ITER disruption studies including 3D volumetric blanket modules

F. Villone[1], L. Barbato[1], S. Mastrostefano[1], A. Portone[2], S. Ventre[1],
R. Albanese[3], G. Rubinacci[3]
[1]*DIEI, Università di Cassino e del Lazio Meridionale, 03043 Cassino (FR), Italy*
[2]*Fusion for Energy, Josep Pla 2, Torres Diagonal Litoral B3, 08019 Barcelona, Spain*
[3]*DIETI, Università Federico II di Napoli, Via Claudio 21, 80125 Napoli, Italy*

Abstract. This paper presents the analysis of disruptions in ITER including 3D volumetric blanket modules. The plasma evolution is computed as a sequence of axisymmetric equilibria, self-consistently coupled to a volumetric 3D description of surrounding conducting structures. The consequences on plasma evolution of different assumptions on the structures are analysed.

1. Introduction

Future magnetic confinement fusion devices, like ITER, have such high performances to require a special care in the dimensioning of various components, posing several challenges both from the physical and from the engineering point of view. Disruptions are a particular concern for ITER [1]: the sudden loss of magnetic confinement, with subsequent release of the magnetic and thermal energy stored in the plasma to surrounding structures, can produce electromagnetic forces and heat loads that require challenging design provisions in several components. In order to extrapolate the available experimental data to ITER, reliable and comprehensive computational tools are needed. Several modelling approaches are available for the analysis of disruptions, but none of them can be applied to all cases of interest, due to specific limitations and ranges of validity. For instance, [2] provides a valuable comparison of two well known axisymmetric codes for the analysis of disruption, DINA and TSC, highlighting the effects of different assumptions and limitations.

In this paper, we apply CarMa0NL [3] to ITER, in order to evaluate the effect of volumetric 3D blanket modules on plasma evolution during a disruption. Indeed, CarMa0NL has the unique capability of self-consistently coupling a nonlinear plasma evolution through equilibrium states (which, on the time scale of interest, well approximate the plasma dynamics) to a volumetric 3D description of surrounding conductors (which is required to accurately estimate the plasma evolution and the related electromagnetic loads).

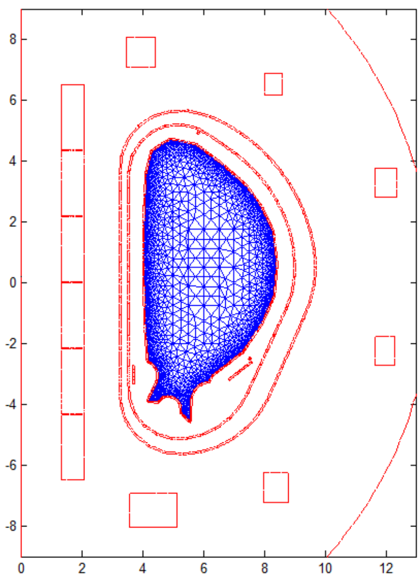
2. Numerical model

The CarMa0NL code [3] decouples the electromagnetic interaction between the plasma and the conductors via a suitable surface. In this way, a different formulation can be used for the plasma and the conductors, adopting for each region the most effective approach. The problem consists of equilibrium equations in the region accessible to the plasma, eddy currents equations in the external region (hosting 3D conductors) and suitable coupling conditions on the coupling surface in between. In doing so, we have postulated that the plasma evolves through equilibrium states (quasi-static evolution). This assumption is valid if the plasma mass can be neglected, so that effects due to plasma inertia are not important. This is true whenever the time scale of the phenomenon under study is much slower than the Alfvén time scale, which is certainly reasonable in the case of disruptions [2].

Fig. 1 shows the 2D triangular mesh used to solve Grad-Shafranov equilibrium equation in the plasma region and the most comprehensive 3D volumetric mesh of the conductors used in the present paper. Other 3D meshes have been produced: axisymmetric (for comparison and validation) and 3D without the blankets (to evaluate the effect of blankets).

3. Results

We analysed one typical ITER disruption: the so called MD-UP [4] event, consisting in a major disruption (1 ms thermal quench, followed by a linear current quench lasting less than 40 ms), causing an upward VDE (Vertical Displacement Event). The plasma current density profile evolution is imposed; no halo currents are considered.



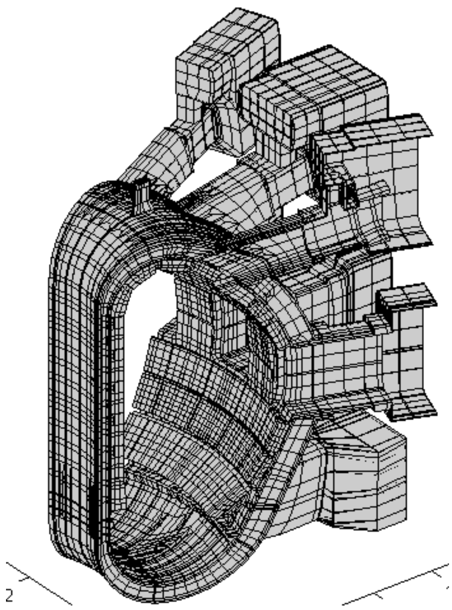


Fig. 1. 2D mesh of the plasma region and detailed volumetric 3D mesh of conductors.

The first tests are carried out with a 3D mesh mimicking an axisymmetric structure with no blankets, to compare the results with available axisymmetric evolutionary equilibrium codes, both linearized (CREATE-L [5]) and nonlinear (PROTEUS [6]). The results reported in Fig. 2 are produced using exactly the same mesh in all the codes for the plasma region; they show a good agreement at initial instant, but highlight a significant nonlinear effect on the vertical position variation. This effect is exacerbated by the presence of a significant cancellation, so that appreciable differences in the vertical position may arise even in presence of small differences in the currents induced in the vessel.

The introduction of volumetric blanket modules significantly affects the initial jump in vertical position due to the thermal quench (Fig. 3). The reason is highlighted in Fig. 4, which shows a plasma configuration during the disruption and some current density patterns inside the structures. Evidently, the blanket modules give a significant net contribution due to specific current loops arising in their structure. Axisymmetric models like TSC and DINA can account this effect only approximately, with different possible approaches [2]. It should be noted that, contrary to CarMa0NL results, DINA simulations includes halo currents, which start to rise at around 27 ms and completely replace the plasma core at around 45 ms.

4. Conclusions

We have analysed one ITER disruptive event (MD-UP) with the CarMa0NL code, including volumetric blanket modules. The results confirm the importance of a correct modelling of such conductors for an electromagnetically self-consistent plasma evolution during the event. Currently, the CarMa0NL code is being complemented with halo currents, in order to allow a more realistic description of the disruptive event. This work was supported in part by Italian MIUR under PRIN grant#2010SPS9B3.

References

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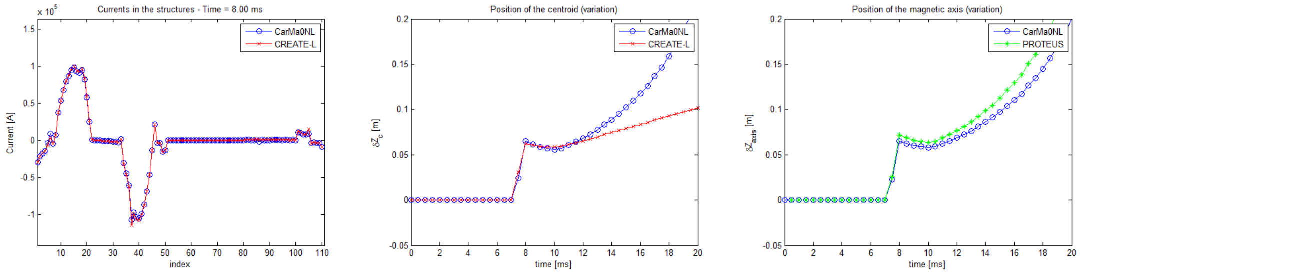

Fig. 2. Comparison with axisymmetric codes: currents in the structures and time behaviour of magnetic axis vertical position

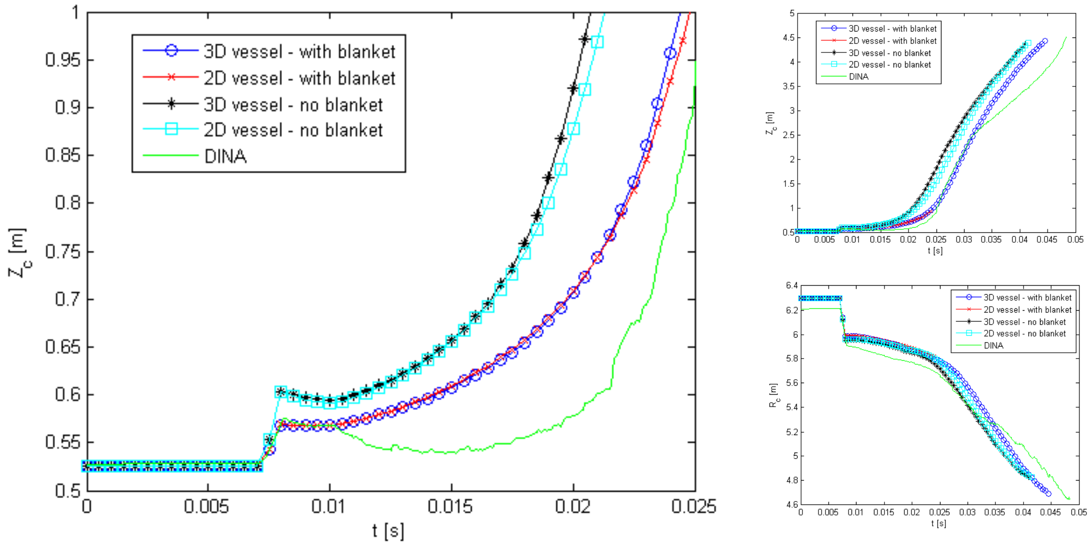

Fig. 3. Time behaviour of plasma centroid position during MD-UP disruptive event

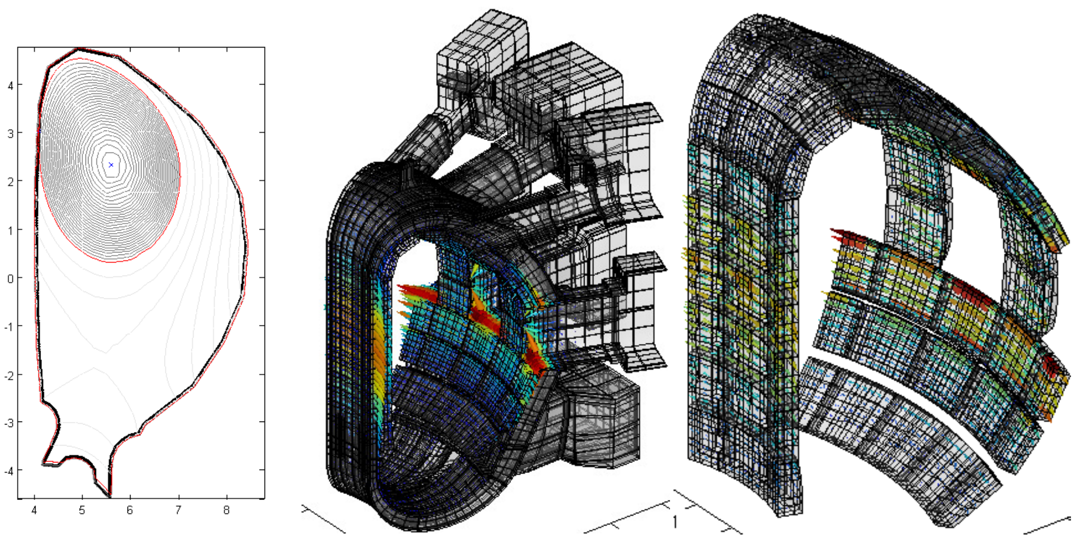

Fig. 4. Plasma config. and current density patterns inside the structures at various instants