Alfvén Instability in ITER Baseline Scenario with I_P=15 MA

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INTRODUCTION

- Burning plasmas in ITER constitute a challenging new field of physics, which requires, in particular, understanding of fundamental issues associated with the super-Alfvénic energy range of fusion-born alpha-particles and ions used in auxiliary NBI heating [1, 2].
- Present-day experiments with NBI and ICRH: fast ion-driven Alfvén instabilities in a broad frequency range, with the effects on fast ion transport ranging from negligible for benign mode saturation to significant for high-amplitude modes (see, e.g., [3] and References therein).
- The ITER scale plasmas with many modes and small ratio between the fast particle orbit and minor radius, $\rho_\alpha / a \cong 10^{-2}$, goes well beyond the present-day experiments. Therefore, extrapolation towards ITER is not straightforward and Alfvén instability remains a significant issue for high-Q operation.
- Since ITER can only tolerate fast particle losses of a few percent, primarily due to first wall damage that they would cause, it is essential that any burning plasma experiment has a window of operation where either the fast ion-driven Alfvén modes are stable, or, if unstable, the effect of instability leads only to a mild rearrangement of the fast-particle distribution.
- The linear instability of Alfvén Eigenmodes (AEs) in the baseline ITER burning plasma scenario with plasma current of I_P = 15 MA [4] is considered in this presentation.

ITER ASTRA PROFILES AND EQUILIBRIUM

We consider plasma parameters and profiles predicted with the ASTRA transport code [4] for ITER baseline scenario with current I_P =15MA, R_0 =621 cm, a =200 cm , and B_0 = 5.3 T. The model is based on 2D SPIDER equilibrium for the baseline 2008 separatrix, and the prediction of the plasma profiles is obtained from 1D scaling-based transport for electron and ion temperatures, T_e, T_i, current density, j , electron and ion densities, n_e, n_D, n_T, n_{He}, n_{Be}. The fuel ion species have deuterium-tritium (DT) mixture close to the optimum, $n_D : n_T \approx$50:50, while density of helium ions resulting from the fusion reactions varies as function of fusion reactivity, and the beryllium impurity ions coming from the first wall satisfy $n_{Be} = 0.02 n_e$. The auxiliary heating and current drive includes two deuterium Negative NBI sources with E_{beam} =1 MeV and total power P_{beam} =16.5 MW (on-axis)+16.5 MW (off-axis), and ECRH from the upper launcher has P_{ECRH} =6 MW.

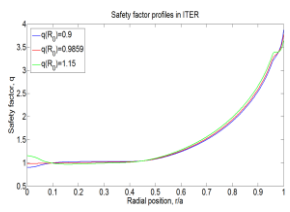

***Figure 1**. q(r)-profiles considered for the baseline scenario with I_P=15 MA.*

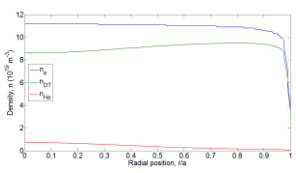

***Figure 2**. Density profiles of electrons (blue), DT mixture (green), and He (red).*

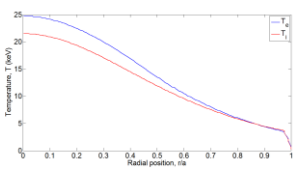

***Figure 3.** Profiles of electron temperature (blue) and DT ion temperature (red).*

Figures 2, 3 show the profiles of densities and temperatures of thermal plasma, for the Q=10 point.

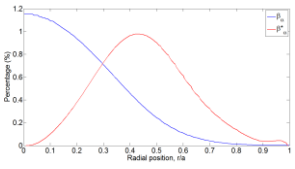

***Figure 4**. Profiles of $\beta_\alpha(r/a)$ (%) and gradient of alpha-particle pressure, $\beta^*_\alpha = -a d\beta_\alpha / dr$*

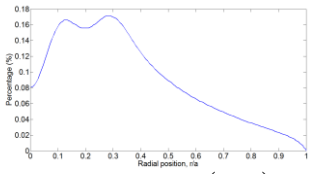

***Figure 5.** Profile of $\beta_{beam}(r/a)$ (%) in the scenario considered.*

Energetic alpha-particle and beam populations shown in Figs.4, 5 are computed within Fokker-Planck approach, and Maxwellian distribution functions are then extracted from the results. Note from Figure 4 that almost all alpha-particles are confined within central region of plasma, $r/a \le 0.5$, with the highest gradient of the alpha-particle pressure at $r/a \approx 0.42$

STRUCTURE OF TAE AND EAE GAPS

- It is instructive to start the analysis of Alfvén instabilities from investigating radial localisation regions of TAE and EAE gaps, where weakly-damped TAEs and EAEs may reside, for different toroidal and poloidal mode numbers, n and m .
- These localisation points are determined via $q(r_{TAE}) = (m - 1/2)/n$ and $q(r_{EAE}) = (m-1)/n$
- The relevant range of the toroidal mode numbers is determined by the efficiency of the alpha particle drive. The maximum power transfer between alpha-particles and an AE is achieved for $n \cong 30$ when drift orbit width of resonant passing alpha-particle, is comparable to the mode width.

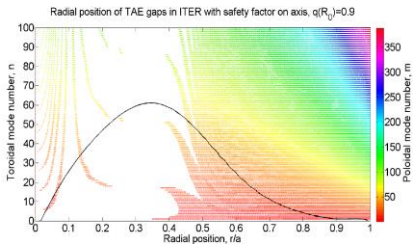

***Figure 6**. Radial localisation of TAE gaps in ITER with q(0)=0.9. Solid line shows normalised radial gradient of alpha-particle pressure. Radial width of a TAE-gap is estimated as $\Delta_{AE} = r/m$.*

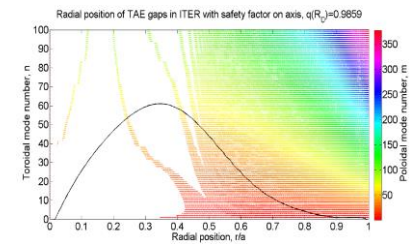

***Figure 7.** Radial localisation of TAE gaps in ITER case with q(0)=0.9859.*

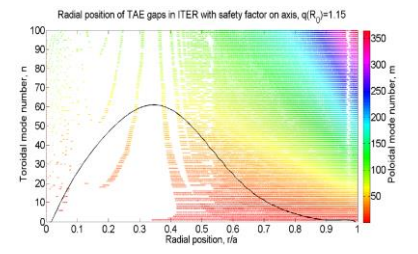

***Figure 8**. Radial localisation of TAE gaps in ITER case with q(0)=1.15.*

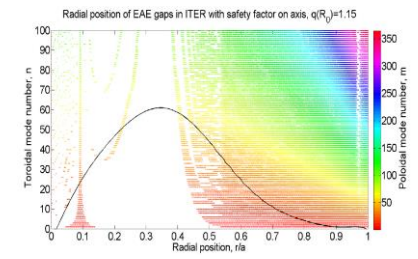

***Figure 9.** Radial localisation of EAE gaps in ITER case with q(0)=1.15.*

CORE-LOCALZED AND GLOBAL MODES AND LOCAL DRIVE/ DAMPING ESTIMATES

In the central region with low magnetic shear, core-localized modes exist as Fig.10 shows. In the region with higher shear values, global modes exist with extended radial width (Fig.11).

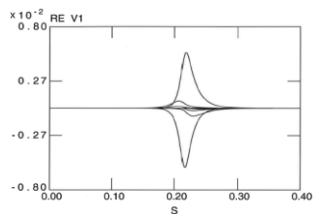

***Figure 10**. Upper core-localised TAE with $n = 20$ in ITER case with $q(0) = 0.9$.*

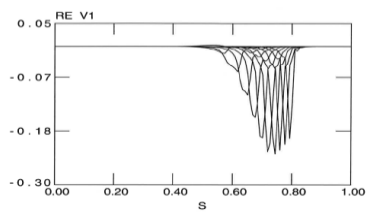

***Figure 11.** Global TAE with $n = 20$ in ITER case with $q(0) = 0.9$.*

Local estimates of TAE drive due to alpha-particles and NBI, together with TAE damping mostly determined by the thermal ion Landau resonance and electron collisions show that TAE instability may occur in the outer plasma region, r/a >0.5.

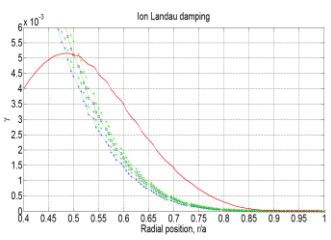

***Figure 12**. Local Landau damping of TAE due to D and T ions and alpha-particle drive.*

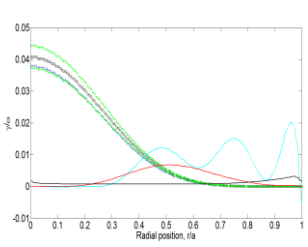

***Figure 13.** Local Landau damping due to D and T ions, α- drive (red) and NBI drive (blue). Trapped electron damping is shown in black.*

CONCLUSIONS

There are two very different regions in the Q=10 ITER operational point with 15 MA:

1) r/a<0.5 where main part of alphas is confined, q-profile is flat, and TAE gaps are scarce. In this region, thermal ion Landau damping absolutely dominates over alpha+beam drive;
2) r/a>0.5 where alpha-population is not very strong, but TAE-gap density is very high (meaning all TAEs are global). In this region, alpha-drive exceeds the ion Landau damping giving the net drive ~1.5 x 10^{-3}. The beam can further destabilise TAEs in this region.

Taking into account the exponential sensitivity of the ion Landau damping to the ion temperature, ***the path* to the Q=10 point (in the region T_i<15 keV) is likely to be more unstable to TAE than the Q=10 point itself.**

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[2] Fasoli A. et al., *Progress in the ITER Physics Basis*, Chapter 5, Nucl. Fusion **47** (2007) S264.
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