TEAM 24 Force calculation with FEM-BEM-Coupling

FORMULATION

For eddy current as well as magnetostatic problems we use a FEM-BEM coupling scheme as described in [1]. For this study, electromagnetic forces **F** and the torque **T** are calculated by

$$\mathbf{f} = \frac{1}{2}\mu_0^{-1} B_n^2 \mathbf{n} - \frac{1}{2}\mu_0 |\mathbf{H}_t|^2 \mathbf{n} + B_n (\mathbf{n} \times \mathbf{H}_t)$$

$$\mathbf{F} = \int_\Gamma \mathbf{f}\, d\Gamma, \quad \mathbf{T} = \mathbf{F} \times \mathbf{a}.$$

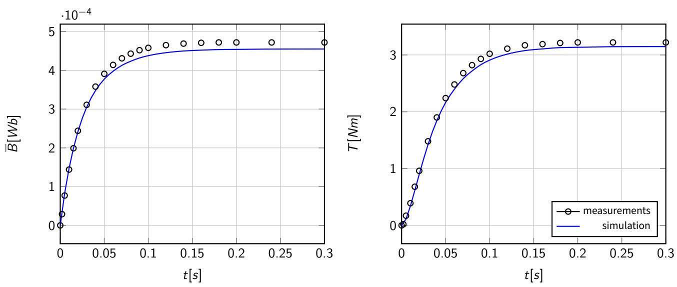
In this equation **f** is the force density, μ_0 the magnetic permeability of free space, **n** the outward normal to the surface and B_n the normal component of the magnetic flux density. $\mathbf{H}_t$ is the tangential component of the total exterior magnetic field.

PROBLEM STATEMENT

The problems stated in the TEAM workshops (Testing Electromagnetics Analysis Methods) serve as benchmarks for numerical software analyzing electromagnetic field problems.
The TEAM 24 benchmark is a non-linear, eddy current problem. The test rig geometry is similar to a Switched Reluctance Motor (SRM) with two rotor poles. The rotor itself is rotated but standing still. Windings are located above the stator and excited by a step voltage. The rig is made of steel which is non-linear and defined by means of a *B*-*H*-curve as well as a measured conductivity σ.
The geometry, the *B*-*H*-curve and σ of the steel, the excitation current as well as measured and simulated results are provided by [2]. In the original document the *B*-*H*-curve of the steel is poorly sampled in the low flux regime which leads to inaccurate results. To overcome this issue, the curve has been fitted to a Fröhlich-like model, re-sampled and interpolated by means of splines. Using the original *B*-*H*-data, the asymptotic torque would be underestimated by approximately 10%

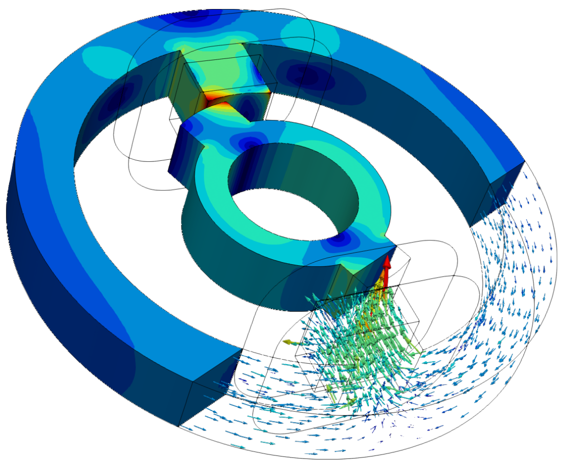
RESULTS

For the presented results, 136 440 hexahedral elements are used to discretize the rig. The coils have been modelled by means of Biot-Savart sources. The coupled system has 475 994 degrees of freedom. For a relative residual error of 10^{-3}, the non-linear solver required to the maximum four Newton-steps to converge.

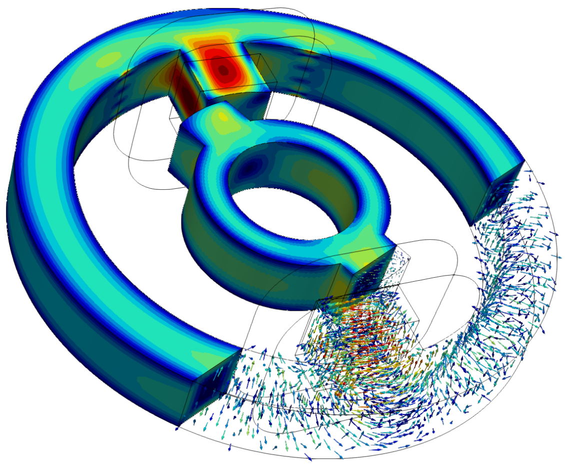


TEAM 24. Flux through a rotor pole (left) and rotor torque (right)

The average flux density $\overline{B} = \int_S \mathbf{B} \cdot \mathbf{n}\, dS \,/|S|$ is evaluated at the search coil location S as defined in [2] and compared to the measurements. The results are shown in Fig. 1 where the rotor torque T was also compared.
The horizontal dashed lines in Fig. 1 show the results from a magnetostatic simulation, where the coils have been modelled by means of Biot-Savart (violet) and taken into account as a full model (olive). Fig. 2 shows the magnitude of the flux density **B** in stator and rotor cut through the search coil. The arrors show the direction of the **B**-field.



TEAM 24. Calculated magnitude of the magnetic flux density $|\mathbf{B}|$ in stator and rotor including cut through search coil (max $|\mathbf{B}| = 2.5\ T$)



TEAM 24. Calculated magnitude of the eddy currents $|\mathbf{J}|$ at $t = 0.03\ s$ (max $|\mathbf{J}| = 6.7 \cdot 10^5\ A$)

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] N. Allen and D. Rodger. Description of team workshop problem 24: Nonlinear time-transient rotational test rig. In *Proc. TEAM Workshop in the Sixth Round*, pages 57–60. Citeseer, 1996.

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