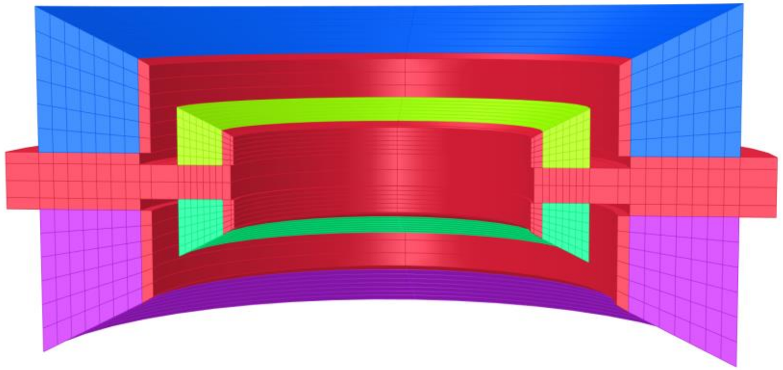
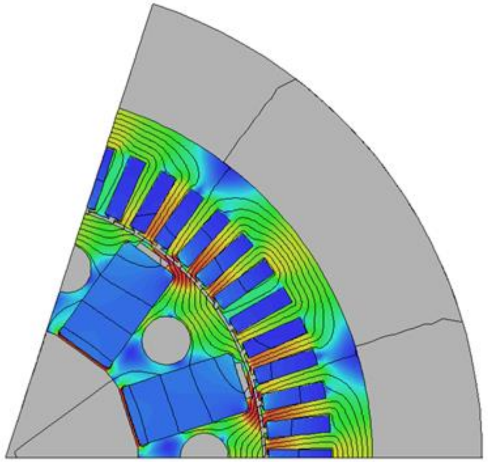
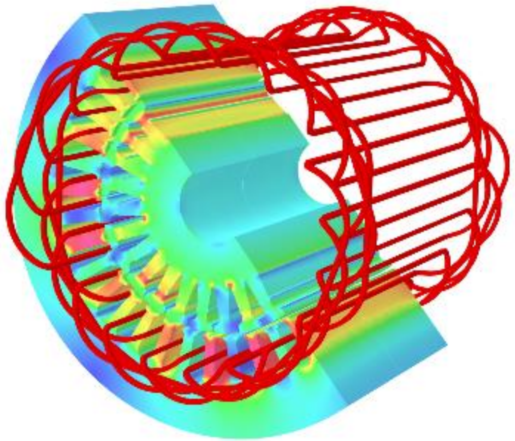
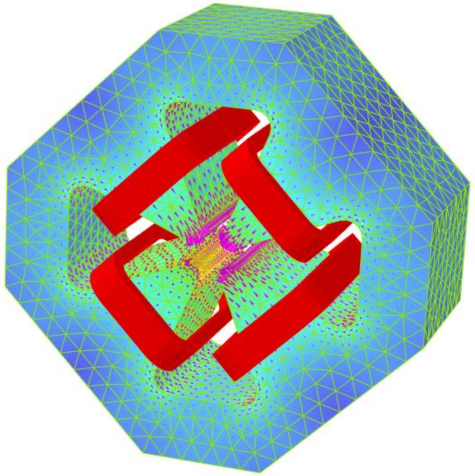



OVERVIEW OF SIMULIA OPERA 2022

Looking toward 2023

Dr Ben Pine and Opera Team

DASSAULT SYSTEMES | The 3DEXPERIENCE® Company

OVERVIEW

Introduction

Opera Solvers

Functional Material Properties

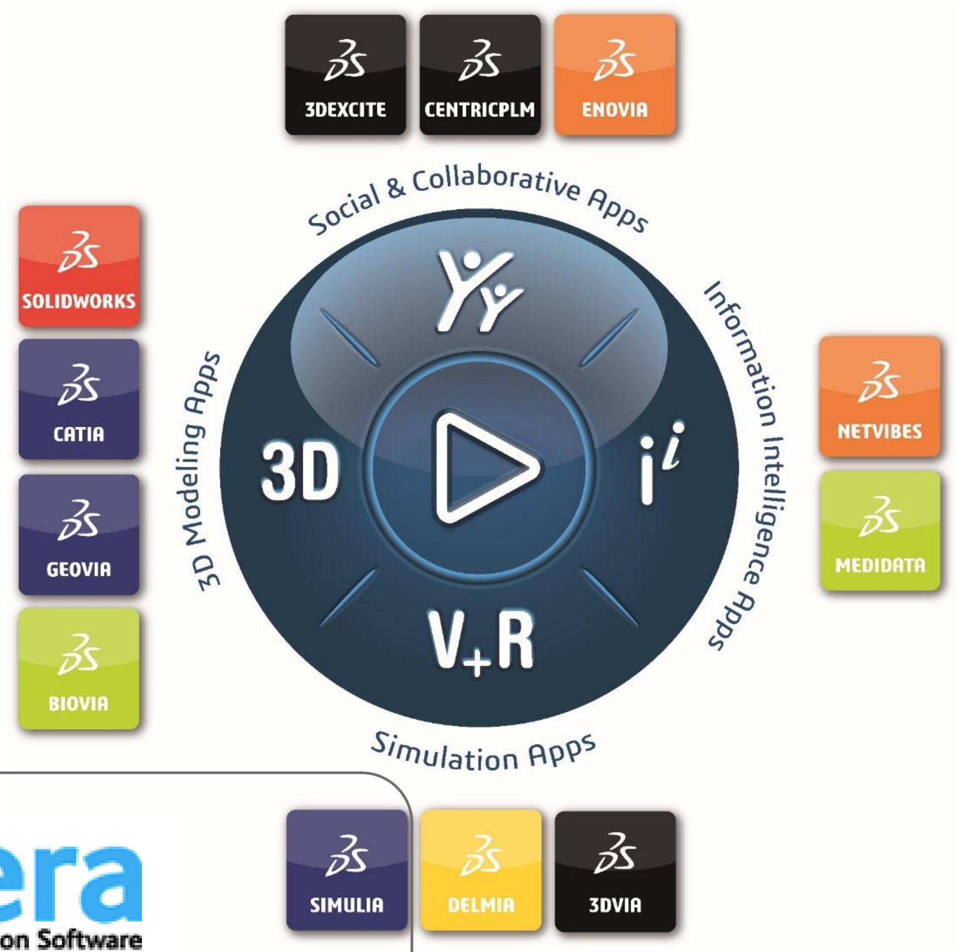
Common Installer for CST Studio Suite® and Opera®

New Workflow for Magnetostatic Analyses

Case Studies

INTRODUCTION

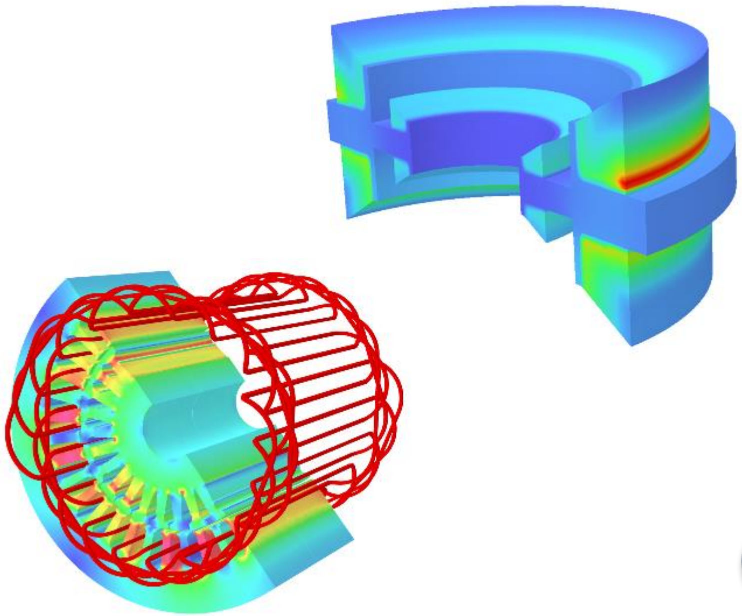
THE **DASSAULT SYSTEMES** BRANDS

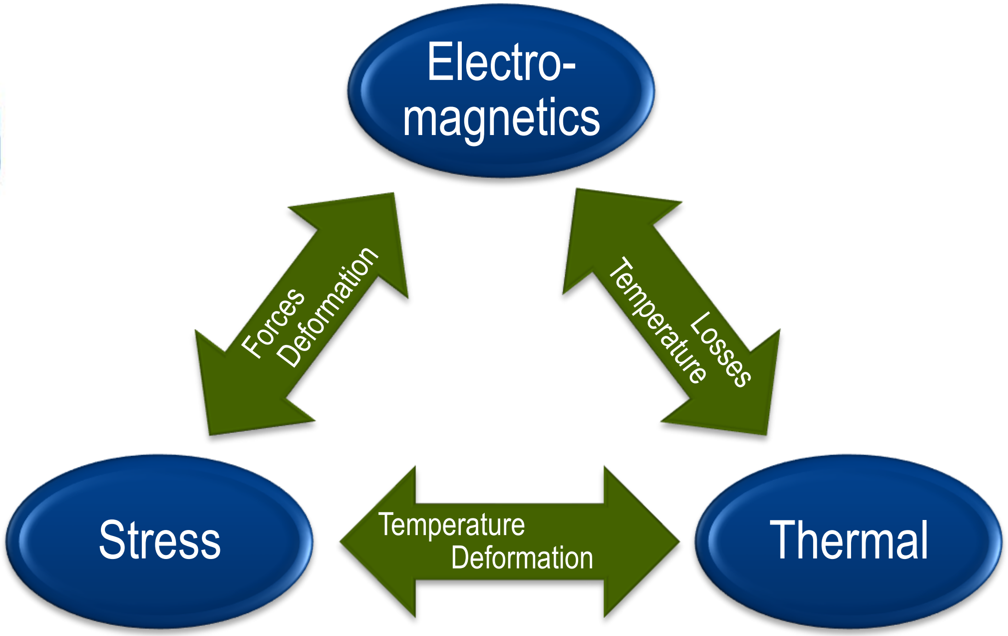


Opera Simulation Software
joins SIMULIA

OPERA

- Opera is a Finite Element Analysis package
  - 2D and/or 3D
  - Multiphysics including:
    - Electromagnetics
    - Space Charge
    - Stress
    - Thermal
- Developed for:
  - Accuracy
  - Capability
  - Reliability
  - Speed
  - Ease-of-use
- Sold direct and by a network of distributors & resellers





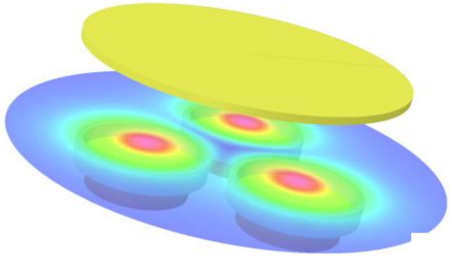
OPERA CAPABILITIES SUMMARY

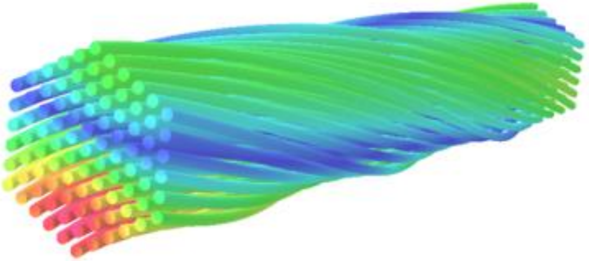
Electromagnetics	Other Physics	Application-specific	Productivity
Static	Space charge	Sputter solver	CAD interops
Low Frequency	Thermal	Quench solver	System interops
High Frequency	Structural	Machines Env	Optimizer
Electromechanical	Circuits	Transformer Env	Python Libraries

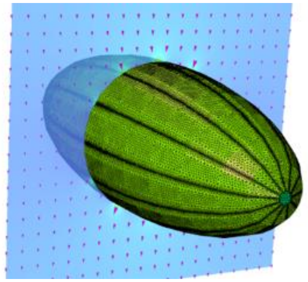
OPERA SOLVERS

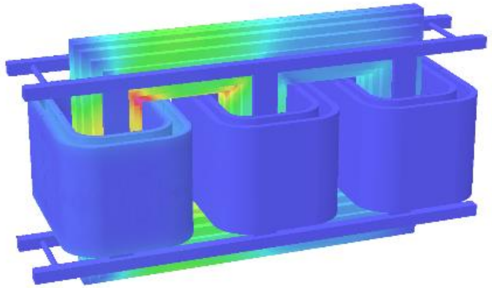
LOW-FREQUENCY ELECTROMAGNETICS

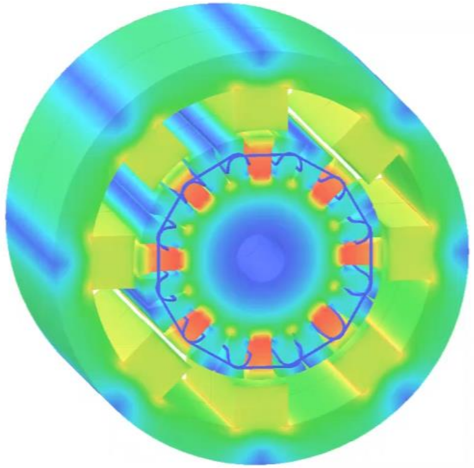
- Electrostatics
- Magnetostatics
- Dynamic Electromagnetics
  - Harmonic
  - Velocity
  - Transient
- with Motion
  - Rotational
  - Linear

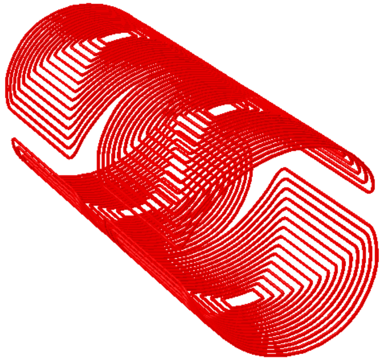


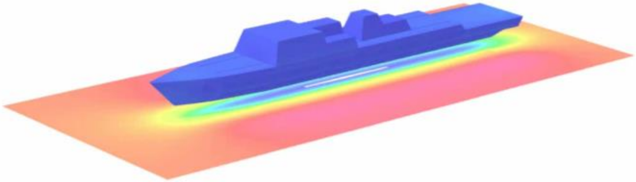






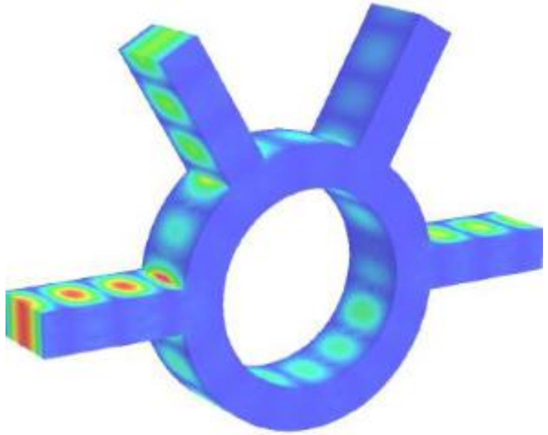


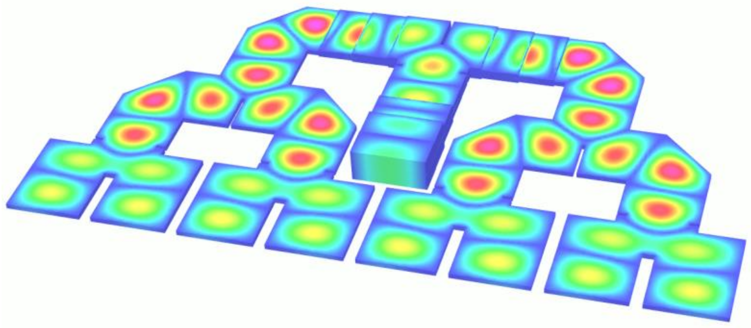


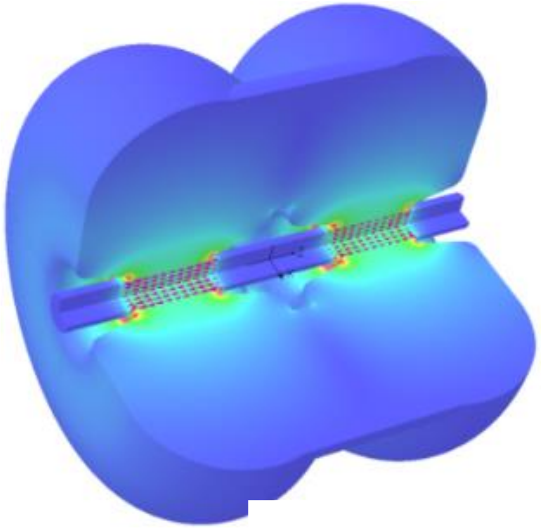


HIGH-FREQUENCY ELECTROMAGNETICS

- Full-wave solver:
  - Modal HF (Eigenvalue analysis)
    - Resonant frequencies and mode structures in cavities
  - Harmonic HF (steady state field solution)
    - Wave propagation in closed and open structures
- Proven in:
  - Particle Accelerators (coupled-cavity resonators)
  - Microwave feed systems (splitters/combiners)
- Multiphysics-capable for heating/deformed cavities

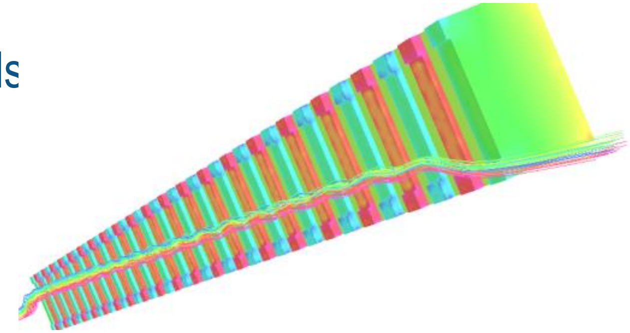


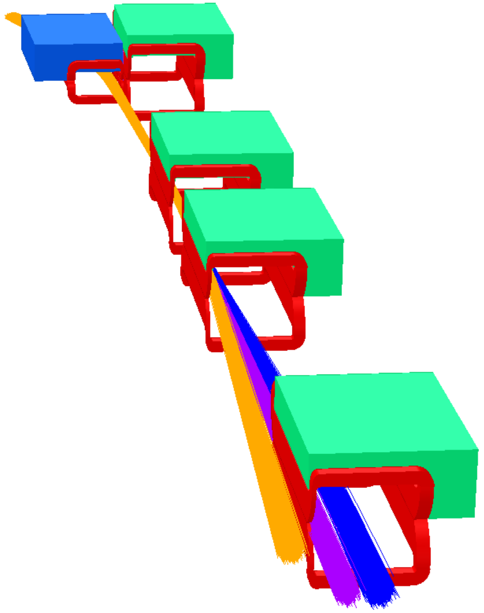




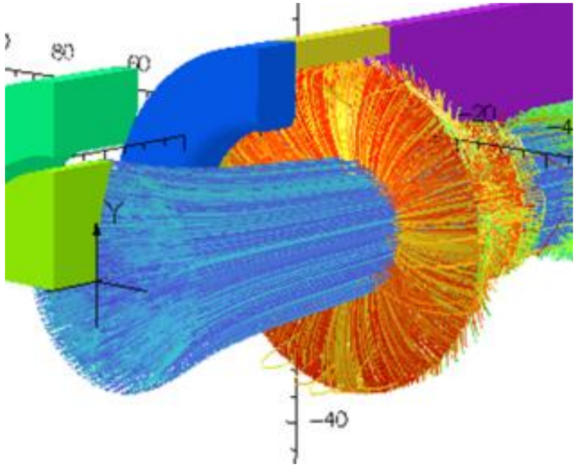
CHARGED PARTICLES

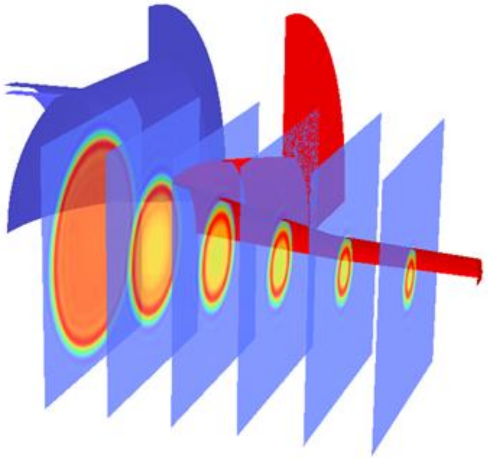
- Self-consistent particle trajectory simulation in combined fields
  - Accounts for space charge effects
  - Relativistically corrected
- Provides primary and secondary emission models
- Allows full range of interactions
  - Particle-field
  - Particle-particle
  - Particle-surface
- Multiphysics – beam-heating





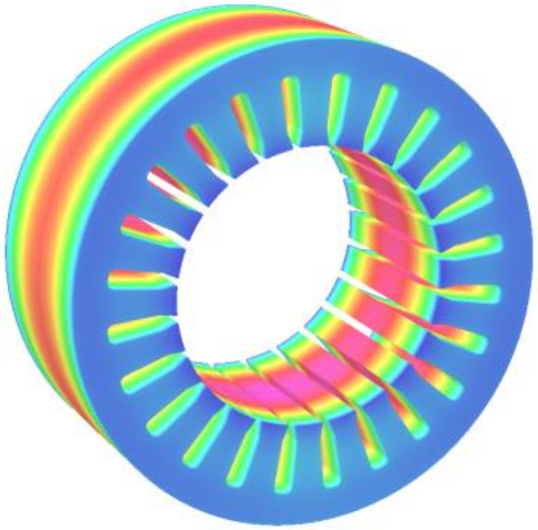
H^-, H and proton beams through ISIS injection magnets

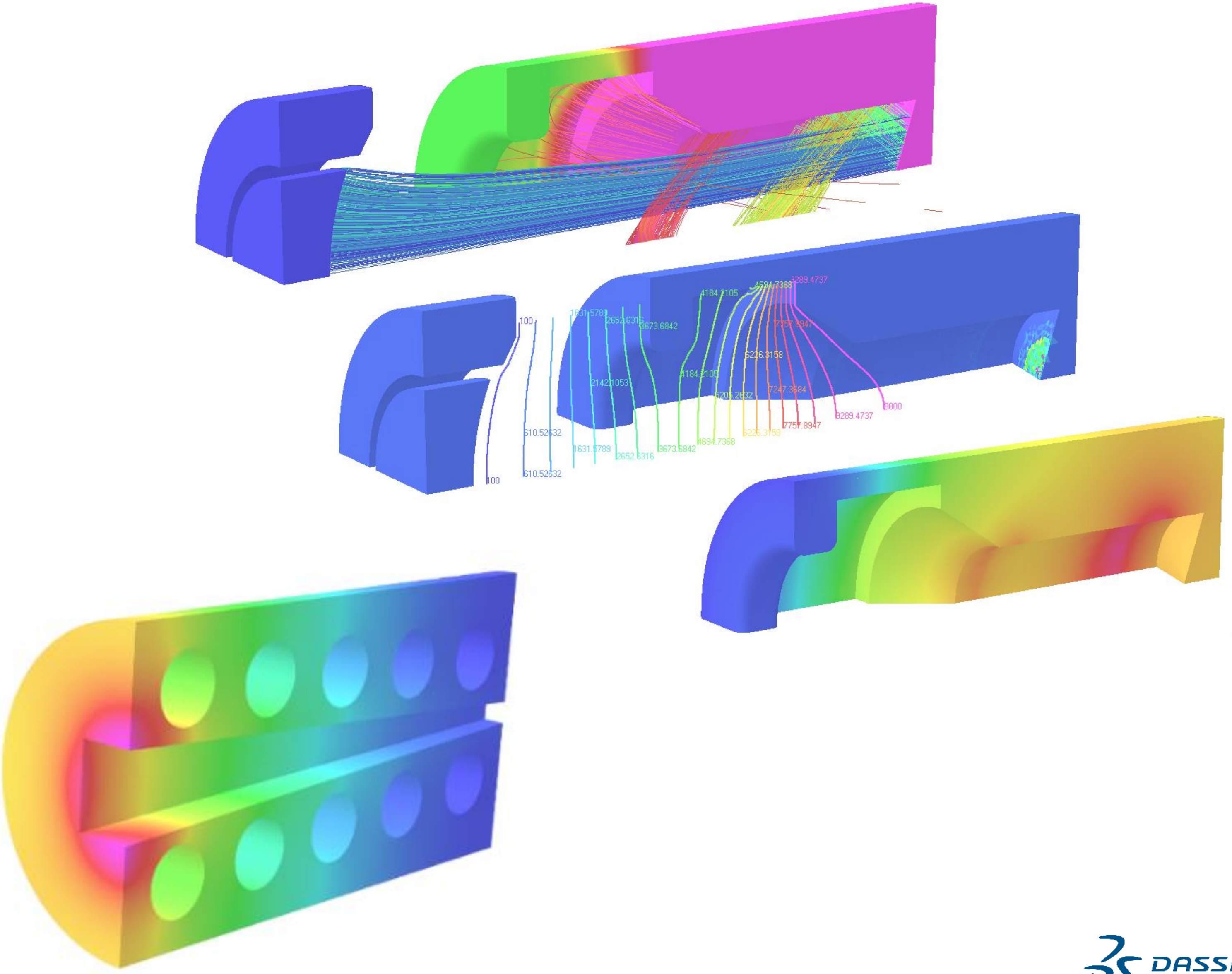




THERMAL SOLVER

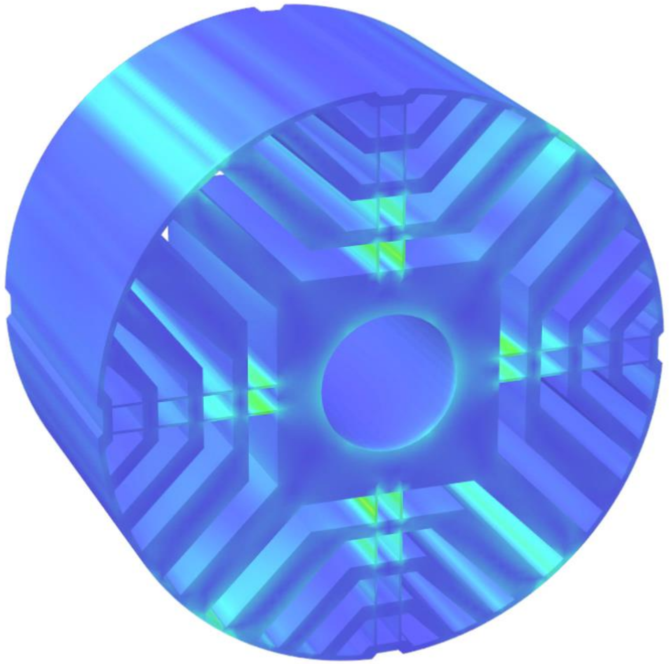
- Static & Transient Thermal Solver
- Multiphysics
  - Automated
  - Manual

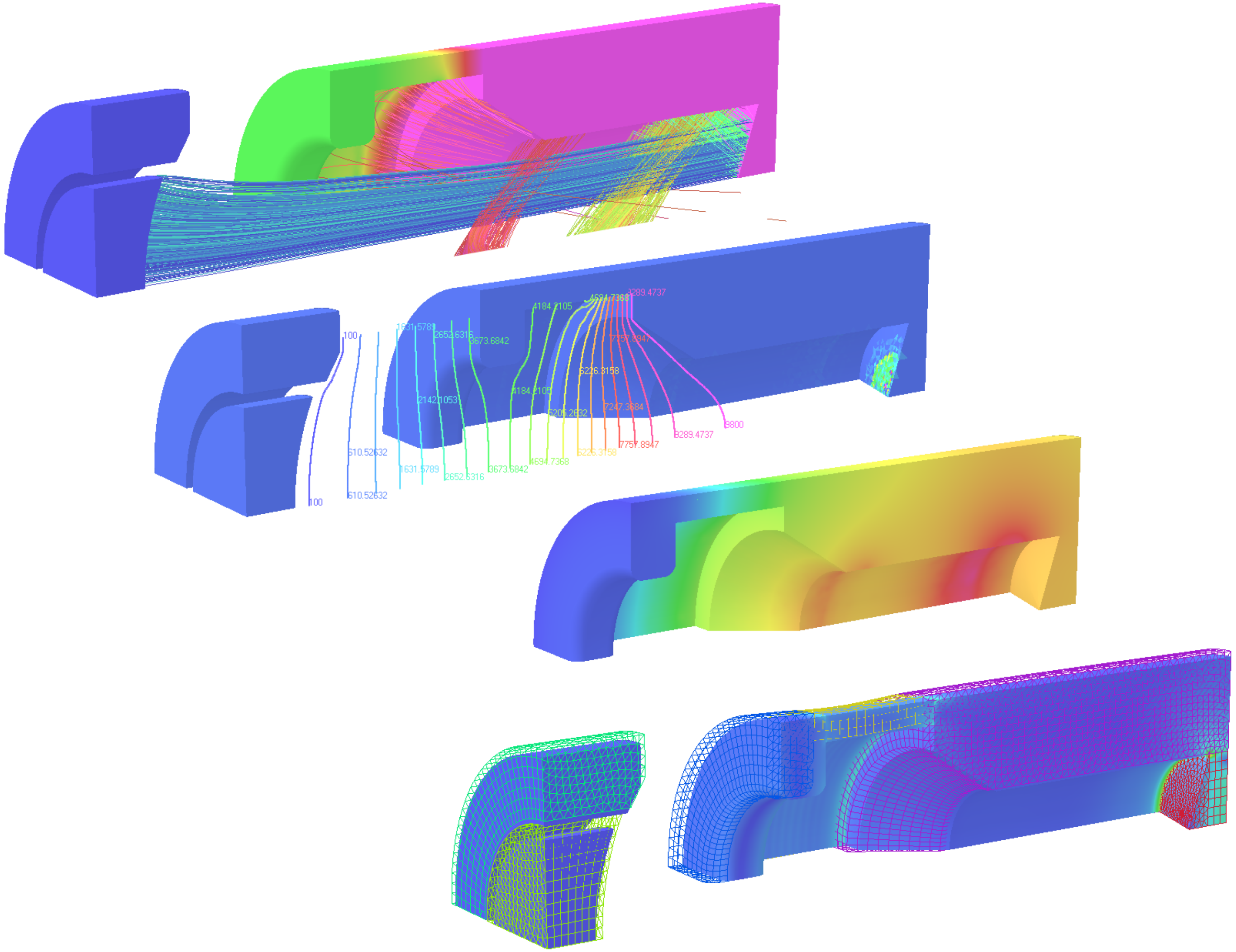




STRUCTURAL SOLVERS

- Static & Eigenvalue Structural Solver
- Multiphysics
  - Automated
  - Manual



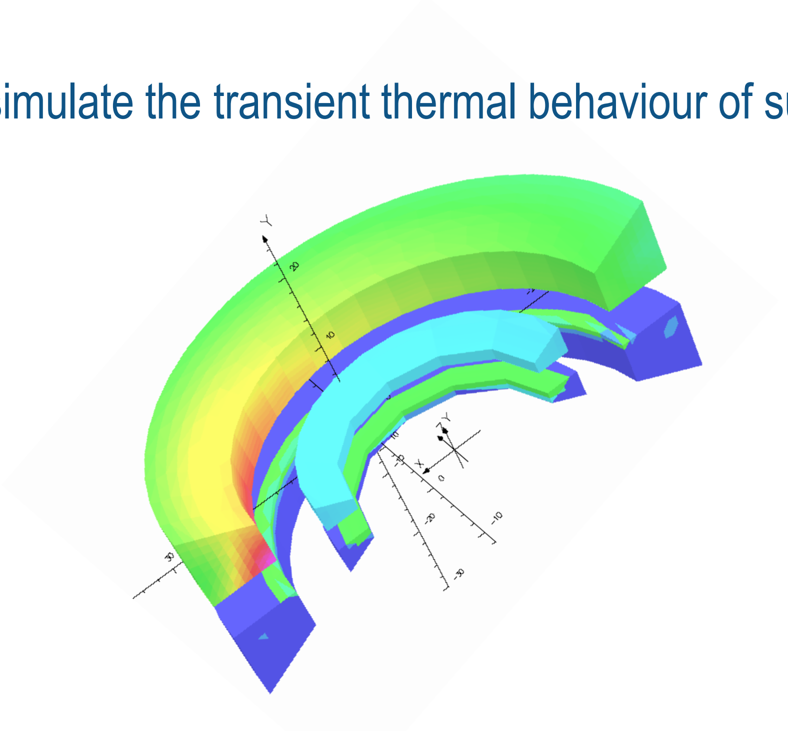


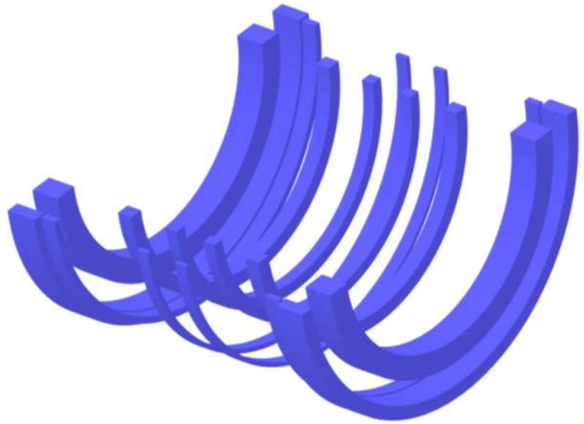
SIMULIA
DASSAULT SYSTEMES

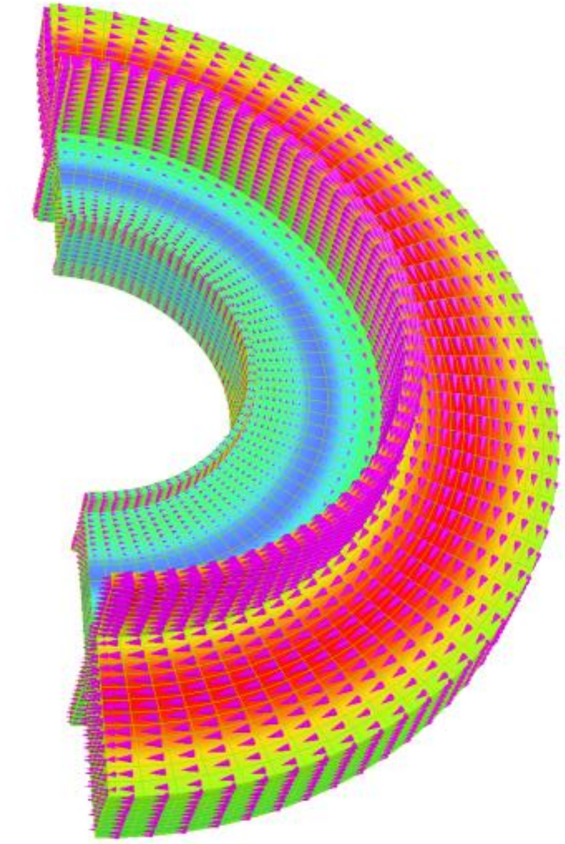
FUNCTIONAL MATERIAL PROPERTIES

QUENCH

- Close-coupled iterative finite element method to simulate the transient thermal behaviour of superconducting magnets.
- Developed in collaboration with industry
- Model includes:
  - Superconducting coils
  - Associated structures (formers)
  - Protection circuit
- Multi-Physics simulation
  - Transient thermal
  - Coupled EM analysis
  - Circuit Equations
- Use Anisotropic mesh to match thermal conductivities



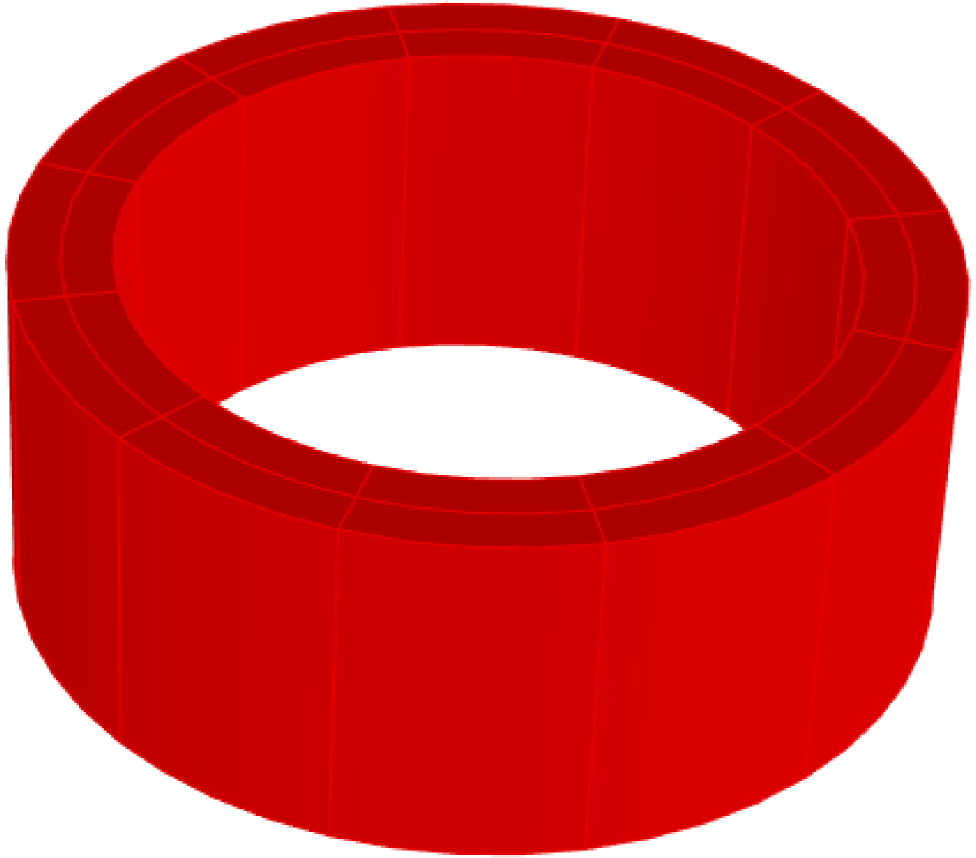




MATERIAL DATA FOR QUENCH ANALYSIS (1/2)

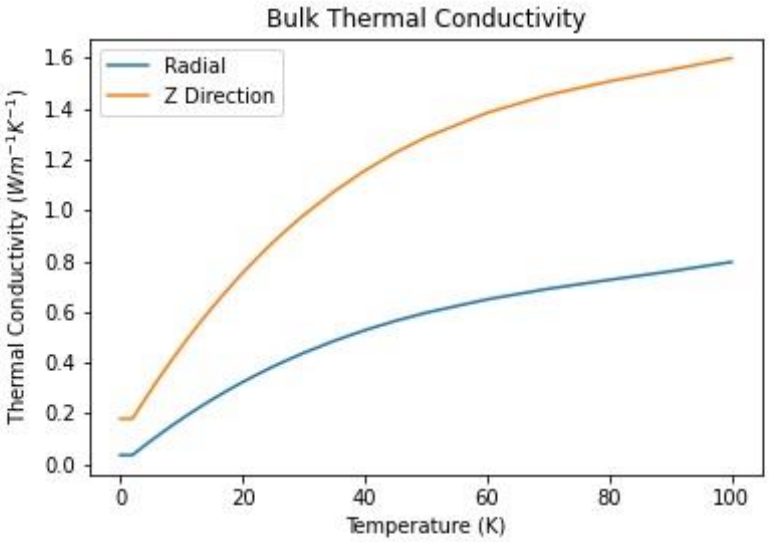
- Coil geometry
- Coil wire: cross section, number of turns, etc
- Circuit
- Material properties
  - Anisotropic nonlinear thermal conductivity
  - Nonlinear specific heat
  - Material density
  - (Nonlinear) electrical conductivity
  - Critical current

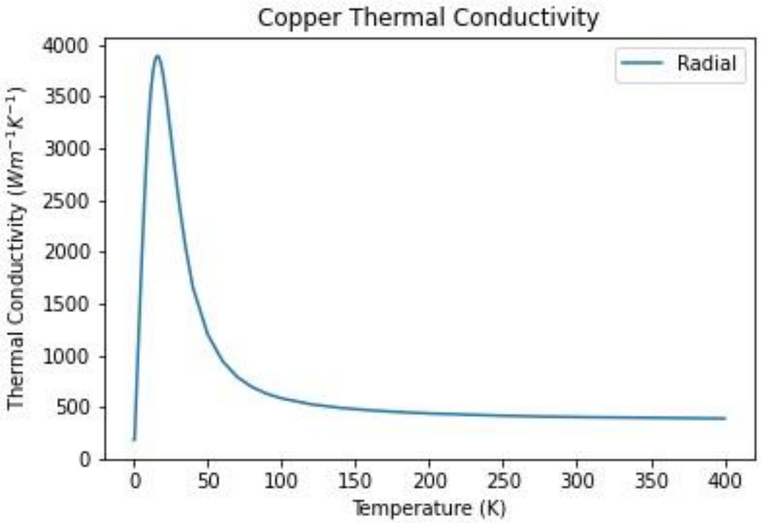
- Material properties are homogenized values
  - As measured for wire or coil
  - Calculated from constituent material curves and volume fractions)



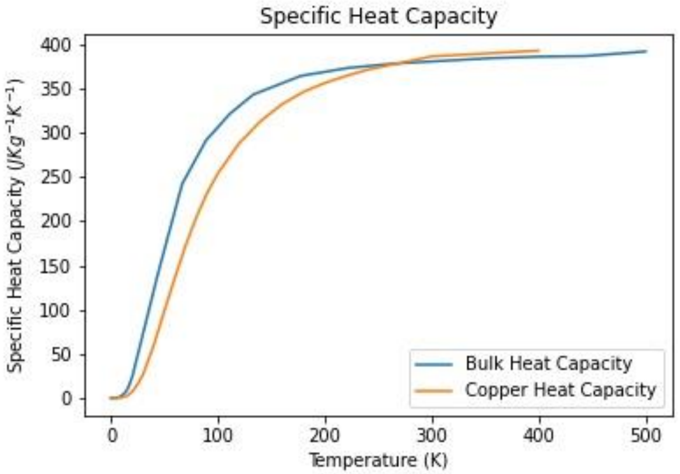
MATERIAL DATA FOR QUENCH ANALYSIS (2/2)

- Thermal conductivity
  - $K = \sum_i f_i K_i$



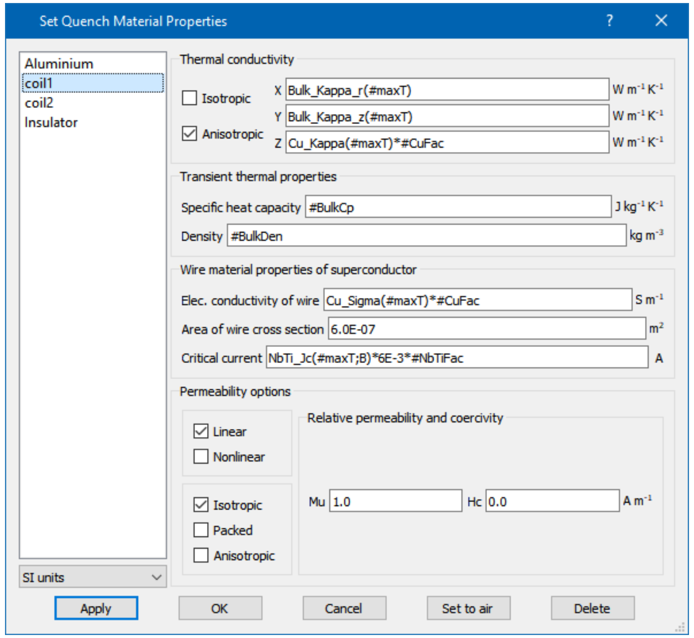


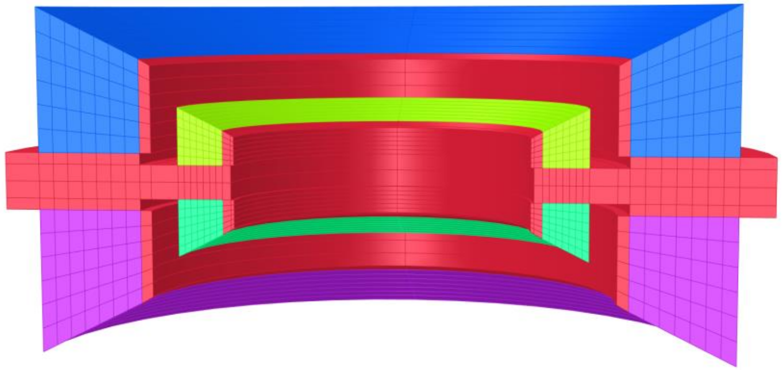
- Specific heat capacity
  - $C_p = \frac{\sum_i f_i C_{pi} \rho_i}{\rho} = \frac{\sum_i f_i C_{pi} \rho_i}{\sum_i f_i \rho_i}$
  - f_i = volume fraction for material i



THERMAL CONDUCTIVITY MODELS

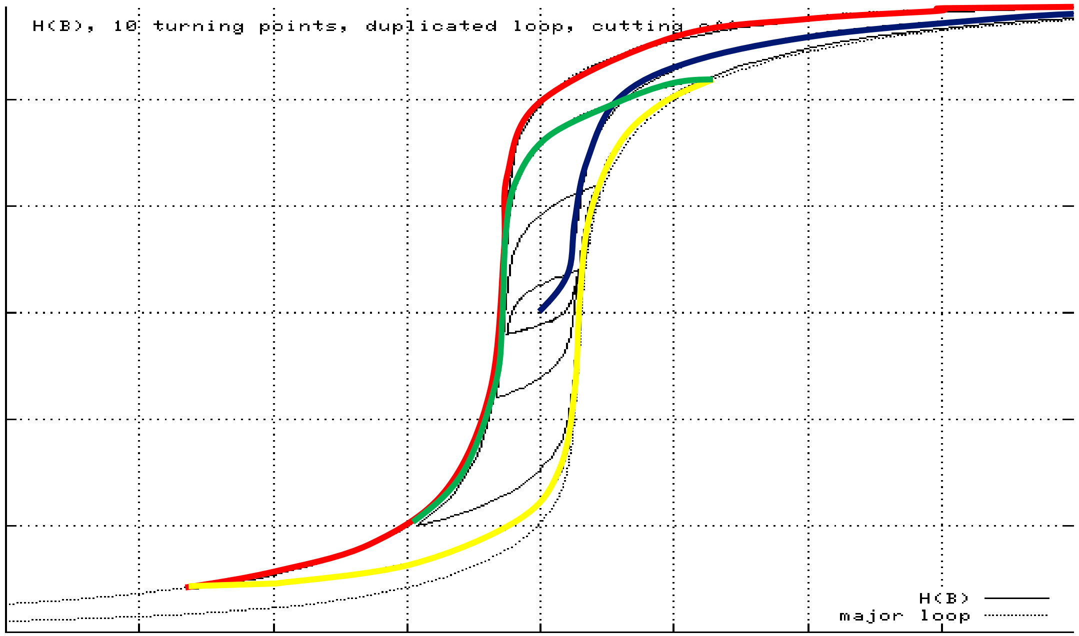
- Thermal conductivity in the conductors is highly anisotropic
- This can be captured using Opera in one of two ways:
  - Anisotropic thermal conductivity
    - Bulk material properties are calculated for the conductor from the fractions of superconducting and normal materials
    - Along with the resin and insulator separating the wires
    - Appropriate functions are used for each of the three conductor directions
    - In Opera the conductor defined Z direction is automatically the direction of current flow
  - Isotropic thermal conductivity
    - A single value for the thermal conductivity along the conductor is used
    - The thermal conductivity in the cross-section of the conductor is instead represented by partitioning the conductor using discrete surfaces
    - Thermal contact boundary conditions are used to control heat flow through the surfaces

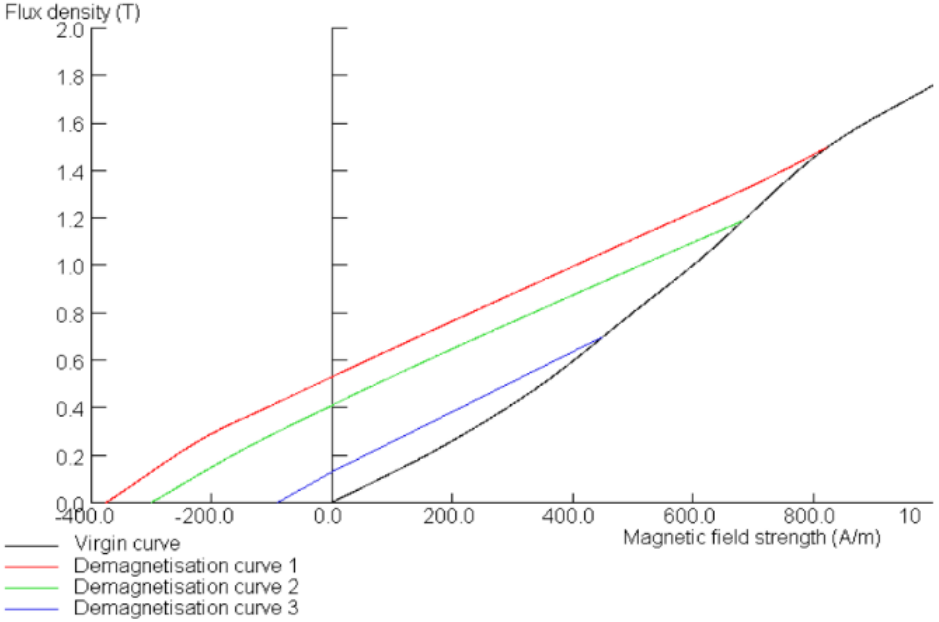




MAGNETIZATION

- Material properties can be single datum points, or any property can be defined as dependent on other fields using multi-variable tables and functions
- Hysteresis & Demagnetisation can be modelled





COMMON INSTALLER FOR CST STUDIO SUITE® AND OPERA®

COMMON INSTALLER FOR CST STUDIO SUITE® AND OPERA®

Continuing the integration of the SIMULIA Electromagnetic solution for Low Frequency

May 2018

Opera is acquired by Dassault Systemes

v2020x (November 2019)

Common licensing for Opera and CST Studio Suite

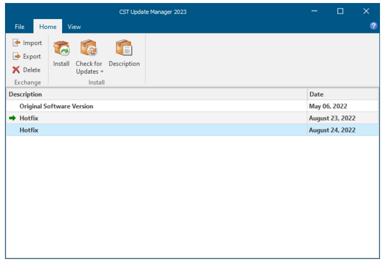
FlexLM

v2022 SP2 (February 2022)

Opera is available through SIMULIA Unified Licensing

v2023x (November 2022)

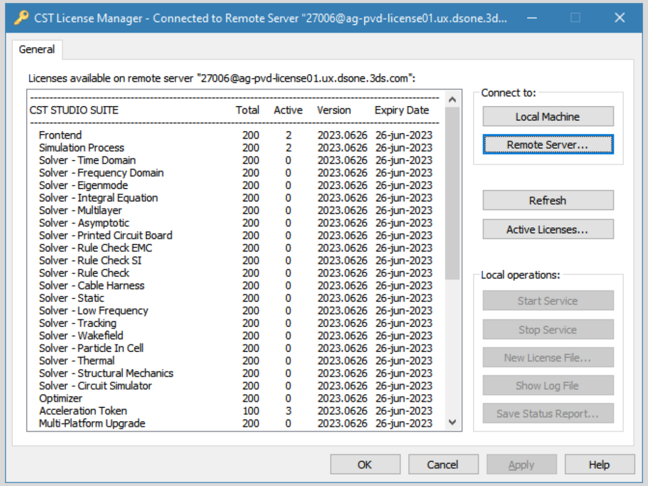
Common installer for Opera and CST Studio Suite



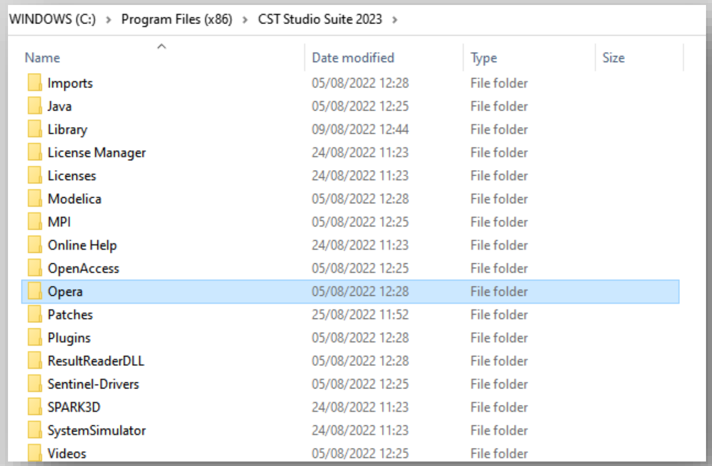
COMMON INSTALLER FOR CST STUDIO SUITE® AND OPERA®

SIMULIA Electromagnetics solution

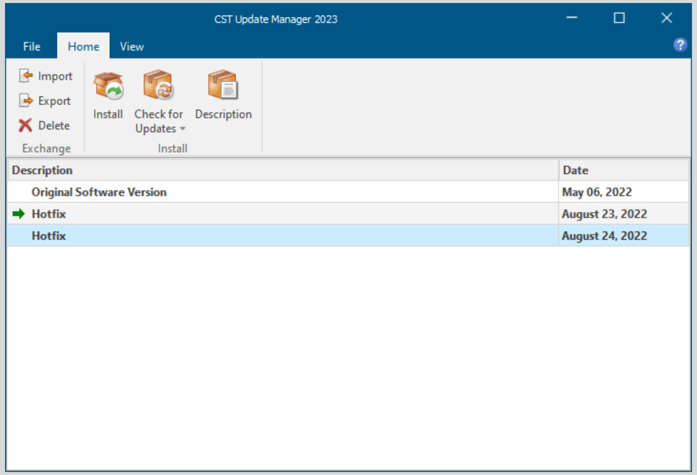
Common license scheme Opera and CST Studio Suite



Single installer package and installation location



Service pack delivery as patches via CST Update Manager



NEW WORKFLOW FOR MAGNETOSTATIC ANALYSES

NEW WORKFLOW FOR MAGNETOSTATIC ANALYSES

Integrating CST Studio Suite GUI and Opera Magnetostatic solver

- Motivation → provide users with a seamless workflow that allows a geometry built in CST Studio Suite to be solved using the Opera Magnetostatic solver

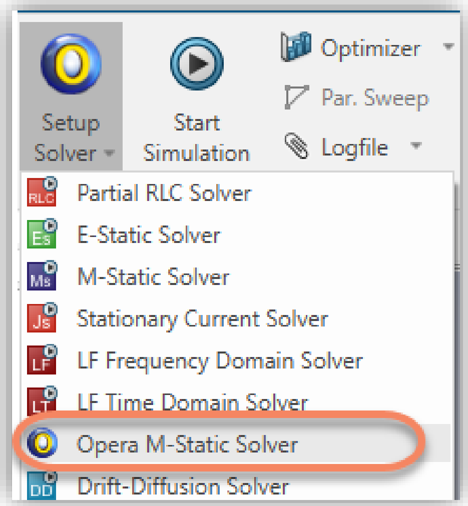
- Benefits of the new workflow
  - connect the highly accurate Opera Magnetostatic solver with the powerful user interface of CST Studio Suite
  - use one single modelling tool for performing LF and HF analysis of coils (e.g. MRI analysis, accelerator magnets)
  - make use of the complete post-processing features in Opera Post-Processor for low frequency applications

NEW WORKFLOW FOR MAGNETOSTATIC ANALYSES

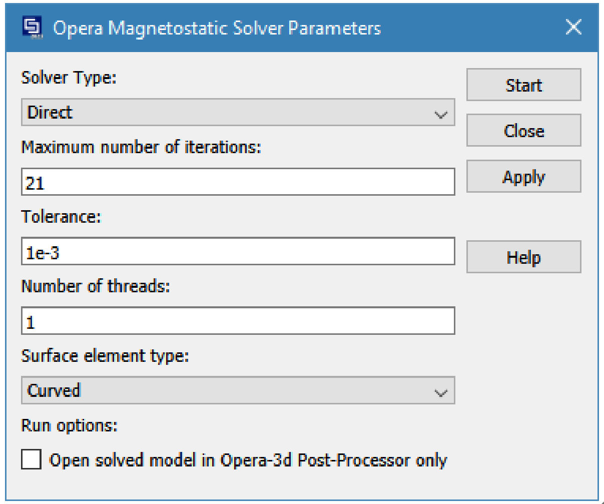
Integrating CST Studio Suite GUI and Opera Magnetostatic solver

- New Features:

new solver option for
Low Frequency applications



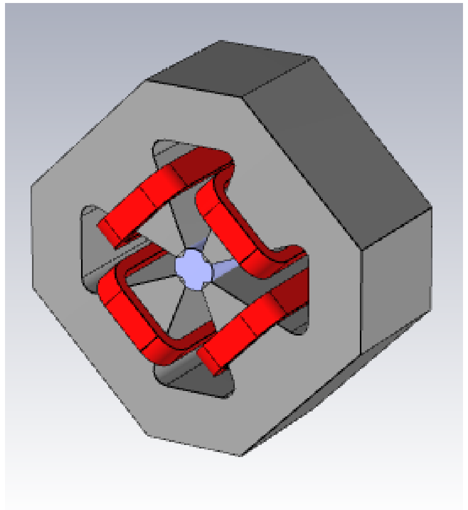
new analysis parameters dialog for
Opera Magnetostatic solver

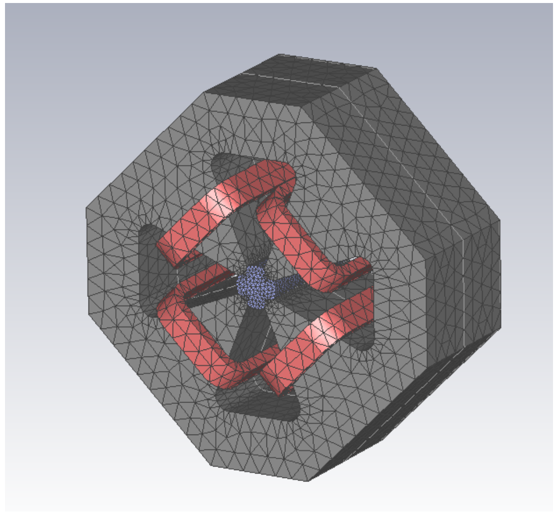


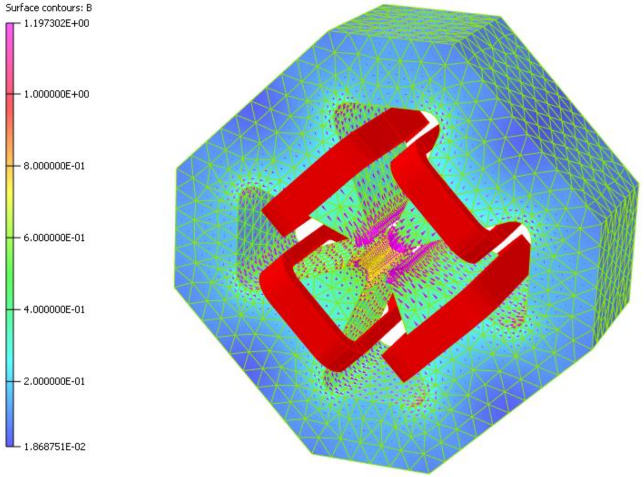
NEW WORKFLOW FOR MAGNETOSTATIC ANALYSES

Integrating CST Studio Suite GUI and Opera Magnetostatic solver

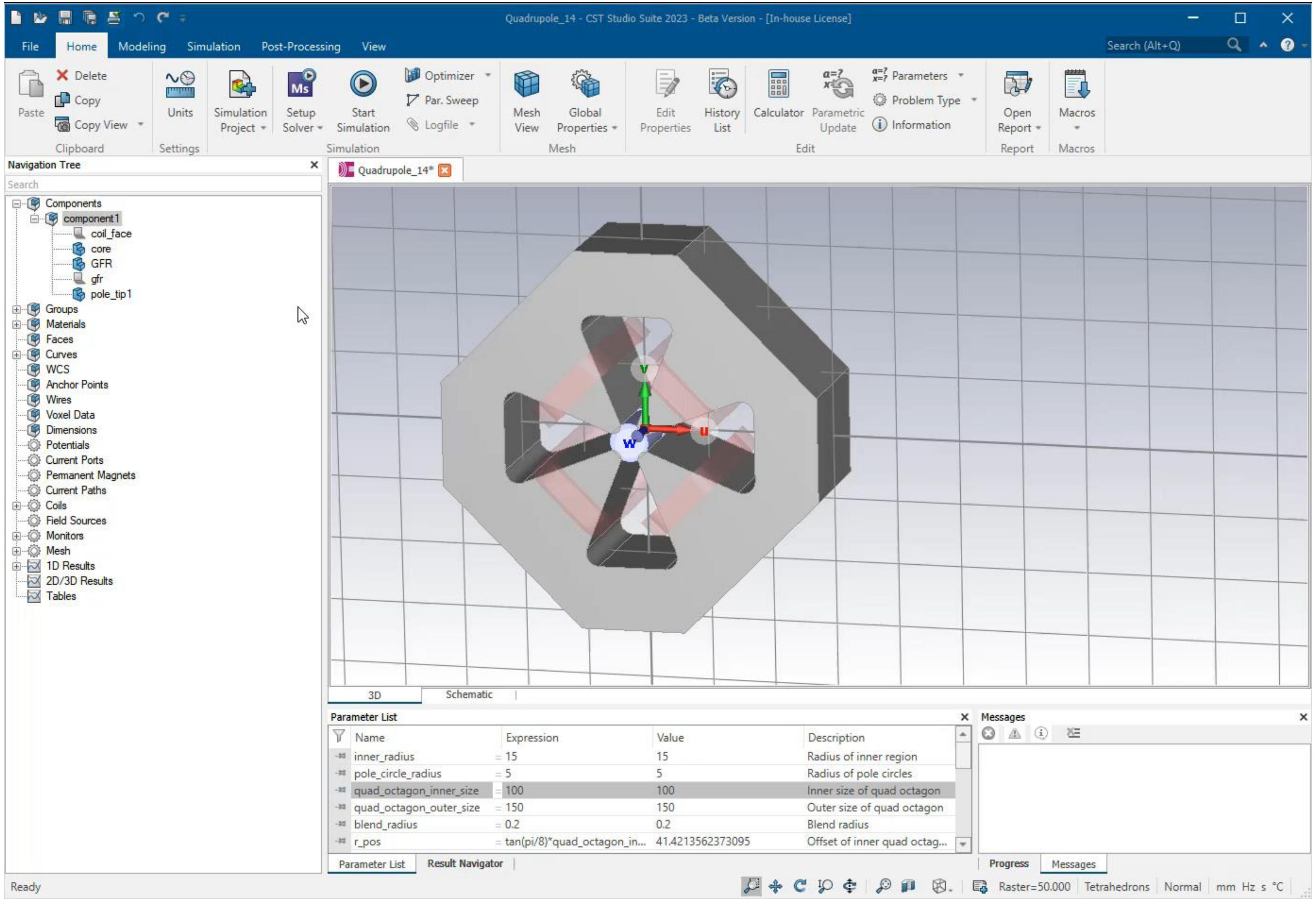
- Capabilities:
  - build, setup and mesh the geometry in CST Studio Suite and directly run it through the Opera Magnetostatics solver
    - supports coils, permanent magnets, EMAG material properties, boundary conditions, symmetries and mesh information
  - post-process the solution using the Opera Post-Processing tools







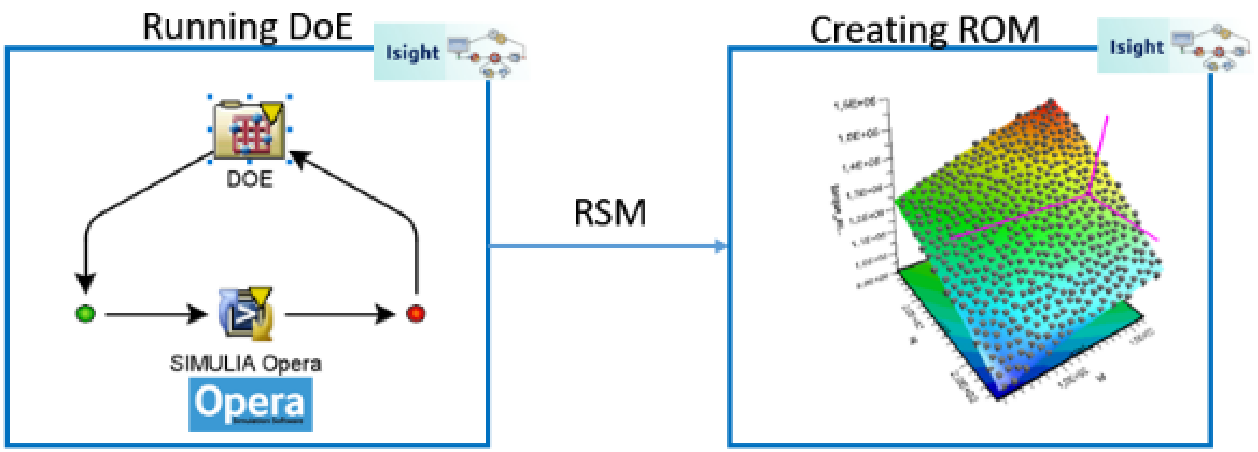
NEW WORKFLOW FOR MAGNETOSTATIC ANALYSES



CASE STUDIES

REDUCED ORDER MODELLING WORKFLOW (1/2)

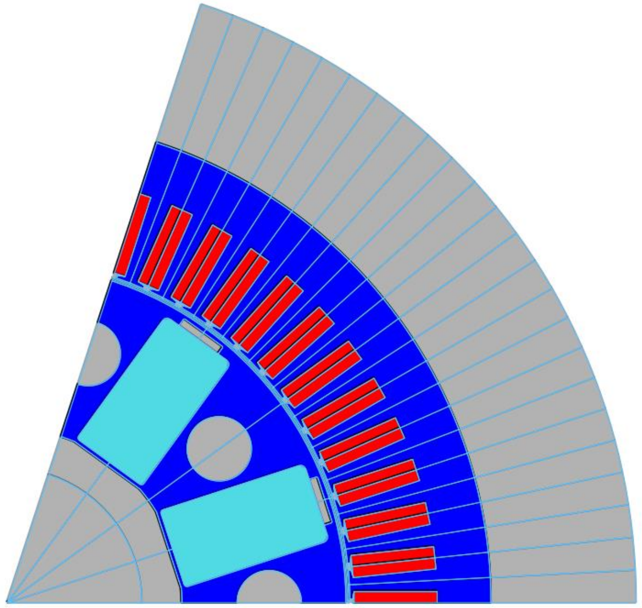
- Reduced Order Modelling (ROM) is a technique to reduce the computational complexity of mathematical models in numerical solutions by producing an equivalent model with a lower fidelity that still retains the required accuracy
- Finite Element solutions from SIMULIA Opera are used to generate samples in a Design of Experiments (DoE)
- The DoE is then used to create a ROM by using an approximation method in SIMULIA Isight
- Both Opera & Isight are coupled for this workflow

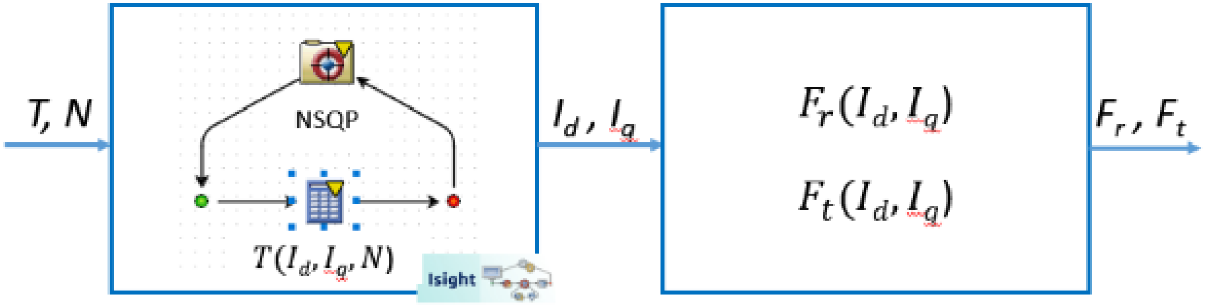


With thanks to Bilquis Mohamodhosen for the slides

REDUCED ORDER MODELLING WORKFLOW (2/2)

- A Permanent Magnet Synchronous Motor has been used to validate this workflow
- Aim: Calculate the radial and tangential forces on the stator teeth over an electrical period so that these forces can be used for Noise, Vibration and Harshness (NVH) analyses
- Inputs:
  - Torque (*T*) and Speed (*N*) at which the machine is operating
- Outputs:
  - Radial (*Fr*) and Tangential (*Ft*) forces
- ROM will be an analytical model that produces *Fr* and *Ft* for any Torque and Speed within the operating range analyzed

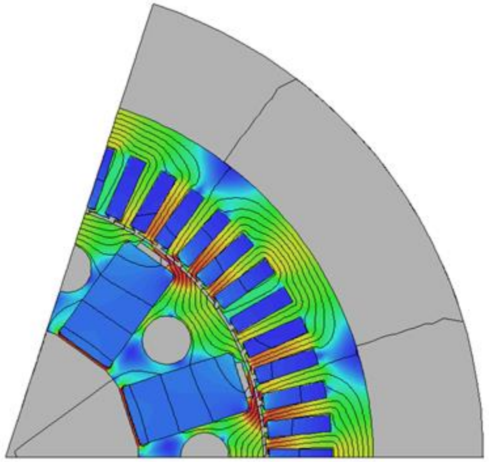




ELECTROMAGNETIC & NVH SIMULATION COUPLING (1/3)

- Electromagnetic design of the electric motor for an EV/HV and design of the mechanical drive train have traditionally been conducted independently
- “Quiet” motors and gearboxes have often shown excessive system NVH when connected on the same drivetrain
  - We need a more integrated approach to the design

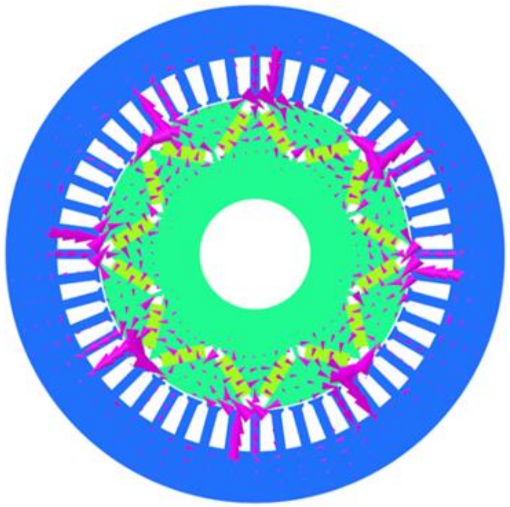
- Sensitivity studies for different types of motor deformations
  - Reliable methodology for integration of software tools
- Electromagnetic software: SIMULIA Opera
- NVH software: any, as long as output file formats are correctly set up

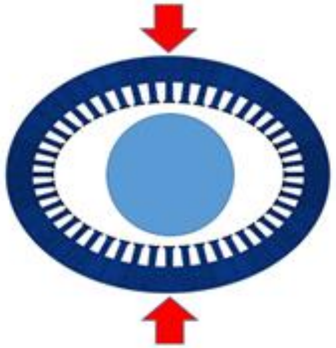


With thanks to Bilquis Mohamodhosen for the slides

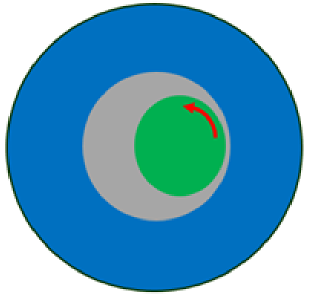
ELECTROMAGNETIC & NVH SIMULATION COUPLING (2/3)

- Various deformations in a motor include:
  - Stator ovalling
  - Static eccentricity
  - Stator tooth rocking
  - Rotor tilt
- These deformations have to be taken into account as they produce spurious harmonics which affect NVH in a motor

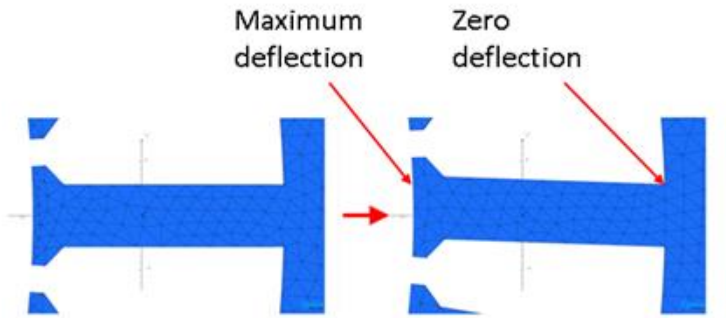




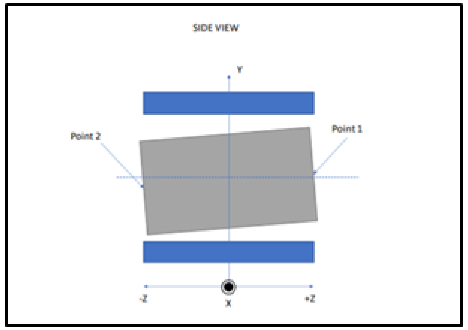
Stator ovalling



Static eccentricity



Stator tooth rocking



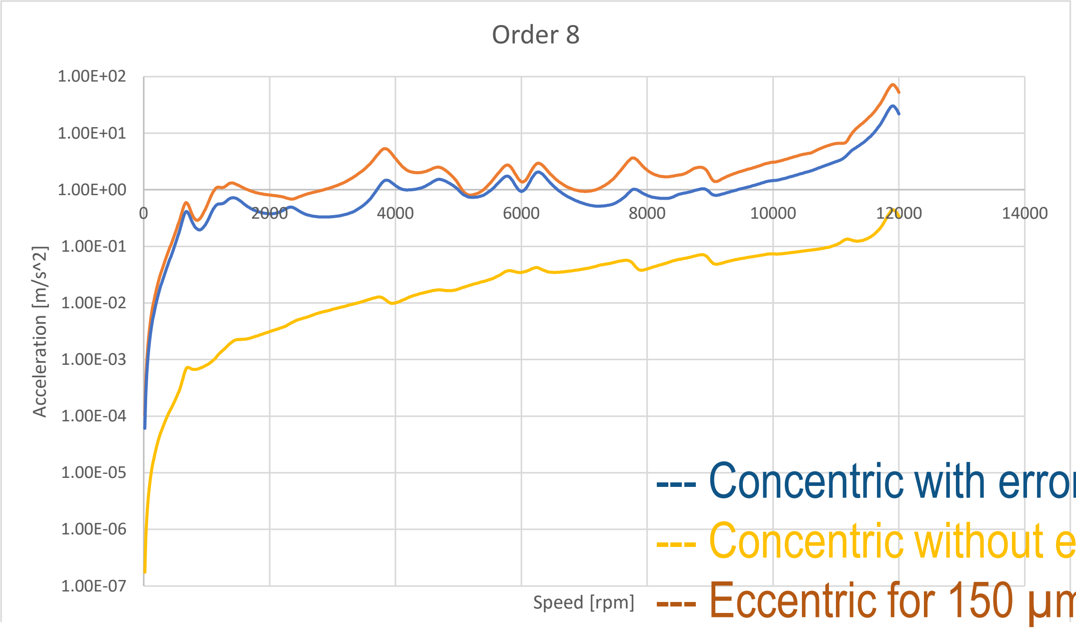
Rotor tilt

With thanks to Bilquis Mohamodhosen for the slides

ELECTROMAGNETIC & NVH SIMULATION COUPLING (3/3)

- Use of node/mesh displacement to account for deformations (instead of rebuilding the geometry)
  - More accurate, with effects due to mesh changes mitigated
- Use of uniform mesh for more reliable force calculations
- Use of 'averaging algorithm' to efficiently eliminate discrepancies in forces

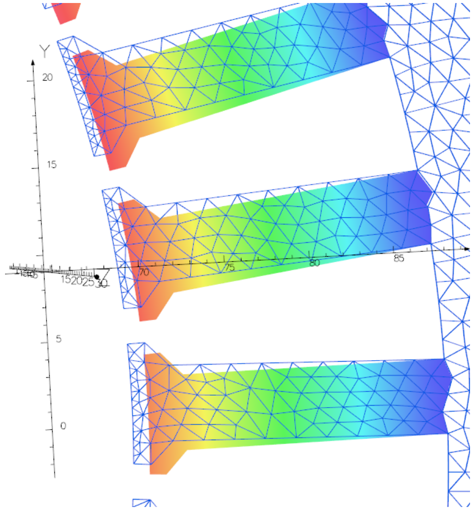
- NVH analysis:



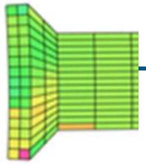
--- Concentric with errors

--- Concentric without errors

--- Eccentric for 150 µm displacement



$-3.5 \leq F_{d_t} \leq 3.5$ N/mm^3



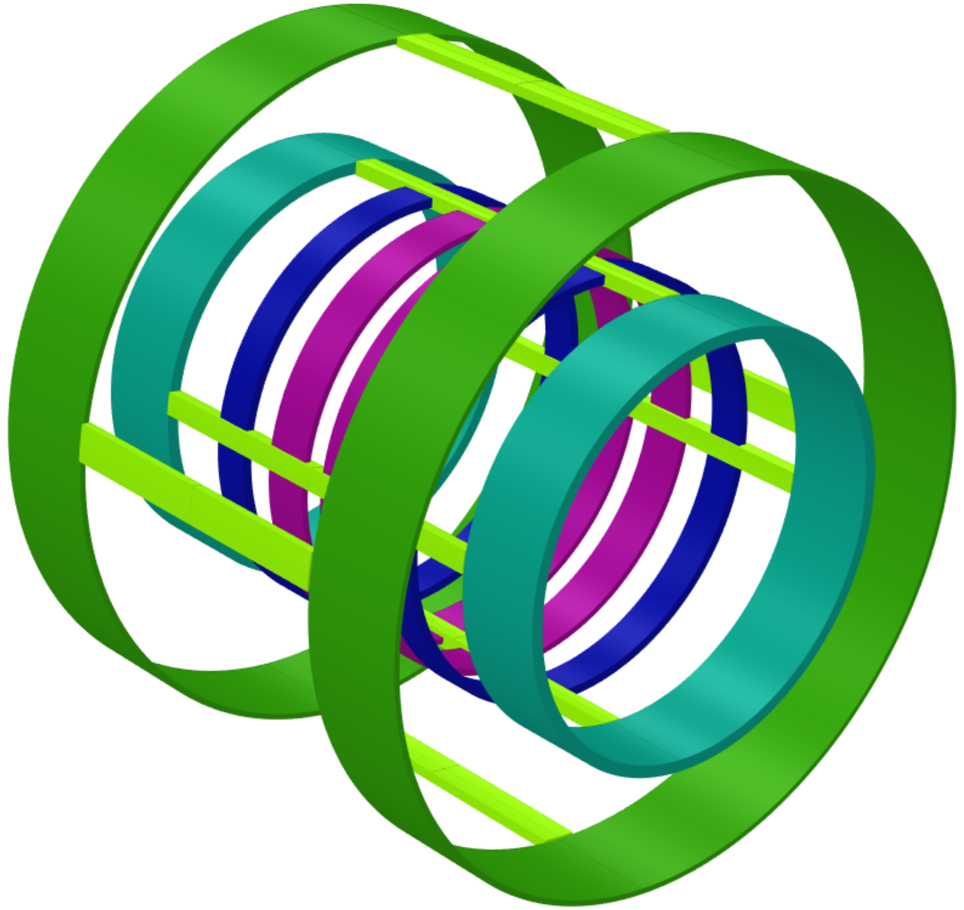
$-0.9 \leq F_{d_t} \leq 0.9$ N/mm^3

OPERA MULTIPHYSICS SIMULATION OF MRI COILS (1/2)

Deformation of coils due to Lorentz forces and effect on field harmonics

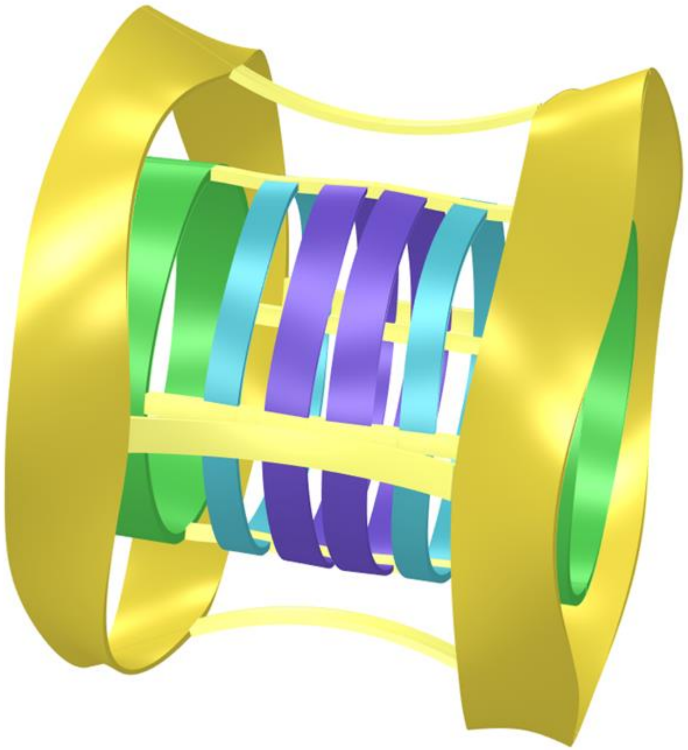
- Superconducting solenoids in MRI magnets are used to produce a highly homogeneous (~ a few parts per million) DC field
  - Modern hospital MRIs operate at 3 T
- The very high fields and currents produce significant Lorentz (J x B) forces which can deflect the coils sufficiently to reduce the quality of the homogeneity
  - Homogeneity is usually expressed in terms of harmonic coefficients (Associated Legendre polynomials)
- This study determines whether the support structure is sufficient to minimize the deflections to an acceptable level
  - Electromagnetic -> Stress -> Electromagnetic

With thanks to Chris Riley for the slides



OPERA MULTIPHYSICS SIMULATION OF MRI COILS (2/2)

Deformation of coils due to Lorentz forces and effect on field harmonics



Deflections of coils and support structure (exaggerated)

Legendre coefficient	Undeflected	Deflected
A00	1,000,000	1,002,406
A20	-309	-312
A40	8.8	8.8
A22	1.1×10^{-9}	$-4.0e \times 10^{-6}$

Effect on harmonic coefficients (in parts per million compared to A00 undeflected)

~0.25% increase in central field will affect resonant frequency for MRI

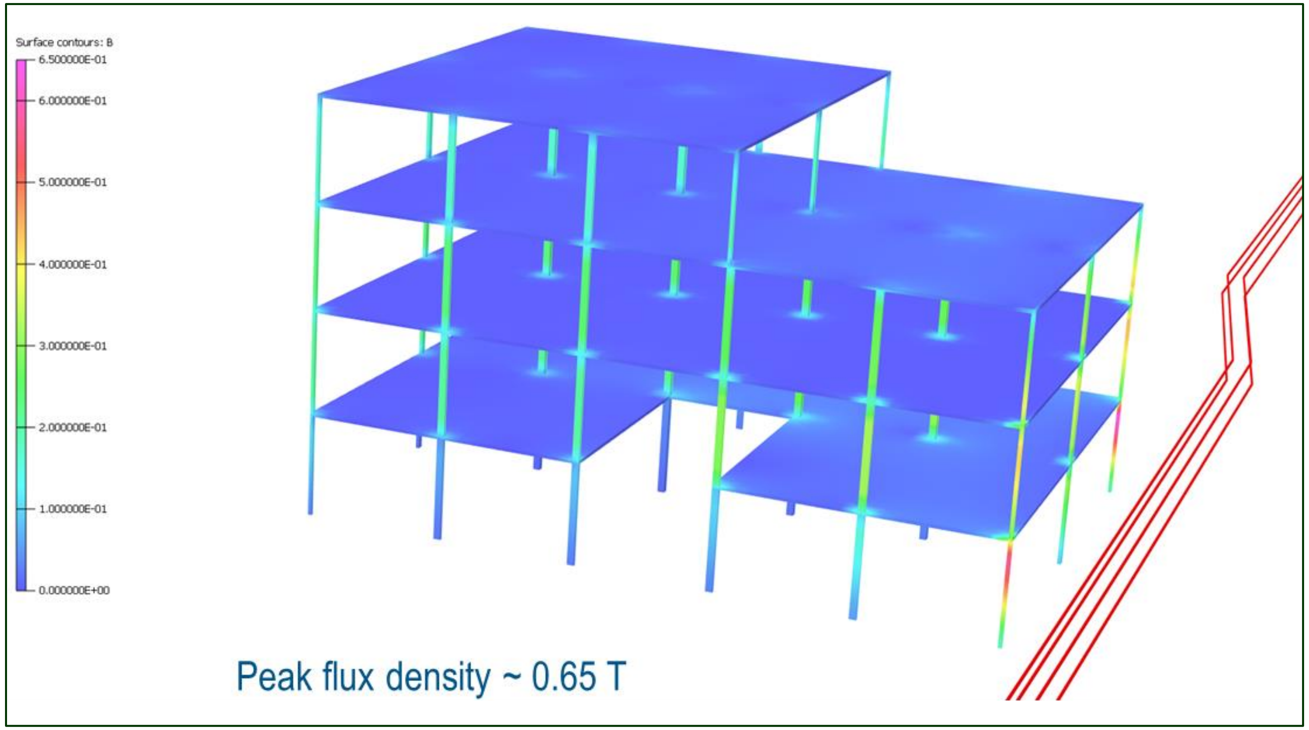
RAILWAY ELECTROMAGNETIC INTERFERENCE (1/2)

Stray fields from railway in a steel reinforced building

- Minimizing EMI from infrastructure such as railways is important
  - Human exposure
    - Limited to 0.5 mT for DC magnetic fields, for example
  - Sensitive instruments
    - Hospitals, scienctific equipment, …….

- Opera has been used to assess the fields
  - Fields from traction circuits (DC/AC)
  - Fields from train positioning systems (AC)
  - Design mitigation systems to reduce EMI

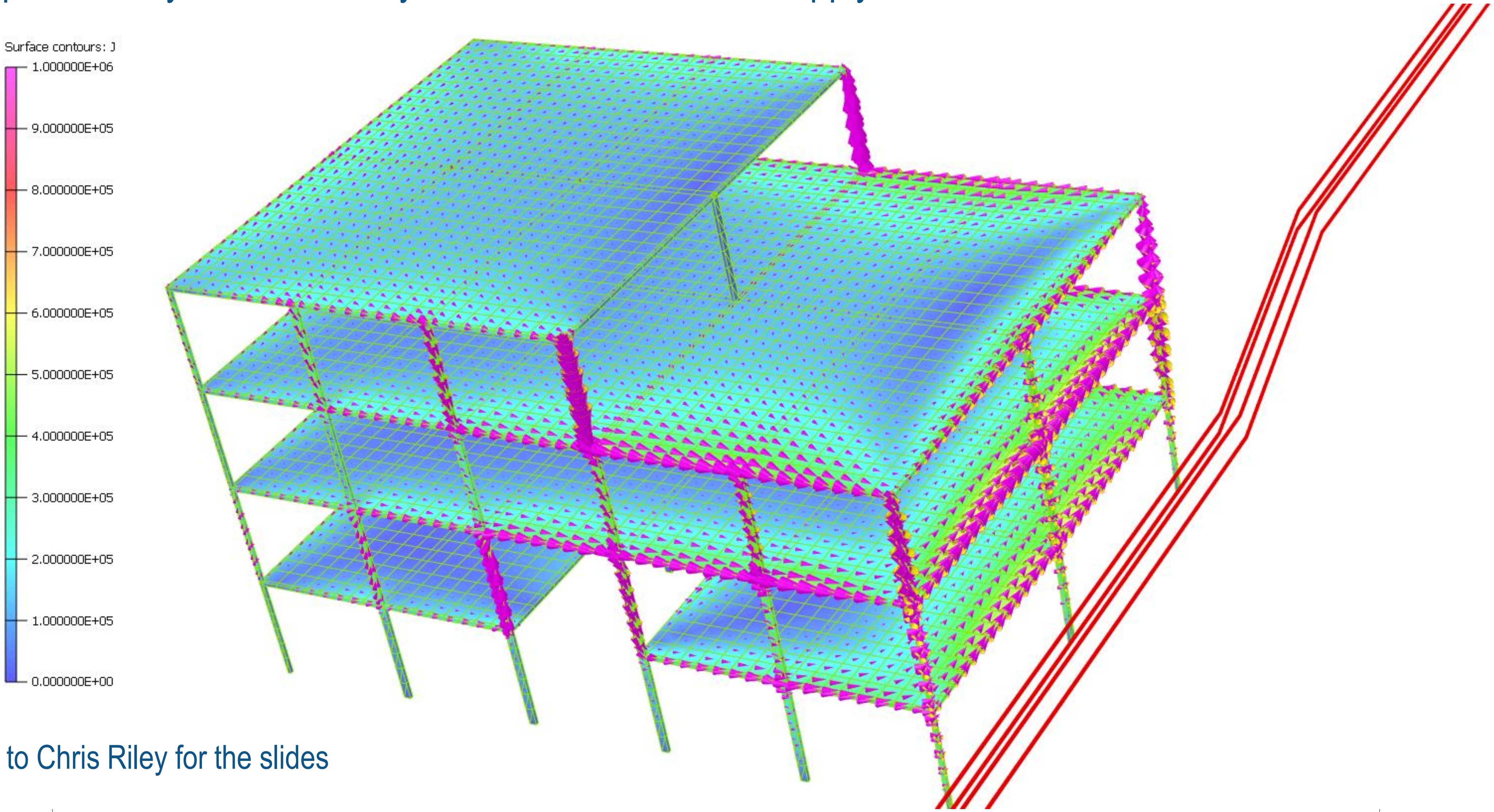
- DC fields in steel structure from nearby traction circuits



With thanks to Chris Riley for the slides

RAILWAY ELECTROMAGNETIC INTERFERENCE (2/2)

Imaginary part of eddy current density in steel from 50 Hz AC supply



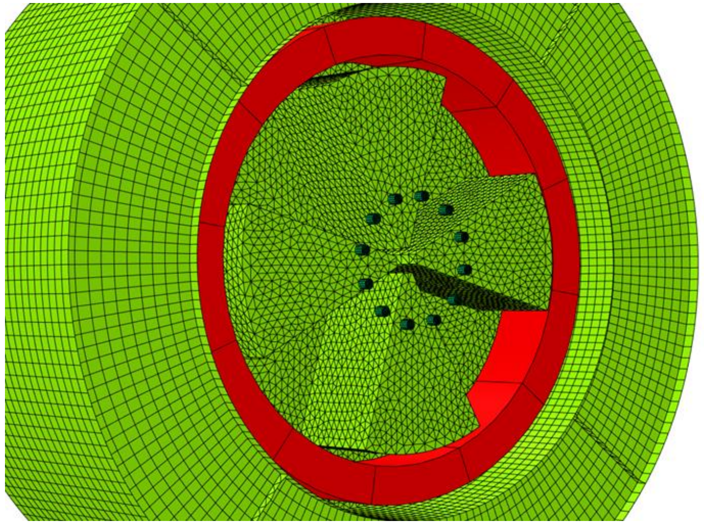
With thanks to Chris Riley for the slides

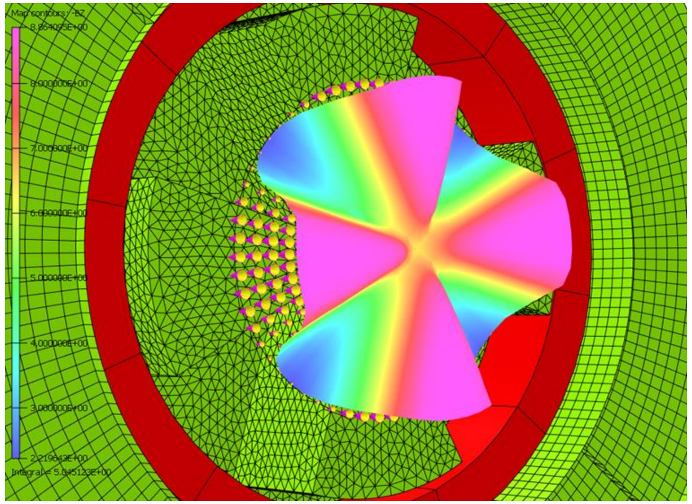
EDDY CURRENTS IN FIELD MEASUREMENT SENSOR (1/2)

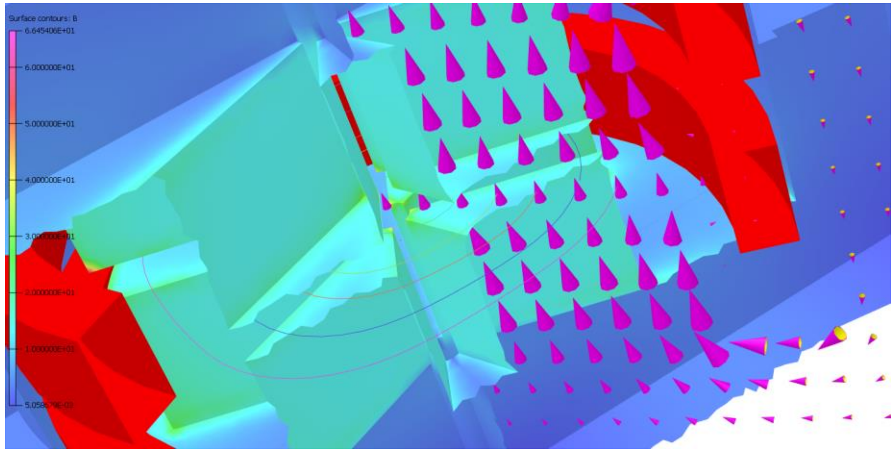
Rotation of sensor array gives eddy currents => Lorentz forces & torque on sensors

- Cyclotron magnets are used in production of medical isotopes
  - Circular set of magnetic dipoles with accelerating particle beam gradually increasing energy / diameter of orbit

- 12 rotating cylinders representing sensors in gaps between magnet poles
  - Used to accurately map mid plane field







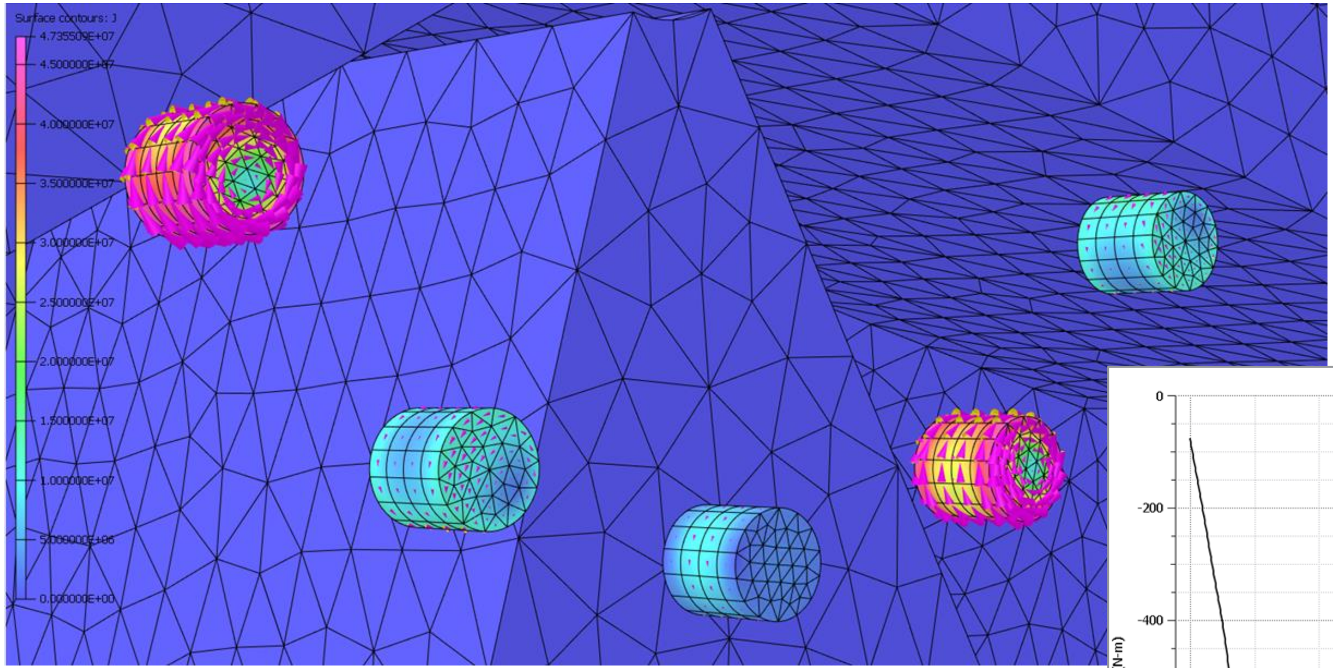
- Upper half of cyclotron & sensors

Flux density on mid plane

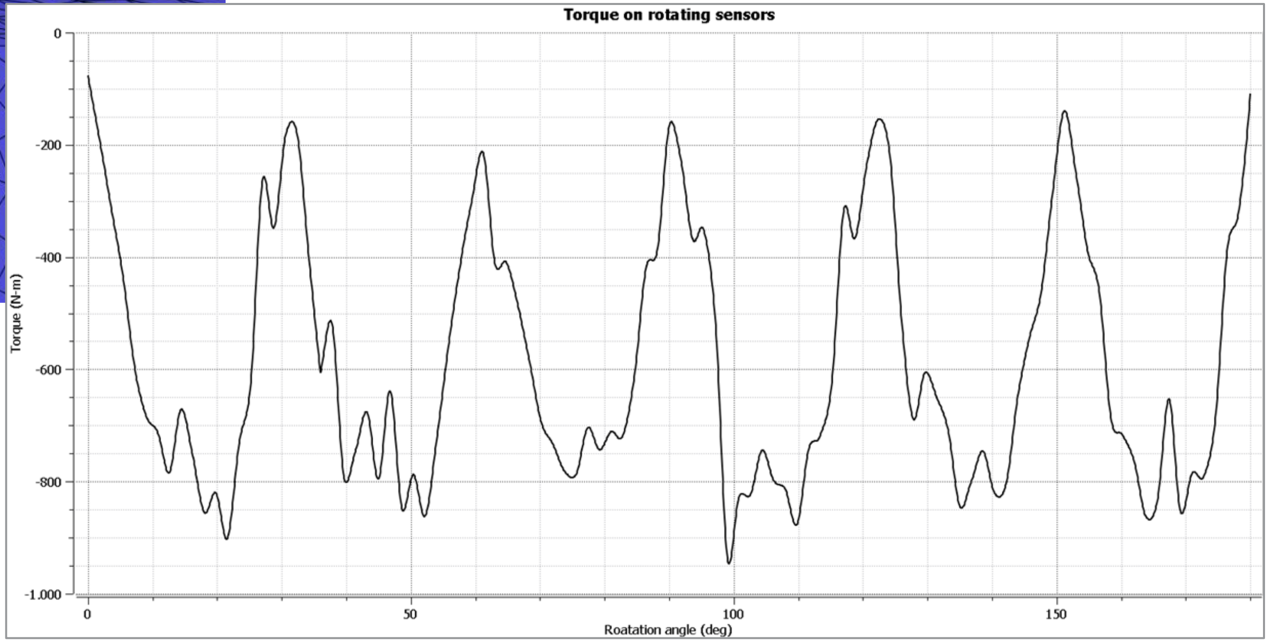
Fields in pole and particle beam tracks

EDDY CURRENTS IN FIELD MEASUREMENT SENSOR (2/2)

Eddy currents in sensor due to rotation and torque during rotation



Highest eddy currents as sensor passes pole edge



Increase in (negative) torque as next sensor(s) pass pole edges

With thanks to Chris Riley for the slides

SUMMARY

Introduction

Opera Solvers

Functional Material Properties

Common Installer for CST Studio Suite® and Opera®

New Workflow for Magnetostatic Analyses

Case Studies

Thank you for your attention
Are there any questions?

Or you can contact me at ben.pine@3ds.com

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