TRATON

TOWARDS VIRTUAL PROTOTYPING: MULTIPHYSICS SIMULATION OF E-MACHINES

Advanced eMotor Design Conference 2025

Ciro Alosa

October 1st, 2025 - Stuttgart

SCANIA / MAN / INTERNATIONAL / VW Truck Bus

CONTENT OF THE PRESENTATION

- About Traton Group
- Introduction to Virtual Prototyping and Motivation
- 2D electro-mechanical simulation considering rotor mechanical stress
- 2D electromagnetic simulation including edge cutting effects
- 3D electromagnetic simulations
- Conclusions and next steps

OUR PURPOSE

TRANSFORMING TRANSPORTATION TOGETHER.

FOR A SUSTAINABLE WORLD.

ABOUT THE TRATON GROUP

With its brands Scania, MAN, International, and Volkswagen Truck & Bus, TRATON SE is the holding company of the TRATON GROUP and one of the world's leading commercial vehicle manufacturers. The product portfolio comprises trucks, buses, and light-duty commercial vehicles.

Our purpose is:
"Transforming Transportation Together. For a sustainable world."

DEVELOPMENT OF THE GROUP AND ITS BRANDS

2015

Volkswagen AG creates Volkswagen Truck & Bus GmbH to bundle its MAN, Scania, and Volkswagen Caminhões e Ônibus brands

2018

Volkswagen Truck & Bus becomes the TRATON GROUP

2019

IPO of TRATON SE

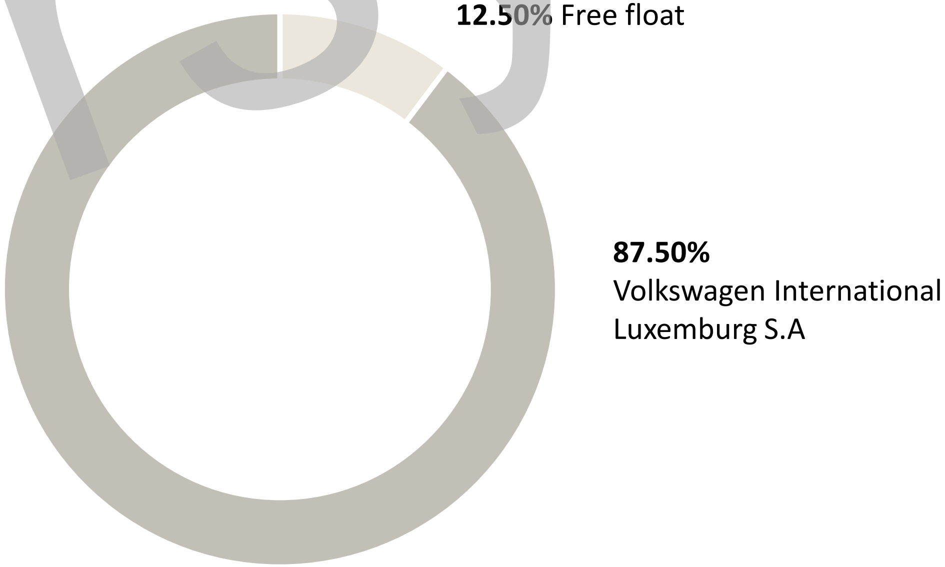
2021

TRATON acquires International (formerly Navistar)

2022

TRATON’s brand Scania with its own production site in China, groundbreaking in Rugao

TRATON SE SHAREHOLDER STRUCTURE



FOUR STRONG BRANDS UNDER ONE ROOF

SCANIA

- Proud leader in premium transport solutions, specializing in heavy-duty trucks with an array of tailored services and applications
- Empowers business partners and customers through strong, trusted collaboration and a firm commitment to guiding them through the shift to fossil-free transportation
- Serves markets across Europe, North and South America, Asia, Africa, and Oceania with a global footprint

MAN

- A strong German heritage brand, operating internationally across Europe, Asia, the Middle East, Africa, and South America
- MAN's USP is its extensive range of transport solutions, from light commercial to durable construction vehicles and heavy-duty trucks.
- What truly sets MAN apart is its unwavering commitment to its customers, constantly striving to optimize their businesses and adapt to the dynamic changes in their requirements.

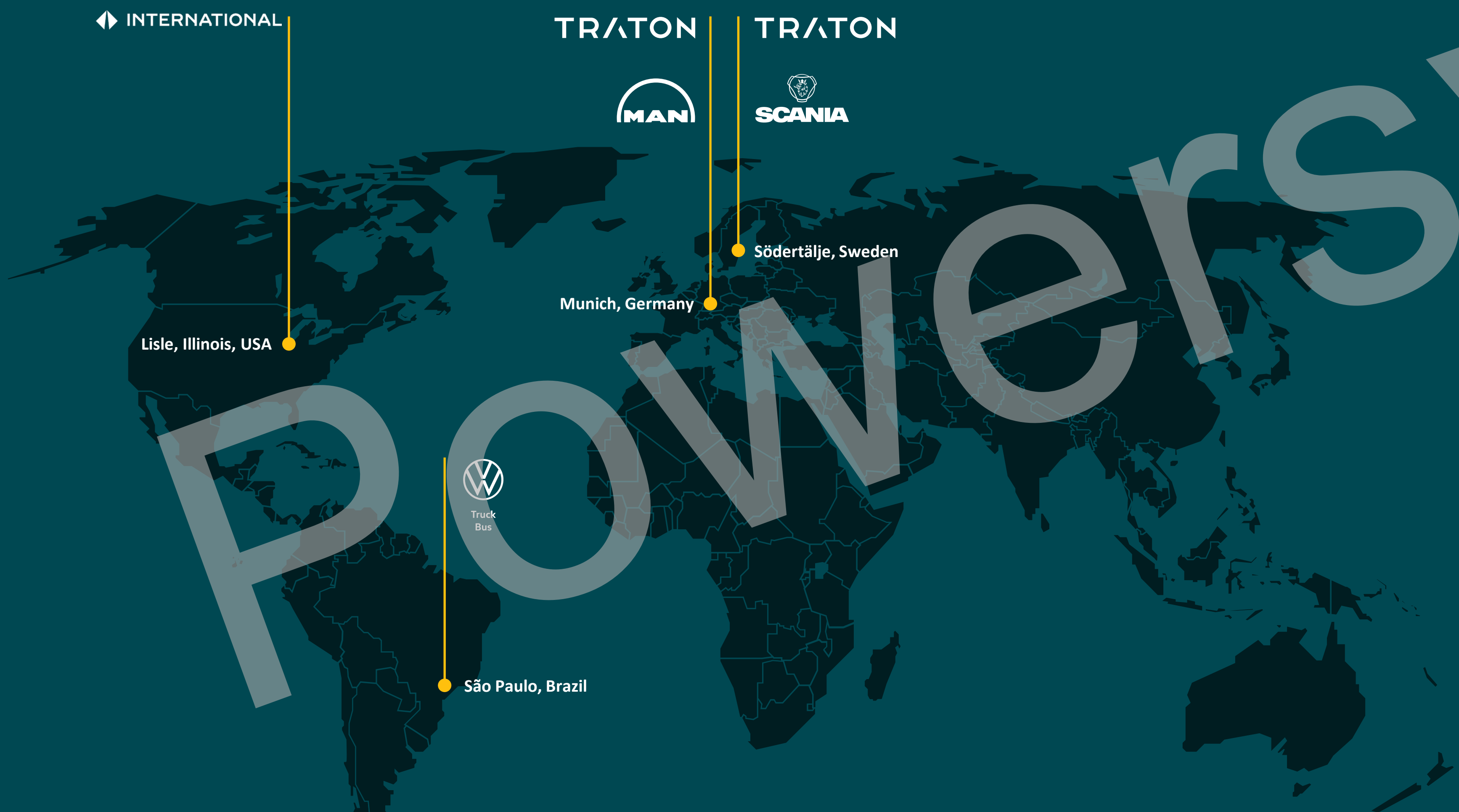
INTERNATIONAL

- High-performance manufacturer of trucks and buses
- International's North American roots date back to the 1800s, when its predecessors pioneered mechanized harvesting. Today, International offers comprehensive mobility solutions for North America.
- Key strengths include its vast dealer network, deep industry expertise and exceptionally strong and loyal customer relationships.
- Formerly Navistar, International is now moving into its next chapter under the new overarching brand.

Truck
Bus

- Stands for unparalleled value-for-money solutions. Its core competence is vehicles that are robust, reliable, and efficient – tailored to meet the unique conditions of emerging growth markets and the specialized applications required there.
- Strong presence in South America, Mexico, Africa, and Asia underlines its adaptability and commitment to meeting the specific needs of its customers in these dynamic regions.

TRATON AT A GLANCE: OUR GLOBAL FOOTPRINT

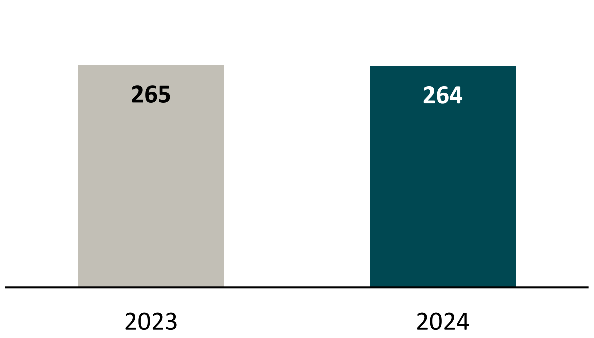


Commercial vehicle brands	4
Countries[1]	12
Production sites	25

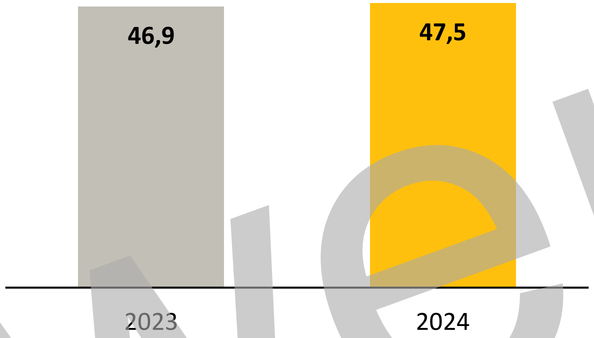
1 Number of countries where the TRATON GROUP has production sites. In addition, our brands Scania, MAN, International, and Volkswagen Truck & Bus also have regional product centers, assembly sites, sales offices, and research & development facilities in many countries around the world.

TRATON AT A GLANCE: FULL-YEAR KEY FIGURES IN COMPARISON

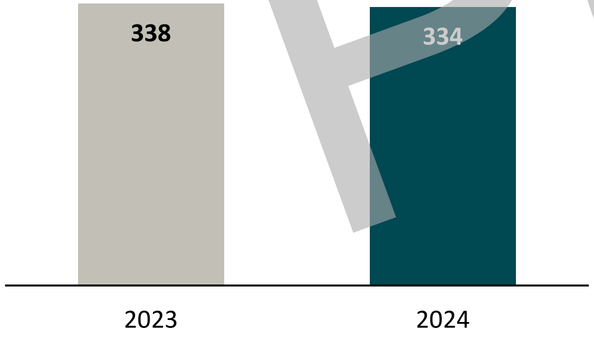
Incoming orders
(k units)



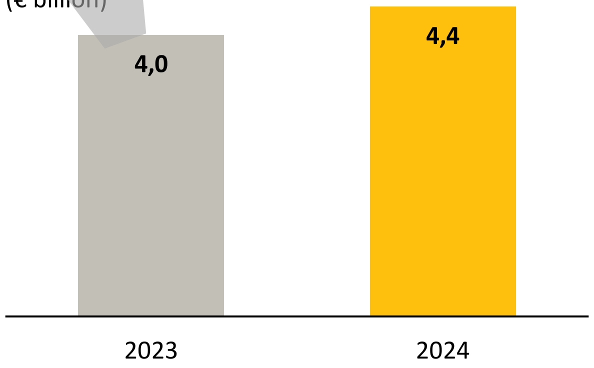
Sales revenue
(€ billion)



Unit sales
(k units)



Adjusted operating result
(€ billion)



Fiscal year 2024
Summary

Active workforce	105,541
Earnings per share	€5.61
Adjusted operating return on sales	9.2%

INTRODUCTION TO VIRTUAL PROTOTYPING AND MOTIVATION

INTRO TO THE VIRTUAL PROTOTYPING USE CASE

POWERSYS

JMAG®
Simulation Technology for Electromechanical Design

TRATON

POWERSYS – TRATON COLLABORATION

REPRESENTS AN INITIAL INVESTIGATION/STEP FOR VIRTUAL PROTOTYPING APPLIED TO ELECTRICAL MACHINES

IDEA IS TO EXPAND TOWARDS A LARGE SCALE VIRTUAL PROTOTYPING FOR POWERTRAIN

MOTIVATION

Design of e-machines for truck applications is challenging

- High torque requirements in combination with high torque density
- High power in combination with high power density
- Reduce amount of rare earth materials
- Agressive cost targets

Competition is intense

- Time to market must be reduced
- Cost must be reduced
- Need for rapid iterations
- Need for fast development time

VIRTUAL VS HARDWARE TESTING

OEMs require multiple prototypes during the development process

Reluctant to change the traditional way of working

Historically, testing has been the sole method to validate design functionality

Virtual testing requires a new method development that involves multiple functions

Even if not needed for e-machines, other interfacing components still need hardware to perform integrated system level validation

HARDWARE TESTING

Hardware testing is one of the **weakest points** in the development process

- requires a long time (several months), from design freeze to end of testing
- needs dedicated resources (materials, engineers) and the cost is high
- despite the creation of multiple prototype generations, design freezes are frequently executed without integrating the lessons learned from previous iterations due to stringent time-to-market demands
- debugging early issues with very quick fix solutions often leads to unreliable conclusions
- testing is done for a single or a few samples, whereas with virtual prototypes one can easily take multiple factors into account and perform multiple iterations

VIRTUAL PROTOTYPING

- **High-fidelity 2D/3D multi-physics models** – capture complex physical interactions
- **Comprehensive behavior coverage** – replicate all key prototype responses
- **Robust sub-component testing** – ensure accurate material and component characterization
- **Reduced hardware prototyping** – reduce reliance on physical prototypes
- **System integration** – coupling with inverter, gearbox, and other interfacing components

BENEFITS OF VIRTUAL PROTOTYPING

reduced amount of prototypes

- reduced time to market
- reduced cost
- less testing needed

faster development time

- fast feedback
- possibility to iterate over a design multiple times before design freeze

reduced time to market

digital twin for predictive maintenance

hardware in the loop

simulation driven design for manufacturing

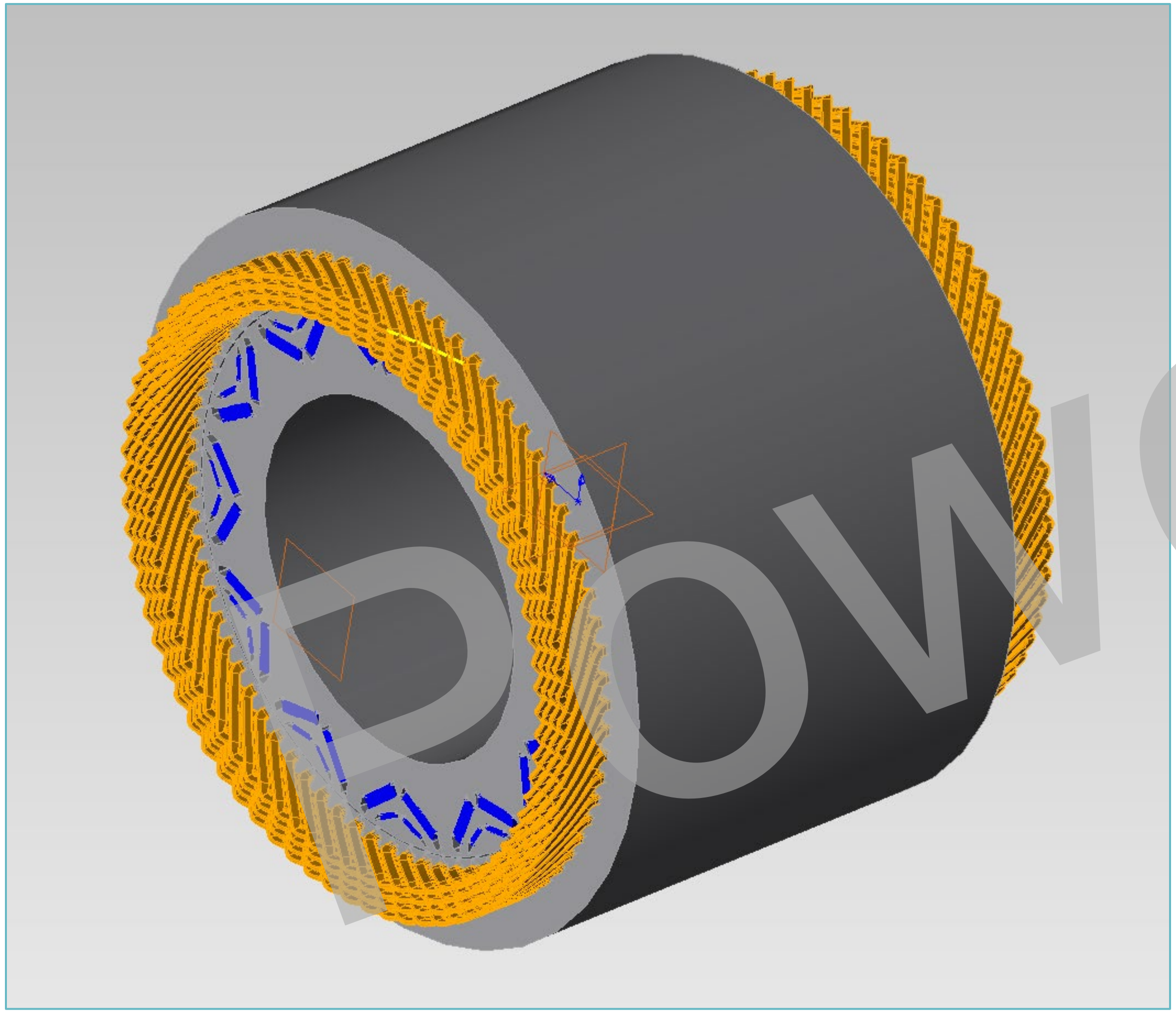
- useful for an in-depth FMEA
- manufacturing effects and tolerances considered
- achieve a more robust design from the beginning

HOW TO ACHIEVE VIRTUAL PROTOTYPING

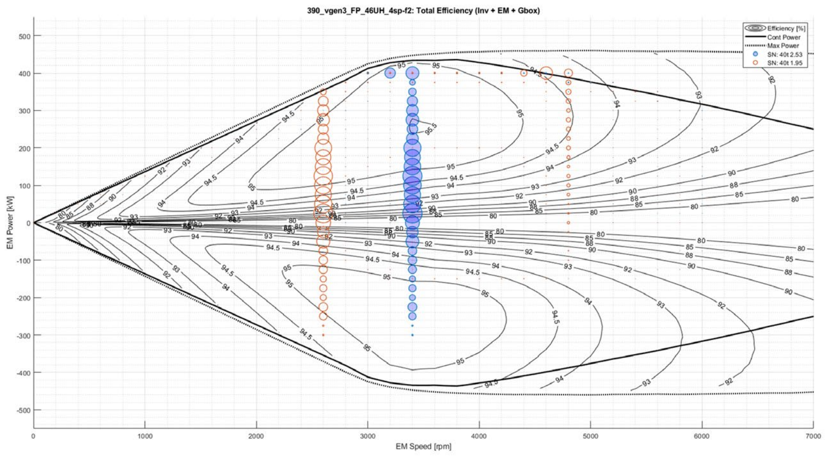
Good knowledge of **software** and method development	• time consuming, need to prioritise with respect to product development • dedicated validation engineers that take place of testing engineers
Extensive **computational power**	• investment in HPC • investment in software licensing
Very good knowledge of the **materials used**, in order to model them effectively in the simulation	• investments in material characterization instruments • sub-component testing is necessary!
Multi-team effort to allow different physics to interact with each other (e.g. coupled simulation)	• need for multi-team coordination, model based design engineering (MBDE) • usually different software are used → need to build interfaces between them
Extensive knowledge of **manufacturing processes** in order to simulate deviations	• not always models available • not so simple to model all the possible effects, especially when impacting life
Validation of simulation at the beginning, focusing on each subcomponent	• fundamental to build knowledge in the company • need to demonstrate that it works!

USE CASE: 2D

ELECTRICAL MACHINE USED FOR INVESTIGATION



Number of Poles	12
Number of Slots	72
Winding	8 Layer hairpin
DC bus voltage	800 V
Maximum speed	7000 rpm
Maximum power	450 kW
Application	Heavy-Duty CV



MATERIAL SCIENCE FOR LAMINATION MATERIALS

Average torque
- Target torque is achieved with higher current rating

Efficiency
- Drive cycle/range requirements are not met

Torque ripple
- NVH requirements are not met
- Data used for NVH simulation is not correct

Soft magnetic materials properties (BH curves and losses) are sensitive to mechanical stress and manufacturing processes

Material degradation effects can significantly reduce the performance of the machine

Manufacturing effects are heavily depend on processes and aging of the tooling

Challenges

- Material supplier usually publish only the typical BH and loss curves.
- Manufacturer must built up their own **material characterization competency**:
  - investments can be large
  - measurements can be incorporated with the serial production to improve quality and generate material data base
- The effects are material and process dependent
- Modelling in FEA simulation can be time consuming

Investigating the effect at the early design phase can support manufacturing FMEA discussions and factory quality assurance in terms of tooling maintenance period

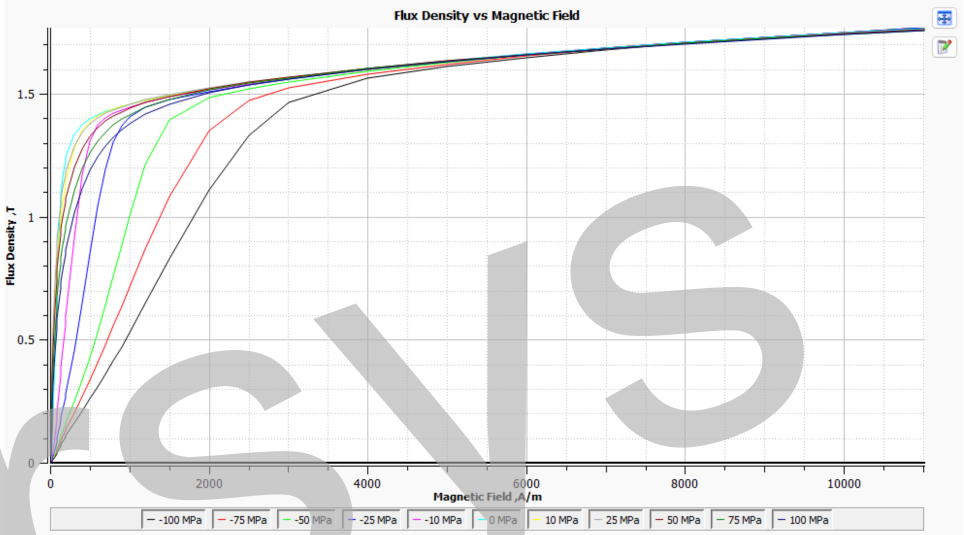
MATERIAL SCIENCE IN JMAG

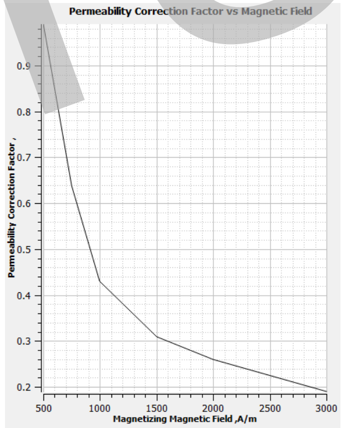
JMAG offers **material models** and built-in **modelling features** which allow to include these effect at the early phase of design (if the relevant data are provided)

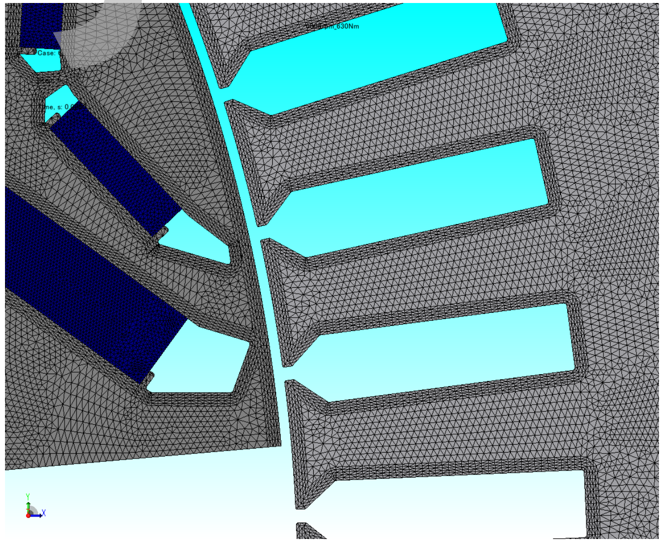
Multiphysics solvers offer the possibility to create analysis groups and exchange field data easily during optimization or during detailed design

Stress dependant BH model and iron loss models are available for isotropic soft magnetic steels

Residual strain condition for edge degradation modelling with automatic layered mesh generation and degraded material property assignment for the mesh is available

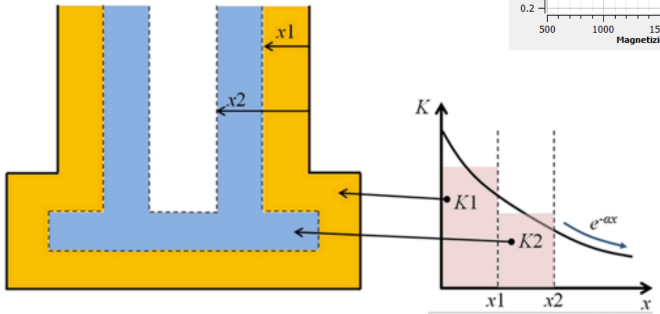






$$K_\mu(H,x) = K_\mu(H,0)e^{-\alpha x}$$

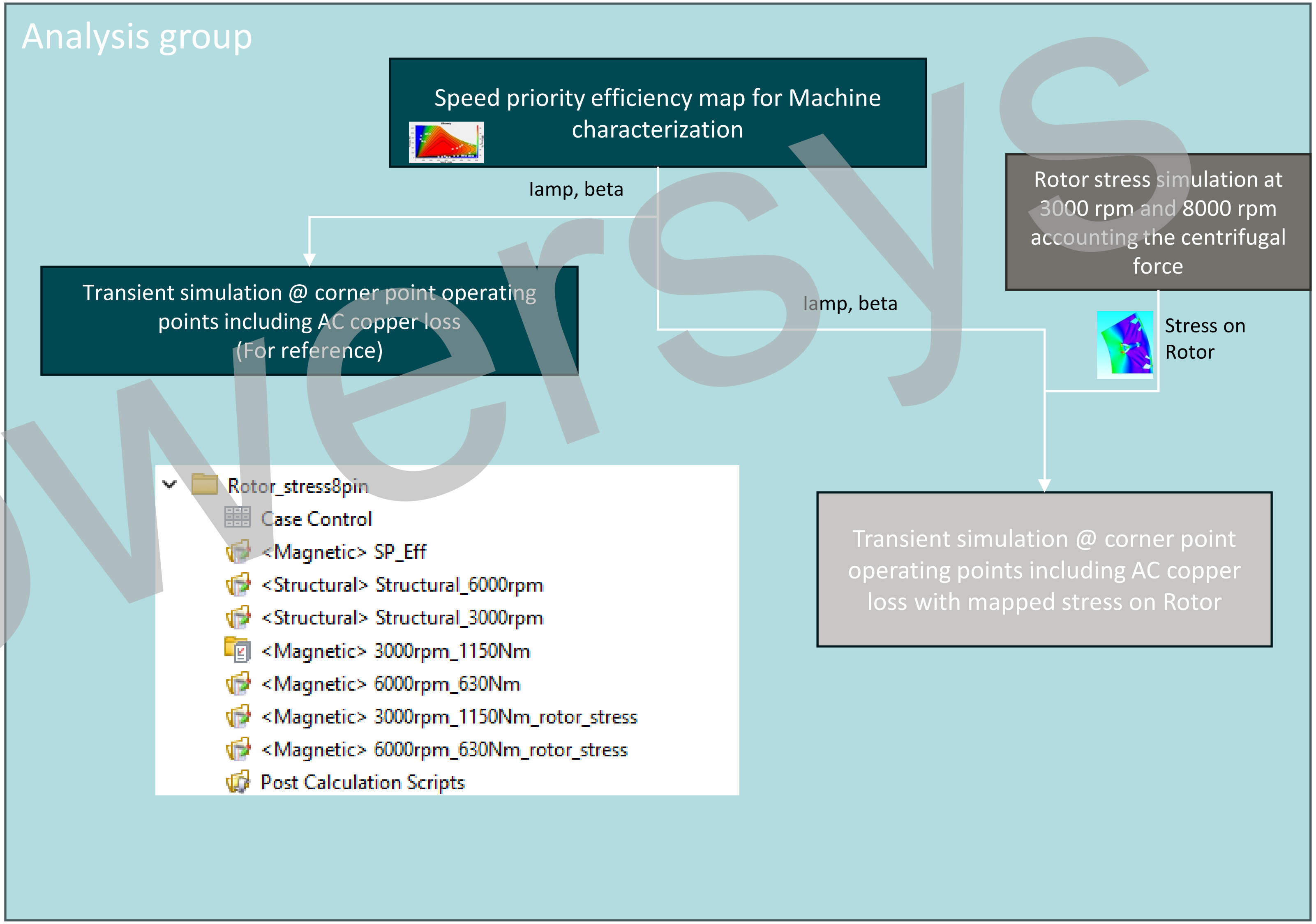
$$\mu'(H,x) = \mu(H)(1-K_\mu(H,x))$$



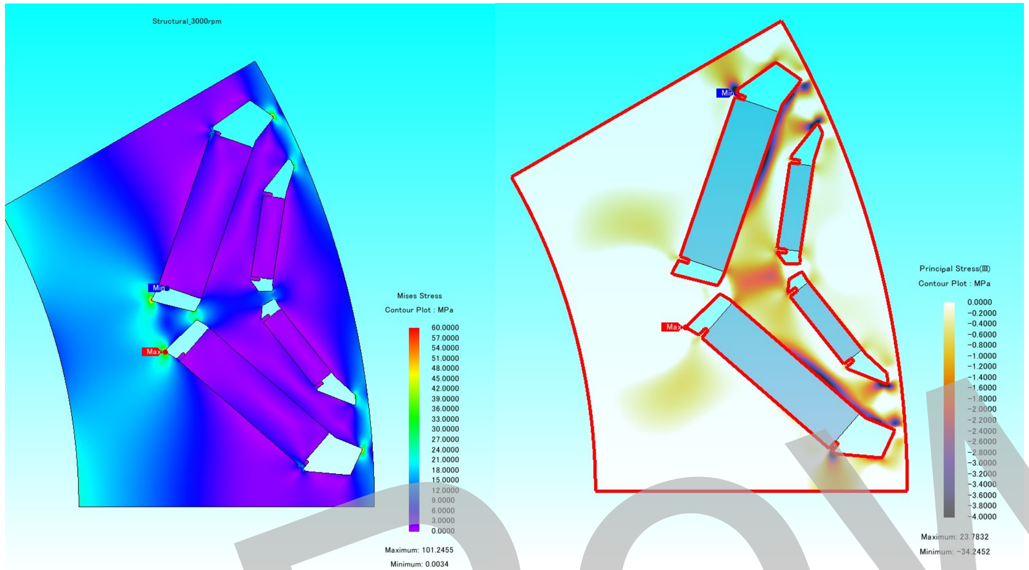
ROTOR STRESS IMPACT WORKFLOW

Selected load points:

- 6000rpm, 630 Nm
- 3000rpm, 1150 Nm



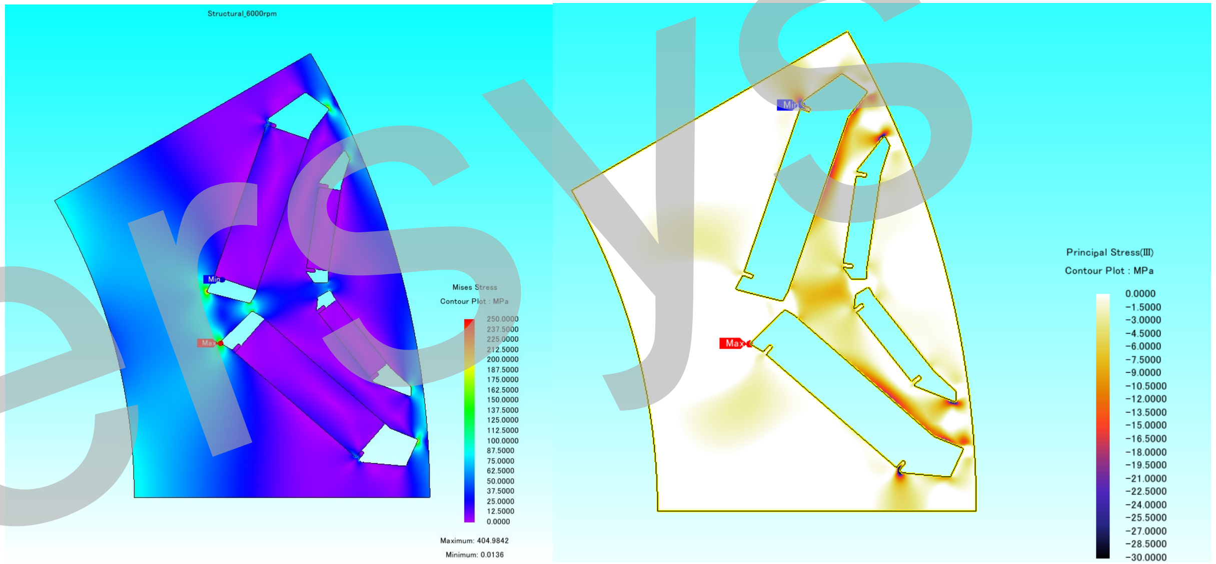
STRUCTURAL SIMULATION RESULTS



Von misses Stress distribution (left) and Principal stress III at 3000RPM

Stress Distributions at 3000 RPM

- **Von Mises Stress**: Low across the rotor body.
- **Principal Stress III**: Shows moderate compressive stress.
- **Interpretation**: The compressive stress at this speed does not significantly affect rotor losses.

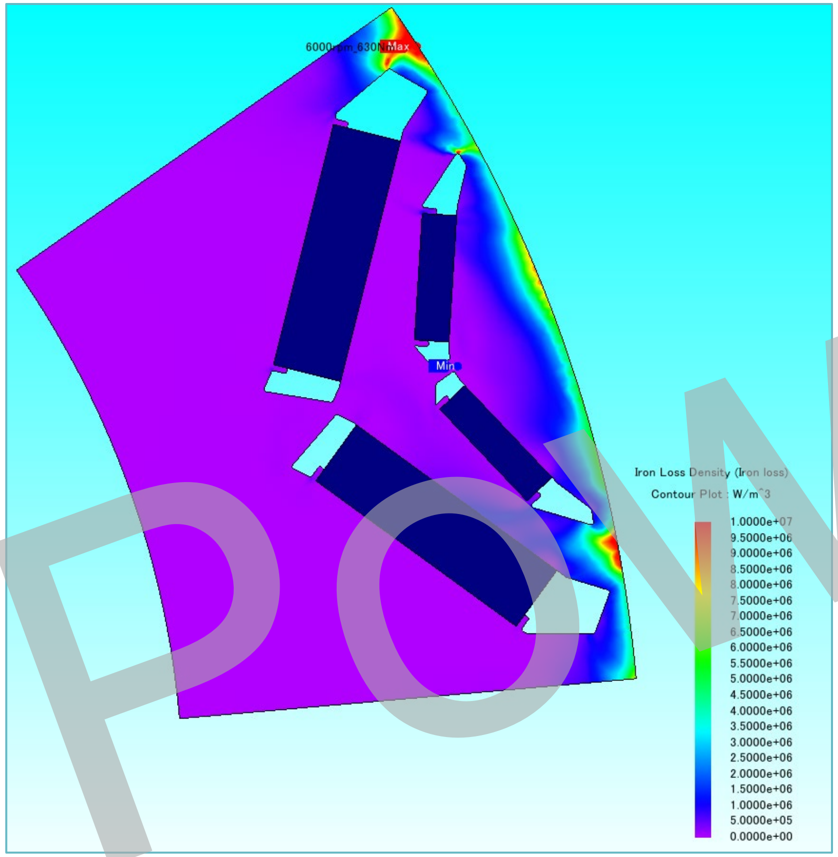


Von misses Stress distribution (left) and Principal stress III at 6000RPM

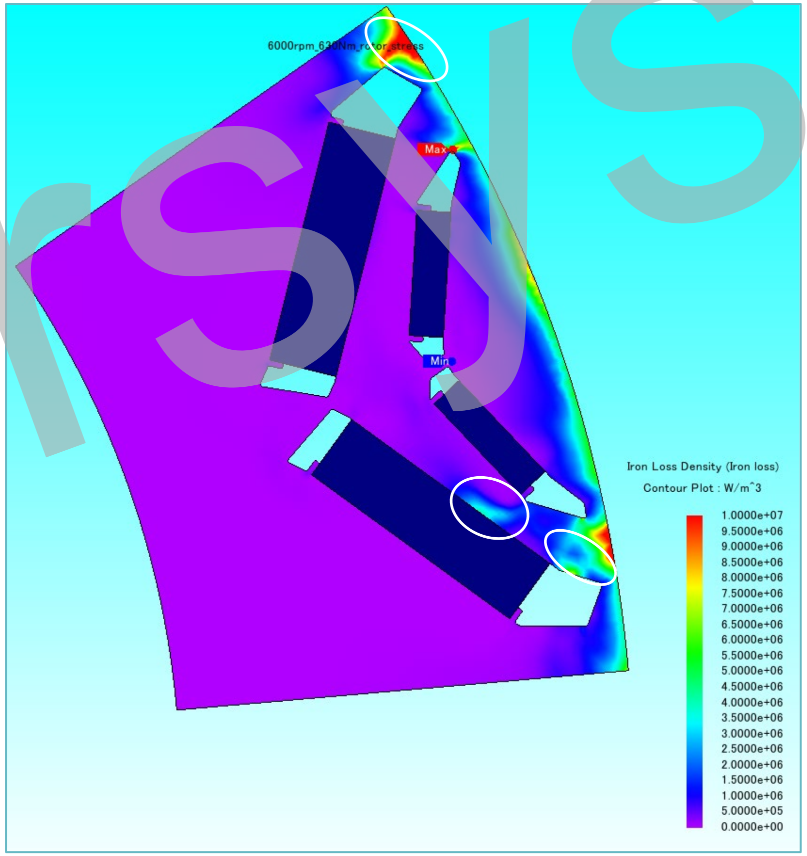
Stress Distributions at 6000 RPM

- **Von Mises Stress**: Noticeably higher compared to 3000 RPM.
- **Principal Stress III**: Increased compressive stress concentrated in the rotor bridge regions.
- **Interpretation**: Higher mechanical stress contributes to increased rotor losses, indicating a stronger interaction between stress state and electromagnetic performance.

ROTOR LOSS @ 6000RPM

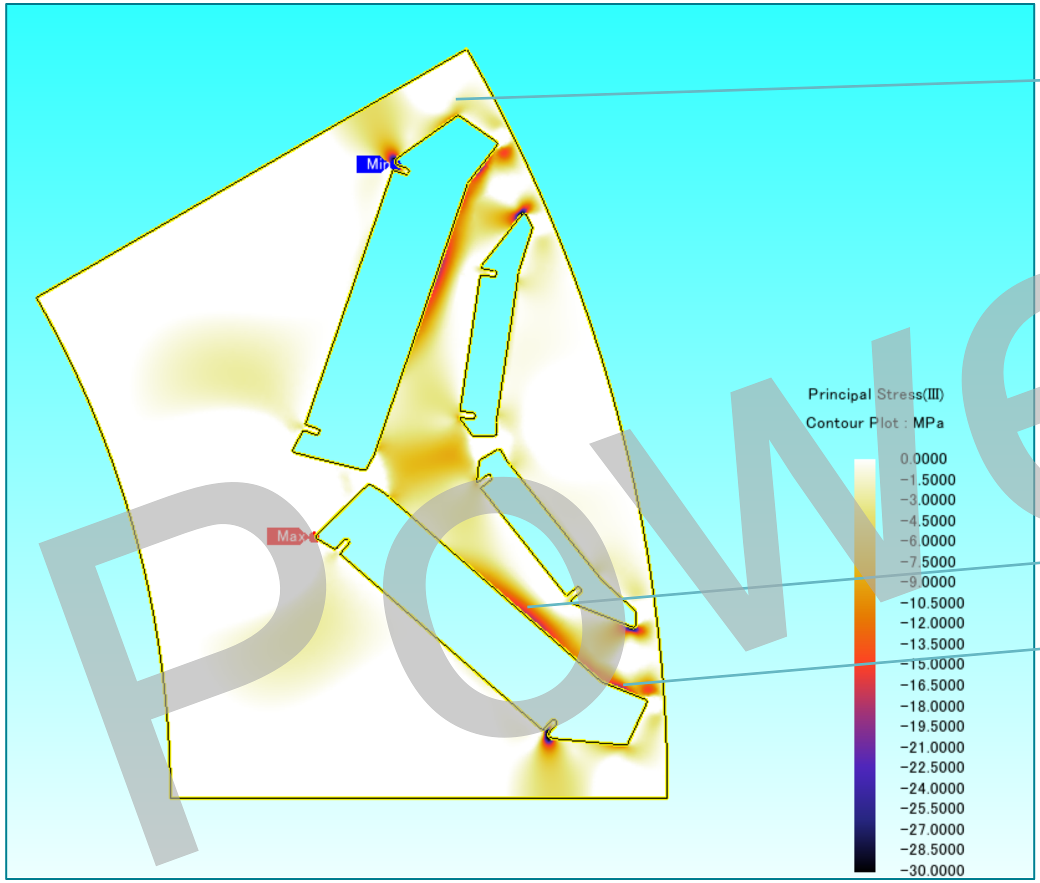


Without stress: 1771 W

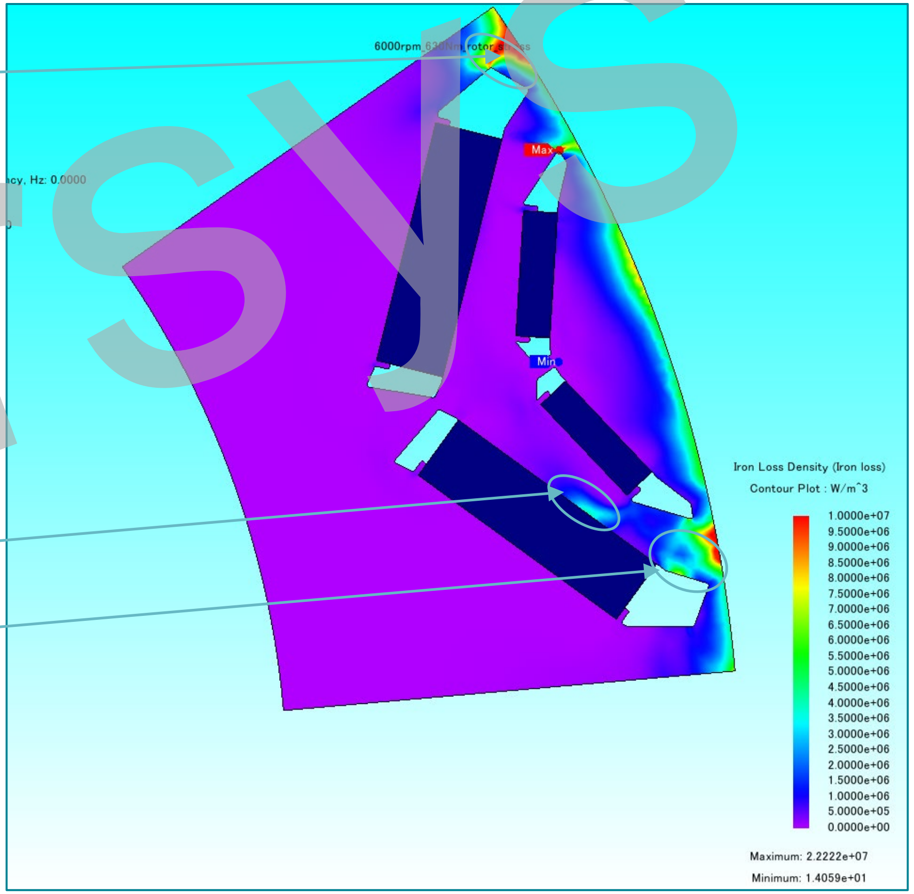


With stress: 1905 W

ROTOR LOSS (STRESSED) VS PRINCIPAL STRESS III 6000RPM

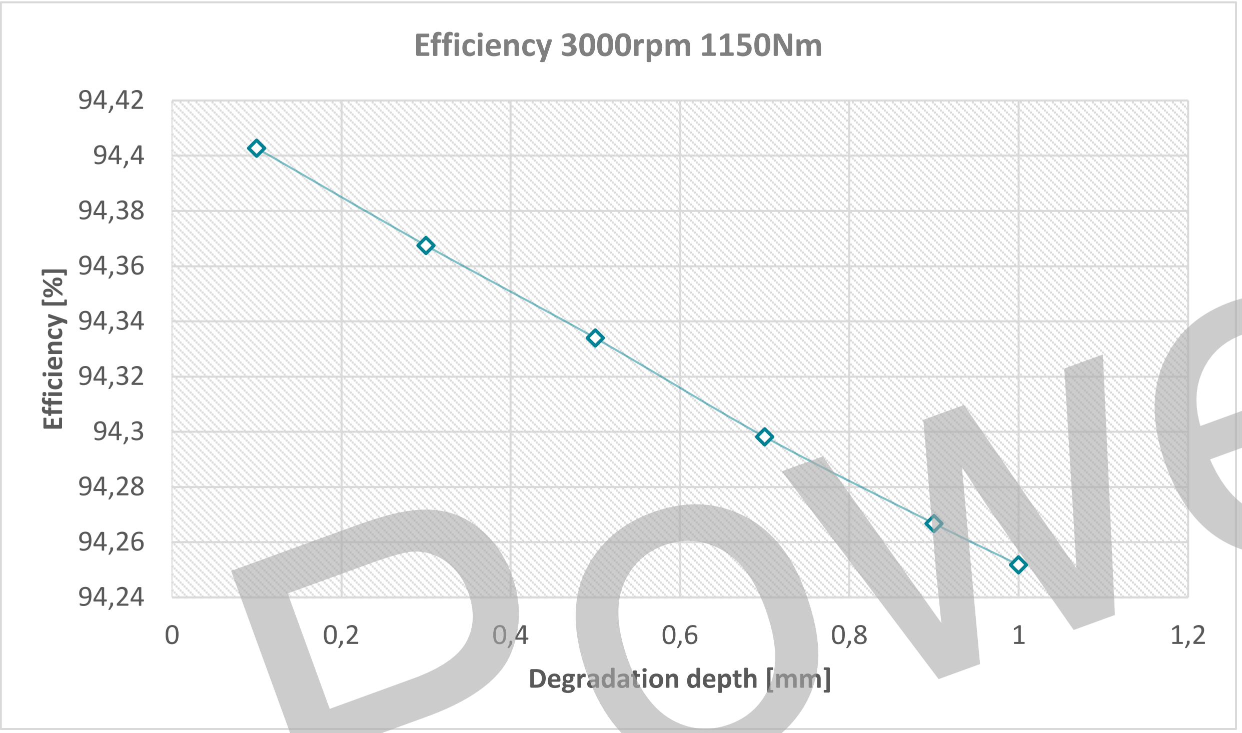


Stress distribution

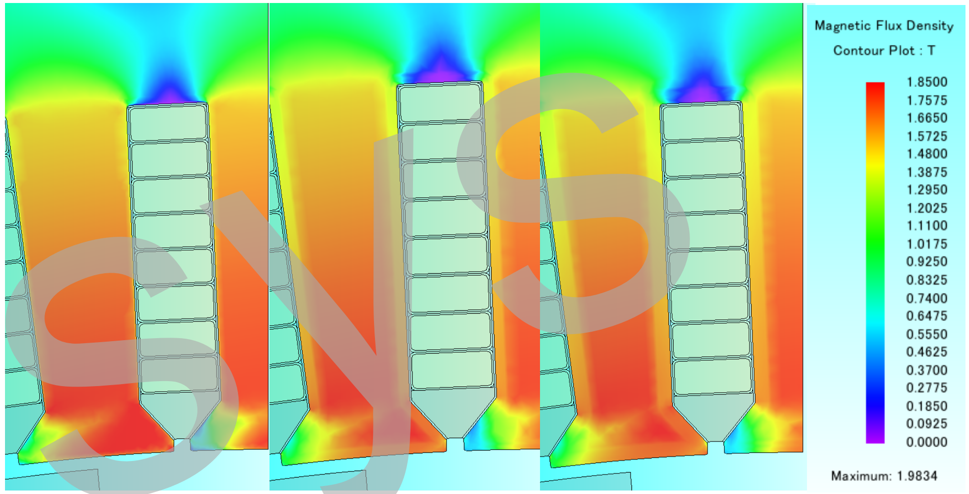


Iron loss distribution

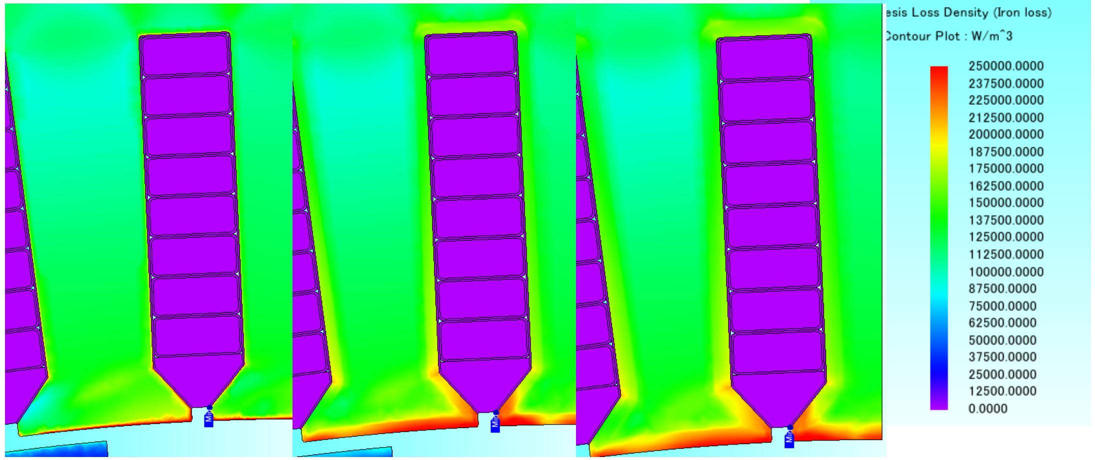
CUTTING EFFECT CONSIDERING DIFFERENT DEGRADATION DEPTHS



Degradation depth →



Cutting effect Flux density at 3000rpm/1150Nm

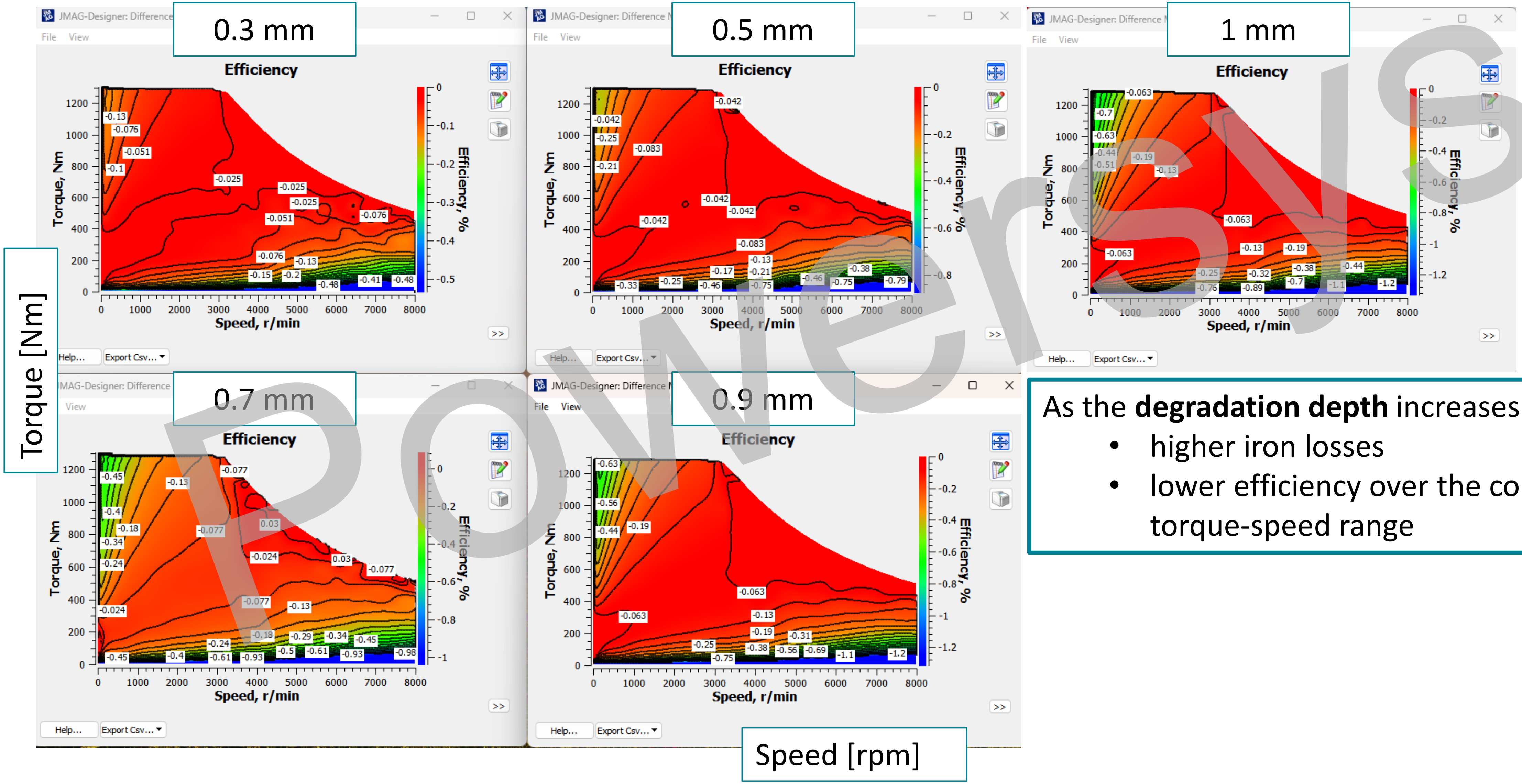


Cutting effect Hysteresis loss density at 3000rpm/1150Nm

Degradation depth	0.1mm	0.3 mm	0.5 mm	0.7 mm	0.9 mm	1 mm
Additional current demand from inverter to achieve the same power*	0%	0.270%	0.580%	0.923%	1.267%	1.435%

**impacting inverter / system efficiency*

CUTTING EFFECT DIFFERENCE MAP OF THE EFFICIENCY

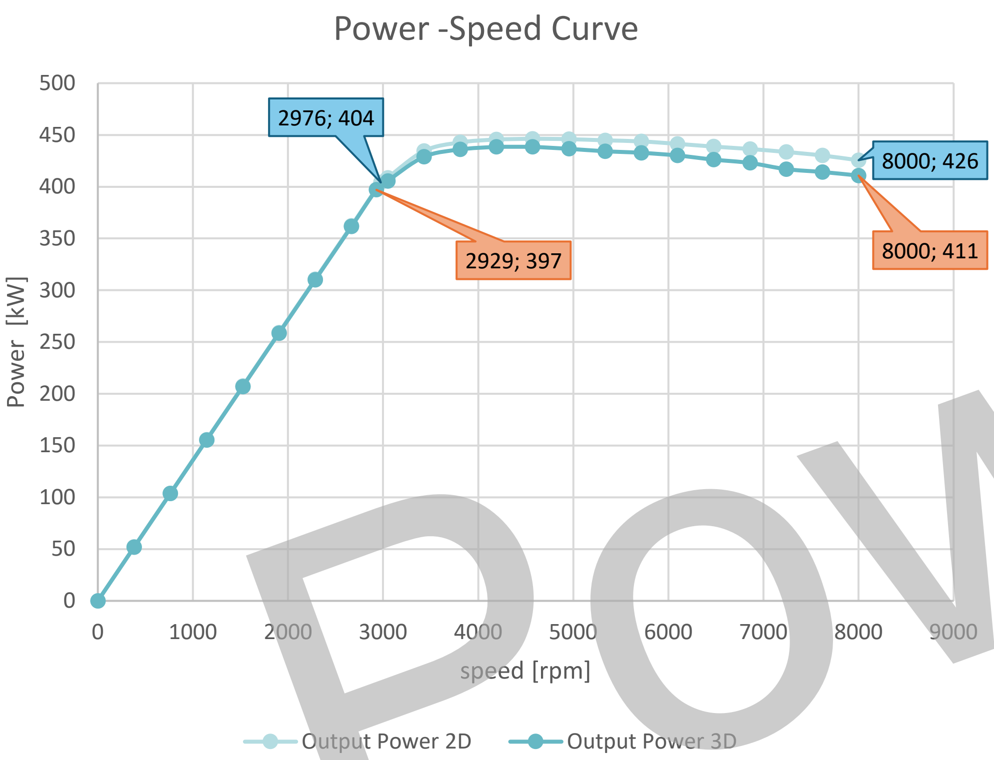


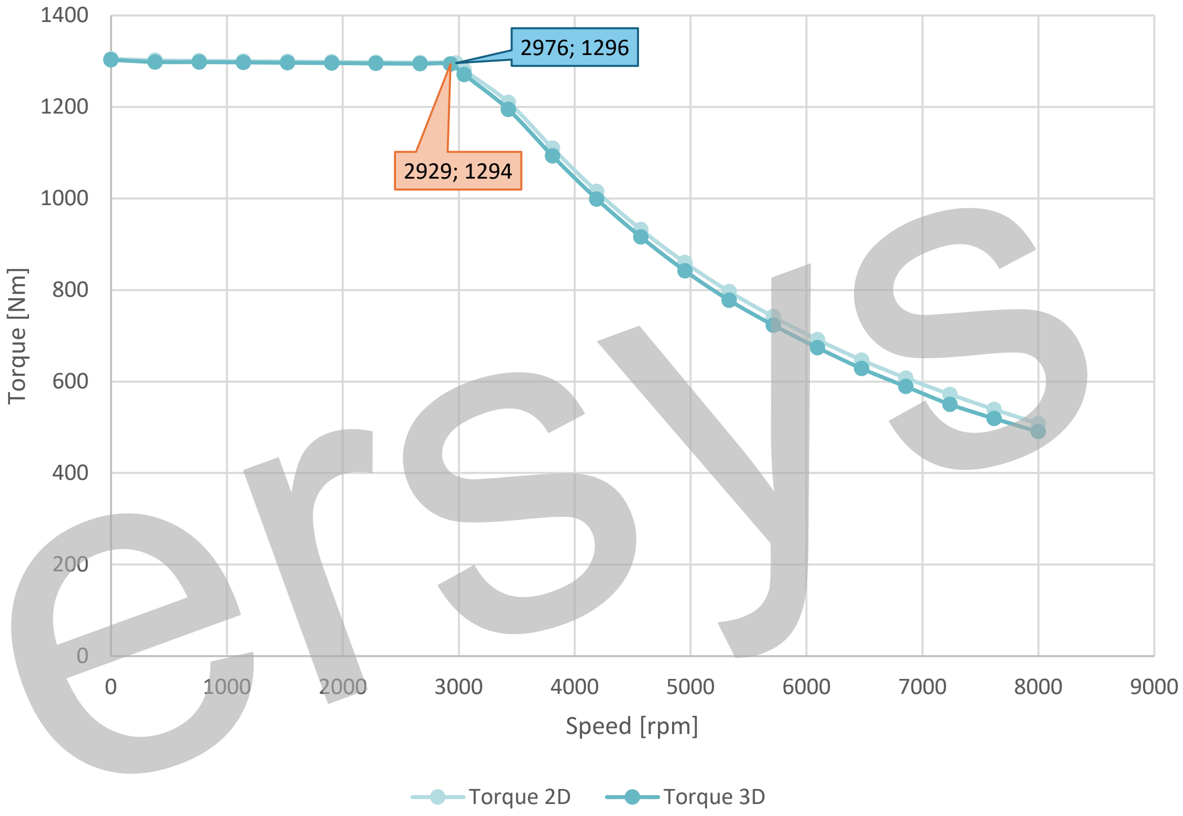
As the **degradation depth** increases:

- higher iron losses
- lower efficiency over the complete torque-speed range

USE CASE: 3D

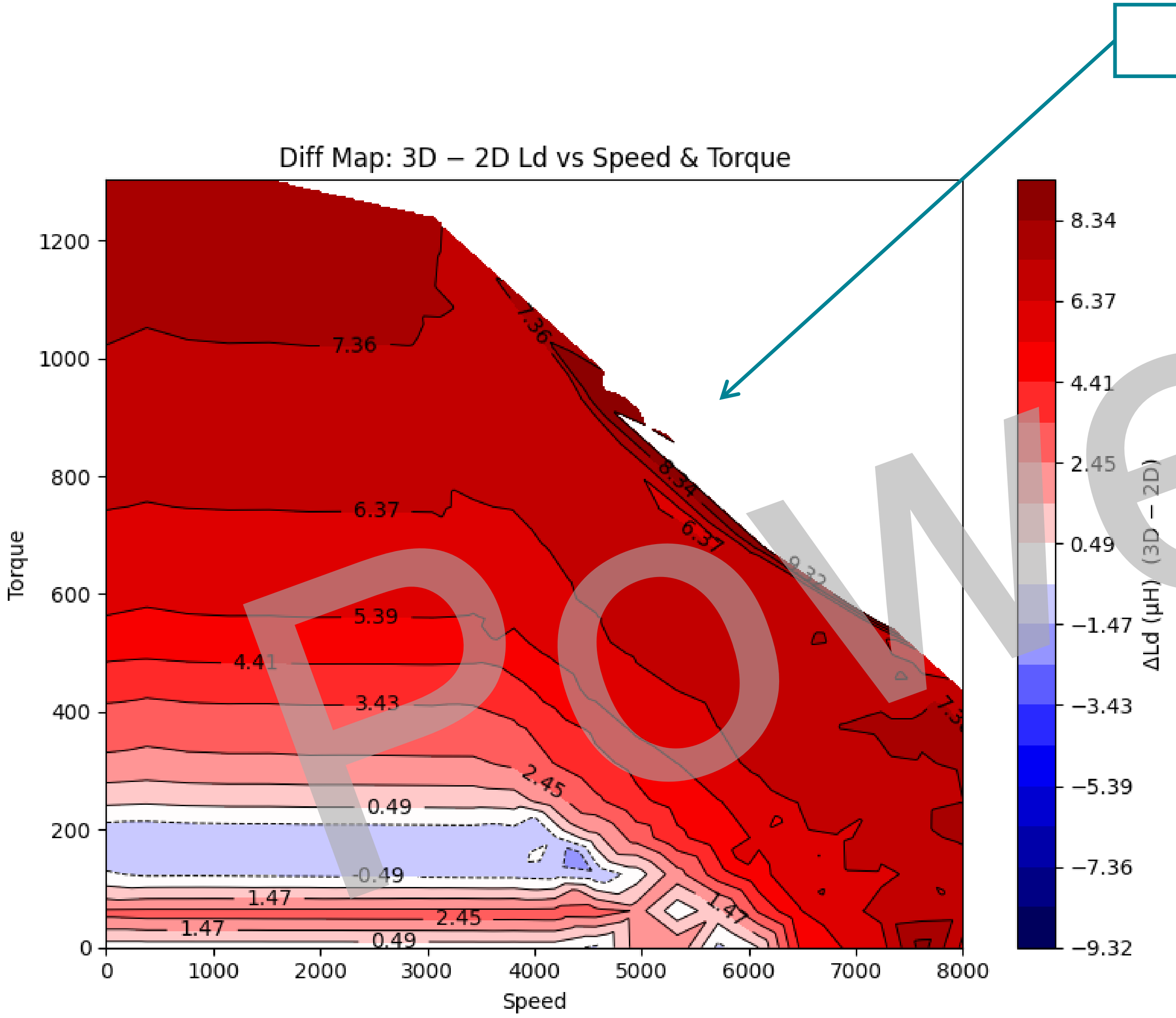
TORQUE SPEED CURVE





	2D	3D
Current Amplitude @3000rpm 1150Nm [A]	660	661
Load Angle @3000rpm 1150Nm [deg]	46.31	45.99
Current Amplitude @6000rpm 630Nm [A]	632	642.5
Load Angle @6000rpm 630Nm [edeg]	73.8	73.97

LD INDUCTANCE MAP 3D VS 2D COMPARISON



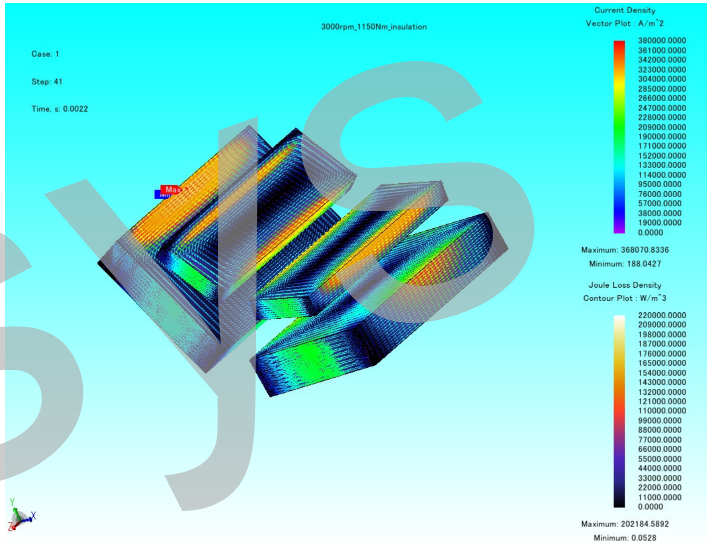
	2D	3D
Number of FEA simulation	497	177
Number of simulated steps	151 (full period)	61 (half period)
Core/case	1	8
Parallel case calculation	36	37
Simulation time	3h 11min	6h 37
Calculation environment	Workstation	HPC

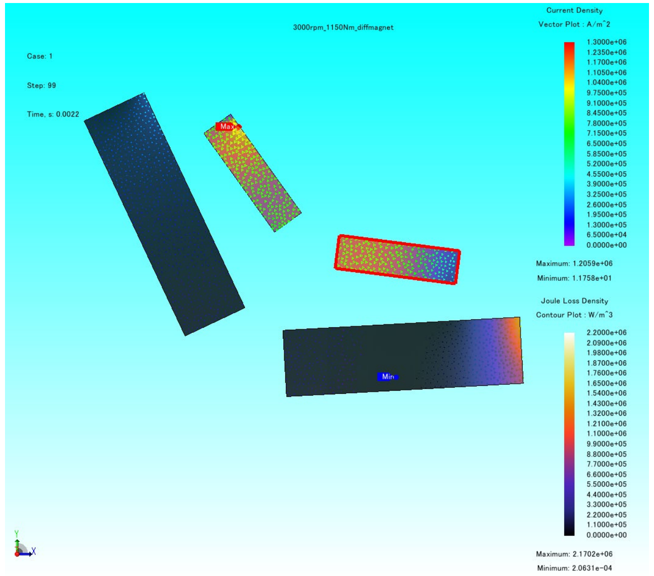
MAGNET LOSS COMPARISON

- Magnet losses can be simulated in 2D, but the phenomena cannot be accurately modeled due to the 3D nature of the eddy currents in the magnets.
- Axial segmentation also plays a role in reducing magnet losses.
- There are some specific methodologies to introduce scaling factors from the 2D magnet loss calculation, mainly based on resistivity scale or dimension scale, but they are not as accurate as 3D simulations.
- A 3D simulation is therefore needed to have an accurate loss characterization of the machine.

	3000rpm 1150 Nm		6000rpm 630 Nm	
	2D	3D*	2D	3D*
Total magnet loss	123 W	18 W	1662 W	290 W

*axial segmentation modeled





CONCLUSIONS AND NEXT STEPS

CONCLUSIONS

Rotor stress impact on rotor losses

- Can be observed an increment on rotor iron losses
- Important to consider material behavior with respect to stress

Material degradation impact

- Reduction of machine efficiency
- Increment of current demand from inverter

End-winding inductance

- Peak power is lower at high speed
- Important for a proper estimation of the machine performance

Magnet loss difference 2D vs 3D

- 2D analysis of magnet losses does not show the reality
- Big difference when axial segmentation is considered

NEXT STEPS

- Detailed 3D simulation for leakage flux analysis and AC losses
- Electromagnetic simulation with PWM currents
- Coupled electro-thermo-mechanical simulation
- Detailed 3D demagnetisation analysis under fault
- Eccentricity investigation

THANK YOU!

Very special thanks to ***Zoltan Nadudvari***
and to ***PowerSys*** *for the support in this activity.*

LinkedIn