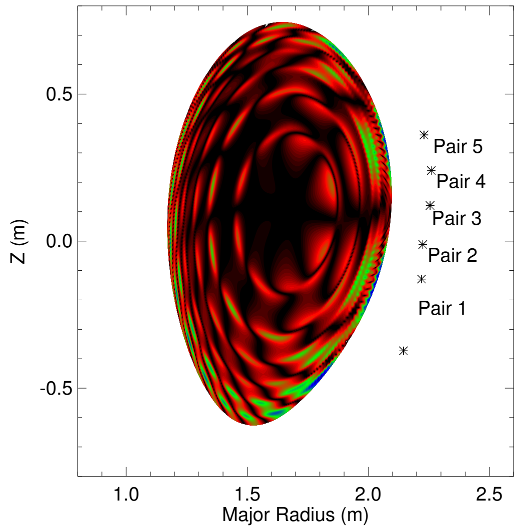


Figure 7 Numerical mesh used in the stability and equilibrium calculations, showing the position of the poloidal array of magnetic probes. Figure 8 MHD perturbation of an n=3 TAE calculated using the MISHKA code and the position of the poloidal array of magnetic probes .

Conclusions

TAE are destabilised by ICRH in ASDEX Upgrade for P_{ICRH} > 2-3 MW in conventional and advanced scenarios, at low density n_e=3-5x$10^{19}m^{-3}$. Most unstable TAEs have toroidal modes numbers (n=3,4,5,6) and experiments with reversed current (I_P) and magnetic field (B_T) showed that the TAE propagate in the current direction. TAE poloidal wave numbers in the outer midplane (low field side) are in the range of 0-3m^{-1} with a weak dependence on the toroidal mode number, consistent with the ideal MHD calculations [13,14].

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References

[1] ITER Physics Basis (chapter 5) 1999 Nucl. Fusion **39** 2471; **[2]** Ali-Arshad S. and Campbell D. 1995 Plasma Phys. Control Fusion **37** 715; **[3]** Wilson et al 1993 Int. Conf. Plasma Physics Cont. Fusion Research 1992: Proc. 14th Int. Conf. (Wurzburg, 1992) vol 1 (Vienna: IAEA) p 661; **[4]** Saigusa et al 1995 Plasma Phys. Control. Fusion **37** 295; **[5]** Fasoli A. et al 1997 Plasma Phys. Control. Fusion **39** B287; **[6]** O.Gruber Nucl. Fusion 41 No 10 (October 2001) 1369-1389; **[7]** R. Betti and J. P. Freidberg, Phys. Fluids **B4**, 1465 (1992); **[8]** B. N. Breizman and S. E. Sharapov, Plasma Phys. Contr. Fusion, **37**, 1057 (1995); **[9]** Cheng C.Z., Chen L. and Chance M.S. 1985 Ann. Phys. **161** 21; **[10]** Huysmans G.T.A. et al 1993 Phys. Fluids B **5** 1545; **[11]** Huysmans G.T.A et al 1992 Phys. Fluids B **3** 1506, **[12]** J.P. McCarthy IPP Report 5/85 (1999); **[13]** W. Heidbrink et al, Nucl. Fusion 37, 1411, 1997; **[14]** E. M. Carolipio Phys. of Plasmas vol 8, number 7 July 2001