MHD modes analysis in high-beta ASDEX Upgrade configurations including a 3D model of conductors

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1. Introduction

The main goal of this work is to analyze MHD modes in high-beta configurations of the ASDEX-Upgrade device, evaluating and quantifying the effect of 3D conductors, e.g. in order to find possible extension of operation space in case of modification of the various conducting structures. Assuming that resistive instabilities (e.g. tearing modes) are suitably prevented, the maximum achievable value of beta is limited by the onset of the ideal external kink instability. The actual limit depends mainly on the stabilizing effect of the conducting components around the plasma: any plasma perturbation induces eddy currents in the conducting structures, which tend to counteract the instability itself. If the conductors are close enough, the instability is slowed down from fast Alfvén times to the electromagnetic times, giving rise to the so-called Resistive Wall Modes (RWM). Several different codes and models can be used to analyse this problem, ranging from linearized axisymmetric codes to nonlinear three-dimensional models. In this paper, we use the CarMa code [1], which is able to analyse RWM in presence of 3D volumetric conducting structures.

2. Reference plasma configuration and geometry

The AUG reference configuration [2] used in this paper is described by a safety factor on axis $q_0 = 1.17$, major radius 1.64 m, toroidal magnetic field at axis $B_\phi = 2.38$ T and toroidal plasma current $I_p = 1$ MA. In the following, the plasma beta has been scanned keeping plasma current and safety factor constant. Fig. 1 reports the plasma boundary and the q profile. For this AUG configuration, the vacuum vessel is relatively far from the plasma - close to or even beyond the limit position, as it will be discussed later. In such situation, a sophisticated and detailed description of the structures is necessary to quantify the actual stabilizing effect [3]. The CarMa code [1] is used to analyse the effect of the main 3D structures (Fig. 2), specifically including the vacuum vessel with port extensions and bellows and the PSL, made of two toroidally continuous copper rings connected by poloidal bridges.

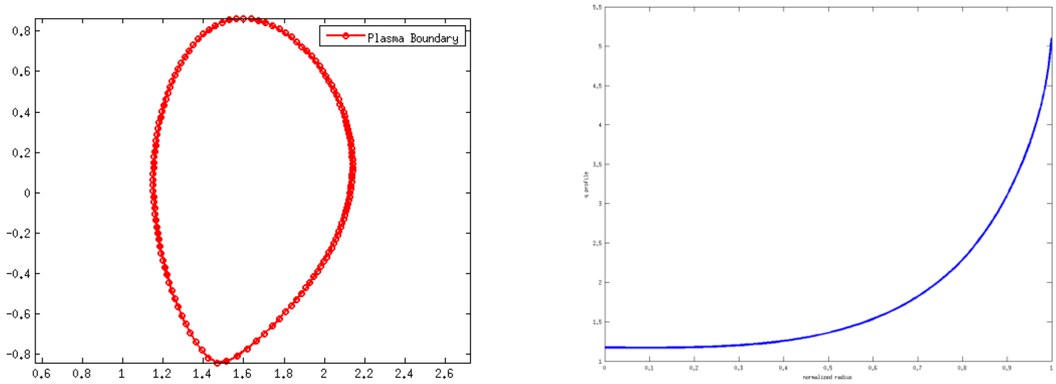
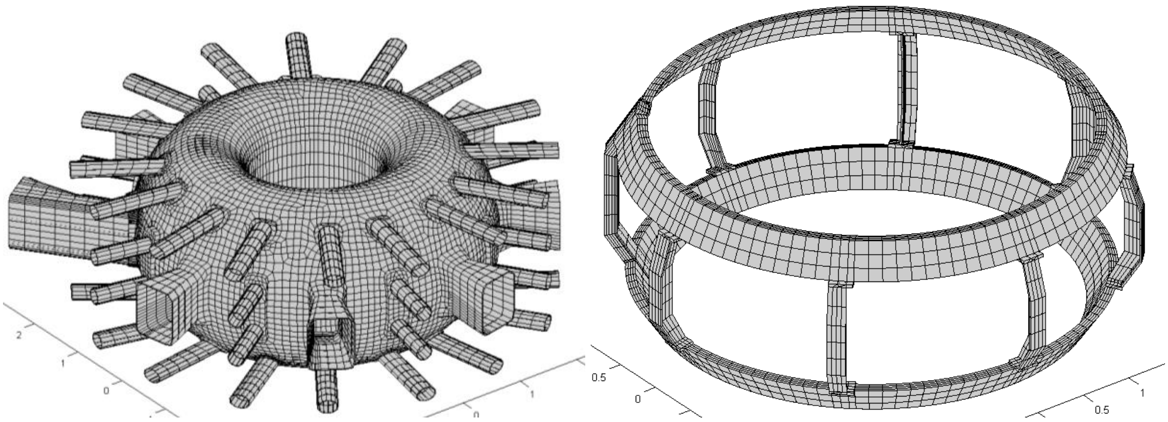


Fig. 1. Plasma boundary and q profile



(a) (b)

Fig. 2. 3D conducting structures considered: (a) vacuum vessel; (b) PSL

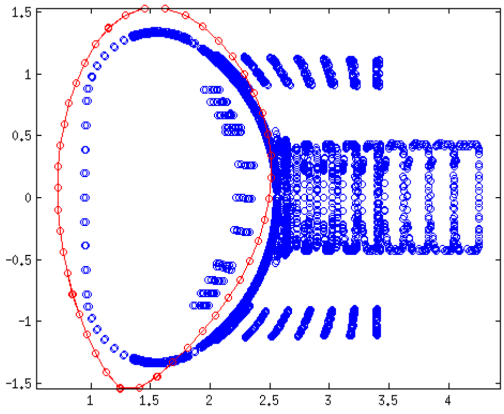


Fig. 3. Ideal wall limit position (red) compared to actual conducting structures (blue)

3. Results

First of all, the no-wall beta limit has been computed as $\beta_{nowall} = 3.06$. A beta value above this value ($\beta_N = 3.21$) has been selected, so as to destabilize the ideal pressure-driven external kink n=1 mode. For this configuration, the limiting ideal wall position has been computed for an axisymmetric wall conformal to the plasma boundary: any conducting structure located outside this position is not able to slow down the instability to electromagnetic times. Figure 3 shows the relative position of the ideal wall limit position with respect to actual structures, showing that the vessel is expected to be only partially effective, while the PSL is close enough to plasma. Indeed, considering an axisymmetric conformal wall located at the radial position of the PSL (Fig. 4a: gray+blue+red), a RWM appears with a normalized growth rate $\gamma\ \tau_w = 0.47$. This value was positively compared against MARS-F [4], which provides the same value within approximately 6%. Fig. 4b shows the corresponding current density pattern. In order to evaluate the effect of the partial poloidal coverage of the PSL, other two cases have been considered. The first one corresponds to rings connected by toroidally continuous bridges (red+blue), providing the same result within a few percents, while the second corresponds to the rings only (red), providing an instability on Alfvén time scale. A computation carried out on the true 3D geometry (Fig. 2) provides again an ideal instability: in other words, considering its realistic geometry, the PSL is not able to stabilize the plasma. A similar consideration applies also to the vessel alone.

Conversely, if both the vessel and the PSL are considered together, the instability is slowed down to electromagnetic time (growth rate $\gamma \approx 163\ s^{-1}$). Figure 5a shows the corresponding current density pattern. We conclude that there is a synergistic effect of PSL and vessel: in a sense, the PSL is close enough to plasma, while the vessel guarantees poloidal continuity.

The current density pattern of Fig. 5a clearly shows some interruptions between consecutive sectors, which are interpreted as being due to the presence of high-resistance bellows. To prove this conjecture, we consider a fictitious case in which the bellows have been removed: the current density pattern (Fig. 5b) shows no interruptions (except for port extensions, obviously) and the growth rate drops to $\gamma \approx 104\ s^{-1}$.

The same analysis has been carried out for a higher beta value ($\beta_N = 3.66$ [2]). The ideal wall limit position in this case is completely inside the vessel, so that the vessel does not contribute to stabilization. A 2D wall located at the PSL position again stabilizes the plasma, but the realistic 3D structure (PSL with bridges + vessel with bellows) cannot slow down the instability to electromagnetic times.

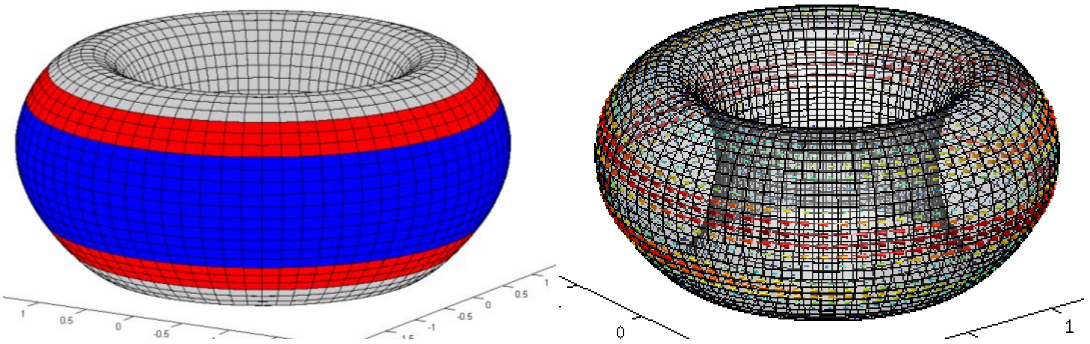

(a) (b)

Fig. 4. 2D wall located at the same position of the PSL: (a) geometry, (b) current density pattern

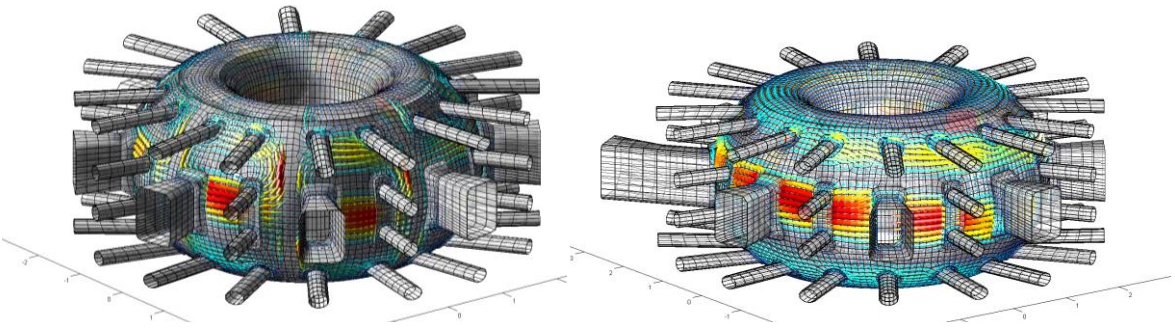

(a) (b)

Fig. 5. Current density patterns in the vessel: (a) reference; (b) no bellows

4. Conclusions

A detailed 3D analysis of the external kink in AUG has been carried out, investigating the 3D effects of conducting structures surrounding the plasma, investigating in particular the effects of partial poloidal coverage of PSL and the connection of rings through bridges, and the influence of the high-resistance bellows between sectors. The main conclusion is that 3D effects may be significant: a 2D wall located at the PSL position may be too optimistic, while the realistic 3D wall is able to stabilize configurations with a normalized beta not much above the no-wall limit. These conclusions may not necessarily apply to other equilibrium configurations. This work was supported in part by Italian MIUR under PRIN grant#2008E7J7A3 and in part by EUROFusion MST1 Work Package.

[1] A.Portone, F.Villone, Y. Liu, R. Albanese, G. Rubinacci, *Plasma Phys. Control. Fusion* **50** (2008) 085004

[2] V. Igochine et al., *40th EPS conference on Plasma Physics* (2013) paper P5.147

[3] E. Strumberger et al., *Phys. Plasmas* **15** 056110 (2008)

[4] Y. Liu et al., *Phys. Plasmas* **7** 3681–90 (2000)