COMSOL CONFERENCE 2017 ROTTERDAM

Finite Element Method based Investigation of IPMSM Losses

Martin Schmidtner,
Prof. Dr. –Ing. Carsten Markgraf,
Prof. Dr. –Ing. Alexander Frey

starkstrom AUGSBURG
FSE Racing Team UAS-Augsburg

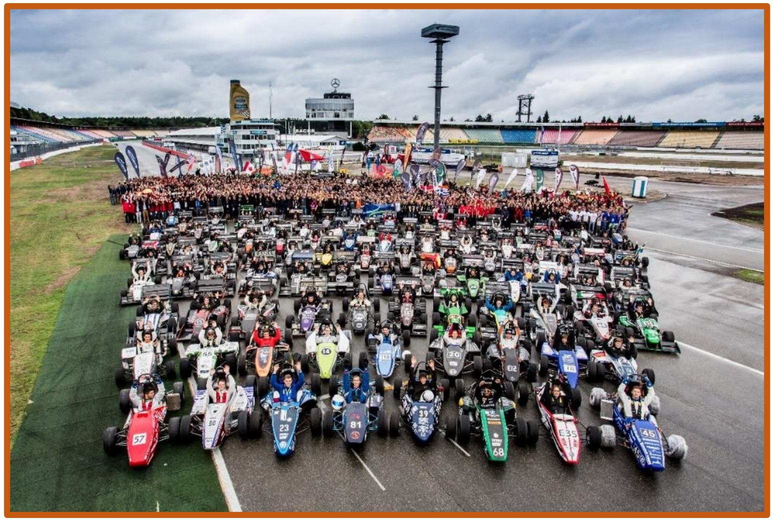
Agenda:

- Introduction
- Motor Concept
- Theory
- Winding Losses
- Iron Losses

Introduction: The Project

- Formula Student:

The Competition challenges teams of university students to conceive, design, fabricate, develop and compete with small formula style race cars.
(rules Formula Student)

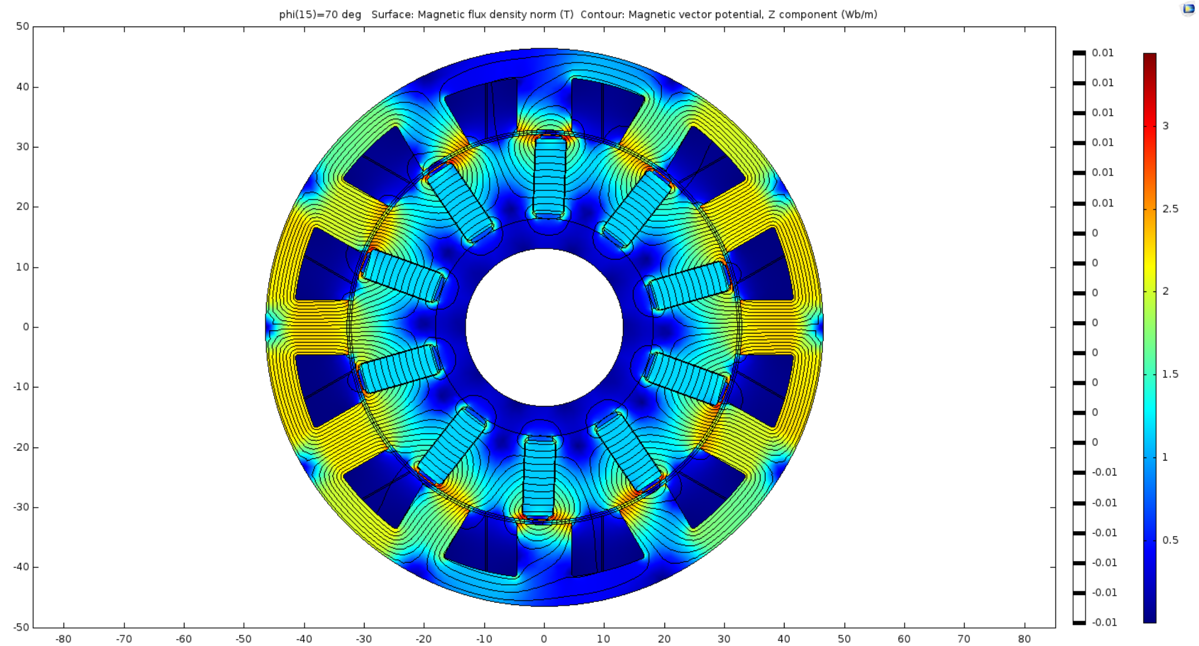


starkstrom AUGSBURG
FSE Racing Team UAS-Augsburg

Introduction: Topic

Develepmoment of a **<u>permanent excited synchronous motor</u>** for a four wheel drived FSE-vehicle:

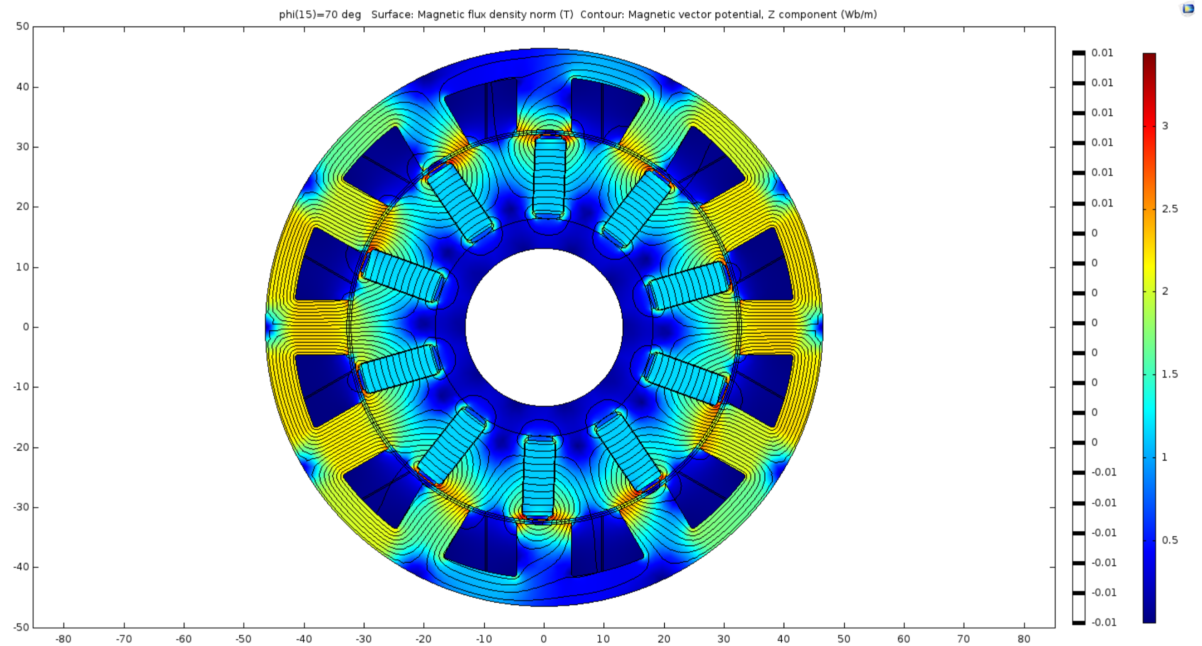
- electromagnetic field calculation
- mechanical design
- thermal behaviour
- building and testing



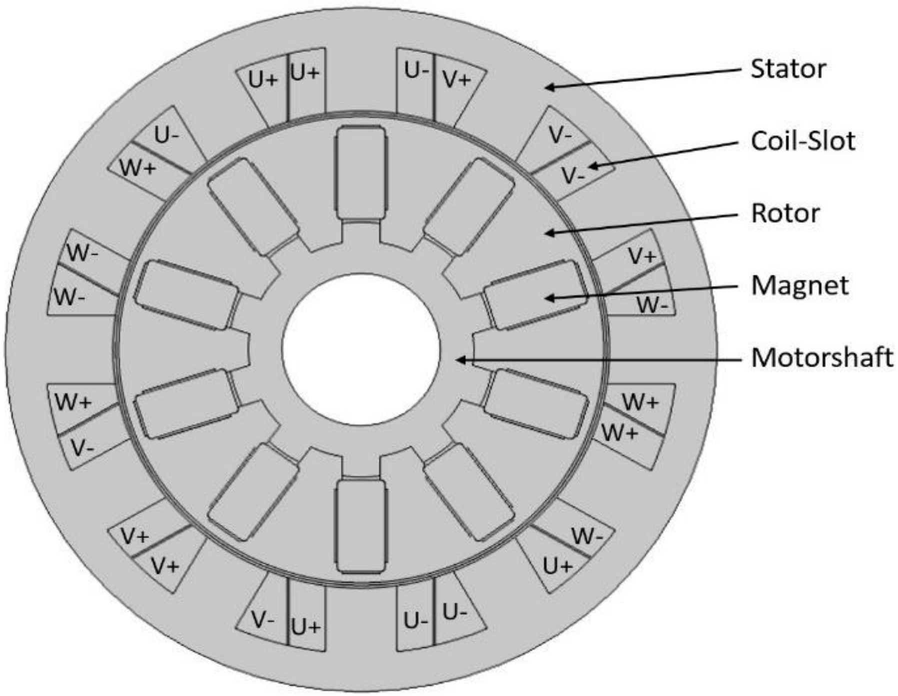
Introduction: Topic

Develepmoment of a **permanent excited synchronous motor** for a four wheel drived FSE-vehicle:

- electromagnetic field calculation
- mechanical design
- thermal behaviour
- building and testing



Motor Concept



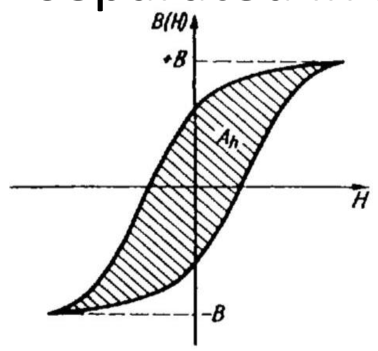
Motor Data	
Motor Type	IPMSM
Connection Type	Star Connection
Stator Slots	12
Pole Pairs	5
Number of Winding	19
Max. Phase Current	70 A
System Voltage DC	600V
Max. Torque	21 Nm
No-Load Base Speed	Ca. 16.000 Nm
Outer Diameter	89,9 mm
Estimated Weight	5 kg
Requested Power Peak	21 kW
Requested Power Nominal	12,5 kW

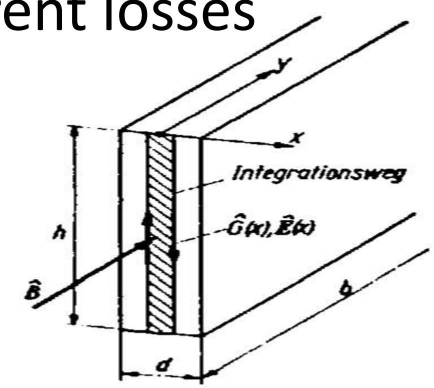
Theory

- **Winding Losses**
  - accrue due to the electrical resistance of the windings
  - resistance depends on material property, geometry and temperature

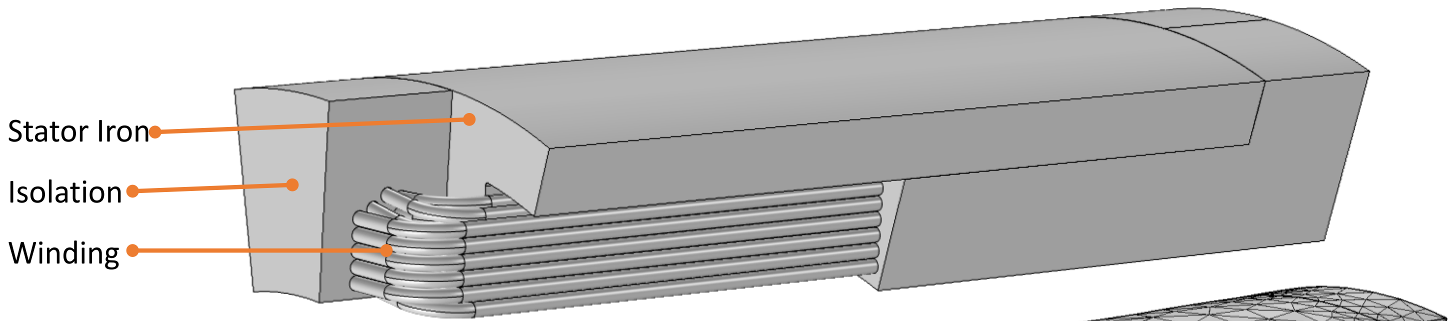
$$R = \frac{L_{coil}}{\sigma_{cop} * A_{coil}} \quad \Rightarrow \quad R(\vartheta) = R_{ref} * [1 + \alpha(\vartheta - \vartheta_{ref})] \quad \Rightarrow \quad P_{win} = m * R * I^2$$

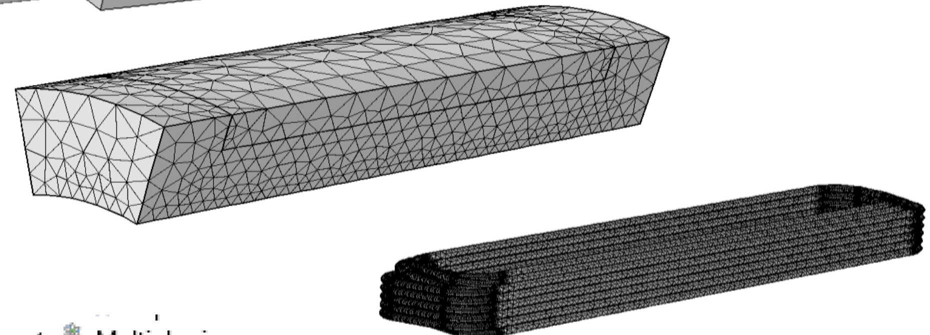
- **Iron Losses**
  - separated in hysteresis and eddy current losses





Winding Losses





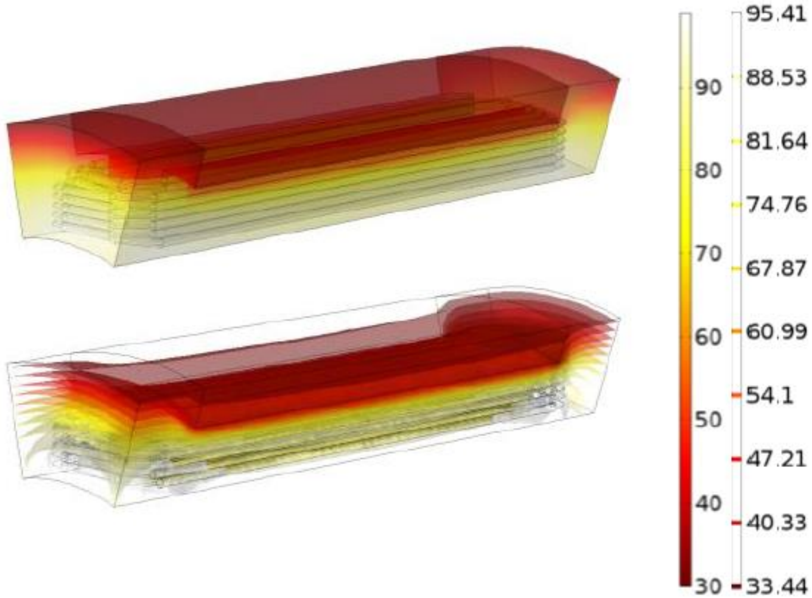
- ➢ 3D transient model
- ➢ Reduced by geometric symmetry
- ➢ Nodes:

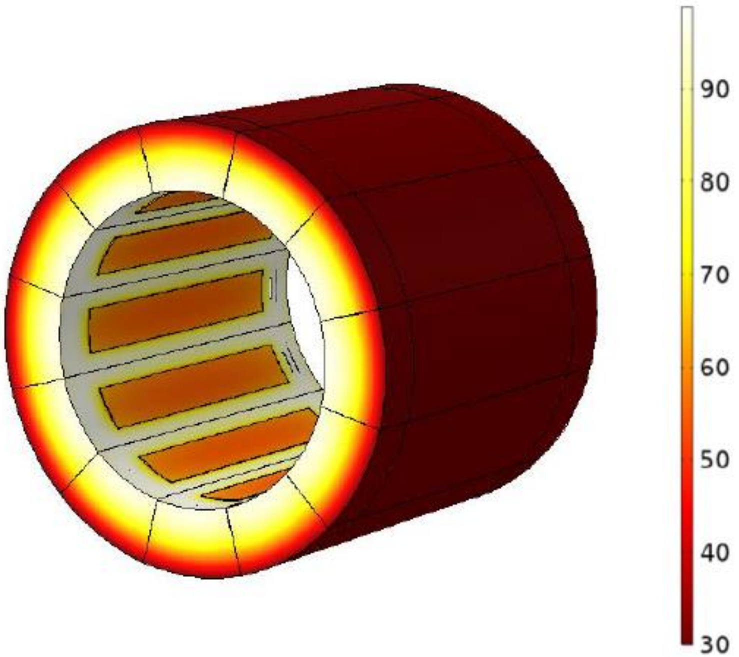
- Electric Currents *(ec)*
  - Current Conservation 1
  - Electric Insulation 1
  - Initial Values 1
  - Terminal 1
  - Ground 1
  - Equation View

- Heat Transfer in Solids *(ht)*
  - Heat Transfer in Solids 1
  - Initial Values 1
  - Thermal Insulation 1
  - Diffuse Surface 1 - Iron
  - Diffuse Surface 1 - Epoxid
  - Heat Flux 1 -Iron
  - Heat Flux 1 -Epoxid
  - Periodic Condition 1
  - Temperatur 1
  - Equation View

- Multiphysics
  - Electromagnetic Heat Source 1 *(emh1)*
  - Boundary Electromagnetic Heat Source 1 *(bemh1)*
  - Temperature Coupling 1 *(tc1)*

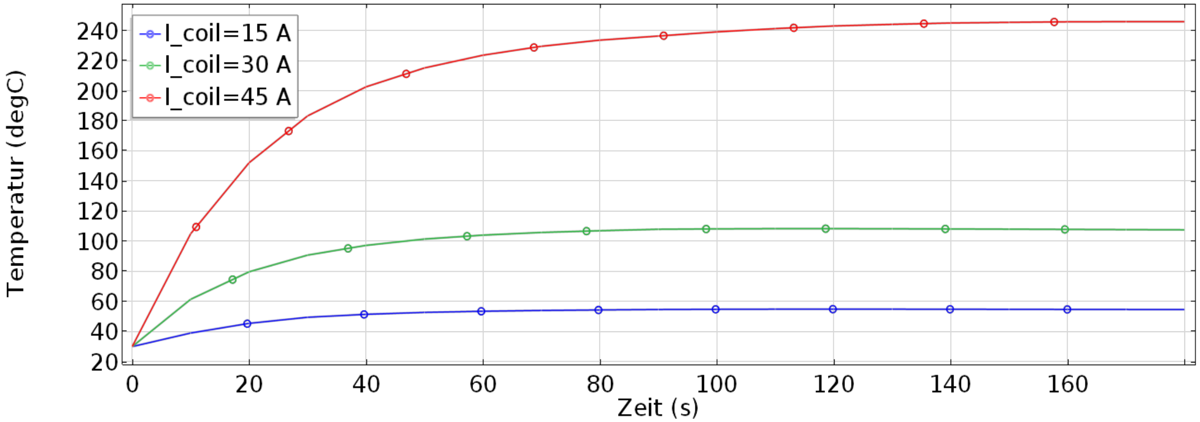
Winding Losses

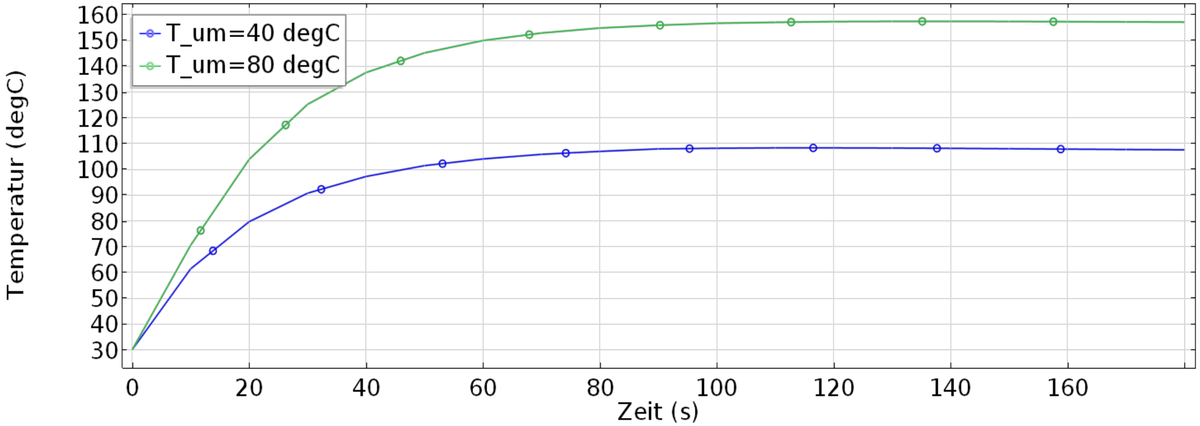




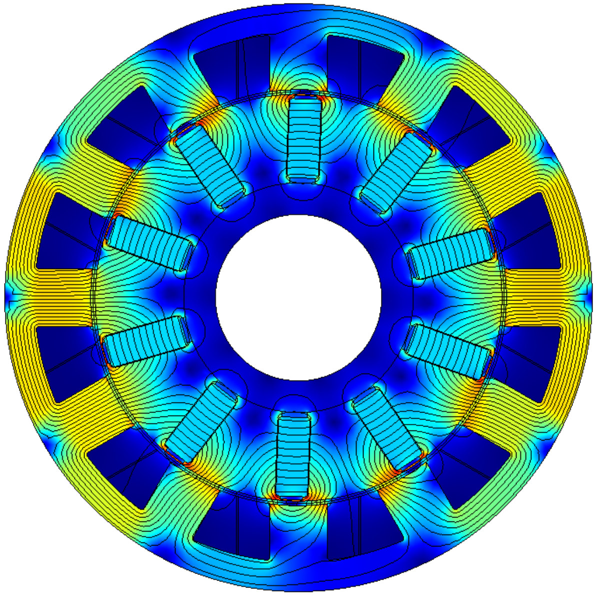
- input current 30 A
- stationary temperature: 95,41 degC
- hottest location at the end windings

Winding Losses





Iron Losses



Postprocessing

Hysteresis

$$p_{hyst} = \frac{1}{\rho * T} \int_0^T \left[H_c * \left(\frac{dB}{dt} \right) \right] dt$$

Eddy Current:

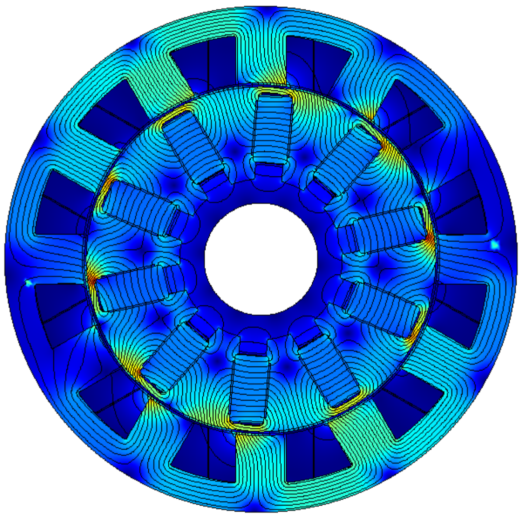
$$p_{eddy} = \frac{1}{2 * \pi^2 * T} \int_0^T \left[k_{eddy} * \left(\frac{dB}{dt} \right)^2 \right] dt$$

$$k_{eddy} = \frac{\pi^2 * \sigma * d^2}{2 * \lambda * \rho} * \frac{\sinh \lambda - \sin \lambda}{\cosh \lambda - \cos \lambda}$$

$$\lambda = \frac{d}{\delta}$$

$$\delta = \frac{1}{\sqrt{\pi * f_{el} * \mu * \sigma}}$$

Iron Losses

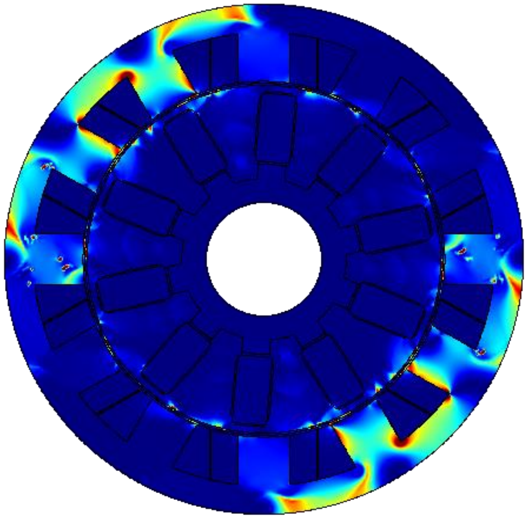


Magnetic Solution

$I = 50A$

$f = 2500\ Hz$

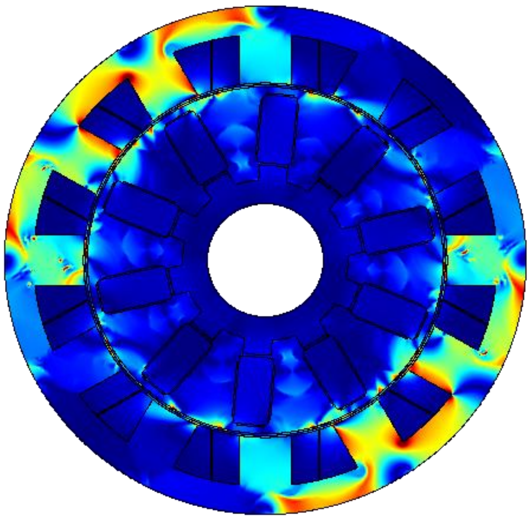
$f = 5000\ Hz$



Eddy Current

$P_{eddy} = 0{,}1\ W$

$P_{eddy} = 0{,}43\ W$

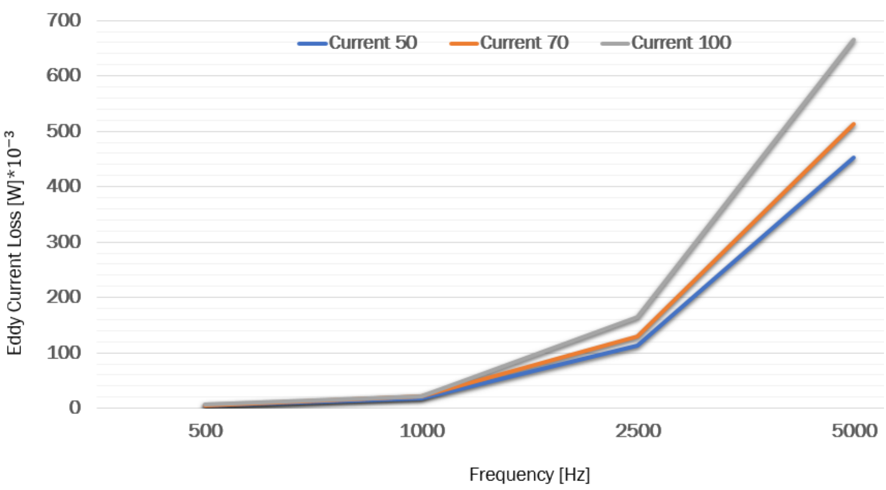


Hysteresis

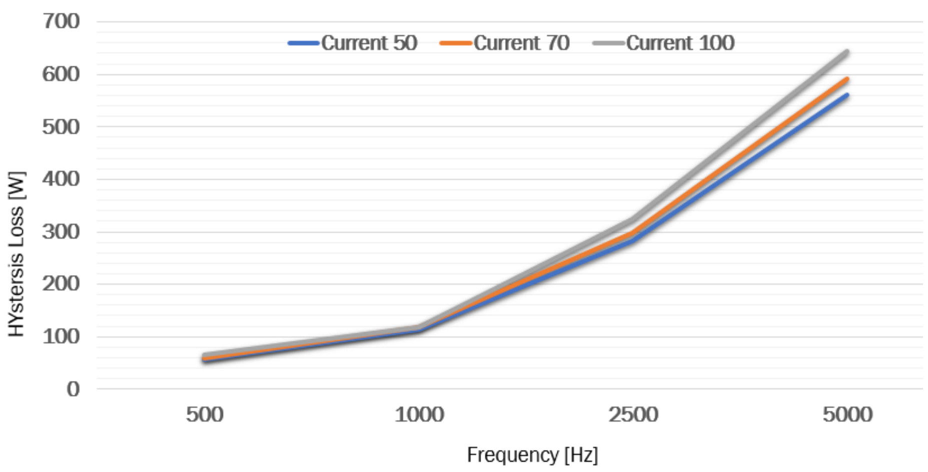
$P_{hyst} = 280\ W$

$P_{hyst} = 550\ W$

Iron Losses



Eddy Current



Hysteresis

Summary

- modelling process defined
  - models meets the qualitative expectations
  - accuracy has to be validated by physical test

- physical tests are necessary
  - fit model parameter
  - prove and increase the accuracy