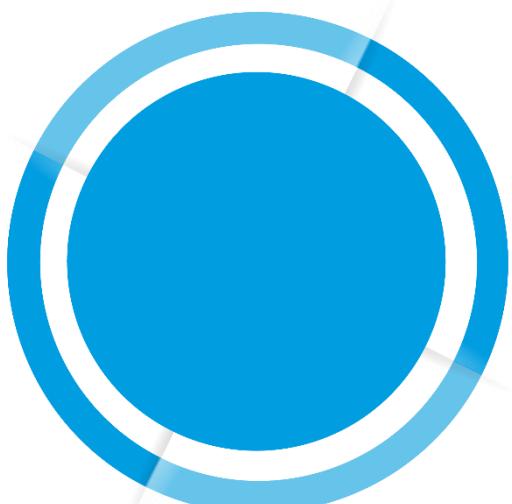


3D Simulation in NGSolve

SyMSpace Days 2024

Armin Fohler



NGSolve

SyMSpace Interface

Applikationen



NGSolve

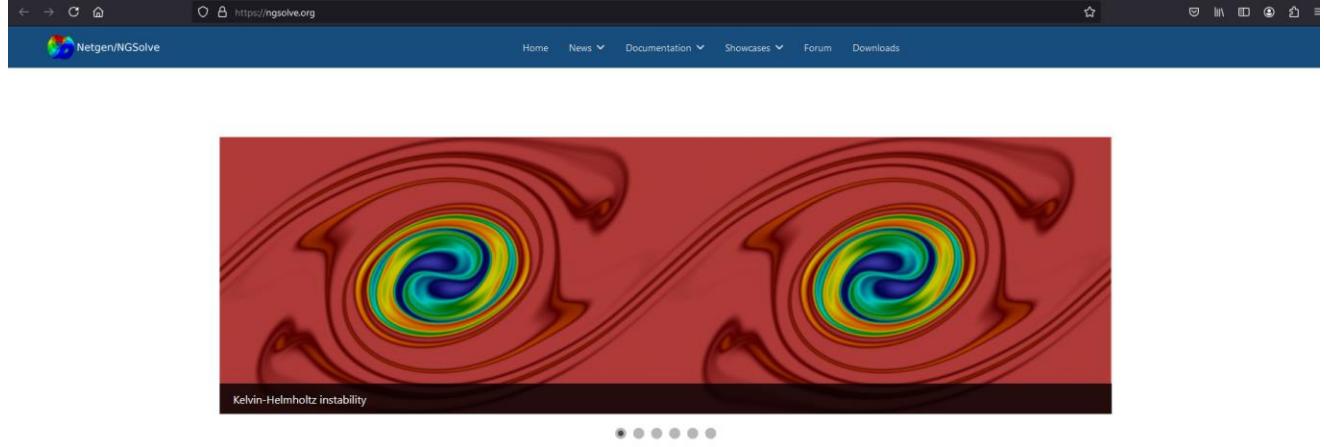


NGSolve

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

Homepage

<https://ngsolve.org/>



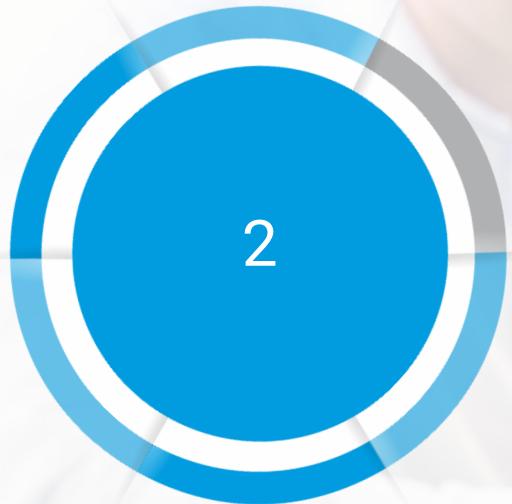
The screenshot shows a web browser displaying the Netgen/NGSolve website at <https://ngsolve.org>. The page features a large, colorful visualization of a Kelvin-Helmholtz instability, showing two vortices with complex internal structures. Below the visualization, the text "Kelvin-Helmholtz instability" is visible. The browser's address bar and navigation buttons are at the top, and a dark blue header bar contains the site's logo and navigation links for Home, News, Documentation, Showcases, Forum, and Downloads.

Netgen/NGSolve is a high performance multiphysics finite element software. It is widely used to analyze models from solid mechanics, fluid dynamics and electromagnetics. Due to its flexible Python interface new physical equations and solution algorithms can be implemented easily.

 All in one Seamless integration from geometric modeling, mesh generation, numerical simulation to visualization	 $\int f(u)$ Flexible Mathematical description of variational formulation allows coupling of arbitrary physical models	 Accurate Cutting edge numerical techniques: high order, vectorial, mixed and discontinuous, Galerkin methods
 Efficient Robust preconditioners adapted to function spaces and differential operators	 High Performance Parallel compute core written in modern C++ combined with flexible models by Python interface	 Open Open source based on the LGPL license, extendable by C+ modules and Python modules

A blurred background image shows two men in a professional setting. One man on the left wears glasses and a light-colored shirt, looking down at a small device. The other man on the right wears glasses and a striped shirt, also looking down. They appear to be in a meeting or presentation.

SyMSpace Interface

A large blue circle with a white outline and a thin black inner border. The number '2' is centered inside the circle.

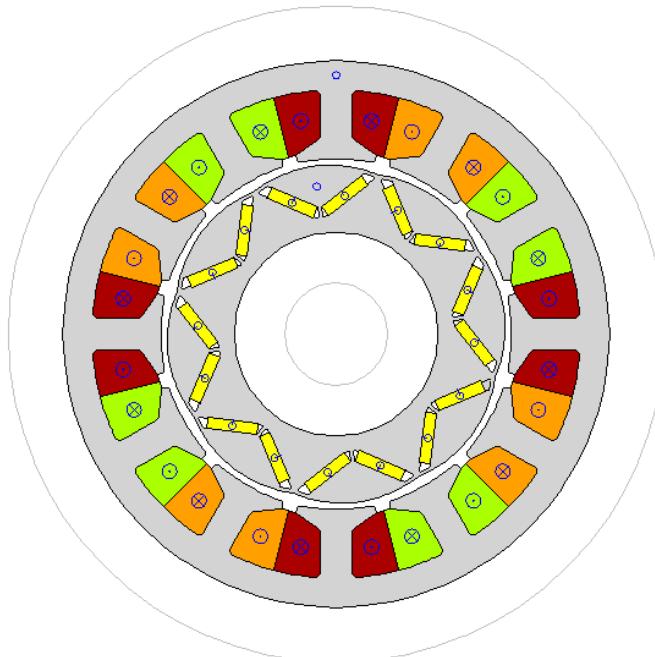
2

SyMSpace/NGSolve Interface



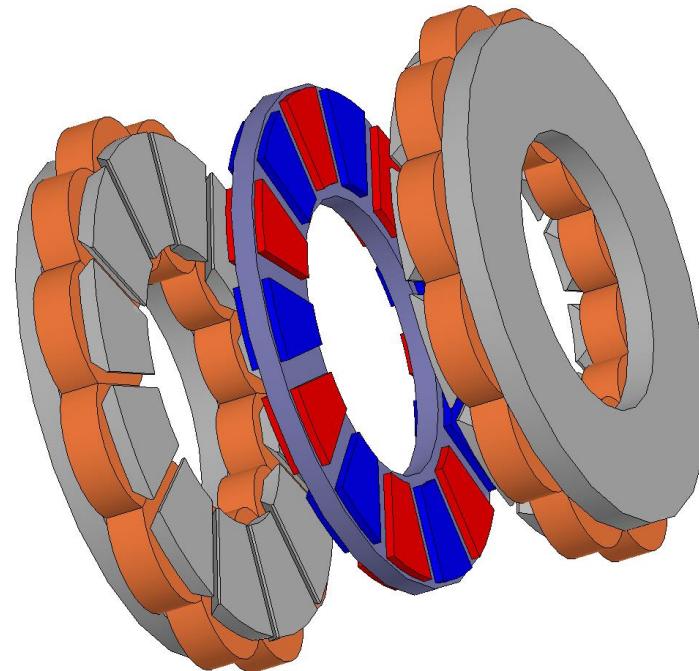
3D Aspects for Electrical Machine Simulations

Radial Flux Machine



- Magnet-Losses
- Endwinding Inductances

Axial Flux Machine



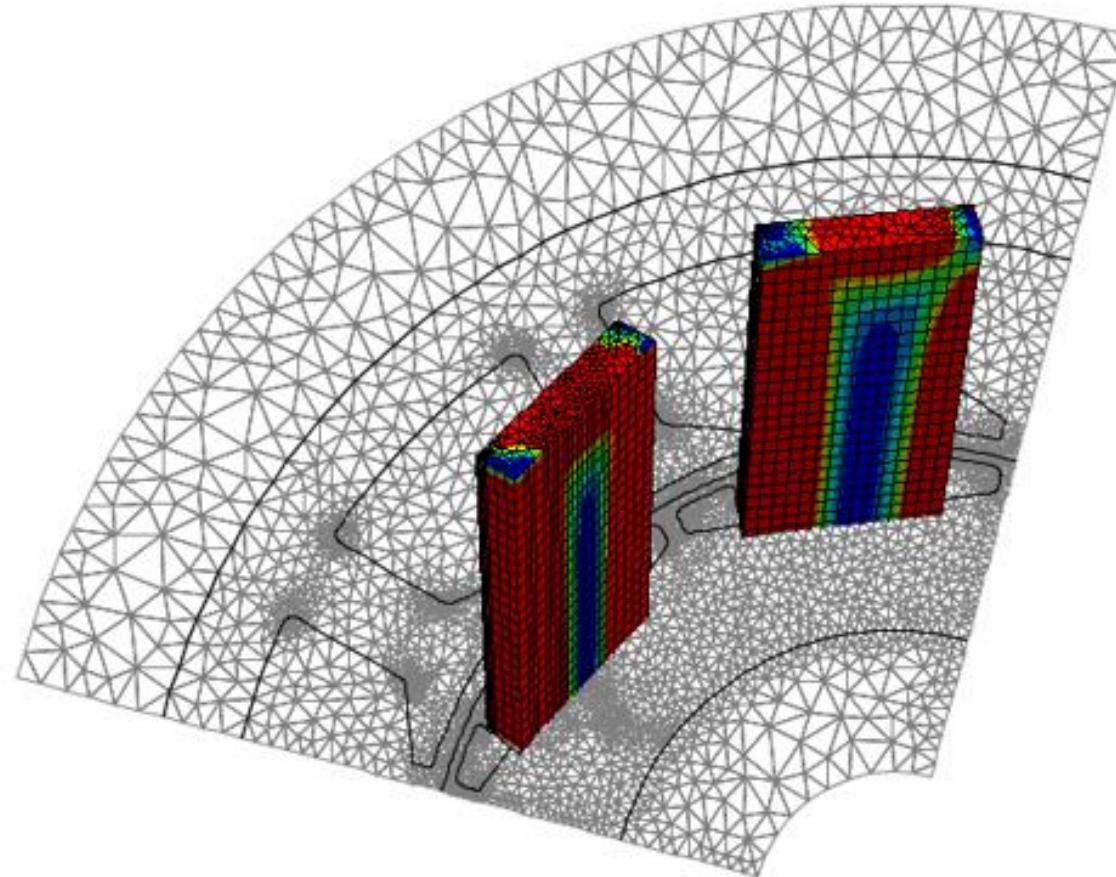
A blurred background image shows two men in business attire, one wearing glasses and a white shirt, the other wearing a striped shirt, both looking down at a small handheld device, possibly a smartphone or a small tablet.

Applikationen

A large blue circular graphic with a thin white border and a thick blue inner circle. The number '3' is centered in the white space.

3

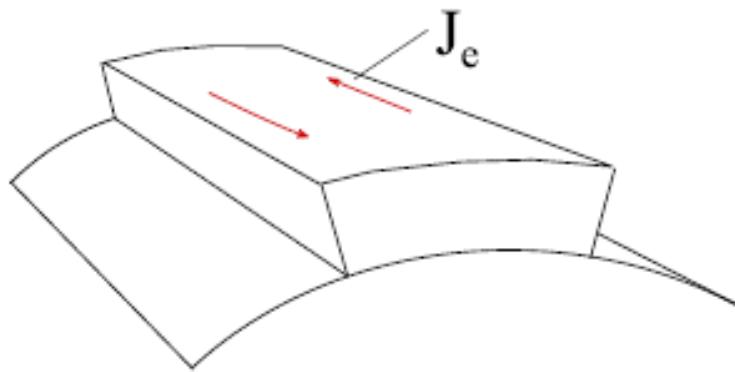
Magnet-Verlust Abschätzung



Herangehensweise

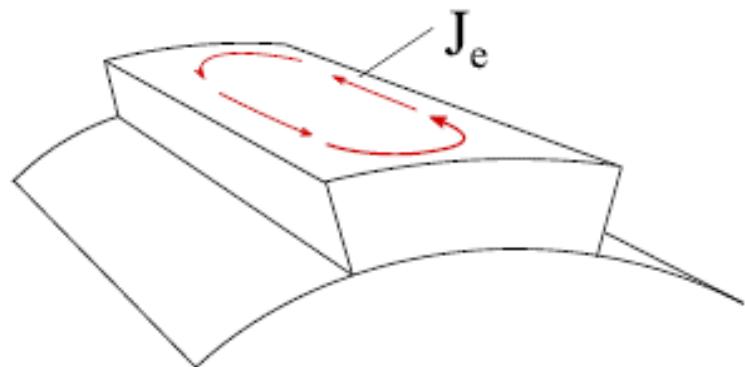
[Carpenter1977]

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

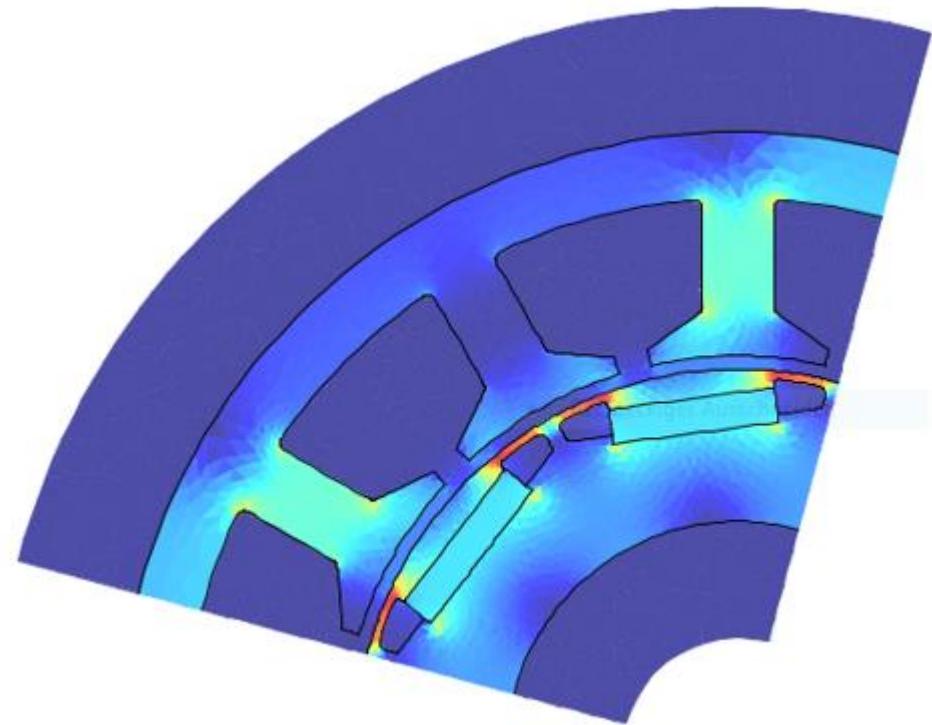
T

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

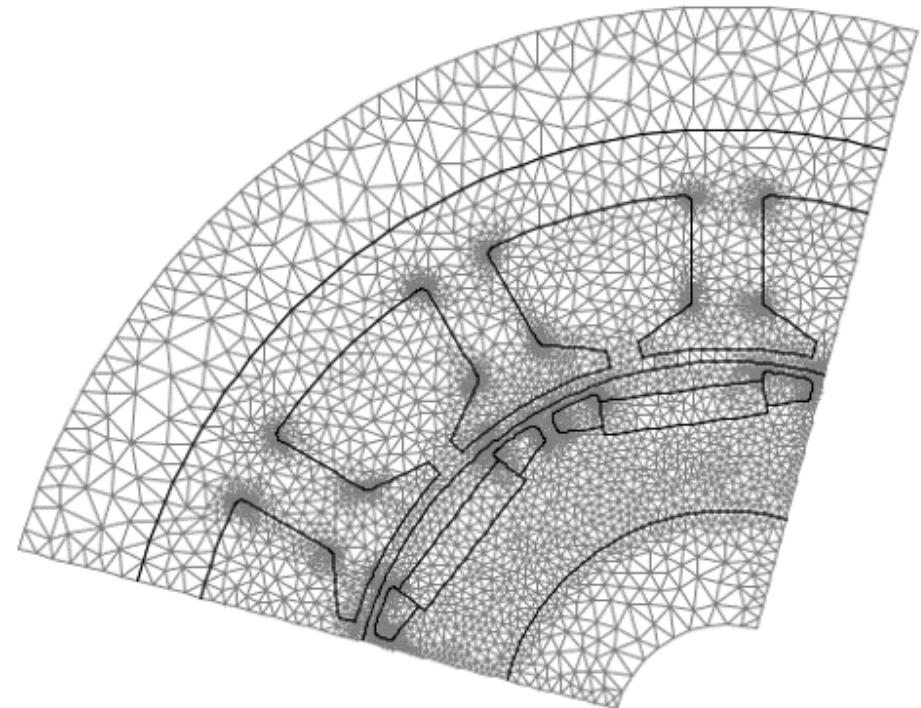
$$\operatorname{curl} \frac{1}{\sigma} \operatorname{curl} T = -\frac{\partial B}{\partial t}$$



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

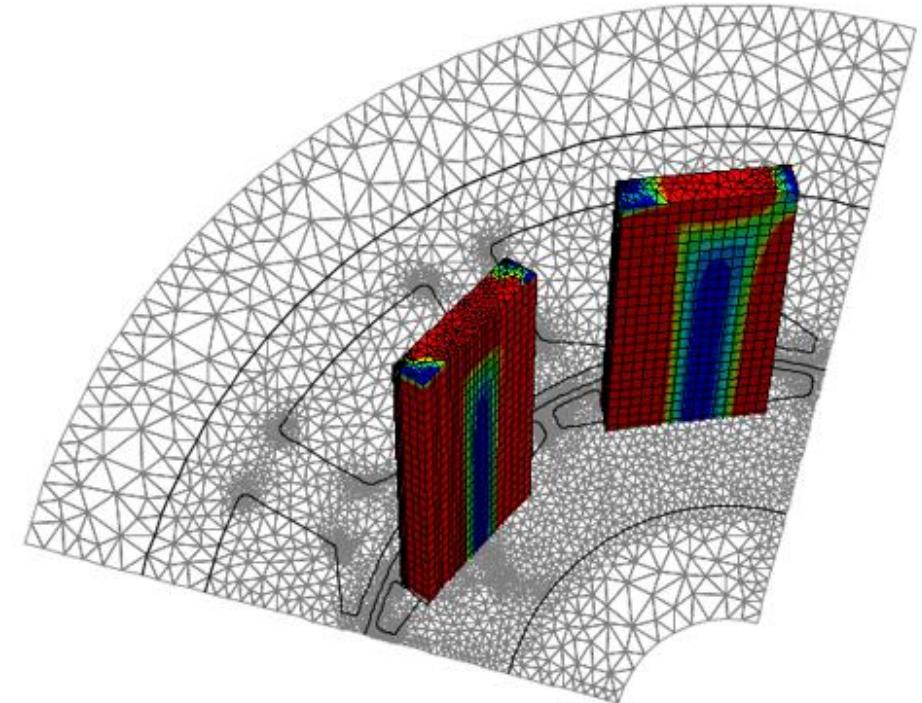
$$\operatorname{curl} \frac{1}{\sigma} \operatorname{curl} T = -\frac{\partial B}{\partial t}$$



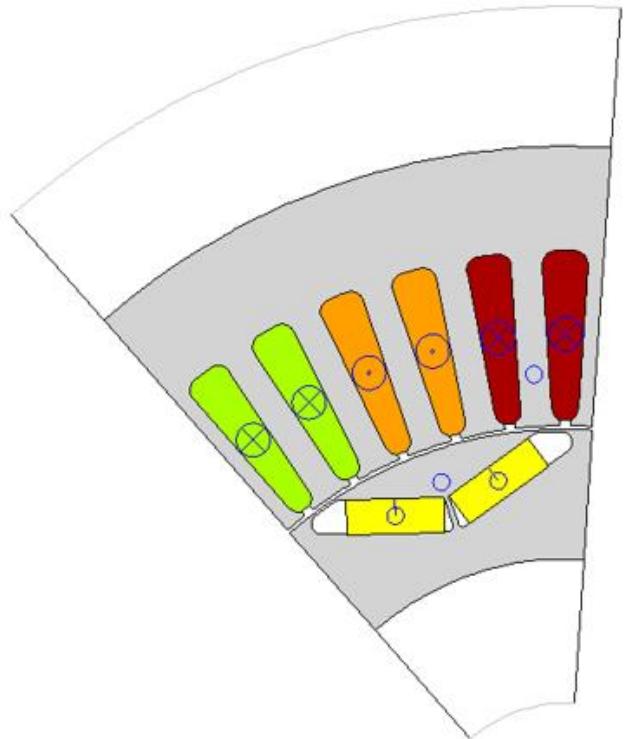
Implementierung III

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

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



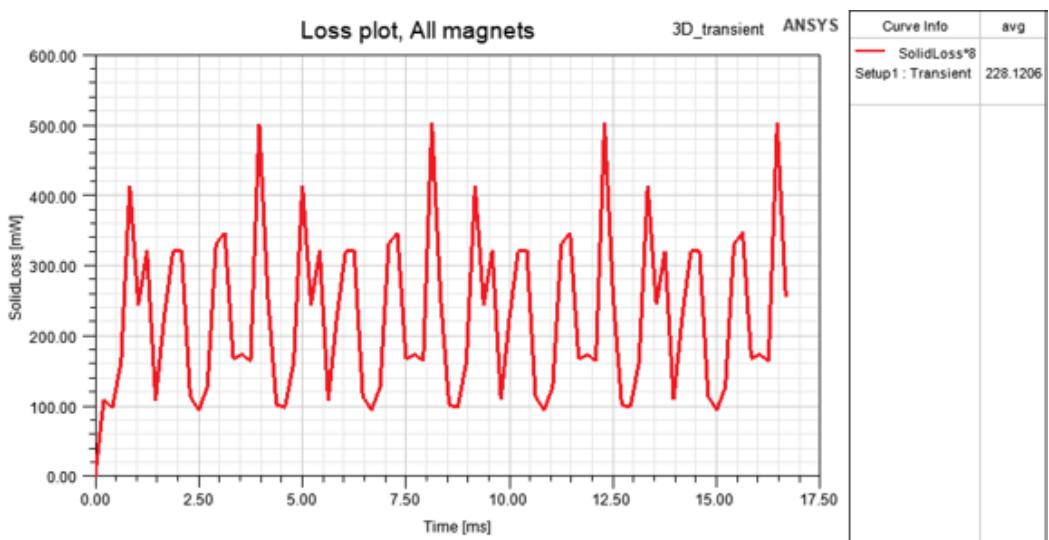
Example: Prius



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

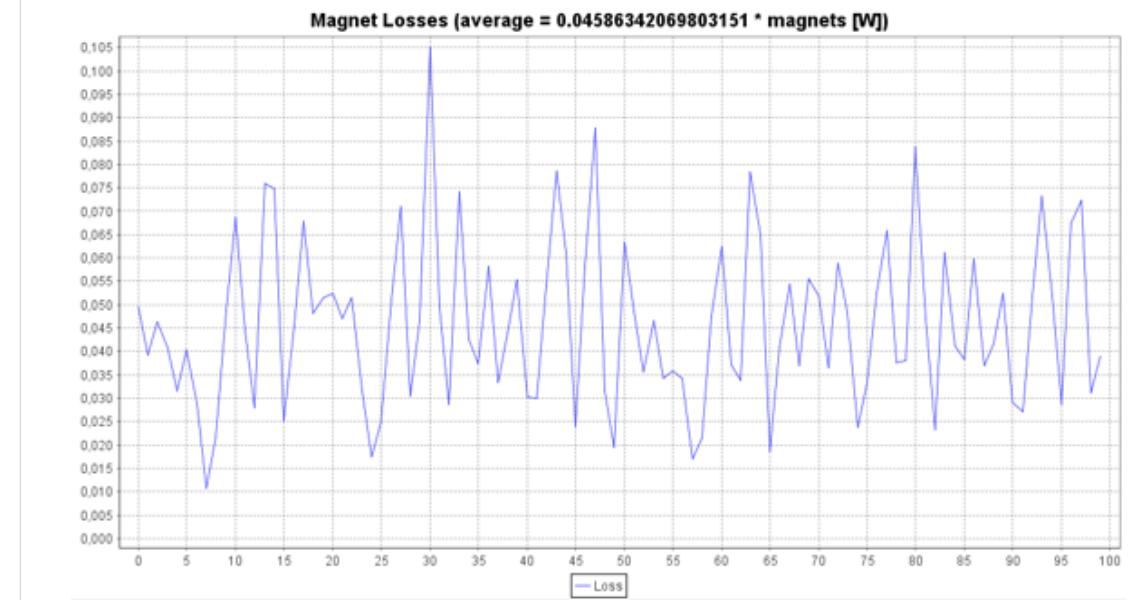
Vergleich: Prius

Ansys Maxwell Simulation



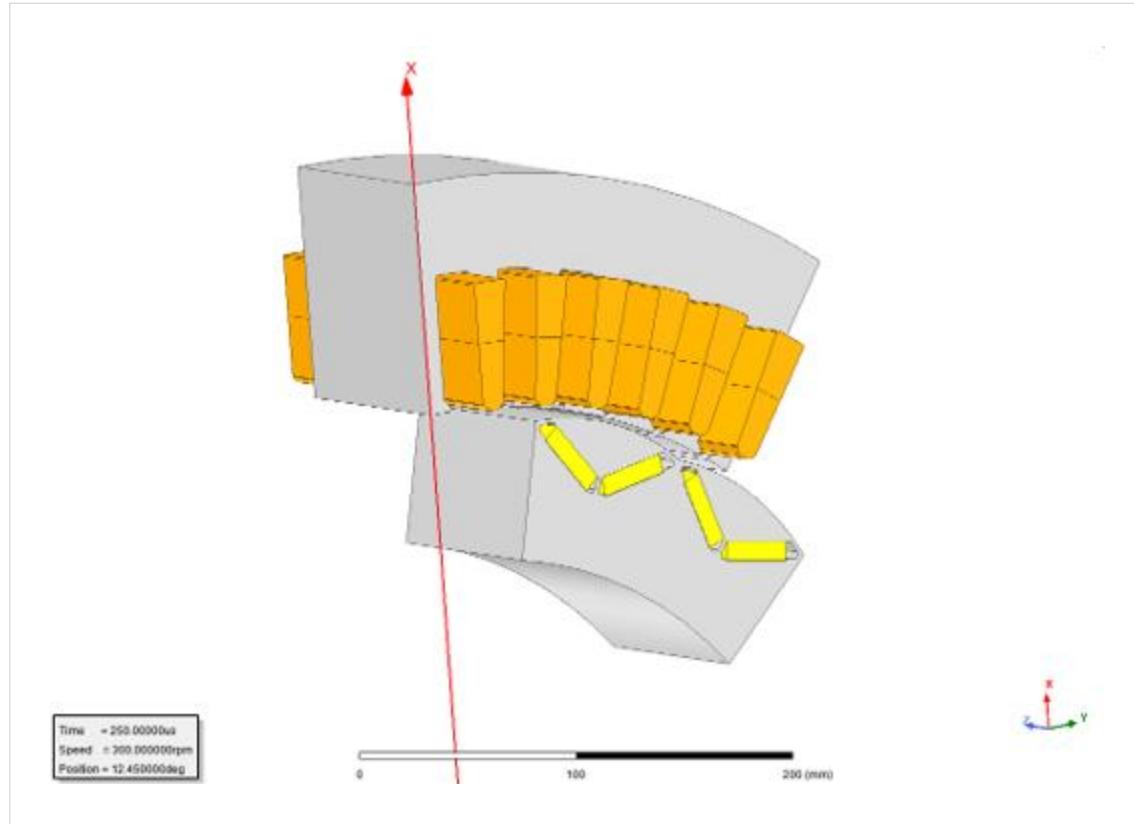
Maxwell avg. losses: 0.228 W

NGSolve Simulation



NGSolve avg. losses: 0.367 W

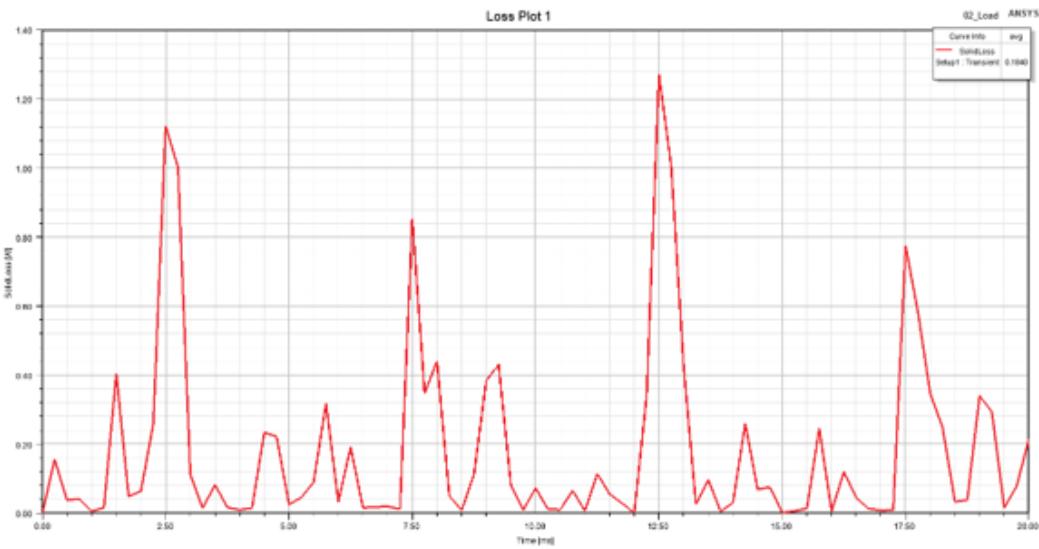
Example: Generator



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

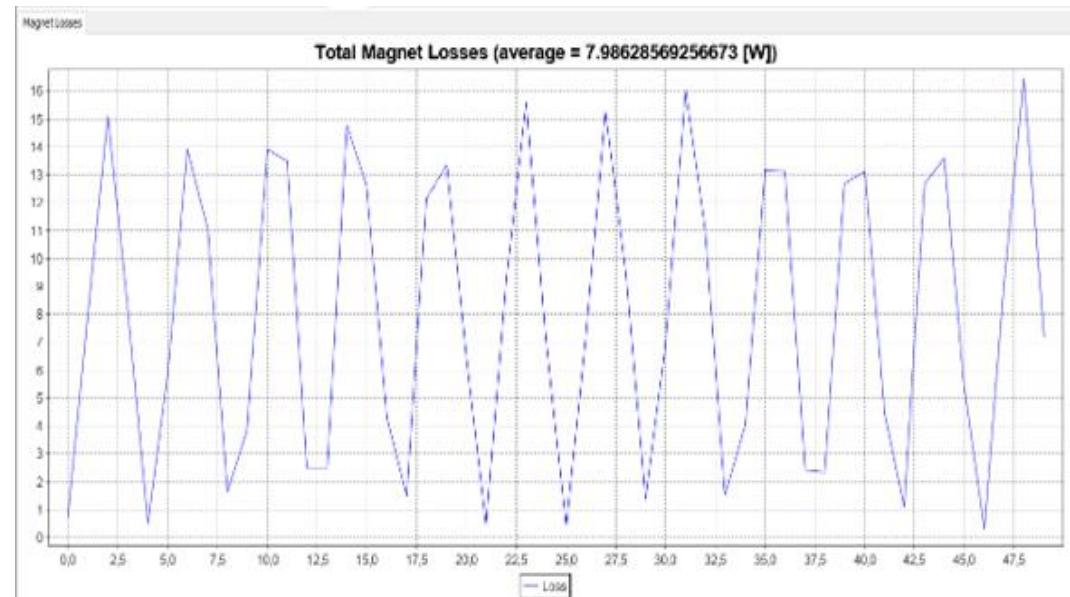
Vergleich: Generator

Ansys Maxwell Simulation



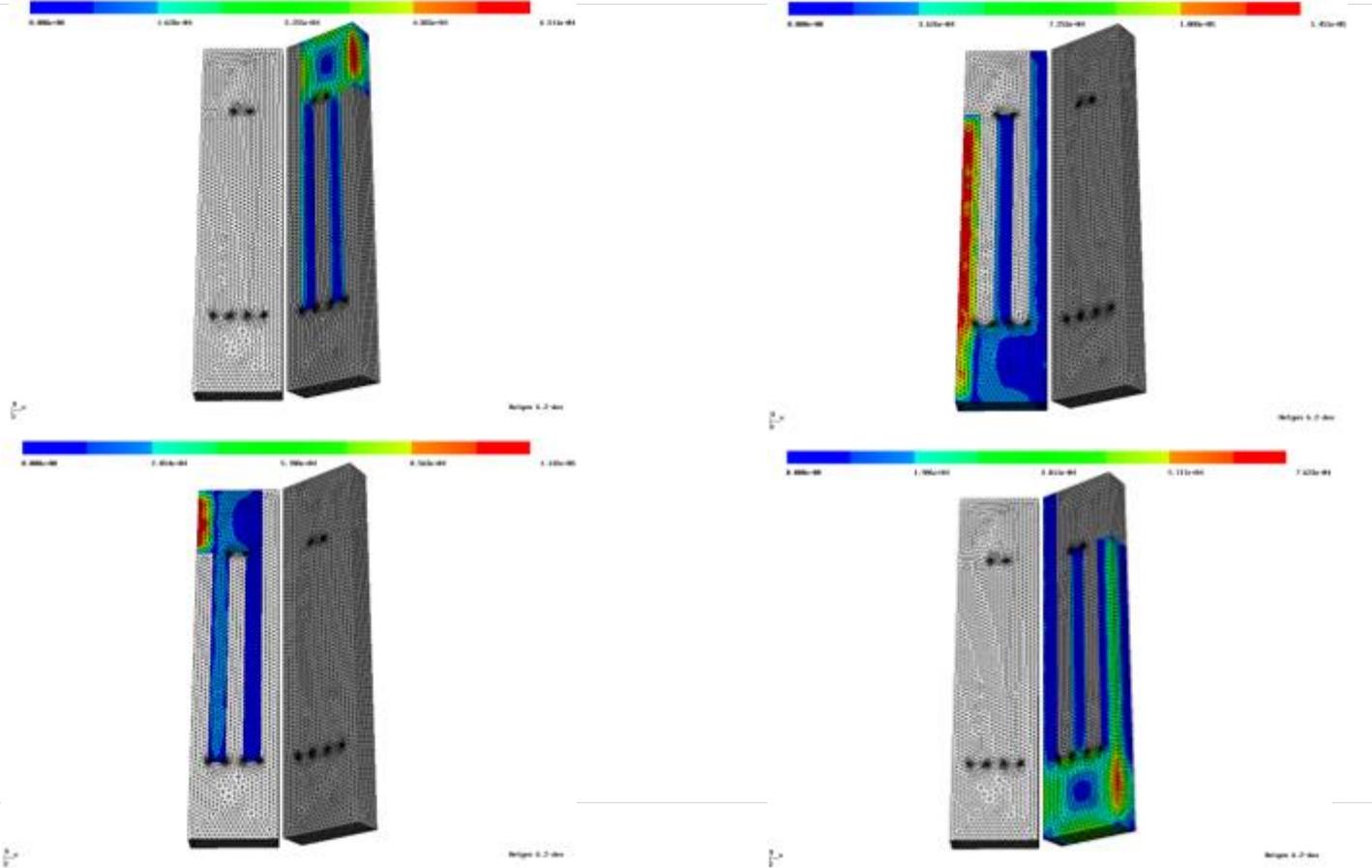
Maxwell avg. losses: 7.36 W

NGSolve Simulation

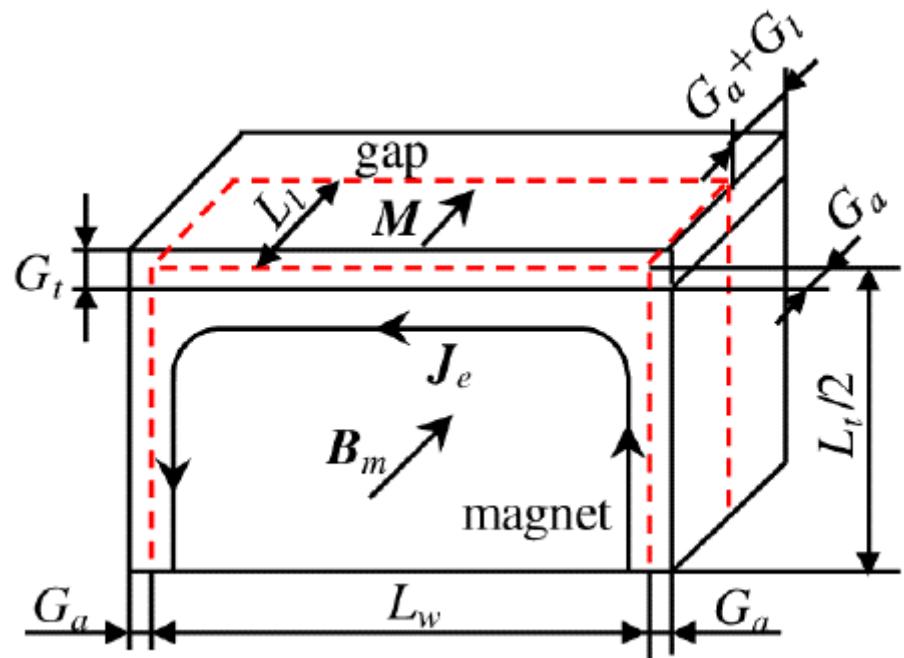


NGSolve avg. losses: 7.98 W

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



Extensions

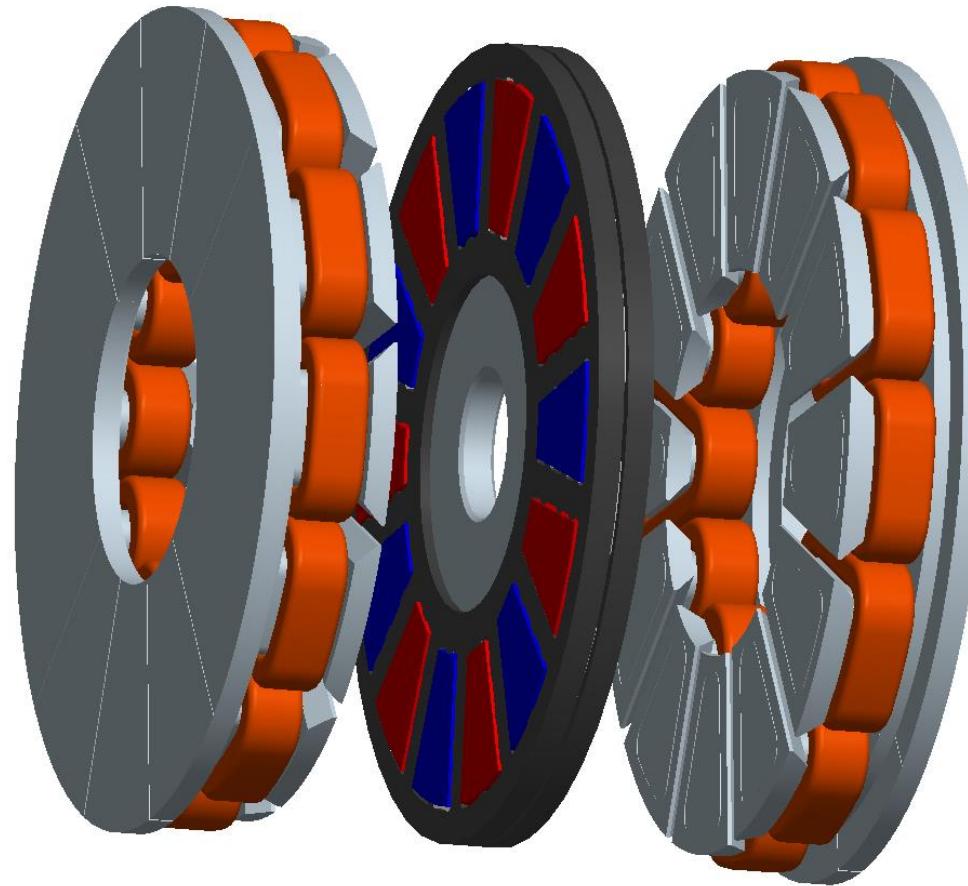


- Berücksichtigung der Rückwirkung
[Okitsu2009]

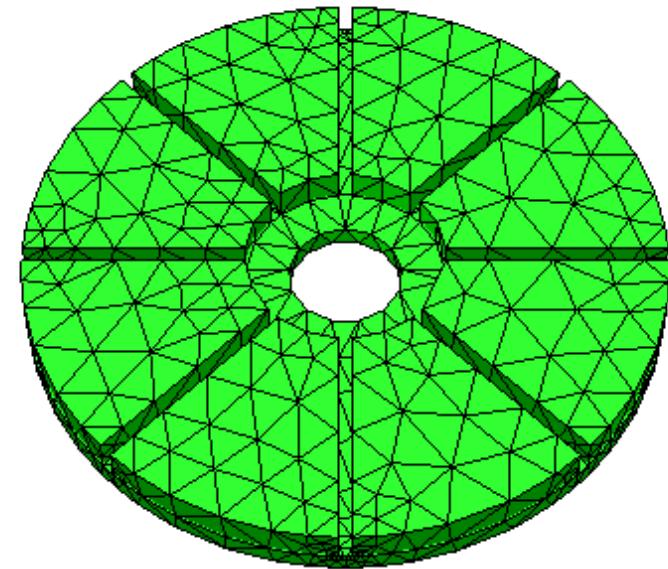
Referenzen

- [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.
- [Stentjes2015]: S. Stentjes, 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.

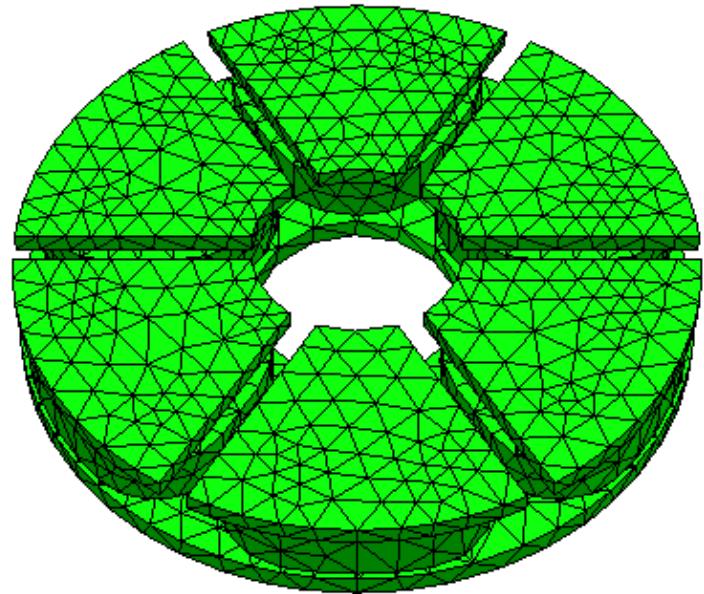
Axial Flux Machine



Geometrie: Rotor

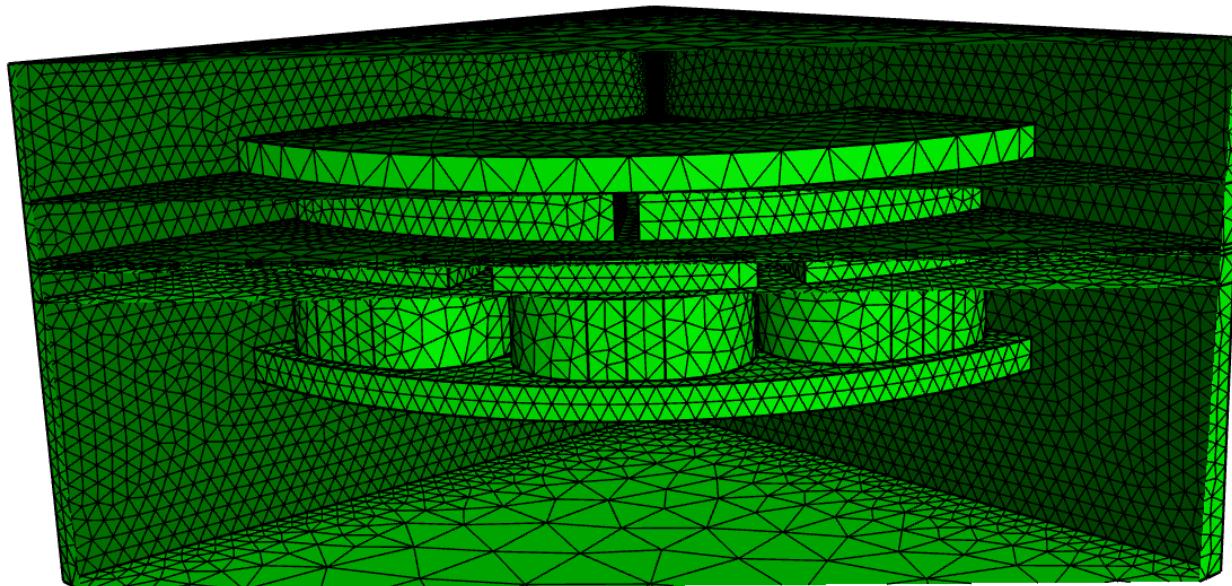


Geometrie: Stator



Netgen 6.2-dev

Geomtrie



Nitsche Mortaring

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

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

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

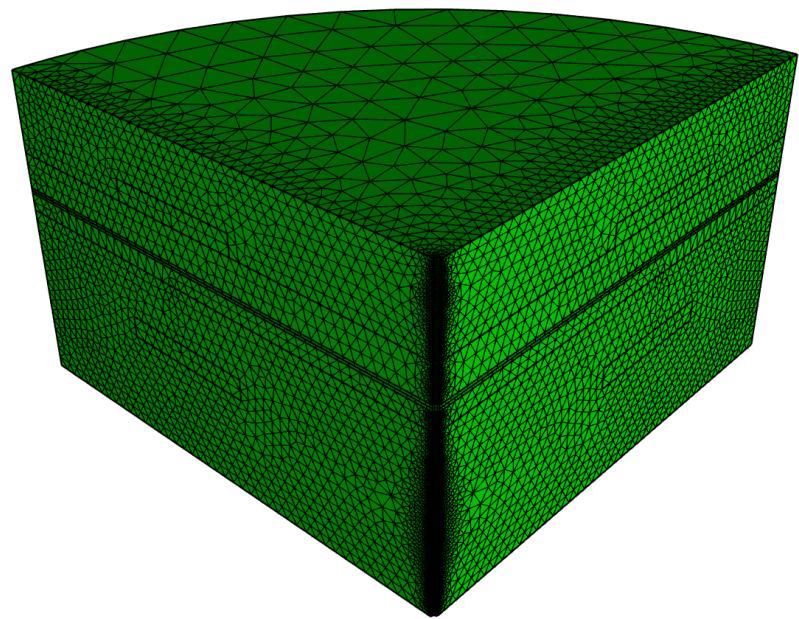
Semilinear Form

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

Linear Form

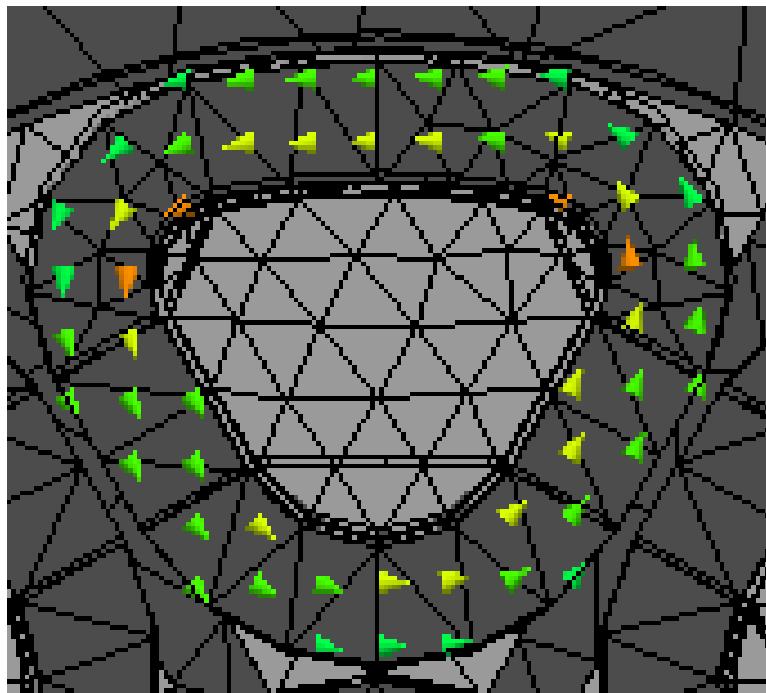
$$\langle f, v \rangle = \sum_{i \in \{R, S\}} \int_{\Omega_i} (J \cdot v + M \cdot \operatorname{curl} v) \, dx$$

Implementierung I



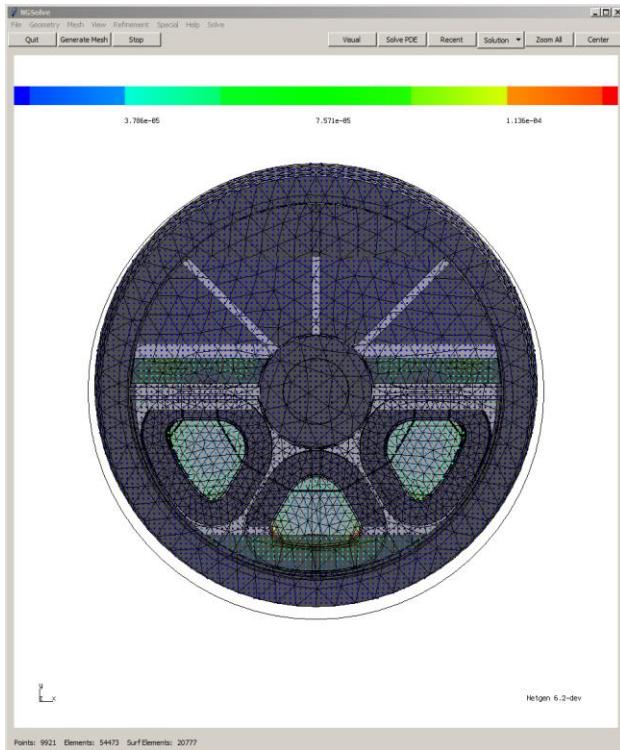
- Geometrien fusionieren
- Berechnung der Bestromungsfelder in den Spulen
- Berechnung des Vektorpotentials
- Bestimmung von Drehmoment und Verketten Flüssen

Implementierung II



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

Implementierung III

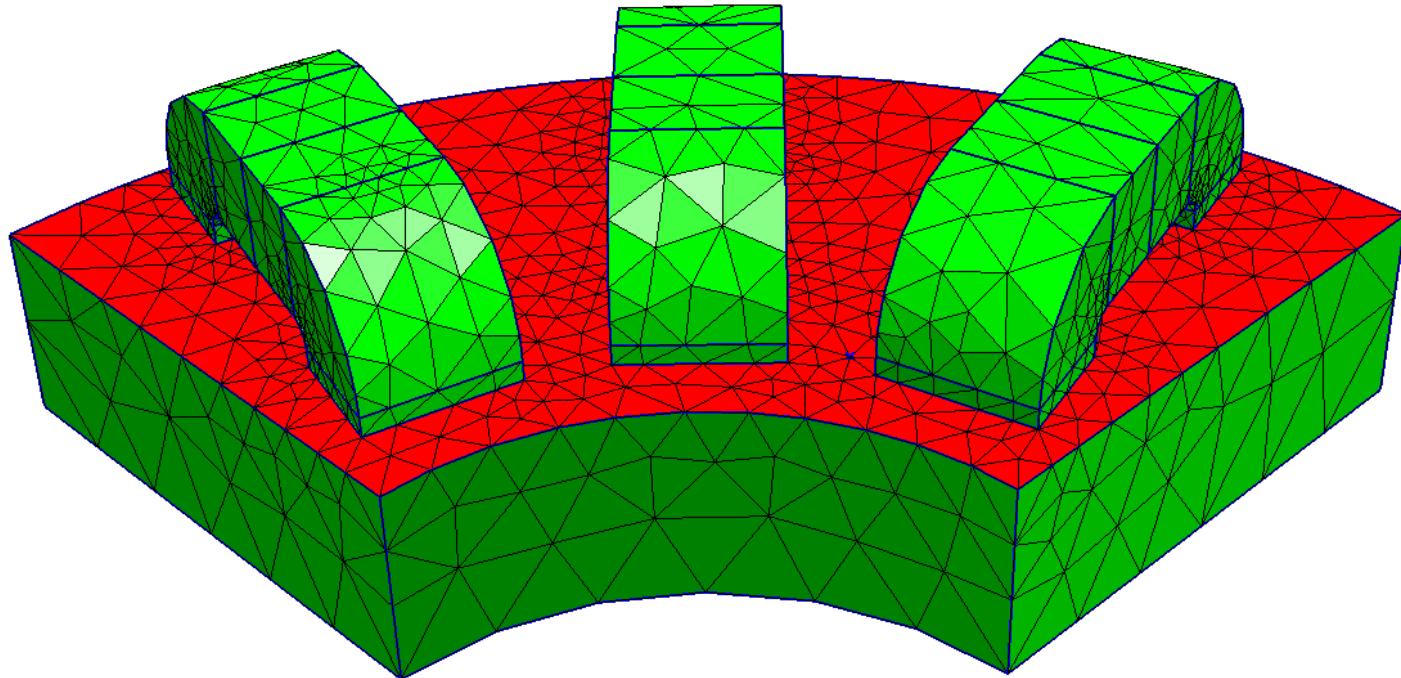


- Geometrien fusionieren
- Berechnung der Bestromungsfelder in den Spulen
- Berechnung des Vektorpotentials
- Bestimmung von Drehmoment und Verketten Flüssen

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





Haben Sie noch
Fragen?