3D Simulation in NGSolve

SyMSpace Days 2024

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LINZ CENTER OF MECHATRONICS

NGSolve

SyMSpace Interface

Applikationen

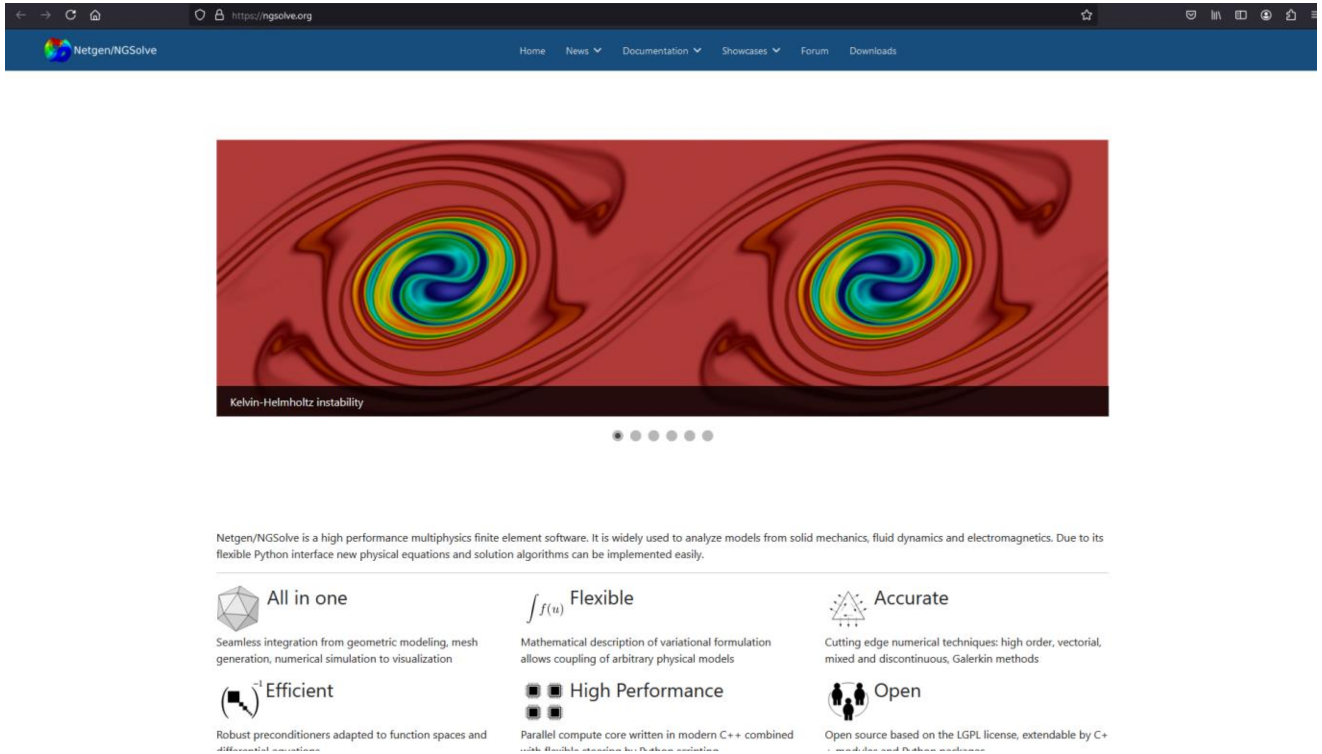
NGSolve

NGSolve

- High performance multiphysics finite element software
- Problembeschreibung über mathematische Formulierung
- Python-Interface
- Entwickelt an der TU Wien
- Aktive Community

Homepage

https://ngsolve.org/



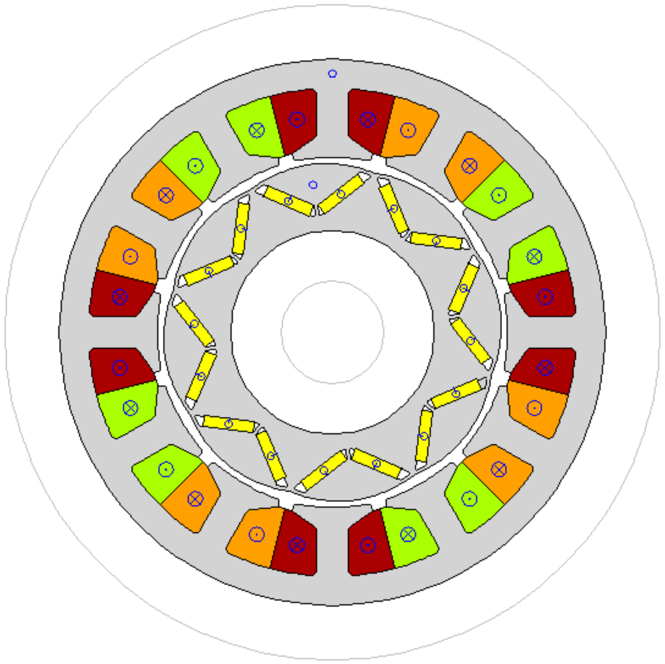
2

SyMSpace Interface

SyMSpace/NGSolve Interface

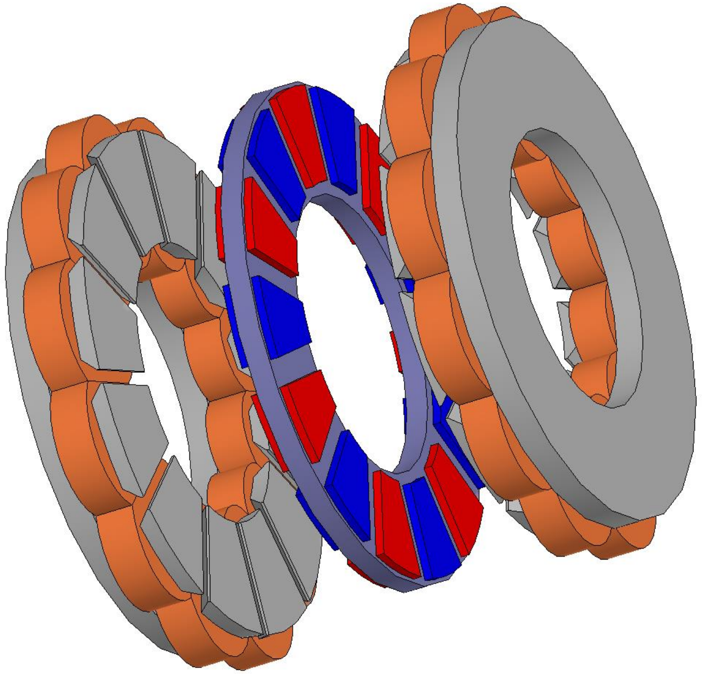
3D Aspects for Electrical Machine Simulations

Radial Flux Machine



- Magnet-Losses
- Endwinding Inductances

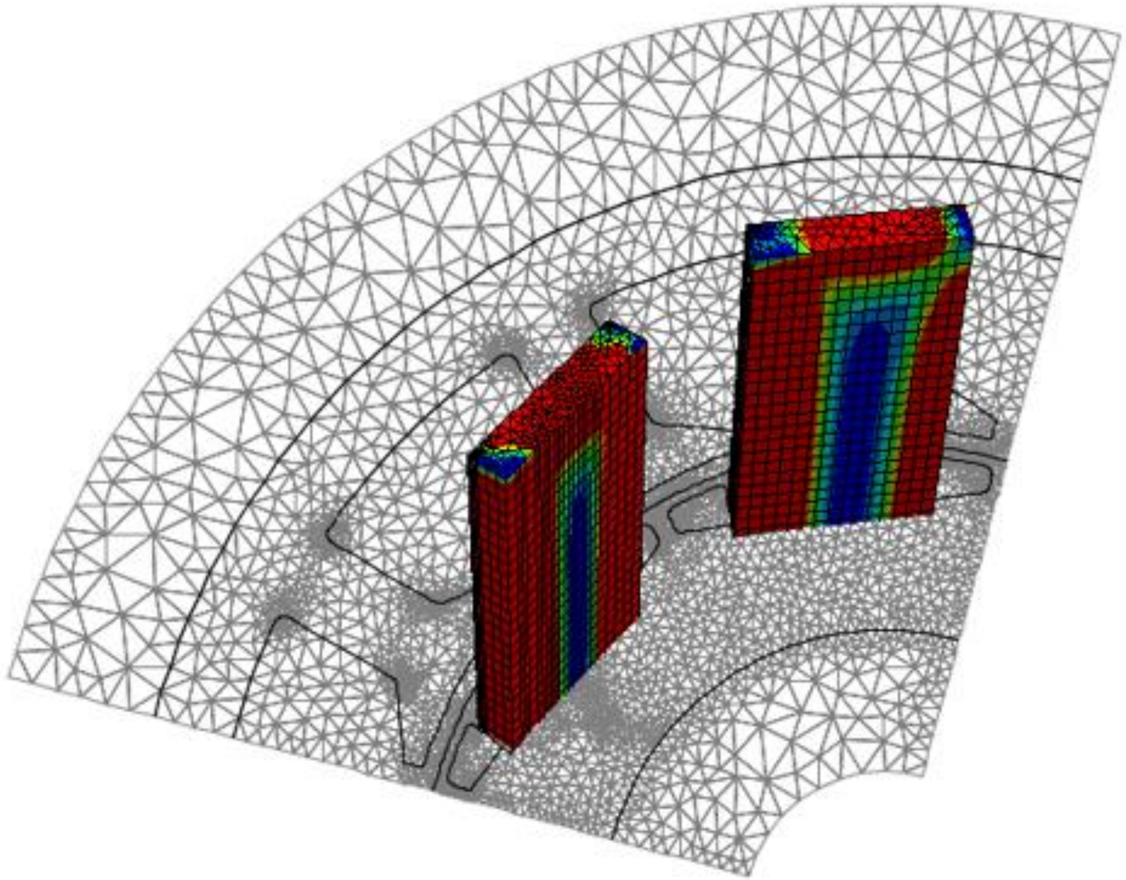
Axial Flux Machine



3

Applikationen

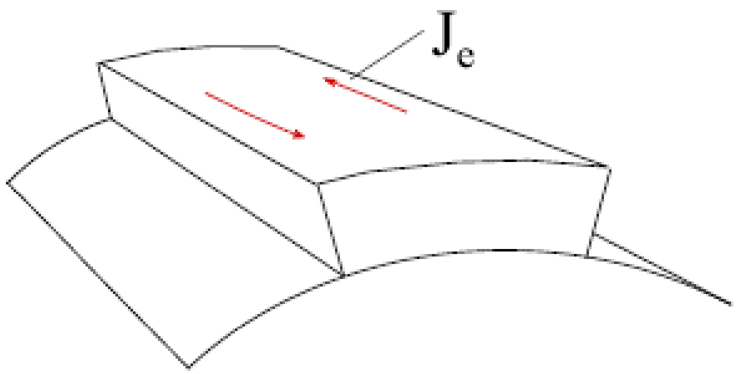
Magnet-Verlust Abschätzung



Herangehensweise

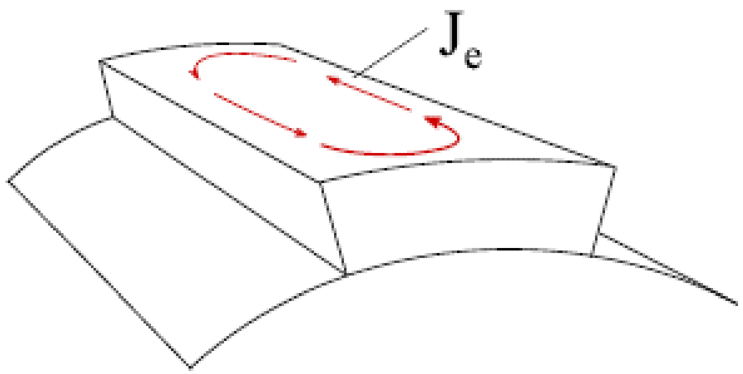
[Carpenter1977]

2D Abschätzung



- Schnelle Berechnung
- Vernachlässigt Rückwirkung
- Magnet ‚unendlich'-lange modelliert

2D/3D Kopplung



- Beinhaltet Endeffekte
- Vernachlässigt Rückwirkung

Model: Eddy Current Problem

Aus

$$\operatorname{curl} E = -\frac{\partial B}{\partial t}$$
$$J = \sigma E$$
$$\operatorname{div} J = 0 \;\rightarrow J = \operatorname{curl} T$$

Resultiert

$$\operatorname{curl} \frac{1}{\sigma} \operatorname{curl} T = -\frac{\partial B}{\partial t}$$

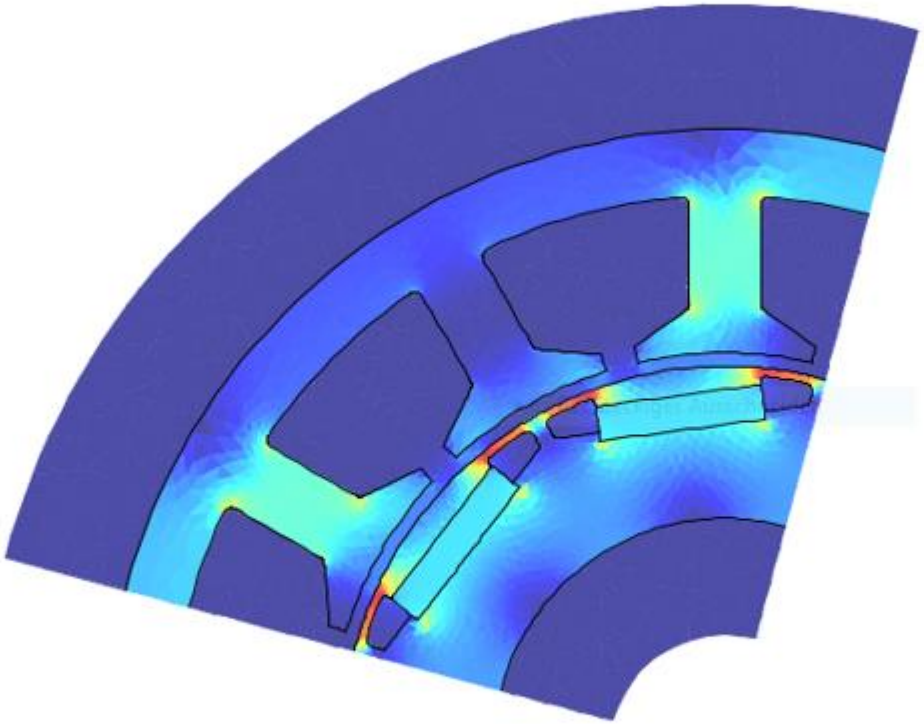
Mit

E	elektrische Feldstärke
B	magnetische Flussdichte
J	elektrische Stromdichte
σ	elektrische Leitfähigkeit
T	elektrisches Vektorpotential

Implementierung I

- 2D Motor Simulation in FEMM42
- Export des Magnet-Meshs und B-Feldes
- Berechnung von $-\frac{\partial B}{\partial t}$
- Extrusion des Meshs
- Lösung von

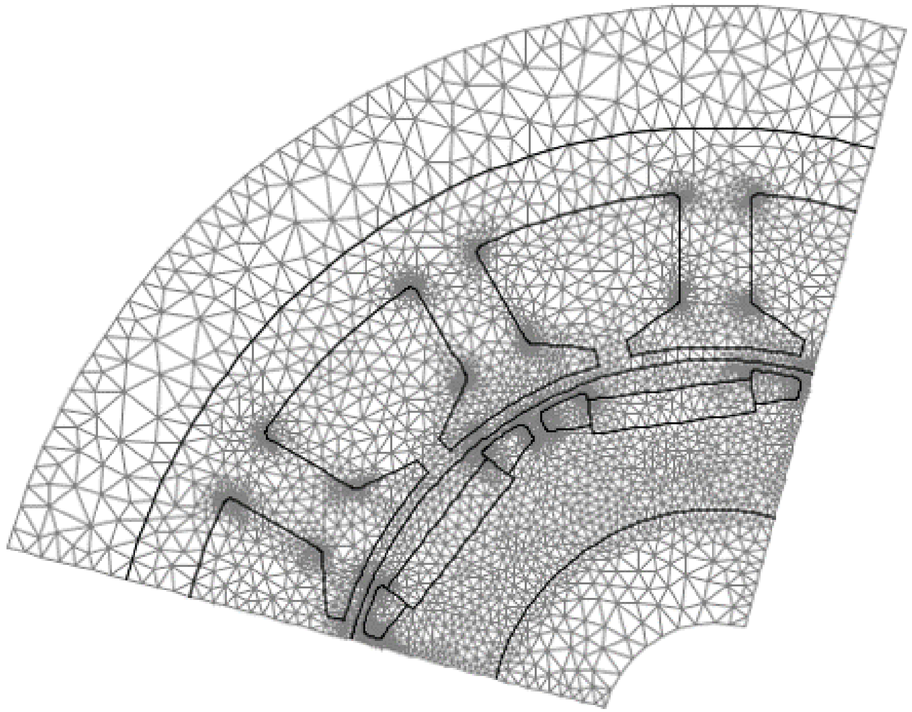
$$\operatorname{curl} \frac{1}{\sigma} \operatorname{curl} T = -\frac{\partial B}{\partial t}$$



Implementierung II

- 2D Motor Simulation in FEMM42
- Export des Magnet-Meshs und B-Feldes
- Berechnung von $-\frac{\partial B}{\partial t}$
- Extrusion des Meshs
- Lösung von

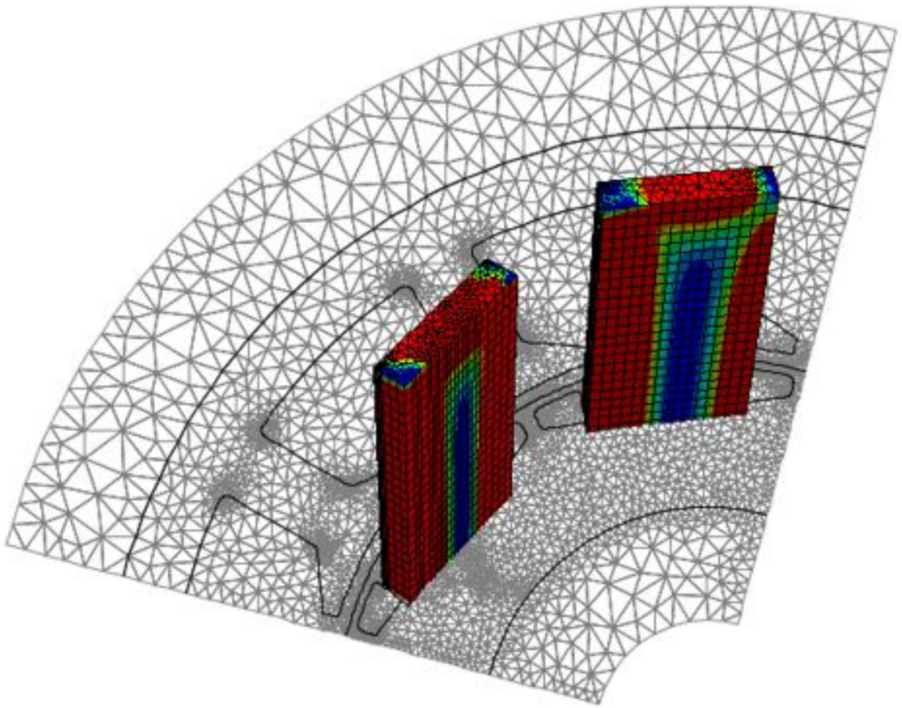
$$\operatorname{curl}\frac{1}{\sigma}\operatorname{curl} T = -\frac{\partial B}{\partial t}$$



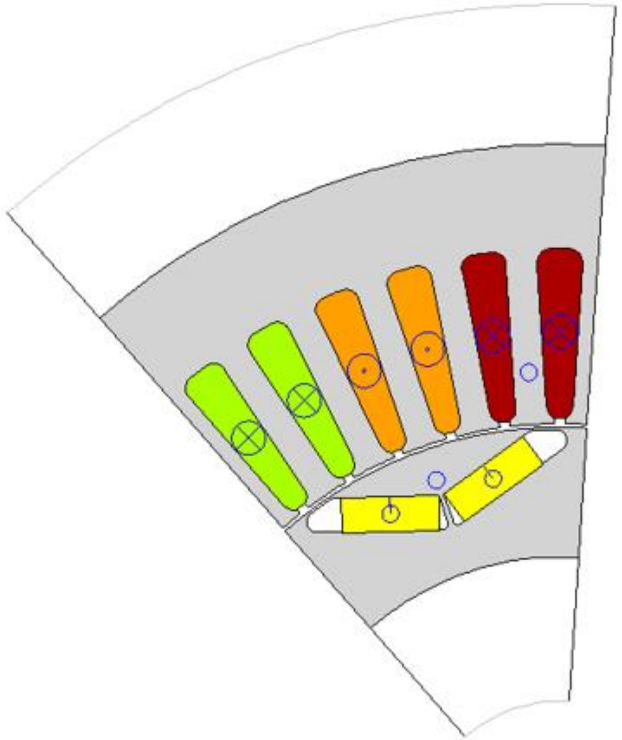
Implementierung III

- 2D Motor Simulation in FEMM42
- Export des Magnet-Meshs und B-Feldes
- Berechnung von $-\frac{\partial B}{\partial t}$
- Extrusion des Meshs
- Lösung von

$$\operatorname{curl}\frac{1}{\sigma}\operatorname{curl} T = -\frac{\partial B}{\partial t}$$



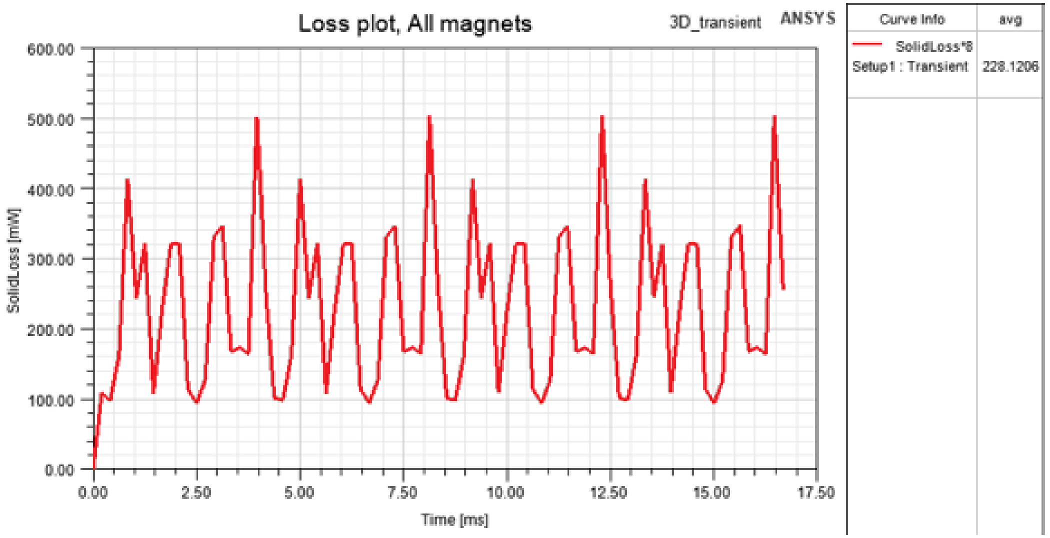
Example: Prius



- Rpm = 1800
- Sigma = 666666.6666
- Simulation length = pi/8
- Magnet length = 84.0 mm (not segmented)

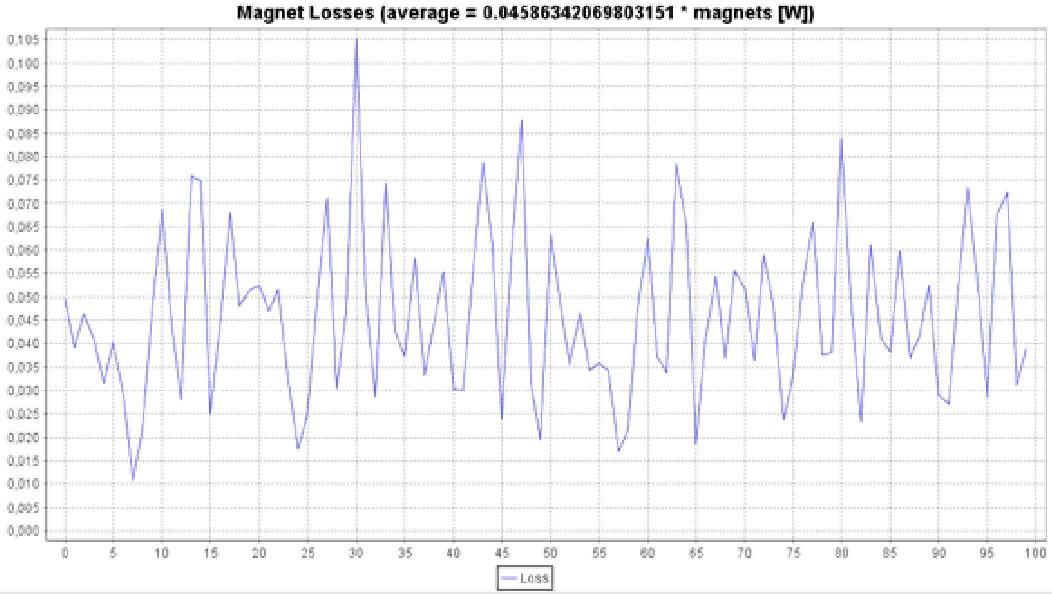
Vergleich: Prius

Ansys Maxwell Simulation



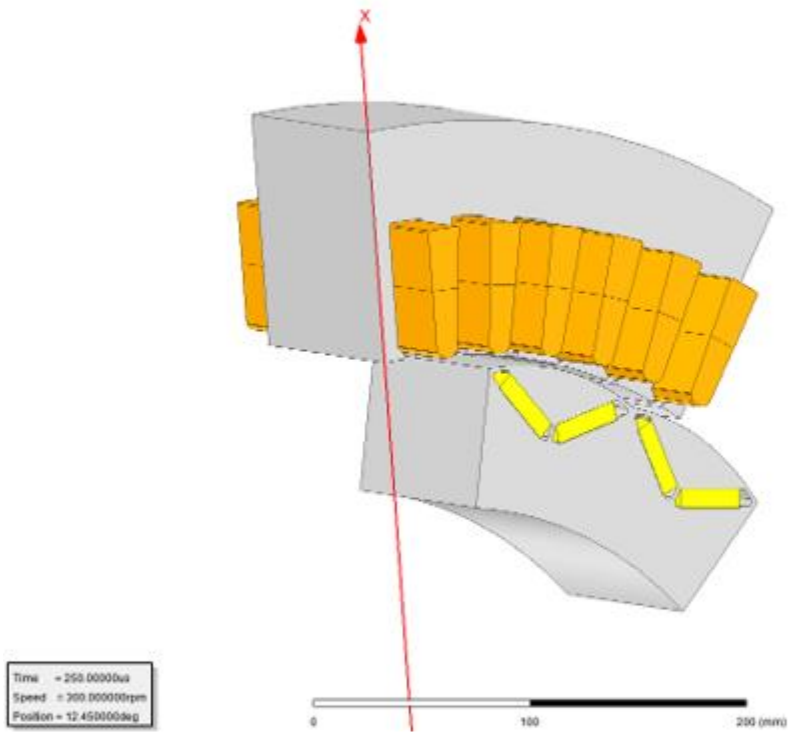
Maxwell avg. losses: 0.228 W

NGSolve Simulation



NGSolve avg. losses: 0.367 W

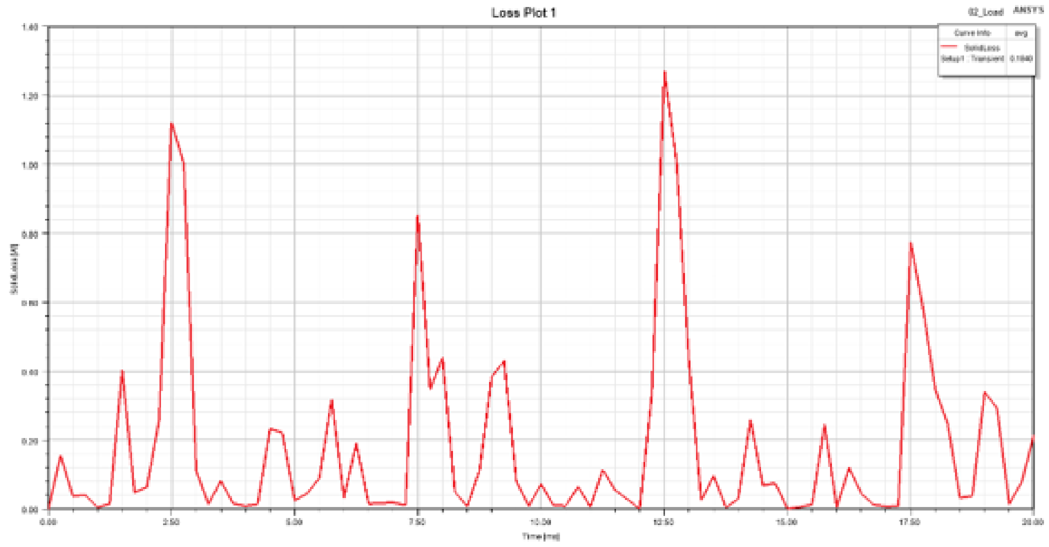
Example: Generator



- Rpm = 300
- Sigma = 666666.6666
- 4 Magnet Segments

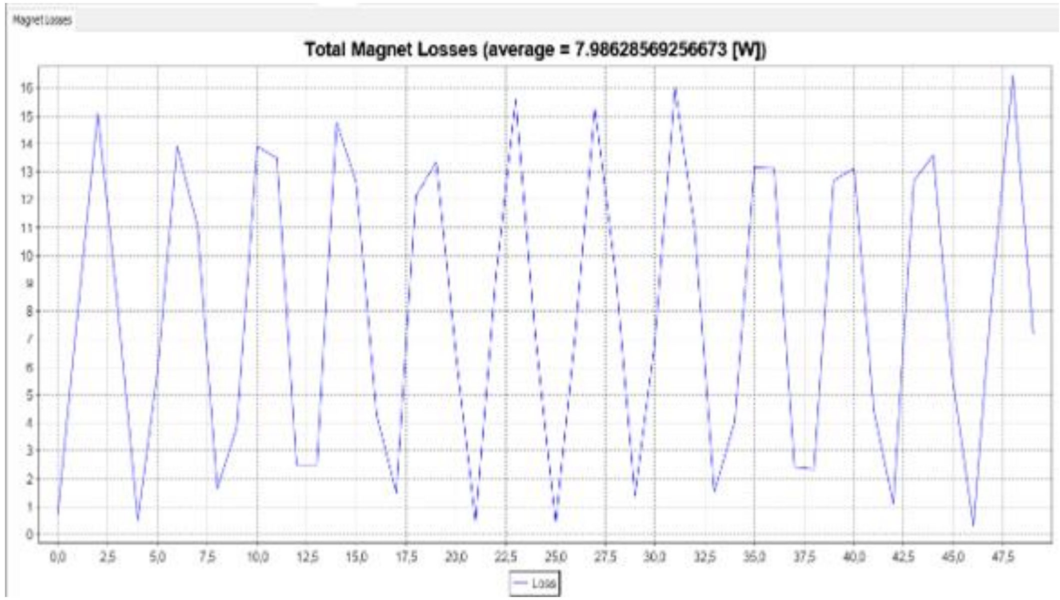
Vergleich: Generator

Ansys Maxwell Simulation



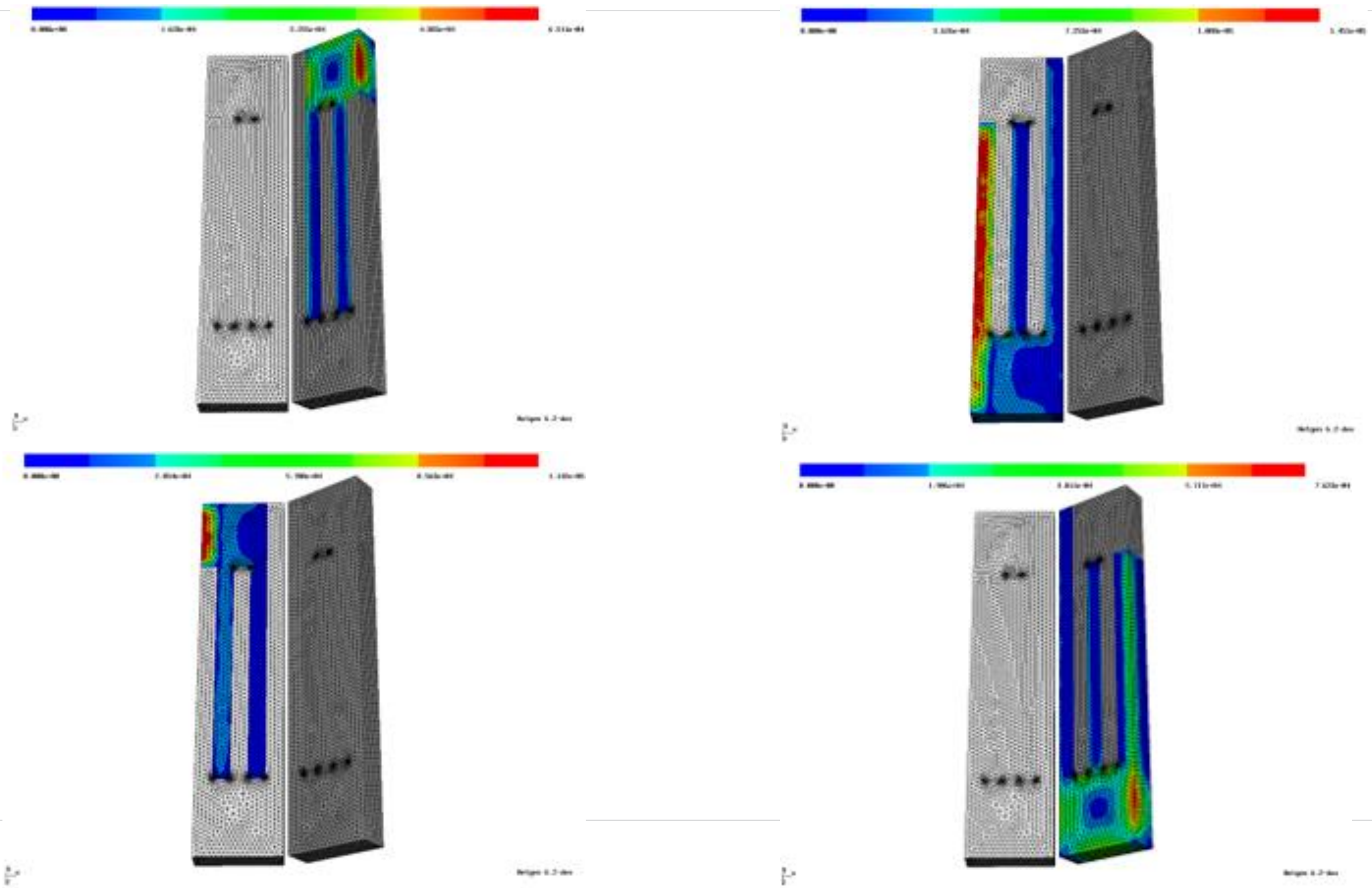
Maxwell avg. losses: 7.36 W

NGSolve Simulation

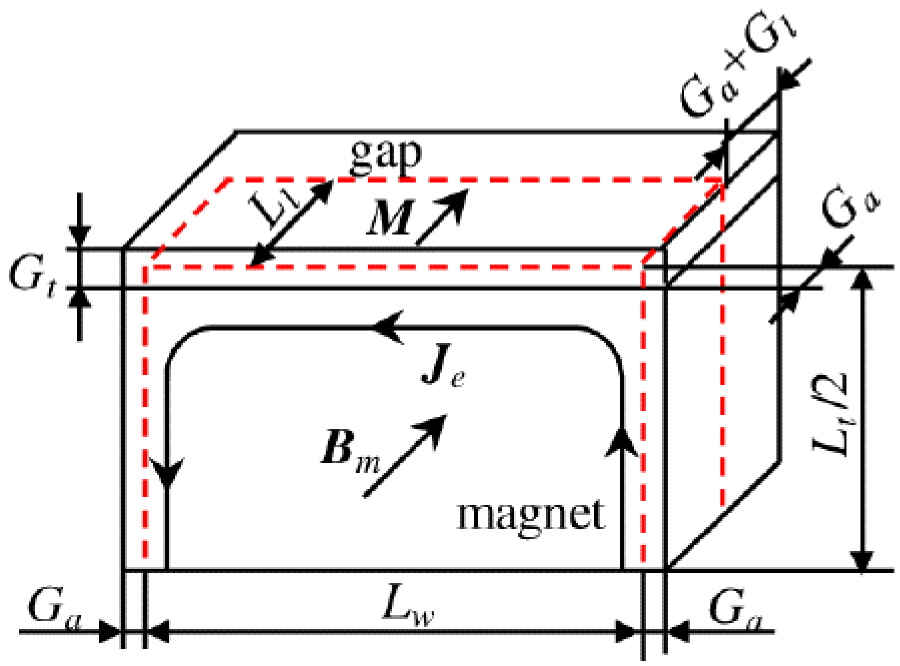


NGSolve avg. losses: 7.98 W

- Segmentierung in der x-y-Ebene
- Snakeline Segmentierung



Extensions



- Berücksichtigung der Rückwirkung [Okitsu2009]

Referenzen

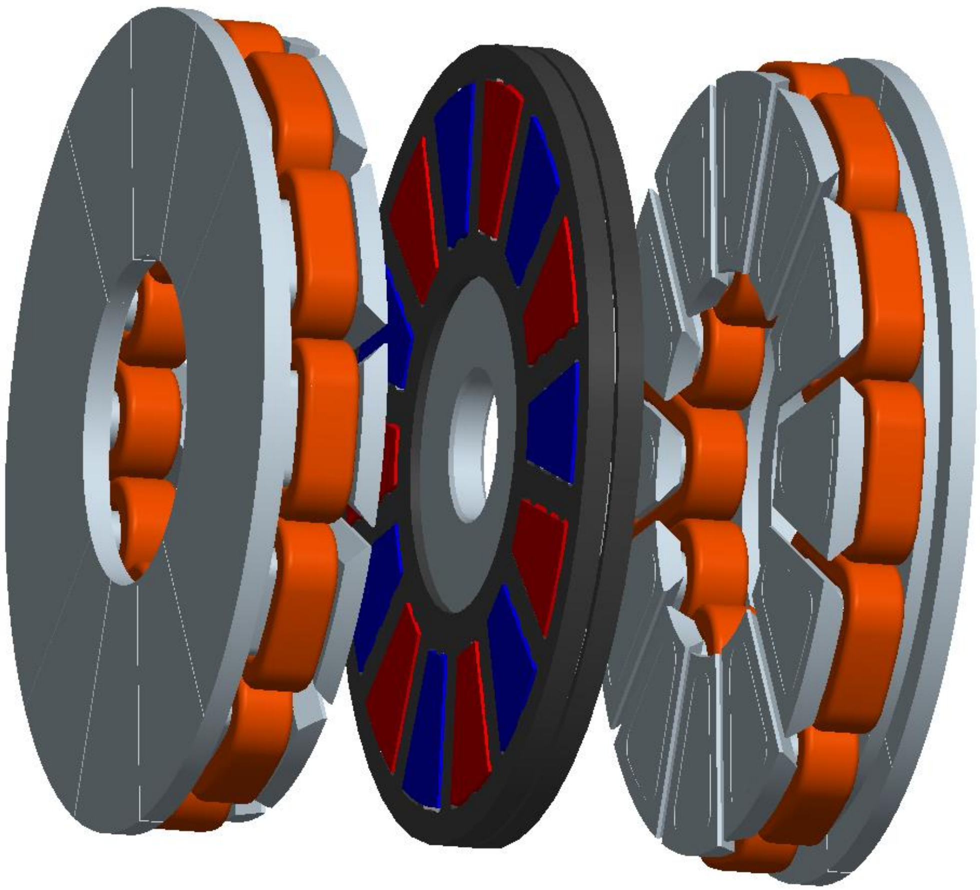
[Carpenter1977]: Carpenter, C.J.: 'Comparison of alternative formulations of 3-dimensional magnetic-field and eddy-current problems at power frequencies', Proceedings of the Institution of Electrical Engineers, 1977, 124, (11), p. 1026-1034.

[Yamazaki2009]: K. Yamazaki and Y. Kanou, "Rotor Loss Analysis of Interior Permanent Magnet Motors Using Combination of 2-D and 3-D Finite Element Method," in IEEE Transactions on Magnetics, vol. 45, no. 3, pp. 1772-1775, March 2009.

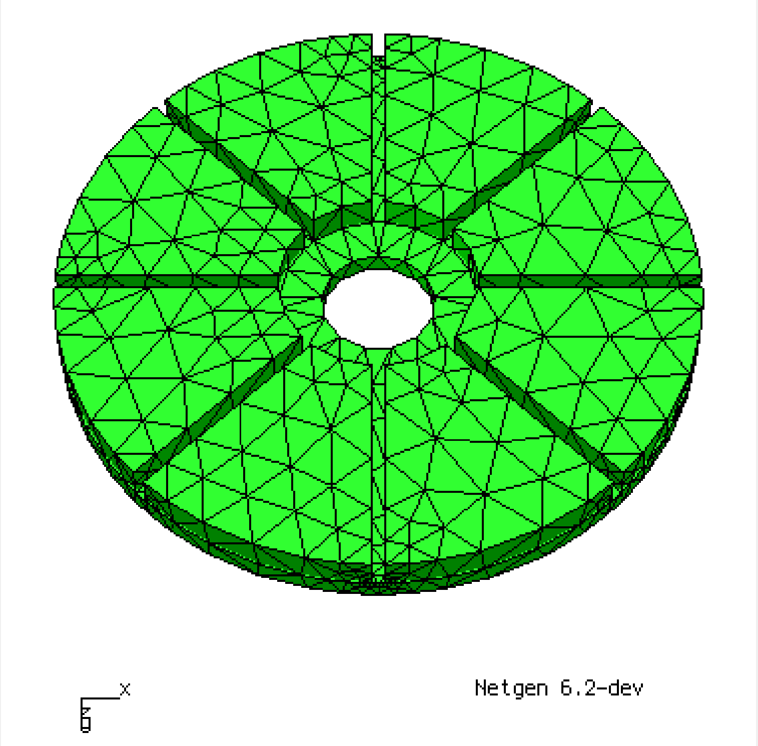
[Okitsu2009]: T. Okitsu, D. Matsuhashi and K. Muramatsu, "Method for Evaluating the Eddy Current Loss of a Permanent Magnet in a PM Motor Driven by an Inverter Power Supply Using Coupled 2-D and 3-D Finite Element Analyses," in IEEE Transactions on Magnetics, vol. 45, no. 10, pp. 4574-4577, Oct. 2009.

[Steentjes2015]: S. Steentjes, S. Boehmer and K. Hameyer, "Permanent Magnet Eddy-Current Losses in 2-D FEM Simulations of Electrical Machines," in IEEE Transactions on Magnetics, vol. 51, no. 3, pp. 1-4, March 2015.

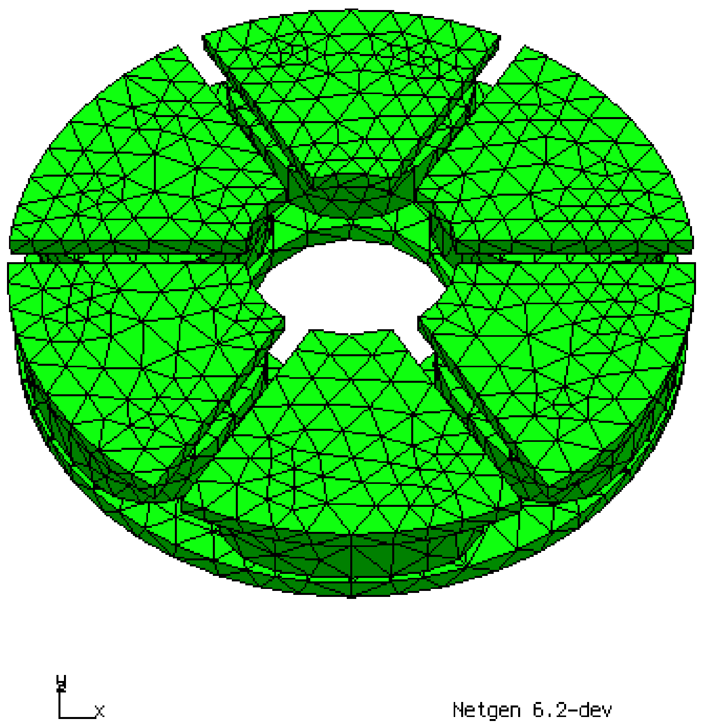
Axial Flux Machine



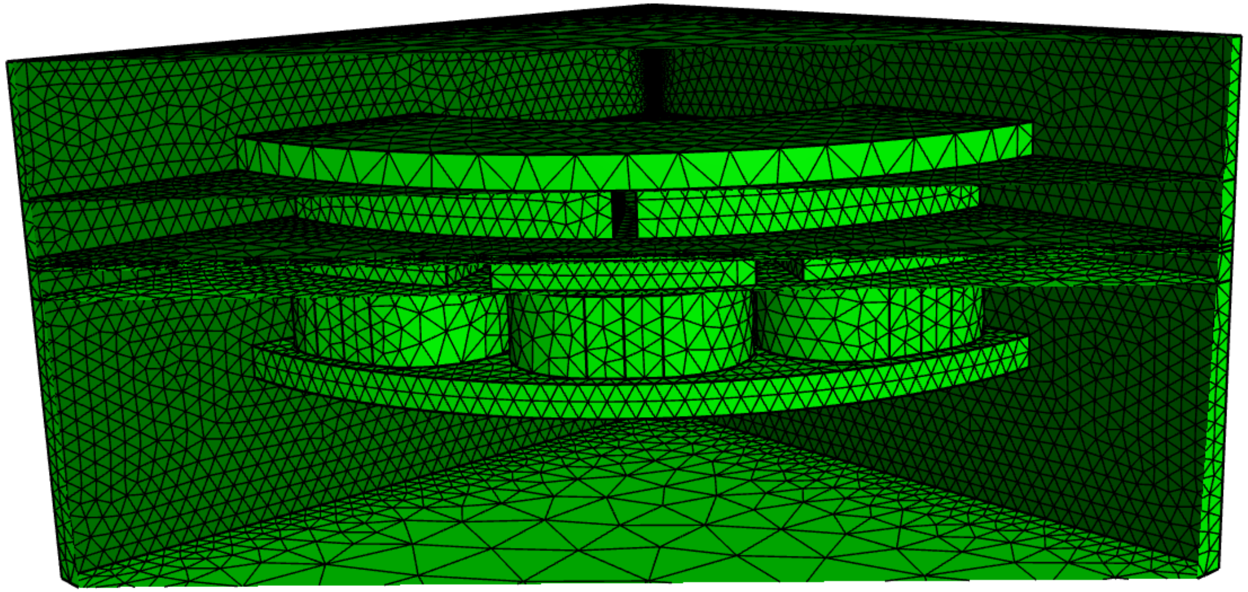
Geometrie: Rotor



Geometrie: Stator



Geomtrie



Nitsche Mortaring

Find $\mathbf{u} \in V$ and $\lambda \in \Phi$ such that

$$a(\mathbf{u}, \mathbf{v}, \lambda, \psi) = \langle f, \mathbf{v} \rangle \qquad \forall \mathbf{v} \in V \text{ and } \psi \in \Phi$$

where $V = \{\mathbf{w} \in H(\text{curl}, \Omega_R) \cap H(\text{curl}, \Omega_S) \,|\mathbf{w} = 0 \text{ on } \partial\Omega\}$
and $\Phi = L^2(\Omega_R \cap \Omega_S)$

Semilinear Form

$$
\begin{aligned}
a(\mathbf{u}, \mathbf{v}, \lambda, \psi) = \sum_{i \in \{R,S\}} \int_{\Omega_i} & \left(\nu(\operatorname{curl} u) \cdot (\operatorname{curl} v) + \kappa u \cdot v\right) dx \\
& + \int_{\Gamma_i} \nu \operatorname{curl} u \cdot \left((v - \psi) \times n\right) ds \\
& + \int_{\Gamma_i} \nu \operatorname{curl} v \cdot \left((u - \lambda) \times n\right) ds \\
& + \frac{\alpha p^2}{h} \int_{\Gamma_i} \nu\left((u - \lambda) \times n\right) \cdot \left((v - \psi) \times n\right) ds
\end{aligned}
$$

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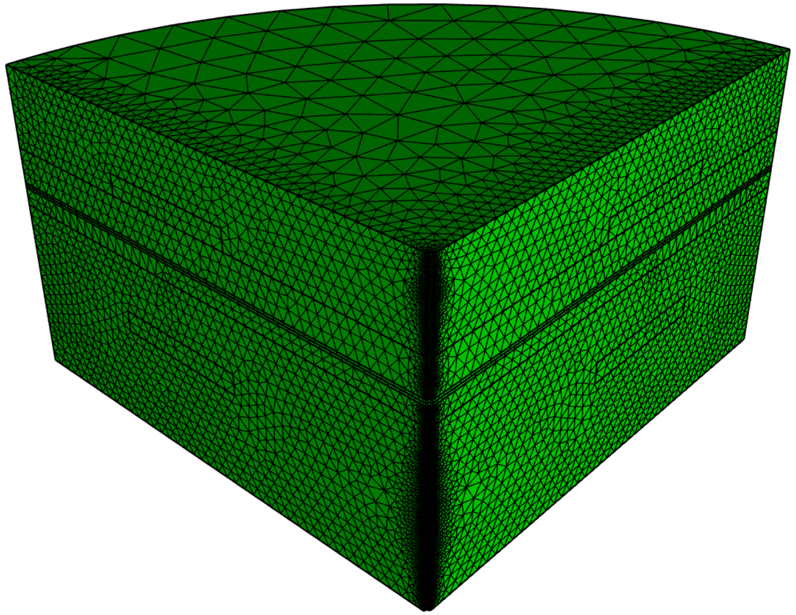
Linear Form

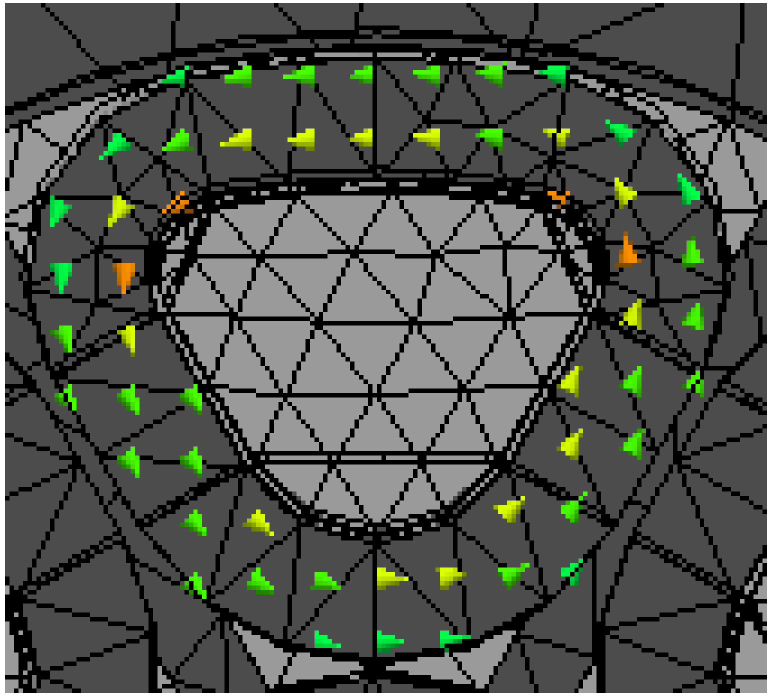
$$\langle f, v \rangle = \sum_{i \in \{R,S\}} \int_{\Omega_i} \left(J \cdot v + M \cdot \operatorname{curl} v \right) dx$$

Implementierung I



- Geometrien fusionieren
- Berechnung der Bestromungsfelder in den Spulen
- Berechnung des Vektorpotentials
- Bestimmung von Drehmoment und Verketten Flüssen

Implementierung II



- Geometrien fusionieren
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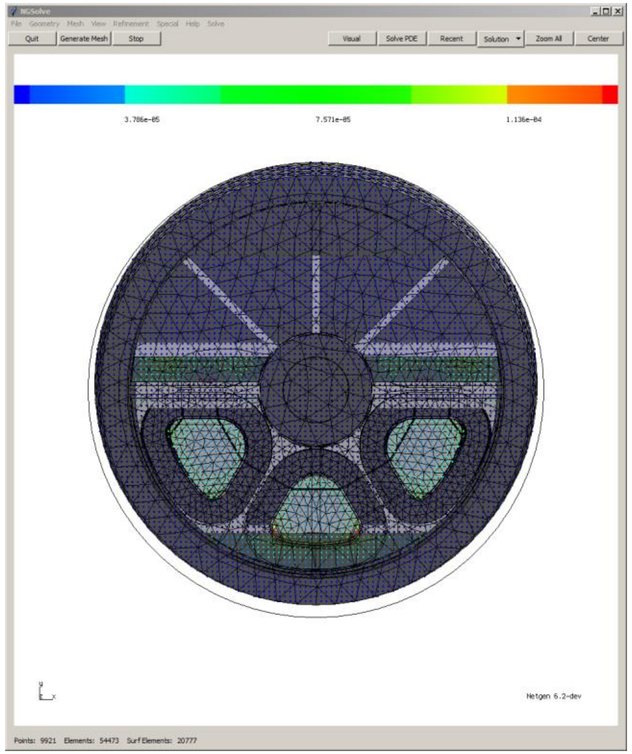
Implementierung III



- Geometrien fusionieren
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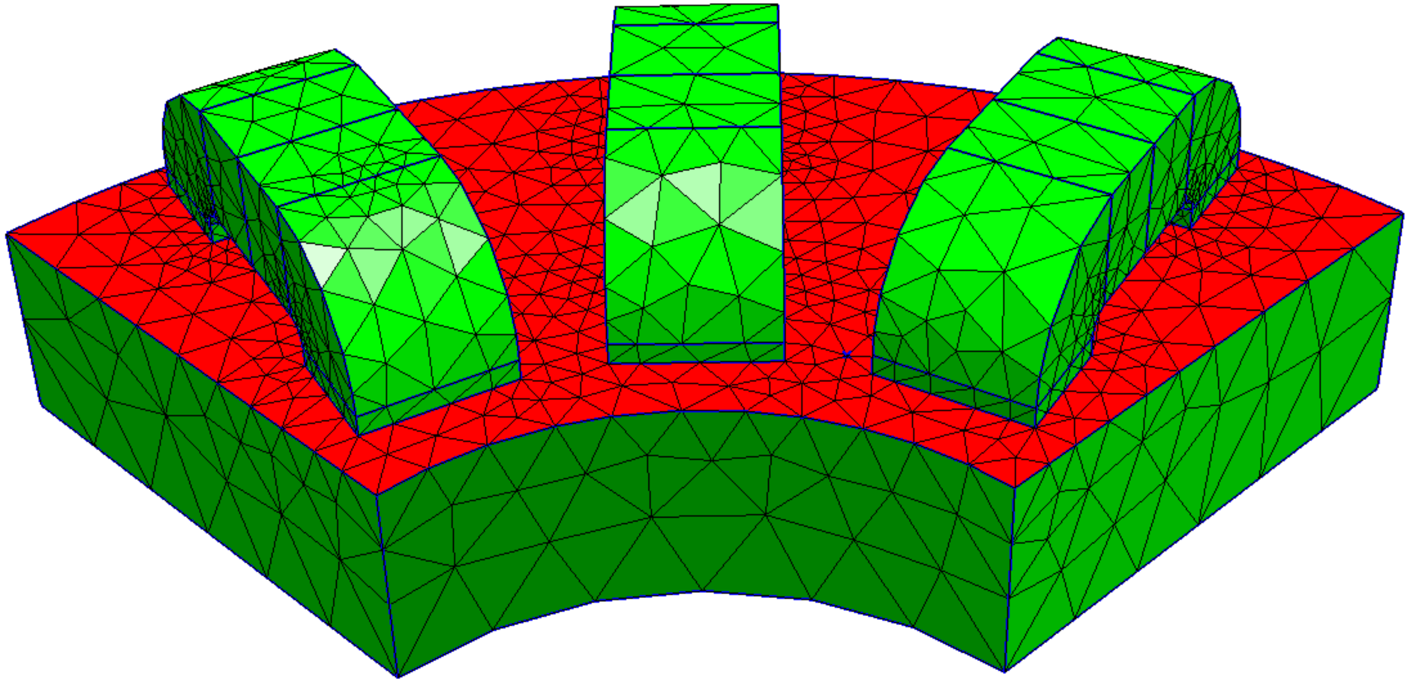
Referenzen

[Hollaus2010]: Hollaus, K., Feldengut, D., Schöberl, J., Wabro, M., and Omeragic, D. (2010, July). Nitsche-type mortaring for Maxwell's equations. In Progress In Electromagnetics Research Symposium Proceedings (Cambridge, USA) (pp. 397-402).

Wickelkopf-Induktivitäten



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Haben Sie noch Fragen?