

## MHD stability studies for high-current scenarios in FAST

G. Calabrò<sup>1</sup>, F. Crisanti<sup>1</sup>, V. Fusco<sup>1</sup>, Y. Liu<sup>2</sup>, P. Martin<sup>3</sup>,  
S. Mastrostefano<sup>4</sup>, F. Villone<sup>4</sup>, G. Vlad<sup>1</sup> and FAST team

<sup>1</sup>Ass. ENEA-Euratom sulla fusione, Frascati (RM), Italy

<sup>2</sup>Euratom/CCFE Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK

<sup>3</sup>Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, Padova, Italy

<sup>4</sup>Ass. EURATOM/ENEA/CREATE, DIEI, Università di Cassino e del Lazio Meridionale, Italy

### Abstract

In this paper we study some high-current equilibria of the FAST tokamak, in order to analyse potentially dangerous ideal MHD instabilities of such low- $q$  configurations, in view of their passive and active stabilization.

### Introduction

The FAST device is presently under discussion as a possible DEMO and ITER satellite [1]. The main FAST goals are: exploring plasma wall interaction in reactor relevant conditions; testing tools and scenarios for safe and reliable tokamak operation up to the border of stability; studying fusion plasmas with a significant population of fast particles. One of the FAST peculiarities is the capability of addressing all of these items simultaneously in a single, fully integrated scenario with dimensionless physics parameters close to DEMO and ITER.

The present paper aims at studying an evolution of the reference scenario, focusing on low- $q$  operation, which allows exploring 10 MA plasmas. In particular, we refer to regions with  $2 < q_{95} < 2.7$  that are interesting to push fusion performances, but could be too risky to be tested in ITER. Specifically, we investigate a new FAST scenario at  $I_p = 10$  MA,  $B_T = 8.5$  T, with a  $q_{95} \approx 2.3$  that would correspond to  $I_p \approx 20$  MA in ITER. The possibility to safely work at  $q_{95} < 3$  ( $q_{95} \approx 2.6$ ) has been shown recently at JET [2], although with a slight degradation of the energy confinement ( $H_{98} \approx 0.9$ ). The key point is to demonstrate the possibility of using in FAST passive conducting structures and active coils to stabilize and control potentially dangerous ideal and resistive MHD modes. To this purpose, FAST will be equipped with a set of feedback controlled active coils located between the first wall and the vacuum vessel and accessible for maintenance with the remote handling system, carrying currents up to 20 kA with AC frequency up to few kHz.

## Reference configurations

The stability analyses are carried out with MARS [3], MARS-F [4] and CarMa [5] codes.

We deal with two different equilibria, labelled EQA and EQB in the following. The plasma boundaries (very similar) are reported in Fig. 1; the main plasma parameters are reported in Table 1, while the  $q$  profiles are shown in Fig. 2. The free boundary equilibria have been computed by means of FIXFREE code [6].

Concerning the conducting structures, we consider the vacuum vessel and some conducting plates (assumed as axisymmetric), shown in Fig. 1. This is a simplified description of the current FAST design. The resistivity is taken as  $1\mu\Omega\text{m}$ .

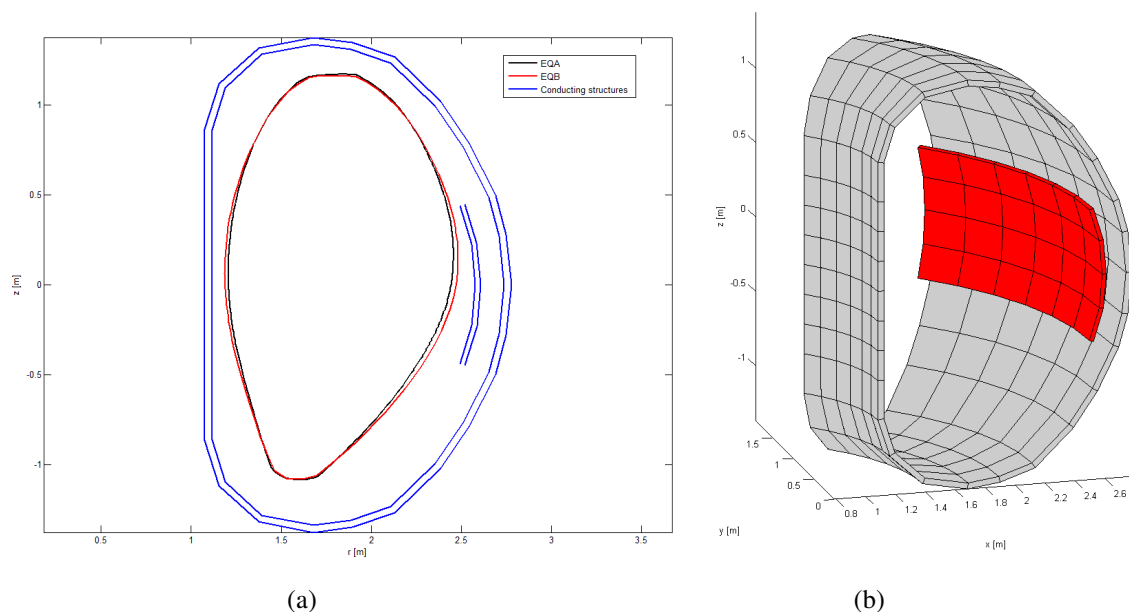


Fig. 1. (a) Plasma boundary and poloidal trace of conducting structures;  
(b) 3D view (cutaway: the actual structures span  $360^\circ$ ) (red: conducting plates)

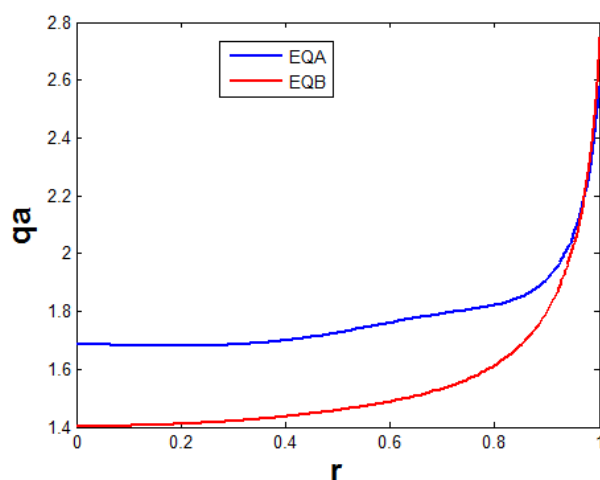


Fig. 2. Safety factor  $q$  profiles

<i>Param.</i>	<i>EQA</i>	<i>EQB</i>
$I_p$ [MA]	10	10
$q_{axis}$	1.684	1.402
$q_{boundary}$	2.577	2.744
$q_{95}$	2.30	2.27
$\beta_p$	0.31	0.52
$l_i$	0.5	0.6

Table 1. Equilibrium parameters

## Results

We study ideal MHD current-driven modes, hence assuming the plasma as perfectly conducting. First of all, the ideal-wall limit position has been computed with the MARS [3] and MARS-F [4] codes. Being  $q_{boundary} > 2.5$ , we expect that the  $n=2$  ideal kink is stable, which has been confirmed by computations. Hence, we focus on  $n=1$  ideal modes. Figure 3 shows the growth rate as a function of the position of an ideal wall conformal to the plasma boundary, for both EQA and EQB. Evidently, for EQA the ideal wall limit position is around  $1.25a$ , while for EQB it is around  $1.41a$  ( $a$  is the plasma minor radius). Fig. 3 shows also the two limiting positions as compared to the conductors. The significant difference is largely due to different  $q$  profiles reported in Fig. 2.

Regarding EQA, the limiting ideal wall position intersects the actual conducting structures - the conducting plates are in fact largely inside, since they roughly correspond to a position around  $1.12a$ . The application of the CarMa code [5] (able to treat general three dimensional conductors), with the discretization reported in Fig. 1, confirms that the actual conducting structures are not able to stabilize the plasma, despite the relative vicinity of the conducting plates. In order to further investigate this point, we applied MARS-F to wall with a partial poloidal coverage, located at  $1.12a$ . The results, shown in Fig. 4, highlights that a much higher poloidal extension of the conducting plates would be needed in order to have a significant stabilizing effect.

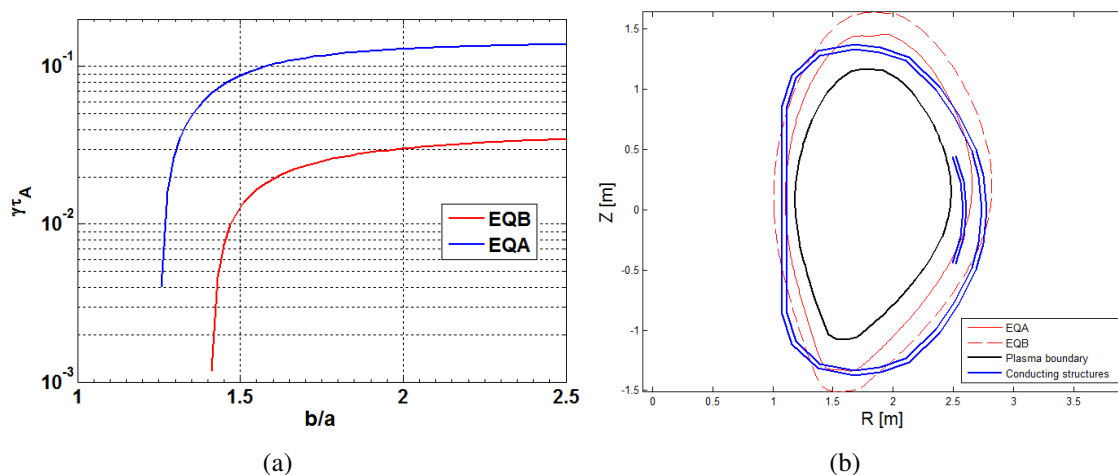


Fig. 3. Ideal-wall limit computations: (a) growth rate scan as a function of wall/plasma minor radius ratio; (b) position of the ideal wall limit as compared with conducting structures

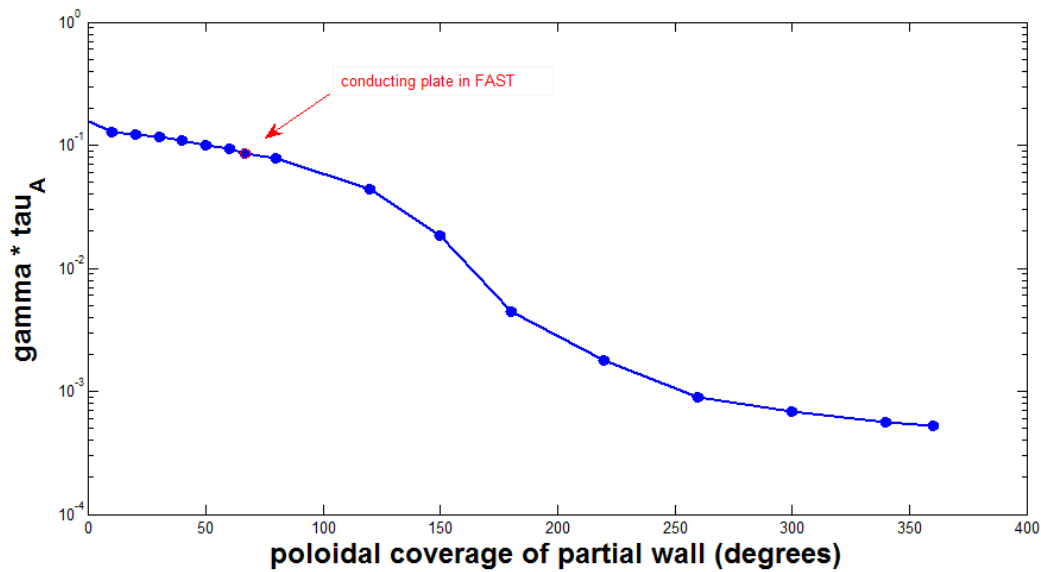


Fig. 4. Stabilizing effect of the conducting plate, as a function of poloidal coverage

Finally, for EQB, the limiting ideal wall position suggests that there is margin for a passive stabilization with the actual wall. Indeed, the application of CarMa to this situation reveals that in this case a (current-driven) Resistive Wall Mode (RWM) develops, with a normalized growth rate  $\gamma \tau_w = 6.9$ . In physical units, since the slowest  $n=1$  time constant is  $\tau_w=31.1$  ms for the simplified conducting structures considered, we have  $\gamma=222$  s<sup>-1</sup>.

## Conclusions

In this paper we have carried out extensive ideal MHD stability analysis of two high-current, low- $q$  fast equilibria. The results of several different codes show that a RWM can develop, whose active stabilization with in-vessel coils will be the focus of further work.

This work was supported in part by Italian MIUR under PRIN grant#2008E7J7A3.

## References

- [1] A. Pizzuto et al Nucl. Fusion **50** 095005 (2010)
- [2] F. Romanelli et al Nucl. Fusion **51** 094008 (2011)
- [3] A. Bondeson, G. Vlad, and H. Lütjens. *Physics of Fluids*, **B4** 1889–1900 (1992)
- [4] Y. Liu et al., *Phys. Plasmas* **7** 3681 (2000)
- [5] F. Villone et al., *Phys. Rev. Lett.*, **100**, 255005 (2008)
- [6] F. Alladio, F. Crisanti, *Nucl. Fusion*, **26** 1143 (1986)