32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.049 (2005)

Analysis of RWM with a 3D Model of Conducting Structures

F. Villone[1], G. Rubinacci[2], Y.Q. Liu[3], Y. Gribov[4]

[1] *Ass. EURATOM/ENEA/CREATE, DAEIMI, Univ. di Cassino, Cassino (FR), ITALY*
[2] *Ass. EURATOM/ENEA/CREATE, DIEL, Univ. Federico II di Napoli, ITALY*
[3] *Ass. EURATOM/VR, Chalmers Univ. Technology, Gothenburg, SWEDEN*
[4] *Physics Unit, ITER Naka Joint Work Site, Naka, Ibaraki, JAPAN*

Abstract

In this paper we present some preliminary results of a coupling between the MHD stability code MARS-F and the three-dimensional eddy currents code CARIDDI, aimed at the analysis of Resistive Wall Modes with 3D conducting structures.

1. Introduction

Ideal external kink instabilities of low $n \neq 0$ toroidal mode numbers limit the achievable normalized β_N. The presence of a stabilizing ideal conducting wall can mitigate this limit, thanks to eddy currents induced by plasma perturbations. The non-vanishing resistivity of any real wall causes a decay of eddy currents and hence a loss of stability. The resulting resistive wall modes (RWM) grow at the time scale of the wall time, thus allowing a possible active stabilization of such modes with magnetic coils. A critical issue is a correct three-dimensional model of the conducting structures (walls) surrounding the plasma, and of the feedback coils.

Aim of this paper is to describe the coupling between the toroidal stability code MARS-F [1] and the three-dimensional magneto-quasi-static code CARIDDI [2], with the final goal of analysing Resistive Wall Modes in the presence of 3D conducting structures.

The paper is organized as follows. Section 2 describes the formulations used by MARS-F and CARIDDI, and the basic ideas of the coupling scheme. In Section 3 some preliminary results are presented, while Section 4 draws the conclusions and illustrates future work.

2. Formulation

MARS-F is an extension of the stability code MARS [3], that solves the single fluid MHD equations. This code has been modified to study stabilization of the RWM by plasma rotation [4, 5], using various damping models to approximate the ion Landau damping. A recent modification is to introduce in the code a semi-kinetic damping model, based on a large aspect ratio calculation [6]. With these modifications, the code has been used to predict the critical rotation speed required to stabilize the RWM, as well as to model the resonant field amplification experiments on JET and DIII-D. Another extension is to add feedback coils directly in the code [1], thus allowing feedback control of the RWM to be studied by solving both MHD equations and the feedback equation in a single code. MARS-F has been used also for numerical simulation of RWM in ITER [7].

One limitation of the code is the 2D representation of the conducting structures, including the vacuum vessels and the feedback coils, since the code assumes exp(jnφ) dependence for the n-th harmonic along the toroidal angle φ. Also, a thin wall approximation is assumed for the wall along the radial coordinate. On the other hand, the vacuum vessels often have 3D features such as slits and ports. The feedback coils have finite toroidal width, and may not cover the whole toroidal circumference. Accurate modeling of these coils also require a 3D representation. The other limitation comes from the Fourier representation of the feedback coils along the poloidal angle.

CARIDDI is a 3D eddy currents finite elements code based on an integral formulation [2]. It requires a discretization only of the conducting structures, which can be also topologically complex, and allows an easy coupling with external circuitry [8]. The introduction of a two-component electric vector potential and the use of edge elements give rise to a very accurate (imposing the right continuity conditions) and effective (requiring a minimal number of unknowns) code, able to deal with arbitrary 3D geometries of conducting structures, hence overcoming the limitations mentioned above. CARIDDI has been extensively used for fusion applications, also coupled with the CREATE-L 2D linearized plasma response model [9].

The magnetic field calculated by the CARIDDI code is used as the boundary condition for the MARS-F code. The boundary surface (i.e. the coupling surface) is chosen as a surface between the plasma boundary and the first conducting structure, which is usually the resistive wall. We propose two types of boundary conditions for the coupling. The first one uses only the normal component of the magnetic field computed by CARIDDI, together with the estimation on the eigenvalue from the previous iteration. The other type uses the ratio of the normal to the poloidal field as the boundary condition for the MARS-F code.

The current density perturbation predicted by MARS-F is used in CARIDDI to compute the induced voltage in the conducting structure. This is the forcing term that allows the computation of the eddy currents induced in conducting structures, from which the magnetic field fed to MARS-F is calculated. Since CARIDDI works in the spatial domain, Fourier transforms must be numerically performed to provide the correct input to MARS-F.

3. Preliminary results

The first tests reported in this paper were made assuming that the vessel is axisymmetric, although CARIDDI describes this 2D vessel with a fully 3D mesh; this allows us to use the results of MARS-F as reference. The vessel is assumed to have a circular cross section of major radius $R_0 = 2$ m, and minor radius $r_w = 0.52$ m; its thickness is 1 cm, while its resistivity is 6.53e-7 Ω m. The plasma minor radius is $a = 0.4$ m.

The first check made was a “consistence” test: given the “exact” $n = 1$ growth rate ($\gamma = 294.9$ s^{-1}) and the plasma current density perturbation provided by MARS, we compared the vessel current density as estimated by MARS-F and by CARIDDI. Figure 1 shows this comparison on the various components, showing a satisfactory agreement. Figure 2 reports a 3D view of the current density as estimated by CARIDDI, in which also the mesh is reported.

Also the various components of the magnetic field on the “coupling surface” have been compared, as reported in Figure 3. Again, the agreement is satisfactory. Using the field as predicted by CARIDDI, and using the coupling scheme described above, MARS-F provided a growth rate which was less than 0.2 % different from the original one.

We also tried to perform a “convergence” test, running the coupling scheme starting from an arbitrary initial guess. Unfortunately, we experienced an undesired sensitivity of the final result on the initial guess itself: starting from a point rather close to the right solution we were able to estimate the growth rate within a few percents, while an arbitrary starting point provided rather large errors.

4. Conclusions and perspectives

In this paper we have presented some preliminary results of the coupling of the MARS-F stability code with the CARIDDI three-dimensional eddy currents code. This coupling has been demonstrated to be consistent, while its convergence still needs further work to increase robustness against the starting guess. Once this problem will be sorted out, it will be possible to model Resistive Wall Modes, in view of their stabilization, in the presence of general 3D conducting structures.

Acknowledgements

This work, supported by the Italian MIUR and the Euratom Communities under the contract of Association between EURATOM/ENEA, was carried out within the framework the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

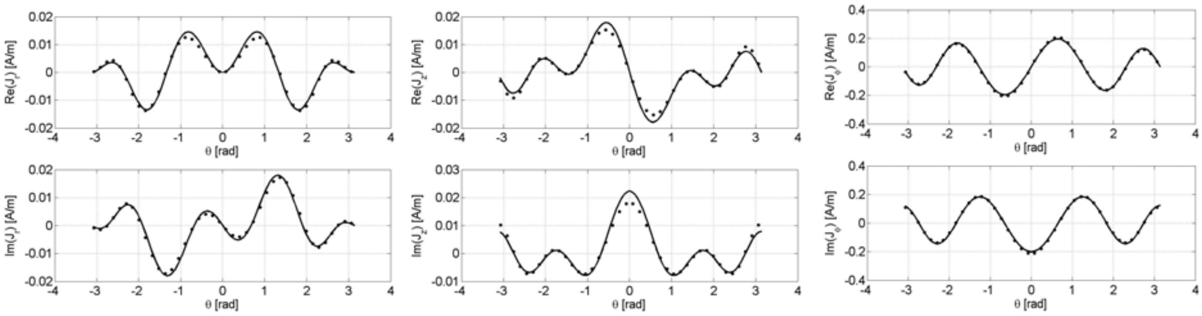

Figure 1. Current densities as predicted by MARS- F (solid) and CARIDDI (dotted)

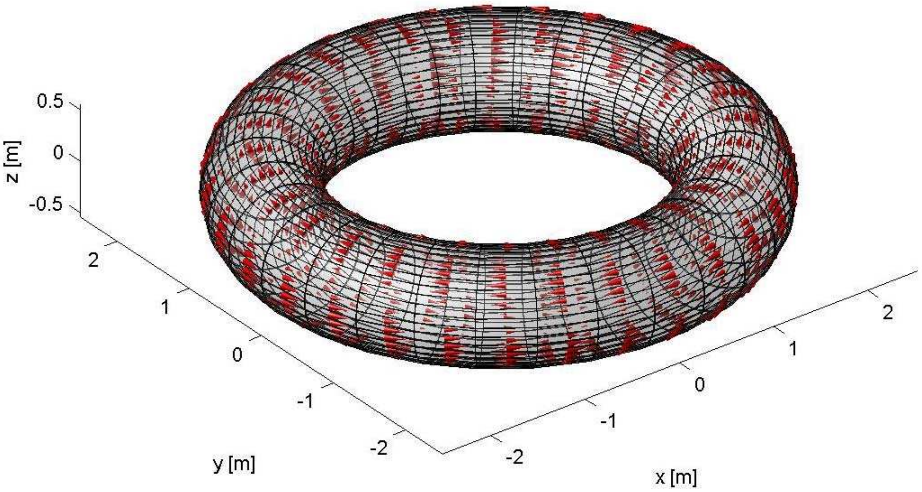

Figure 2. 3D view of the current density (imaginary part) as predicted by CARIDDI

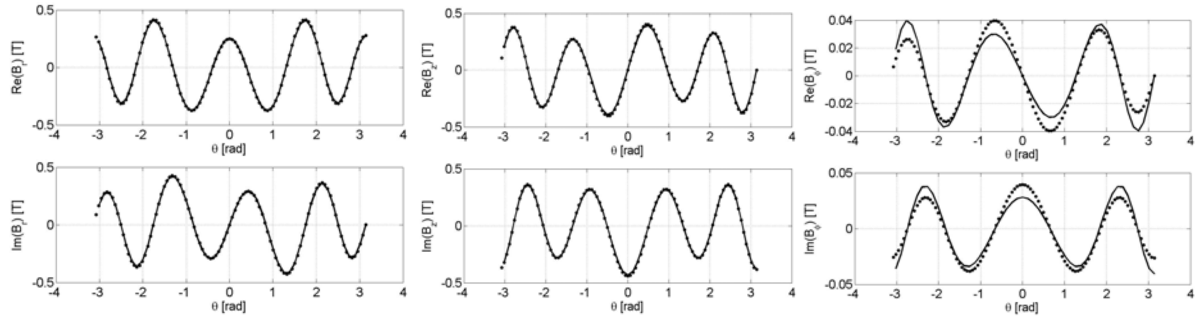

Figure 3. Magnetic fields as predicted by MARS- F (solid) and CARIDDI (dotted)

[1] Y.Q. Liu, et al., *Phys. Plasmas* **7**, 3681 (2000)

[2] R. Albanese, G. Rubinacci, *Adv. Im. El. Phys.*,**102**, 1-86, Academic Press (1998)

[3] A. Bondeson, et al., *Phys. Fluids B,* **4**, 1889 (1992)

[4] Bondeson, A. and Ward, D.J., *Phys. Rev. Lett.* **72**, 2709 (1994)

[5] M.S. Chu, et al., *Phys. Plasmas* **2**, 2236 (1995)

[6] Bondeson A. and Chu M.S., *Phys. Plasmas* **3** 3013 (1996)

[7] Y.Q. Liu, et al., *Nucl. Fusion* **44**, 232 (2004)

[8] G. Rubinacci, A. Tamburrino, F. Villone, *IEEE Trans. Mag.*, **38**, 581 (2002)

[9] R. Albanese, R. Fresa, G. Rubinacci, F. Villone, *IEEE Trans. Mag.*, **36**, 1804 (2000)