RESULTS OF A 3D-EM-CODE COMPARISON ON THE TRISPAL-CAVITY BENCHMARK

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Abstract

Several 3D electromagnetic codes (MAFIA, CST MicroWave-Studio, Vector-Fields Soprano, Ansoft HFSS, SLAC Omega3P) have been tested on a 2-cell cavity benchmark. Computed frequencies and Q-factors were compared to experimental values measured on a mock-up, putting the emphasis on the effect of coupling slots. It comes out that MAFIA limitations due to the staircase approximation is overcome by all other codes, but some differences still remain for losses calculations in re-entrant corners.

INTRODUCTION

Up to recent times, we mainly used the MAFIA code to design cavities for particle accelerators applications in Bruyeres-le-Chatel. Despite of its proper quality, the meshing method used by this software introduces a "staircase" approximation causing some artifacts on calculated results. In many cases, a proper choice of the mesh grid and a proper post-processing permit to get rid of these artifacts (see for example [1]).

To correct the artifacts, the first step is to start from an accurate 2D simulation, and in a second step, to take into account every 3D aspect of the structure: coupling holes, tuning plungers, RFQ vane ends, pumping grids... Their effect can be estimated individually with a fair accuracy by the comparison of two simulations using an identical mesh, with and without each considered 3D aspect. This method gives good results for global structure parameters (frequency resonance, Q-value, R/Q, external Q), but can be difficult to apply for local parameters such as local losses or peak fields. And, of course, it can only be applied on "2D-like" structures.

Because of these limitations, and to take advantage of computer and software evolutions, we considered to change our tool, and compared on the same benchmark MAFIA and four other 3D EM codes (fig. 1):

- Microwave Studio 4.3 (CST)
- Soprano (Vector Fields)
- High Frequency Structure Simulator 9.0 (Ansoft)
- Ω3p (eigen mode solver developed at SLAC)

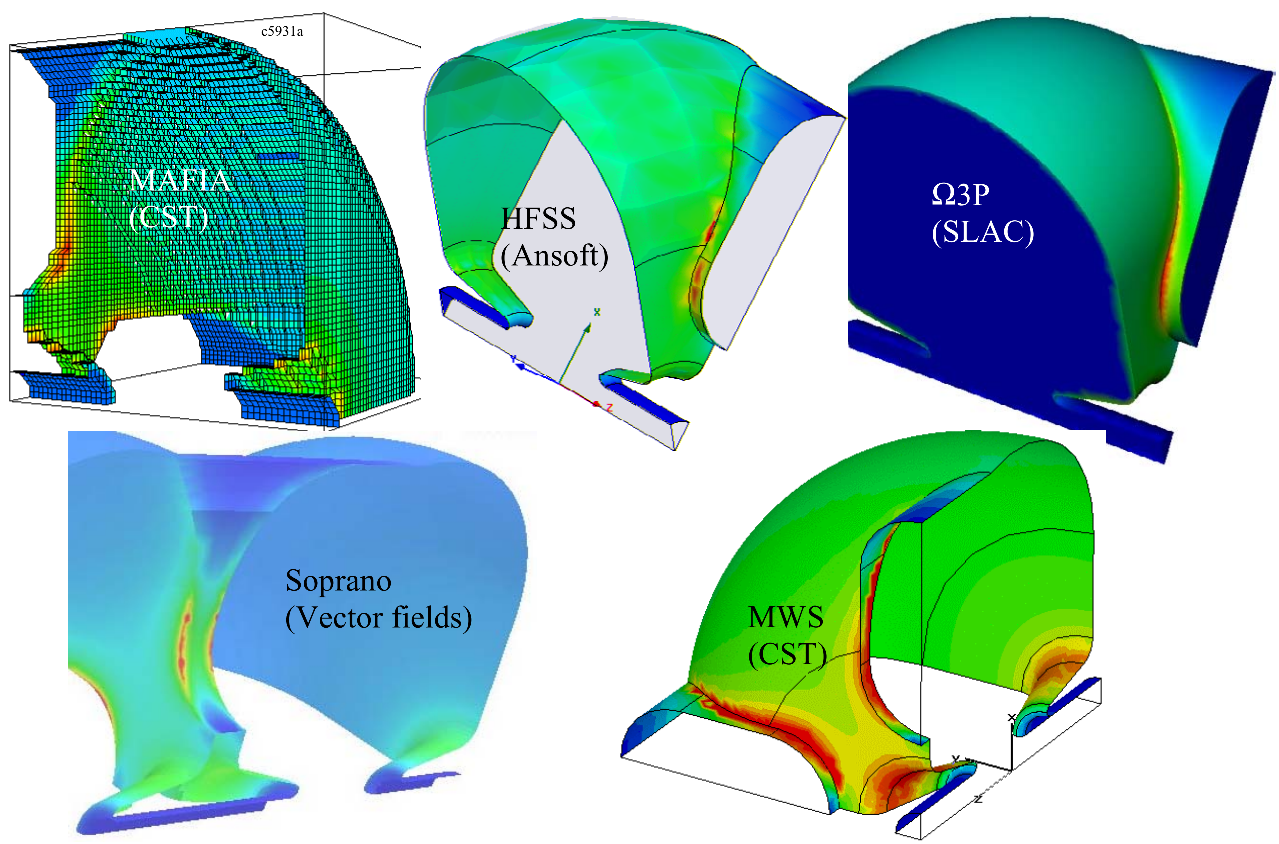

Figure 1: Losses in Trispal benchmark for tested 3D-codes (pi-mode).

BENCHMARK

The benchmark is the cavity mock-up build at the time of the Trispal project (fig. 2). This modular structure can be mounted in a single-cell (and purely axi-symmetrical) configuration. It can also be mounted in a 2-cell configuration in which the cells are coupled through coupling holes or slots (fig. 3). This cavity was accurately measured in term of resonance frequency and Q-value in 1997 [2].

A major issue is to get a reliable Q value in spite of successive assembling and dismantling. The electrical seal is made of a 0.8-mm soft solder wire squeezed to 0.4 mm with a mechanical limitation that makes the contact quality independent of the tightening strength. To estimate the quality factor reliability, we made a series of measurements alternating both configurations (single or double-cell) and changing the seal each time. After a few first tries to train the operator, the statistical r.m.s deviation for Q between nine successive measurements is about 0.4 %.

Measured data exhibit a Q-drop caused by coupling holes. This is due to the high increase of surface current density in the edge of the holes. Simulating such a case is a good way to test how a code deals with local losses in re-entrant corners, and it was used to validate the new MAFIA algorithm for computation of RF losses [3].

The high increase of magnetic field in re-entrant corner had already been measured on the IPHI RFQ mock-up, and compared to MAFIA and Soprano simulations [4]. But the conclusions at that time were not clear quantitatively, because losses were deduced from magnetic field measurements based on the bead-pull technique which brings some artifacts.

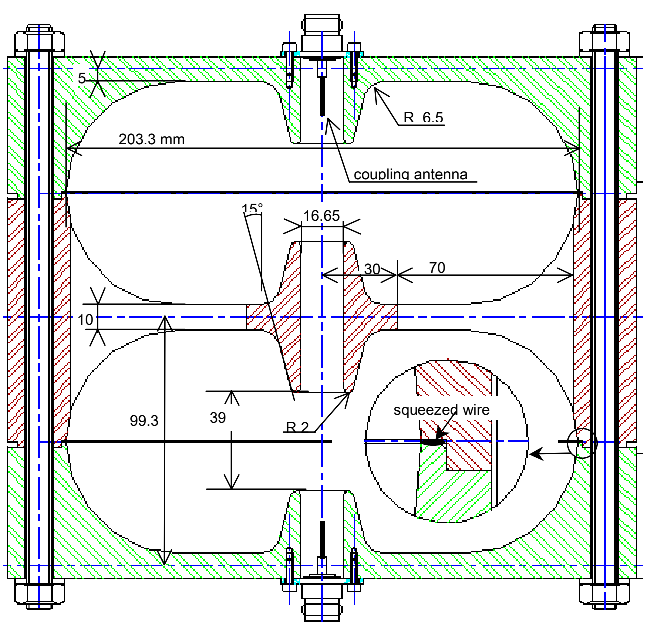

Figure 2: Transverse section of the Trispal cavity mock-up (2-cell configuration).

Single Cell Results

Measured and computed values are displayed in table 1. The 51 nΩ.m estimated resistivity of the material (a 96% Al and 4% Cu alloy) is taken into account in displayed Q values.

MAFIA gives a frequency resonance +0.75% above experimental value, which is not so bad considering the staircase approximation. All of the other codes (including Superfish) gave a resonance frequency of the single-cell cavity very close to the experimental value (1080.8 MHz). We observe that Soprano, HFSS, Ω3p and Superfish are all gathered around +0.10% from measurement, while MWS is -0.03%. But the mechanical machining is not precise enough to tell which code is the best.

From a Q-factor point of view, all the codes (except MAFIA) are between +3% and +5.5% above measurement. Such a positive difference of a few percent is expected because of surface imperfection and seal losses in the real cavity. Again, the unrealistic MAFIA result (-16 % vs. measurement) is an artifact due to the staircase approximation.

Dual-Cell Results

In the 2-cell cavity, the fundamental TM010 mode splits into two modes (0 an π) depending on the field condition in the symmetry plane between the cells. Dual-cell results are appreciated from a relative point of view by comparing the two modes either to each other or to the single-cell mode. This compensates most of mesh induced bias and puts the emphasis on coupling holes.

We define the following parameters, where indices π, 0 and 1 indicate pi-mode, 0-mode and single-cell mode, respectively:

- frequency shift due to hole volumes : $\alpha = 2(f_1\text{-}f_0)/f_0$
- coupling coefficient : $\gamma = 2(f_0\text{-}f_\pi)/f_0$,
- pi-mode Q-drop : $\delta Q_\pi = Q_\pi^2/Q_1^2\text{-}1 \approx 2(Q_\pi\text{-}Q_1)/Q_1$
- 0-mode Q-drop : $\delta Q_0 = Q_0^2/Q_1^2\text{-}1 \approx 2(Q_0\text{-}Q_1)/Q_1.$

The folding factor 2 is to be compatible with an infinitely long structure with coupling holes on both side of each cell.

Compared to experimental values, the frequency shift α and the coupling coefficient γ are both slightly underestimated by all the codes. The discrepancies, referred to absolute frequency, are always (including MAFIA) less than 0.2% for α and 0.1 % for γ. Though these discrepancies seem low, they are non negligible compared to typical α and γ values (about 1.4%) and cannot be attributed to errors in coupling slots dimensions. Ω3p values are the closest from experimental values, probably because of the smaller mesh grid used in this simulation.

On the other hand, extra losses due high current density on the edge of coupling slots in π-mode (specially along the re-entrant corner) are diversely computed. Simulated losses are displayed for different software on figure 1. As MAFIA, MWS HFSS and Ω3p predictions for δQ_π are between -19.4% and -24.9 % (-22.5% measured), Soprano underestimates this phenomenon (-5.6%). The same thing happens if the zero-mode is considered: while MAFIA, MWS HFSS and Ω3p values for δQ_0 are between -1% and +3% (+1% measured), Soprano gives +11%. We observe that MAFIA and MWS used with the old algorithm for Q-calculation [3] give about the same discrepancies than Soprano.

CONCLUSION

Though they use different techniques and mesh types, the four newly tested codes give all very good results in frequencies. About losses, they also give satisfactory values, except that Soprano still underestimates losses in re-entrant corners. All of them overtake the limitation suffered by MAFIA users due to staircase approximation.

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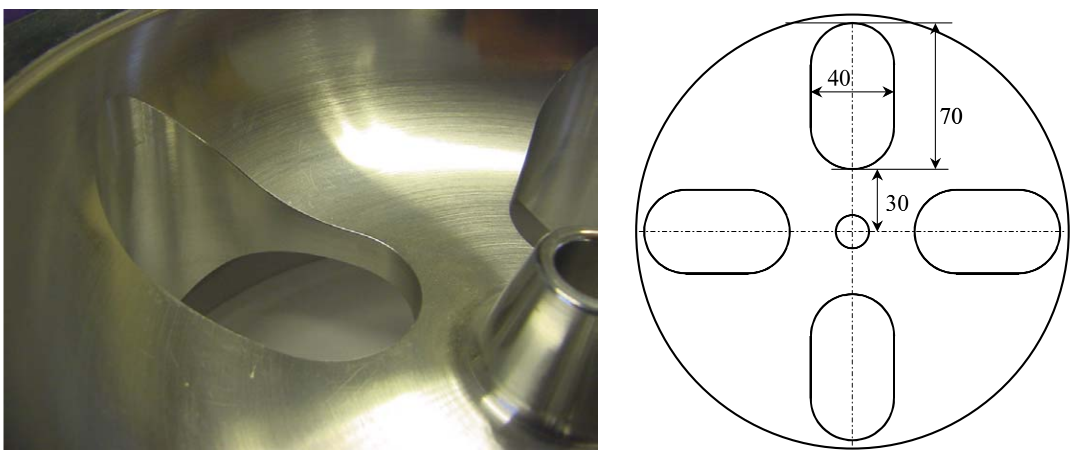

Figure 3: Coupling slots.

Table 1: Frequency and Q-factors for single-cell and 2-cell modes

		measurment	Superfish	Mafia	MWS	Soprano	HFSS	Ω3p
H wall	fq	1064.415		1073.912	1064.796	1066.673	1066.800	1066.090
(π mode)	Q	11340		9724	11665	12901	11789	12111
E wall	fq	1072.412		1081.556	1072.605	1074.267	1074.700	1074.100
(0 mode)	Q	12938		11023	13481	13982	13536	13738
single-cell	fq	1080.841	1081.770	1088.948	1080.451	1081.828	1082.200	1082.250
	Q	12880	13584	11032	13285	13275	13601	13509
coupling γ		1.49 %		1.41 %	1.46 %	1.41 %	1.47 %	1.49 %
fq.shift α		1.57 %		1.37 %	1.47 %	1.41 %	1.40 %	1.52 %
δQ(π)		**-22.5 %**		**-22.3 %**	**-22.8 %**	**-5.6 %**	**-24.9 %**	**-19.6 %**
δQ(0)		**+0.9 %**		**-0.2 %**	**+3.1%**	**+10.9 %**	**-1.0 %**	**+ 3.4 %**