INTEGRATION OF A LARGE-SCALE EIGENMODE SOLVER INTO THE ANSYS© WORKFLOW ENVIRONMENT

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Abstract

The numerical computation of eigenfrequencies and eigenmodal fields of large accelerator cavities, based on full-wave, three-dimensional models, has attracted considerable interest in the recent past. In particular, it is of vital interest to know the performance characteristics, such as resonance frequency, quality figures and the modal fields, respectively, of such devices prior to construction given the fact that the physical fabrication of a cavity is expensive and time consuming, a device that does not comply with its specifications can not be tolerated; a robust and reliable digital prototyping methodology is therefore essential. Furthermore, modern cavity designs typically exhibit delicate- and detailed geometrical features that must be considered for obtaining accurate results. At PSI the three-dimensional finite-element code femaxx has been developed to compute eigenvalues and eigenfields of accelerator cavities (Arbenz et al., 2006). While this code has been validated versus experimentally measured cavity data, its usage has remained somewhat limited due to missing func tionality to connect it to industrial grade modeling software. Such an interface would allow creating advanced CAD geometries, meshing them in ANSYS and eventually exporting and analyzing the design in femaxx. We have therefore developed pre and postprocessing software which imports meshes generated in ANSYS for a femaxx run. A postprocessing step generates a result file than can be imported into ANSYS and further be analyzed there. Thereby, we have integrated femaxx into the ANSYS© workflow so that detailed cavity de signs leadingto large meshes can be analyzed with femaxx, taking advantage of its capability to address very large eigenvalue problems. We have also added functionality for parallel visualization to femaxx. We present a practical application of the pre and postprocessing codes and compare the results against experimental values, where available,and other numericalcodes when the model has not yet been fabricated.

CURRENT FEMAXX CAPABILITIES

The femaxx code solves the curl-curl equation (1) for cavity structures that may be filled with dielectric and magnetic media with properties other than air, using a Jacobi-Davidson type of algorithm (Arbenz et al., 2001; Geus, 2002) subject to boundary conditions which may be of the perfect electric conductor (PEC), the perfect magnetic conductor (PMC) and the finite conductivity metal type. Symmetry is achieved by using PEC and PMC boundary conditions. The material properties are assumed to be loss-free. The ohmic conductivity s of materials inside the cavity is neglected. Using a perturbative approach (Ramo et al., 1984) losses due to conducting cavity walls are accounted for :

$$\nabla \times \frac{1}{\mu_r} \nabla \times \mathbf{E} - k_0^2 \epsilon_r \mathbf{E} = 0, \tag{1}$$

where both μ_r and $\epsilon_r \ \epsilon \ \mathcal{R}$ and $k_0 = 2\pi/\lambda_0$. The size of problems addressed is in the range of large accelerator cavities with up to several millions of tetrahedra. Computation times are comparable with the ANSYS© (single CPU) electromagnetic solver. The femaxx code has been parallelized and demonstrated to scale roughly with the number of CPU employed. In particular it runs in parallel on large distributed memory cluster computers ; it has now built in parallel visualization of modal fields and parallel computation of quality figure which is described in a compact user manual. Most important, for its efficient application in the accelerator design community it now offers workflow integration into the commercial finite element package ANSYS©.

CAD WORKFLOW INTEGRATION

We have first defined an output format, which is written by the ANSYS© application using its scripting language ; second, we have implemented a preprocessor which reads the ANSYS© generated mesh information; in particular, the preprocessor parses the mesh file and builds the topological data structures that make up a mesh, i.e. vertices, faces and tetrahedra. Based on the topological fact that a triangle that is part of the boundary has only one single adjacent tetrahedron, the boundary of the tetrahedral mesh is extracted. The boundary is then further subdivided into different types, such as PEC, PMC, symmetry boundaries and finite conductivity boundaries which contribute to the cavity's losses. The data is stored in a file compliant to the HDF5 format definition. This is particularly useful because serial and parallel data access can be mixed in a seamless way.

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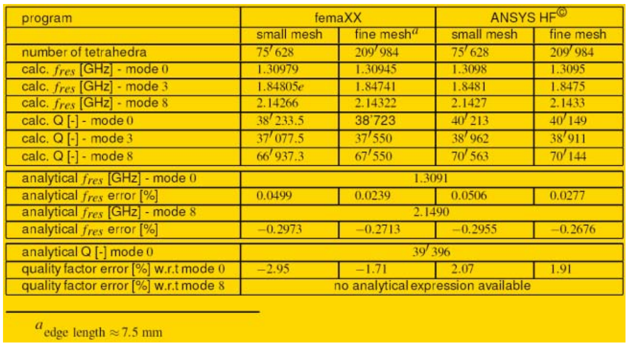
SPHERICAL CAVITY

WITH RADIUS = 0.1[M]



program	femaXX		ANSYS HF©	
	small mesh	fine mesh[a]	small mesh	fine mesh
number of tetrahedra	75′628	209′984	75′628	209′984
calc. f_{res} [GHz] - mode 0	1.30979	1.30945	1.3098	1.3095
calc. f_{res} [GHz] - mode 3	1.84805e	1.84741	1.8481	1.8475
calc. f_{res} [GHz] - mode 8	2.14266	2.14322	2.1427	2.1433
calc. Q [-] - mode 0	38′233.5	38'723	40′213	40′149
calc. Q [-] - mode 3	37′077.5	37′550	38′962	38′911
calc. Q [-] - mode 8	66′937.3	67′550	70′563	70′144
analytical f_{res} [GHz] - mode 0	1.3091			
analytical f_{res} error [%]	0.0499	0.0239	0.0506	0.0277
analytical f_{res} [GHz] - mode 8	2.1490			
analytical f_{res} error [%]	−0.2973	−0.2713	−0.2955	−0.2676
analytical Q [-] mode 0	39′396			
quality factor error [%] w.r.t mode 0	−2.95	−1.71	2.07	1.91
quality factor error [%] w.r.t mode 8	no analytical expression available			

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[a] edge length ≈ 7.5 mm

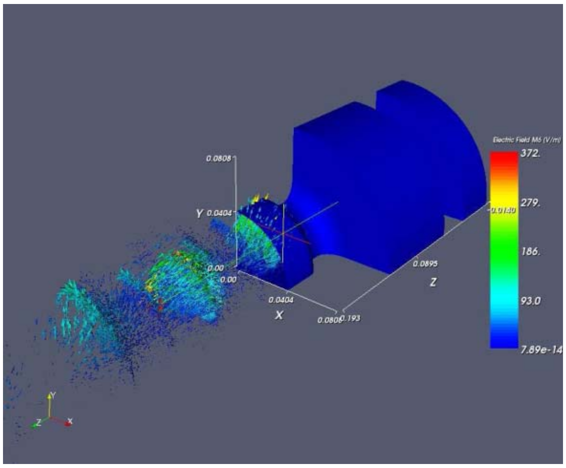
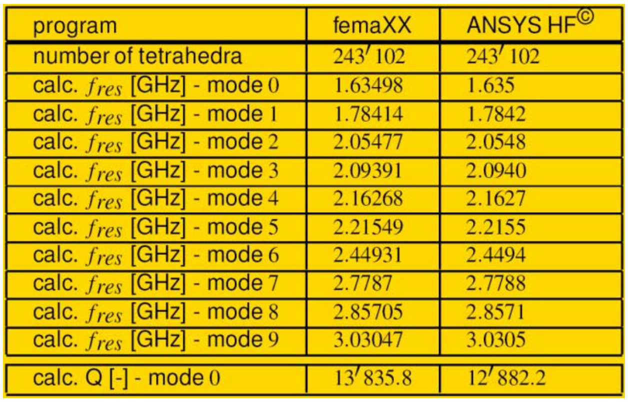


Figure 1: PSIXFEL/LEG Cavity Geometry and Field intermediatecavity design, courtesy J. Y. Raguin

CAD GEOMETRY EXAMPLE



program	femaXX	ANSYS HF©
number of tetrahedra	243′102	243′102
calc. f_{res} [GHz] - mode 0	1.63498	1.635
calc. f_{res} [GHz] - mode 1	1.78414	1.7842
calc. f_{res} [GHz] - mode 2	2.05477	2.0548
calc. f_{res} [GHz] - mode 3	2.09391	2.0940
calc. f_{res} [GHz] - mode 4	2.16268	2.1627
calc. f_{res} [GHz] - mode 5	2.21549	2.2155
calc. f_{res} [GHz] - mode 6	2.44931	2.4494
calc. f_{res} [GHz] - mode 7	2.7787	2.7788
calc. f_{res} [GHz] - mode 8	2.85705	2.8571
calc. f_{res} [GHz] - mode 9	3.03047	3.0305
calc. Q [-] - mode 0	13′835.8	12′882.2

CONCLUSIONS AND FUTURE WORK

We have extended the femaxx code by the parallel calculation of quality figures. We have implemented a preprocessor which reads ANSYS© generated meshes, including information of boundary types and symmetry and then stores this informationin a file compliant to the HDF5 data format. We have tested and demonstrated the ANSYS© workflow integration, based on analytically tractable cases and existing cavity designs, in operational use at PSI. In particular, we have analyzed a spherical resonators, accessible to analytical calculations, the copper cavity, which is in operational used at the PSI cyclotron and an intermediate cavity design for the planned Xray free electron laser (XFEL) linear accelerator at PSI. For in-house codes to be exploited fully, they must integrate into commercial environments. Thereby, they can use existing advanced user interface funtionality whose inhouse development is not practical in a research environment. This functionality has made the femaxx code more easily usable by the RF community at PSI. Additionally, a short user manual has been written. Current design trends imply that the loss-free eigenvalue solver be extended for modeling cavities containing lossy dielectrics, lossy magnetics and conductive materials.

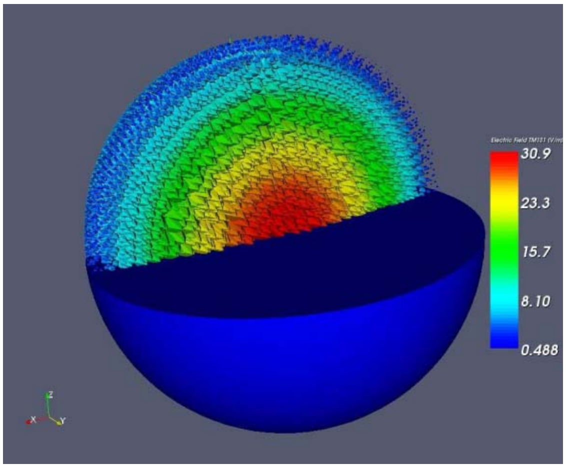


Figure 2: Spherical Cavity Modal Fields Spherical cavity dominant mode

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