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Multimodal ITER RWM analysis including 3D conducting structures

F. Villone[1], Y.Q. Liu[2]

[1]*Ass. EURATOM/ENEA/CREATE, DAEIMI, Università di Cassino, Italy*

[2]*Euratom/UKAEA Fusion Association, Culham Science Centre, OX14 3DB, UK*

Resistive Wall Modes (RWM) are MHD instabilities (usually external kink) that often set performance limits to advanced scenarios of present and future fusion devices (e.g. ITER). Commonly, they are classified using the toroidal mode number n.

In RFP devices, it is common practice to have RWM with multiple n's evolving simultaneously. Hence, it is fundamental to have a computational tool which is able to take this multimodal evolution into account [1], like the CarMa code [2]. In addition, this code is able to rigorously deal with three-dimensional conductors, hence studying the subsequent multimodal coupling which takes place even in linear MHD.

In tokamaks in general, and in ITER in particular, usually only the n=1 RWM is taken into account, being the first one to be destabilized with increasing normalized beta. However, it might happen also in these cases that multimodal RWM may take place. For instance, it is well known that plasmas with elongated cross-sections usually show an unstable axisymmetric vertical evolution, sometimes called a VDE (Vertical Displacement Event) when vertical control is lost.

This instability can be classified as a n=0 RWM, and in some cases can occur simultaneously together with a n=1 RWM, giving rise to a multimodal unstable plasma evolution. The resulting plasma movement can be thought as a combination of a vertical axisymmetric movement with a helical kink.

Aim of this paper is to study the simultaneous n=0 / n=1 evolution of ITER plasmas.

The CarMa0 code

In order to evaluate the effects of three-dimensional conducting structures on the evolution of the vertical instability, an extension of the CarMa code [2] has been developed, able to deal with n = 0 modes (in addition to $n\neq0$ as standard CarMa). This extension, referred to as CarMa0 in the following, makes use of a coupling surface S, like standard CarMa, but it resorts to the magnetic flux per radian ψ (as suggested in [3]) rather than the normal component of the magnetic field as it is done for $n\neq0$ [2].

Inside *S*, a linearized version of Grad-Shafranov equation is repetitively solved:

$$L\psi = j_\varphi(\psi) \text{ inside } S \quad (1)$$

where L is the Grad-Shafranov operator and $j_\varphi(\psi)$ is a linearization of the non-linear dependence of the toroidal current density on ψ. Eq. (1) is solved imposing that ψ assumes on *S* a set of independent values such that any arbitrary distribution of flux over *S* can be recovered as a suitable linear combination. To this purpose, we use the CREATE_L axisymmetric linearized plasma response model [4]. As in the $n\neq0$ case, we pay particular attention to the subtraction of the plasma contribution to the flux, to get the flux due to the external (3D) conductors. Such conductors are treated with a volumetric finite elements mesh, and their currents are computed with a volumetric integral formulation as in [2]. The poloidal flux on *S* due to 3D currents is computed via Biot-Savart integrals, while the flux due to plasma over the 3D structures is computed by means of an equivalent axisymmetric surface current located on *S*, providing the same magnetic flux as plasma outside *S*. This equivalent current is related to the normal derivative on *S* of the poloidal flux, rather than the tangential component of magnetic field as in [2] for the $n\neq0$ case.

ITER multimodal analysis

First of all, we have benchmarked the CarMa0 code on a pure $n=0$ case. An ITER configuration with β_p = 0.21, l_i = 1.11 , I_p = 15 MA has been studied with a rather coarse mesh of the double shell vacuum vessel, with the Outer Triangular Support (OTS) but with no copper cladding – this was done only for assessing the correctness of the procedure. The mesh has a number of conducting patches representing the ports; hence it is possible to study two limiting cases (axisymmetric case: patches with the same resistivity as vacuum vessel; holes: patches with very high resistivity)

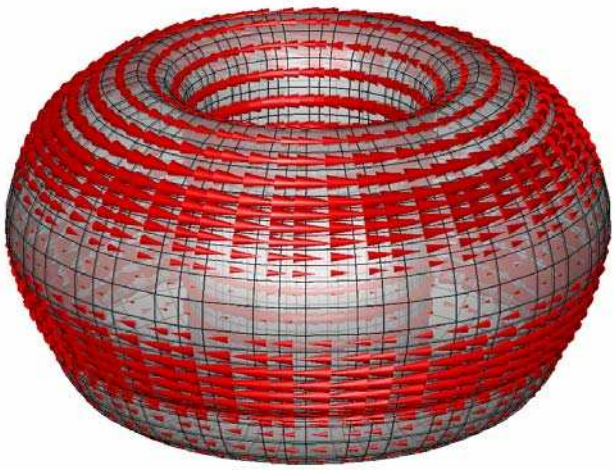

Fig. 1. Coarse ITER 3D mesh used and current density pattern of the $n=0$ unstable mode.

and an "intermediate" case which has been proven to be equivalent to the true port extensions in terms of growth rate estimates [5]. Table 1 reports the growth rates predicted by a purely 2D code (CREATE_L [4]) and those computed using CarMa0 on the various meshes illustrated above. First of all, we notice that the agreement in the axisymmetric case is good, considering the coarseness of the mesh (see Fig. 1, where also the current density corresponding to the unstable mode is reported). Secondly, the assumption of pure holes instead of the equivalent patches is quite pessimistic, although less than what happens for the n=1 RWM [5]. The reason for this difference is that in the n=0 case the current density of the unstable mode almost vanishes naturally in the region where the central port is located, while this does not happen in the n=1 case.

Also a full multimodal n=0 / n=1 analysis has been performed, for an ITER Scenario 4 configuration with normalized beta β_N=2.7. The n=0 (resp. n=1) plasma response matrix has been computed by CREATE_L (resp. MARS-F). The reference equilibrium is reported in Fig 2; for the n=1 computation, the plasma boundary has been slightly smoothed, while in the n=0 case the X-point has been treated self-consistently. A full double shell 3D mesh with port extensions has been used (Fig. 3 shows only the inner shell). The multimodal resulting model has three unstable eigenvalues: $\gamma_{1,2}$ = 10.4 s^{-1}, γ_3=7.66 s^{-1}. The first two (which coincide) correspond to two eigenvectors with a n=1 spatial behaviour, simply shifted of $\pi/2$ toroidally; the third one corresponds to an eigenvector with a n=0 spatial behaviour. These values are almost identical to those computed with monomodal models, built using the same n=0 and n=1 plasma response matrices, but each at a time and not together. This demonstrates that for this ITER configuration there is little coupling of n=0 and n=1 modes due to 3D structures.

If we let the plasma evolve with no active control from a suitable initial condition exciting all the unstable eigenmodes, after a while we end up with a current density pattern in the conducting structures mixing a n=0 and a n=1 behaviour (Fig. 3), which is the reaction to a plasma deformation given by the combination of a vertical axisymmetric movement with a helical kink. Obviously, the corresponding electromagnetic loads on the conducting structures could be computed.

CREATE_L (2D)	***CarMa0 (2D)***	***CarMa0 (holes)***	***CarMa0 (patches)***
12.03	12.67	16.56	14.58

Table 1. Growth rates (in s^{-1}) as predicted by CarMa0 with various assumptions on the vacuum vessel

[1] F. Villone et al., *Phys. Rev. Lett.* **100** (2008) 255005

[2] A. Portone, F. Villone et al., *Plasma Phys. Contr. Fusion* **50** (2008) 085004

[3] A. Portone, *Nucl. Fusion* **44** 265–278 (2004)

[4] R. Albanese, F. Villone, *Nucl. Fusion* **38** 723–738 (1998)

[5] F. Villone et al., *35th EPS Conference*, Hersonissos, 9 - 13 June 2008, ECA Vol.32, P-2.080 (2008)

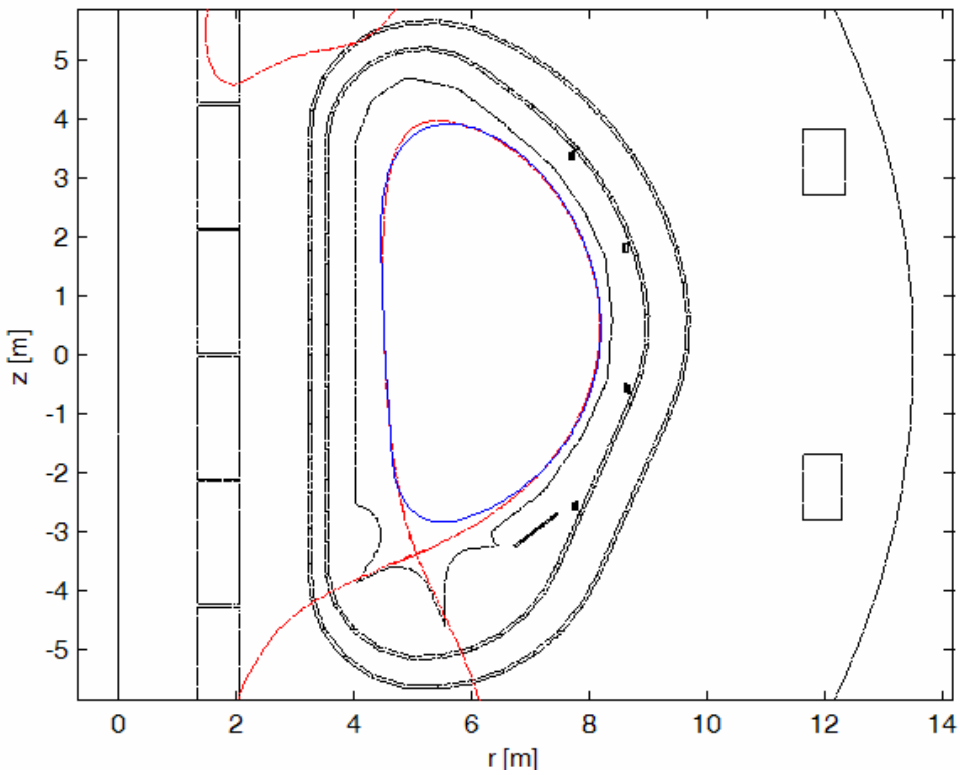

Fig. 2. Equilibrium configuration. Red: CREATE_L equilibrium; blue: smoothed equilibrium

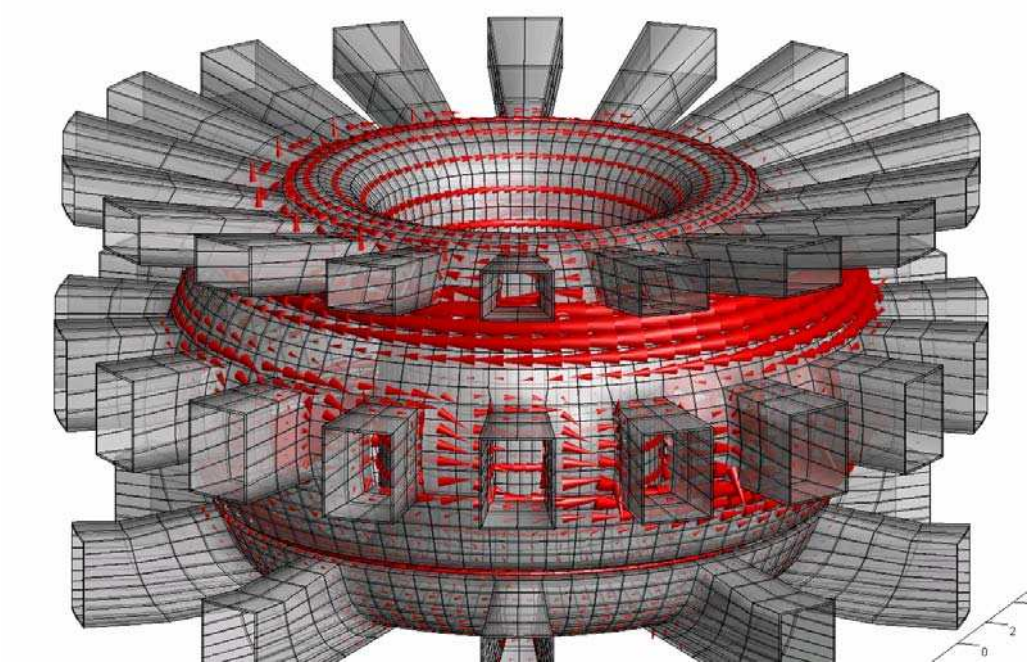

Fig. 3. Current density pattern, due to multimodal evolution of n=0 + n=1 instabilities.