VDE growth rate analysis in EAST including three-dimensional structures

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Abstract. This paper presents the comparison of experimentally measured growth rates of Vertical Displacement Events (VDEs) in the EAST tokamak with the predictions of a 3D linearized plasma response model (CarMa0). The agreement is good for a large range of growth rates, highlighting the importance of 3D effects for vertical stability studies in EAST.

1. Introduction

The EAST tokamak [1] is an experimental device with ITER-like fully superconducting poloidal and toroidal coils, which has been designed and constructed to explore the physical and engineering issues under steady state operation for support of future reactors. The main conducting structures surrounding the plasma, which are relevant for vertical stability analysis, are the vacuum vessel and the plasma facing components (PFCs), mainly including low field plates, passive plates, divertor outer plates, divertor dome plates, divertor inner plates and high field plates.

The aim of this paper is to estimate, with suitable numerical modelling, the growth rate of the axisymmetric vertical instability in EAST, during a so-called Vertical Displacement Event (VDE). The difficulty in giving a reliable model of EAST resides in the fact that the vacuum vessel, which is the main toroidally continuous conducting structure, is too far from the plasma to guarantee stability - indeed, with the vessel only, the growth rate of VDE would be on the Alfvén time scale, so that the plasma mass cannot be neglected [2]. Conversely, the instability is slowed down to electromagnetic times only thanks to the other conducting structures, which are much closer to the plasma, but however are toroidally segmented. Hence, the pattern of the current densities induced in conductors by any plasma movement has an intrinsic three-dimensional behaviour, flowing partly in the vessel (to guarantee the toroidal continuity) and partly in the plasma facing components (to guarantee effective stabilization), through suitable electrical connections between the two. Consequently, an accurate study of VDE growth rate in EAST must necessarily resort to linearized models able to include self-consistently 3D structures around the plasma. The CarMa0 code [3], which is used in the present paper, is one of the few computational tools available with such features.

2. Numerical model

The CarMa0 code [3] couples self-consistently a linearized axisymmetric plasma response (computed with the CREATE_L code [2]) with a 3D finite elements mesh of the conducting structures, through suitable coupling conditions on a surface placed in between. Fig. 1 shows a simplified EAST geometry, showing the main structures, and the detailed 3D finite elements mesh used. The PF coils (including the in-vessel IC coils), have been supposed as current-driven with fixed currents. A state-space model is obtained, whose state variables are the 3D currents in the conducting structures. The unstable eigenvalue of the dynamical matrix is the estimated growth rate of VDE for the configuration under analysis.

Also purely 2D models have been produced, with the CREATE_L code [2], with different simplifying assumptions on the conducting structures: a) only vessel; b) vessel + all PFC (toroidally continuous); c) vessel + only passive plates (PP) (toroidally continuous).

Assumption a) provides an instability on the Alfvén time scale, as discussed above, and hence will not be discussed any longer. Assumption b) provides a lower bound for the actual growth rate, since the hypothesis of toroidal continuity is optimistic. Assumption c) is the result of two conflicting hypotheses: toroidal continuity is optimistic, while neglecting all PFC but PP is pessimistic. Eventually we found that in fact assumption c) provides an upper bound for the growth rate, since the pessimistic hypothesis prevails.

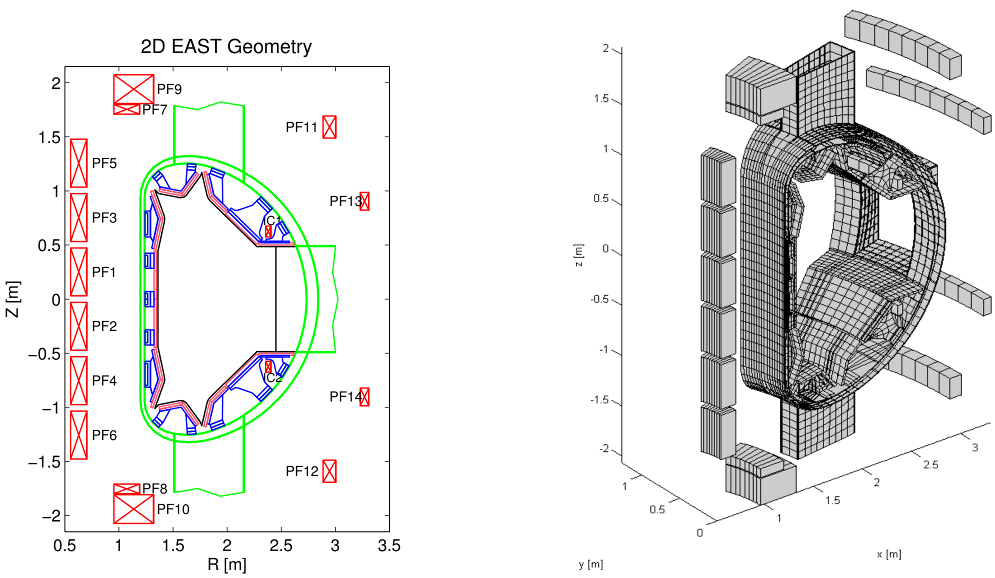

Fig. 1. 2D geometry and detailed 3D mesh considered.

3. Results

Three shots have been analysed, with "slow", "intermediate" and "fast" growth rates, in order to span most of the possible cases in EAST. Some details are reported in Fig. 2 and Table 1. In these experiments, the plasma is left free to evolve by imposing a fixed current in the control coils. The vertical position shows an exponentially unstable behaviour, from which the experimental estimate of the growth rate can be derived. Two procedures have been used (Fig. 2): an exponential fitting of the time trace and a linear fitting of its logarithm [4]. The estimated experimental value has been taken as the average of the two.

The various numerical estimates of the growth rates are reported in Table 2. Fig. 3 shows some details of the current density pattern in the structures, highlighting the 3D features. Evidently, the 3D model is able to give reliable predictions in all cases, while 2D models fail.

4. Conclusions

The features of EAST make 3D effects very important in estimating the growth rate. The CarMa0 code, able to couple an axisymmetric plasma to 3D structures, has been successfully implemented, hence providing reliable estimates of the growth rate with a good match to experimental values. Future activity will be addressed to the comparison on a larger set of experimental data, the analysis of Quasi-Snow-Flake configurations, the assessment of the new in-vessel conducting structure recently implemented and the development of nonlinear 3D models (e.g. for disruption analysis). This work was supported in part by Italian MIUR under PRIN grant 2010SPS9B3 and by the National Magnetic Confinement Fusion Research Program of China under Grant Nos 2012GB105000 and 2014GB103000.

Shot	I_p *[kA]*	β_p	l_i	R_c, Z_c *[m]*	κ	δ
35290	398	0.32	1.36	1.87, -0.052	1.60	0.42
43888	387	0.45	1.34	1.86, -0.006	1.93	0.58
36539	397	0.33	1.52	1.84, -0.015	1.83	0.52

Table 1. Equilibrium parameters for the configurations under analysis.

Shot	*Lower bound (2D)*	*Upper bound (2D)*	*3D calculation*	*Exp. value*
35290	70	144	88	84
43888	142	373	246	220
36539	169	508	320	316

Table 2. Growth rate estimates [s^{-1}].

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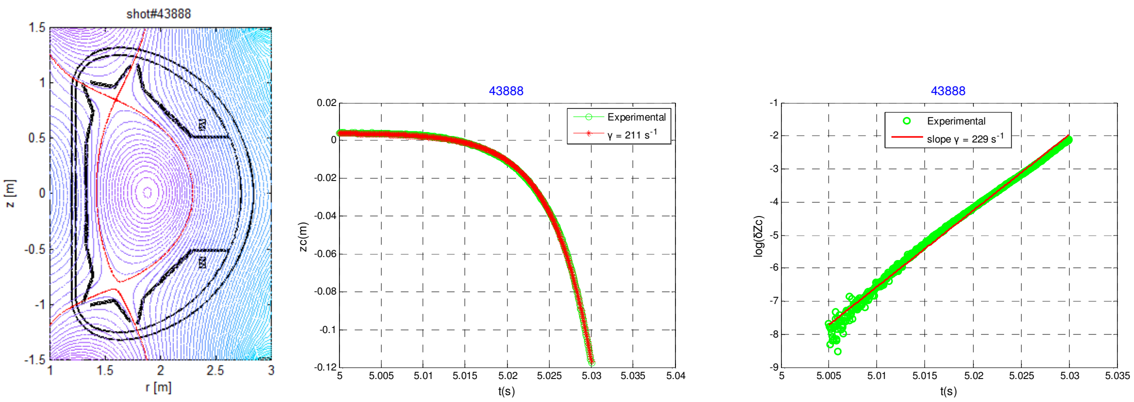

Fig. 2. One of the plasma configurations under analysis and growth rate estimate.

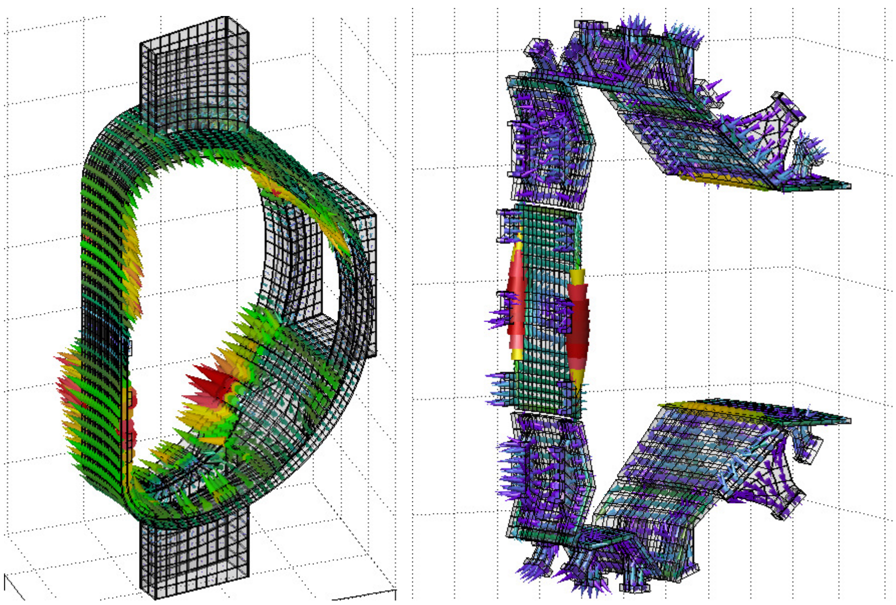

Fig. 3. Details of 3D current density patterns in the vessel and in the PFC.