TEAM Workshop Problem 13 with FEM-BEM-Coupling

FEM-BEM COUPLING

The numerical analysis of electrical devices by means of Finite Element Methods (FEM) is often hindered by the need to incorporate the surrounding air. Next to the complexity of the discretization of the air region, this exterior region has to be truncated by artificial boundaries incurring a certain modelling error.

TAILSIT takes an alternative approach by using the Boundary Element Method (BEM) in conjunction with FEM. Whereas the solid parts of the electrical device are discretized by FEM which can easily take account for material non-linearities, the surrounding domain is represented by the BEM via a surface-only discretization. Thus, no mesh for the air is needed and the errors incurred by above mentioned truncation are avoided. Furthermore, moving or deforming parts are included straightforwardly. For complex geometries this approach significantly reduces the time required to create a simulation model.

FORMULATION

Relating the magnetic flux density $\mathbf{B} = \mathbf{curl}\,\mathbf{A}$ to a vector potential $\mathbf{A}$, the magnetostatic problem is solved by finding $\mathbf{A} \in H(\mathbf{curl})$ such that

$$\langle \mathbf{H}(\mathbf{curl}\,\mathbf{A}), \mathbf{curl}\,\mathbf{A}' \rangle_\Omega - \langle \mathbf{n} \times \mathbf{curl}\,\mathbf{A}, \mathbf{n} \times \mathbf{A}' \times \mathbf{n} \rangle_\Gamma = \langle \mathbf{j}_s, \mathbf{A}' \rangle_\Omega$$

for all suitable test-functions $\mathbf{A}'$. The domain of interest is Ω and Γ is its boundary with outward normal $\mathbf{n}$. The right hand side is given by an excitation source current density $\mathbf{j}_s$. Typically, the magnetic field $\mathbf{H}$ depends non-linearly on $\mathbf{B}$, $\mathbf{H} = \mu(\mathbf{B})^{-1}\mathbf{B}$. FEM formulations usually approximate or neglect the boundary term $\langle \cdot, \cdot \rangle_\Gamma$. In contrast to that, with a coupled FEM-BEM formulation this term is taken into account by means of boundary integrals [1]. Hence, no mesh for the surrounding air is needed.

PROBLEM STATEMENT

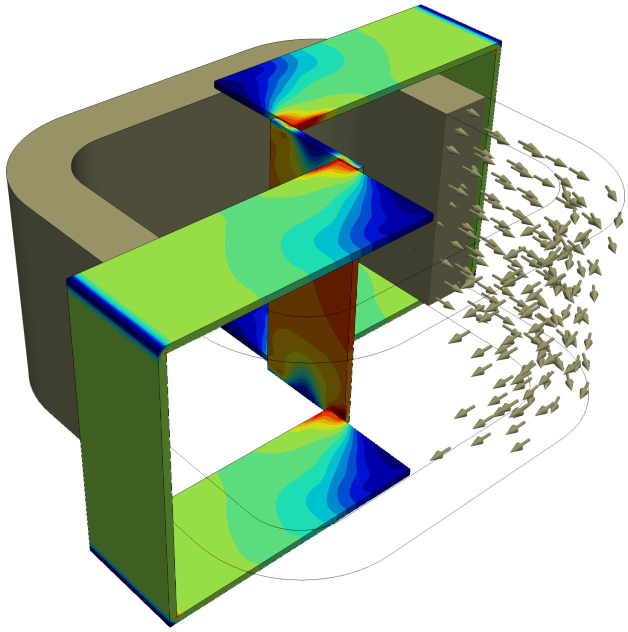
The problems stated in the TEAM workshops (Testing Electomagnetics Analysis Methods) serve as benchmarks for numerical software analyzing electromagnetic field problems.

The TEAM 13 benchmark is a non-linear, magnetostatic problem. The geometry consists of two opposing, dislocated thin U-shaped channels made of steel. A thin steel plate is inserted between the two channels inducing very small air gaps. An exciting coil with a rectangular cross section is situated between the channels. The material behavior of the steel is non-linear and defined by means of a B-H-curve. Due to the dislocation of the steel channels, a three-dimensional magnetic flux density field $\mathbf{B}$ is generated.

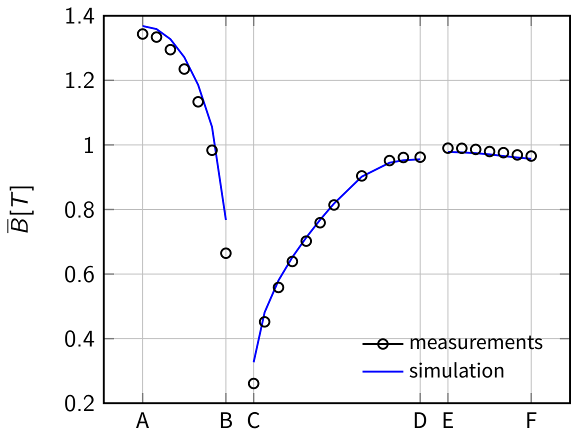
The geometry, the B-H-curve of the steel, the excitation current as well as measured and simulated results are provided by [2].

RESULTS

For the presented results, 103 024 hexahedral elements are used to discretize the steel plates and the coil. The FEM part has 353 528 and the BEM part 43 710 degrees of freedom. For a relative residual error of 10^{-3}, the non-linear solver required four Newton-steps to converge. Average flux densities $\overline{B} = \int_S \mathbf{B} \cdot \mathbf{n}\, dS\, / |S|$ for a variety of cross sections S are compared to measurements in order to validate the results.



TEAM 13. Calculated magnitude of the magnetic flux density $|\mathbf{B}|$ (max $|\mathbf{B}| = 1.8\ T$) and the excitation current (arrows)



TEAM 13. Average magnetic flux densities $\overline{B}$ for various cross sections compared to the measurements. Measure line A-B is located along the middle plate, C-D on top and E-F sideways of the steel channel

REFERENCES

[1] L. Kielhorn, T. Rüberg, and J. Zechner. Simulation of electrical machines: a FEM-BEM coupling scheme. *COMPEL-The international journal for computation and mathematics in electrical and electronic engineering*, 36(5):1540–1551, 2017.

[2] T. Nakata and K. Fujiwara. Summary of results for benchmark problem 13 (3-d nonlinear magnetostatic model). *COMPEL-The international journal for computation and mathematics in electrical and electronic engineering*, 11(3):345–369, 1992.

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