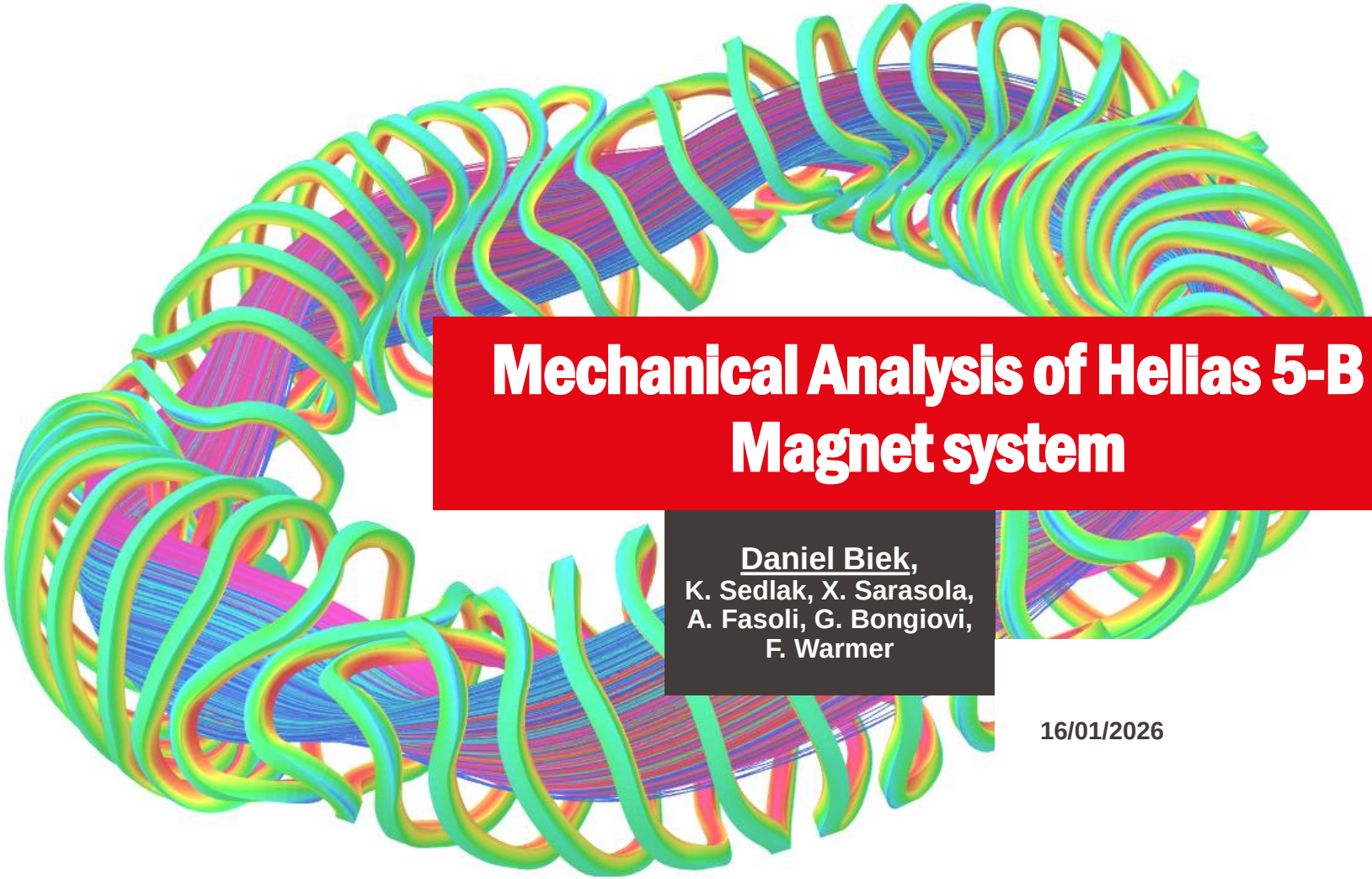


Mechanical Analysis of Helias 5-B Magnet system

Daniel Biek,
K. Sedlak, X. Sarasola,
A. Fasoli, G. Bongiovi,
F. Warmer

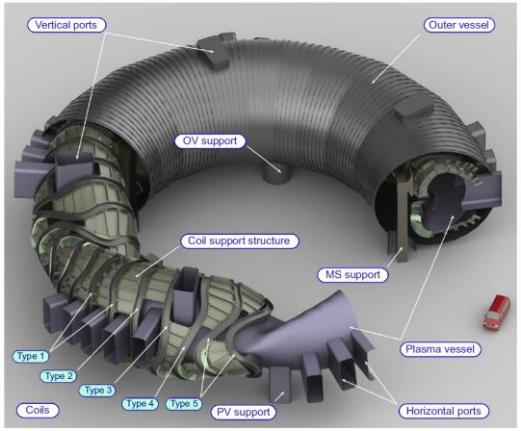
16/01/2026

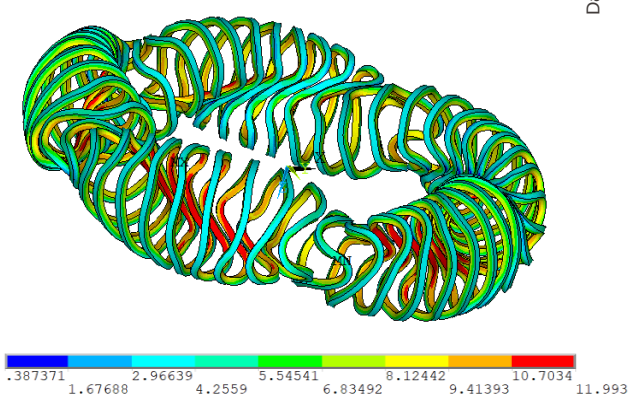
Swiss
Plasma
Center

Daniel Biek

Introduction

- **Aim: Development of a parameterized code for the analysis of stellarator coils**
- Test case: Helias 5-B
  - Optimized stellarator
- Nb3Sn Coils
- Electromagnetic and thermal-hydraulic analysis have been performed

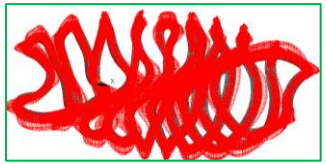




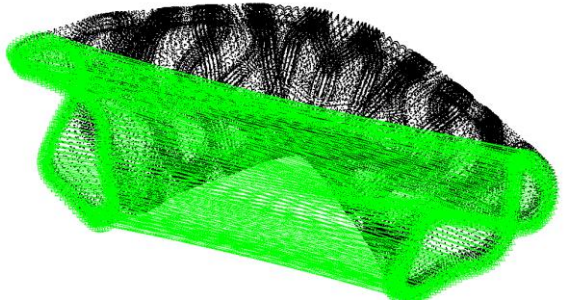
Case	$T_{hot,SC}$ [K] [Limit: 250K]	$T_{hot,Steel}$ [K] [Limit: 150K]
BBL+spiral – HF zone	134.21	119.94
BBL+spiral – LF zone	134.03	115.53
BBL+spiral – Middle	130.68	115.31

Daniel Biek

Design procedure – Mechanics



Fully bonded or sliding contact btw. Case and Coil



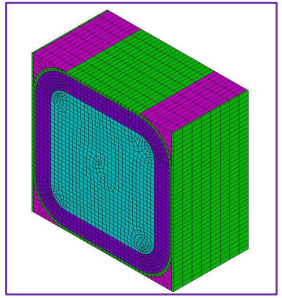
Lorentz Force from EM simulation

Mechanical Analysis: Coil Cases and Intercoil structure

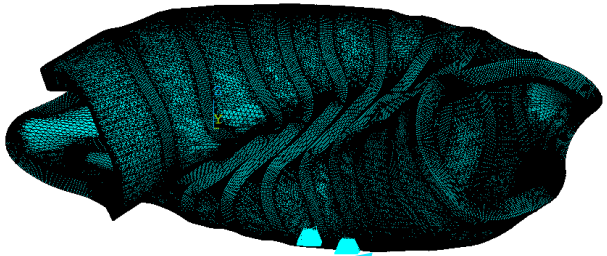
1. Cool-down to 4.2K
2. EM load during operation

Boundary Conditions:
1. Gravity support: Sliding contact
2. Periodic boundary conditions

Smeared mechanical properties



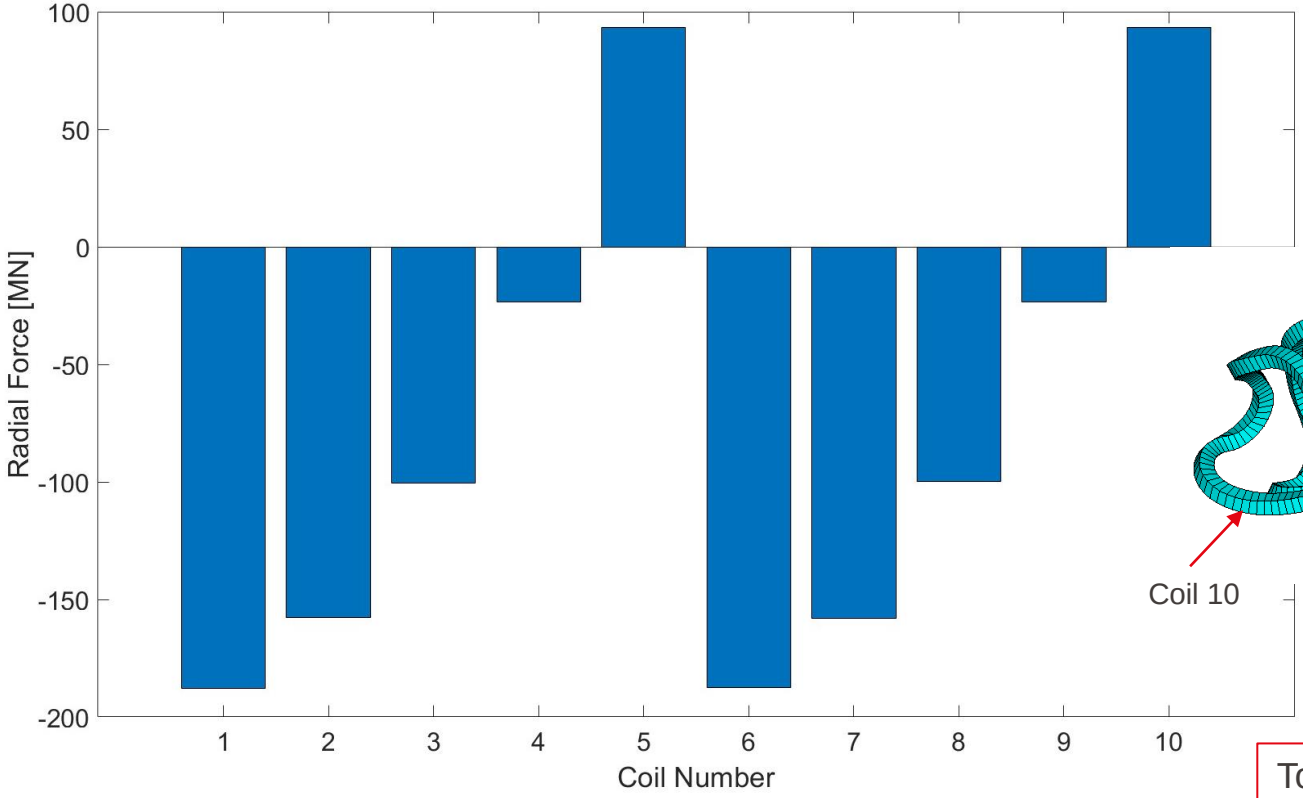
Intercoil Structure: Space filled between coils

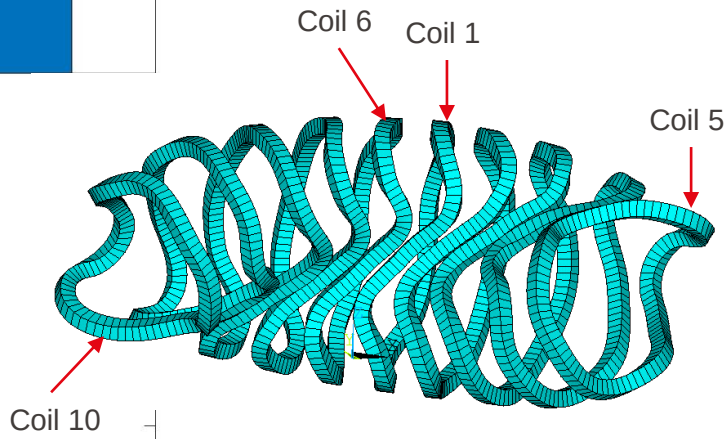


Gravity support

Daniel Biek

Coil net forces

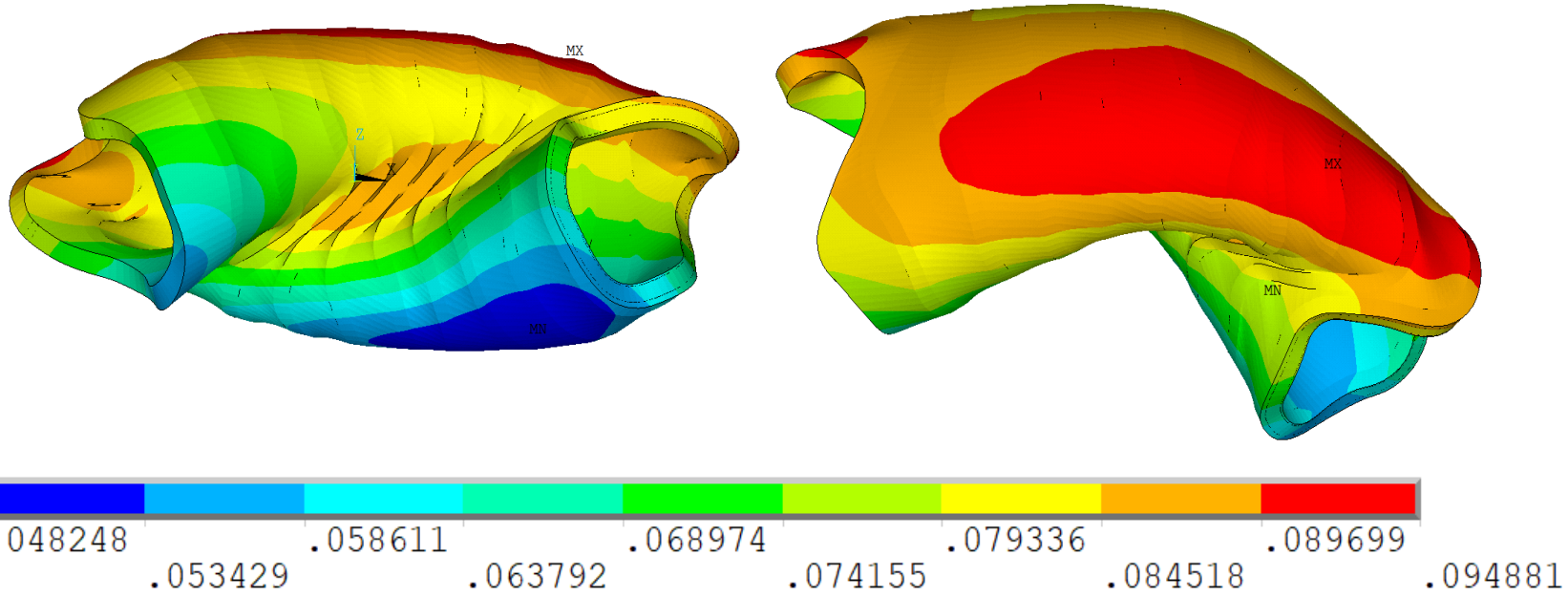




Total radial force: 750.73 MN
Whole system: 3759 MN

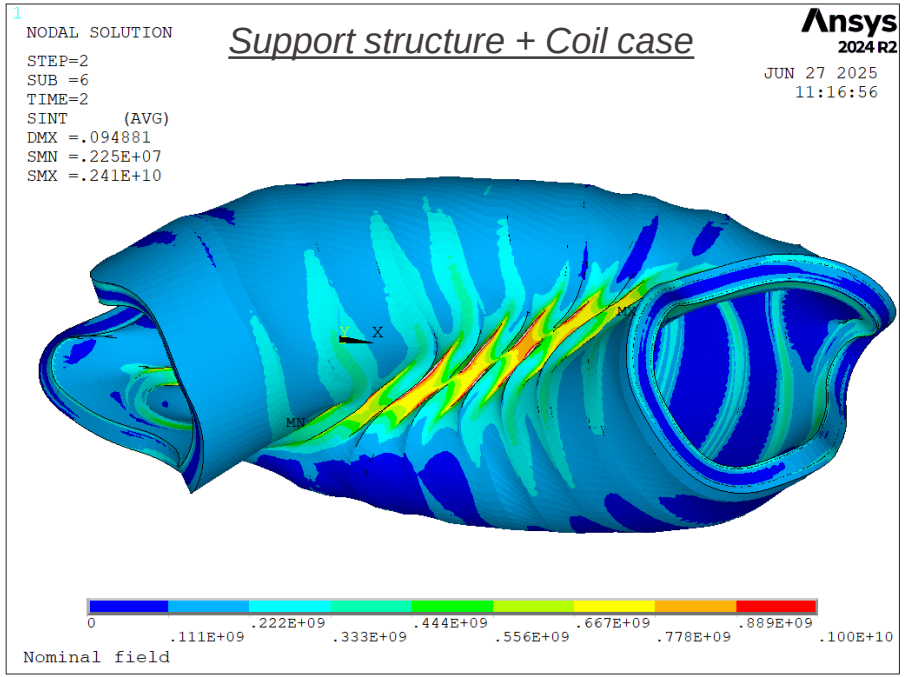
Mechanical Analysis – Displacement

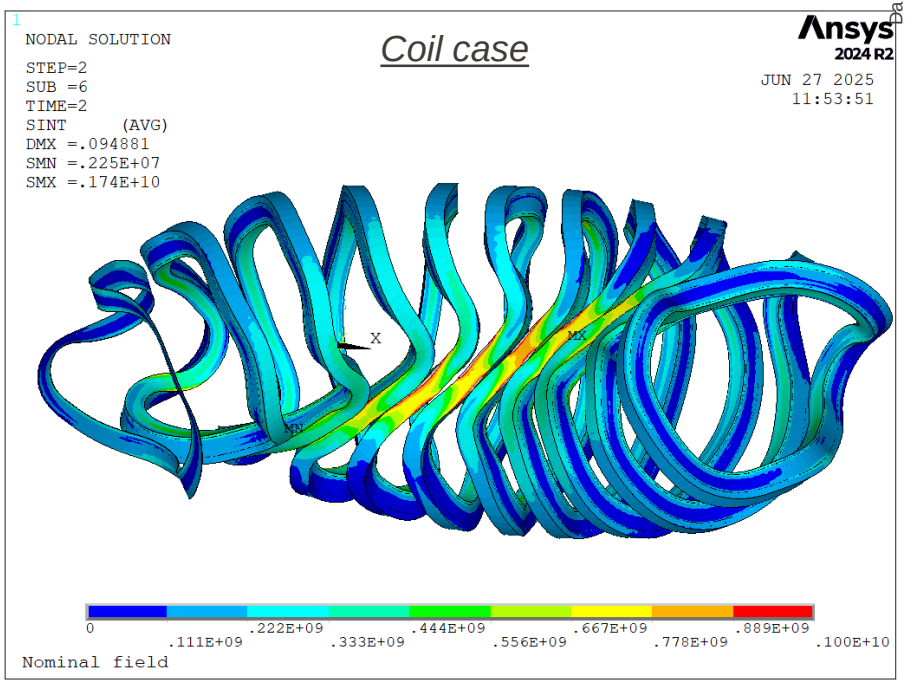
Daniel Biek



Mechanical Analysis – Stress intensity

Daniel Biek

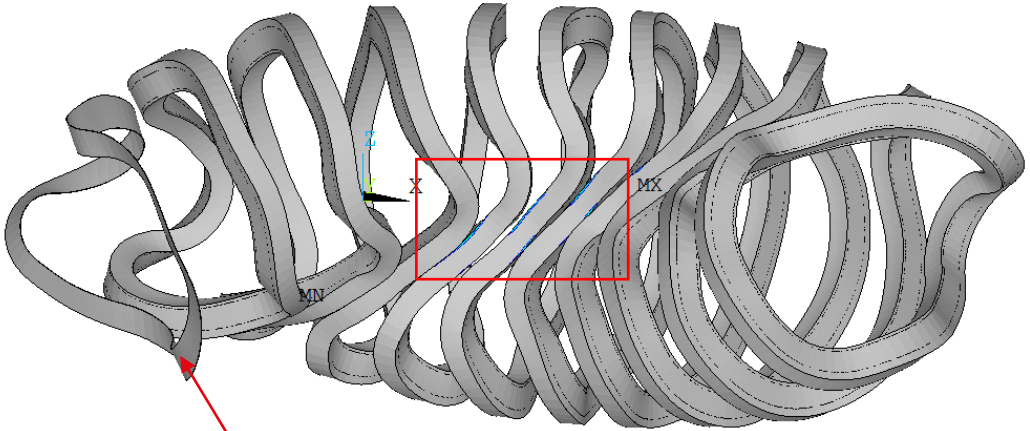


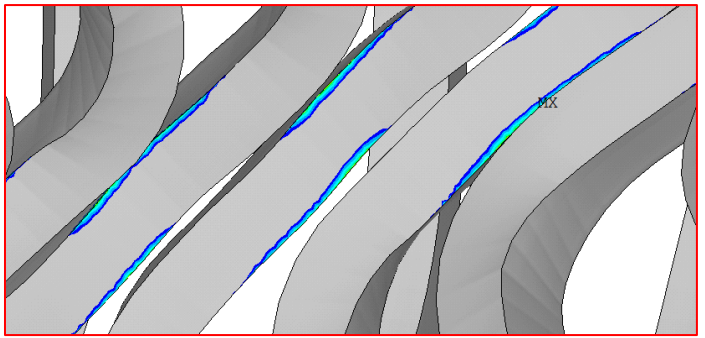


Stress intensity (Pa) from 0 to 1GPa (yield strength at 4.2K)

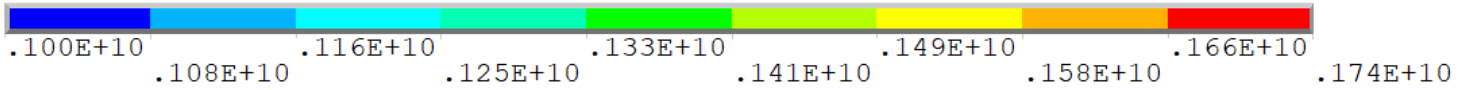
Daniel Biek

Mechanical Analysis – Stress intensity in the coil case



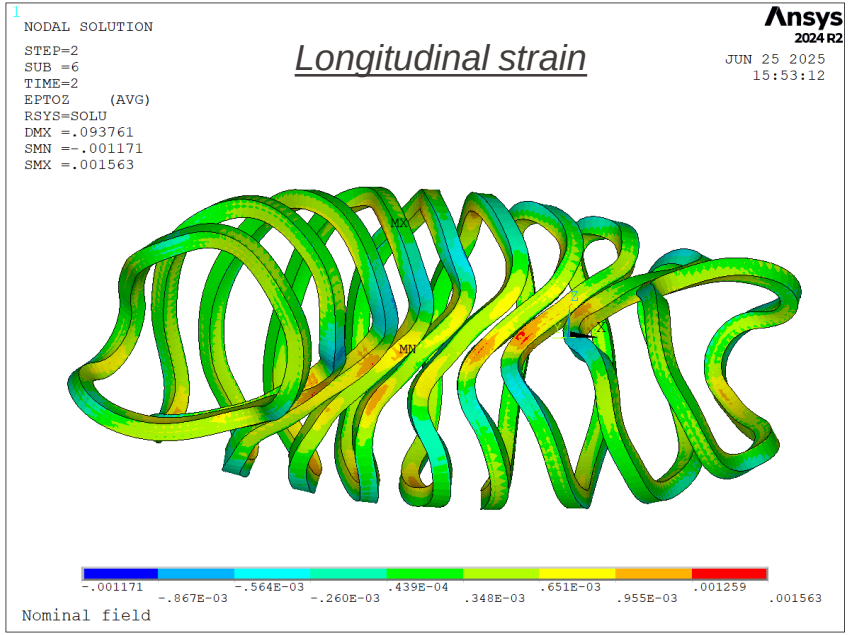


Outer boundary of the neighboring period



Mechanical Analysis – Winding pack

Daniel Biek

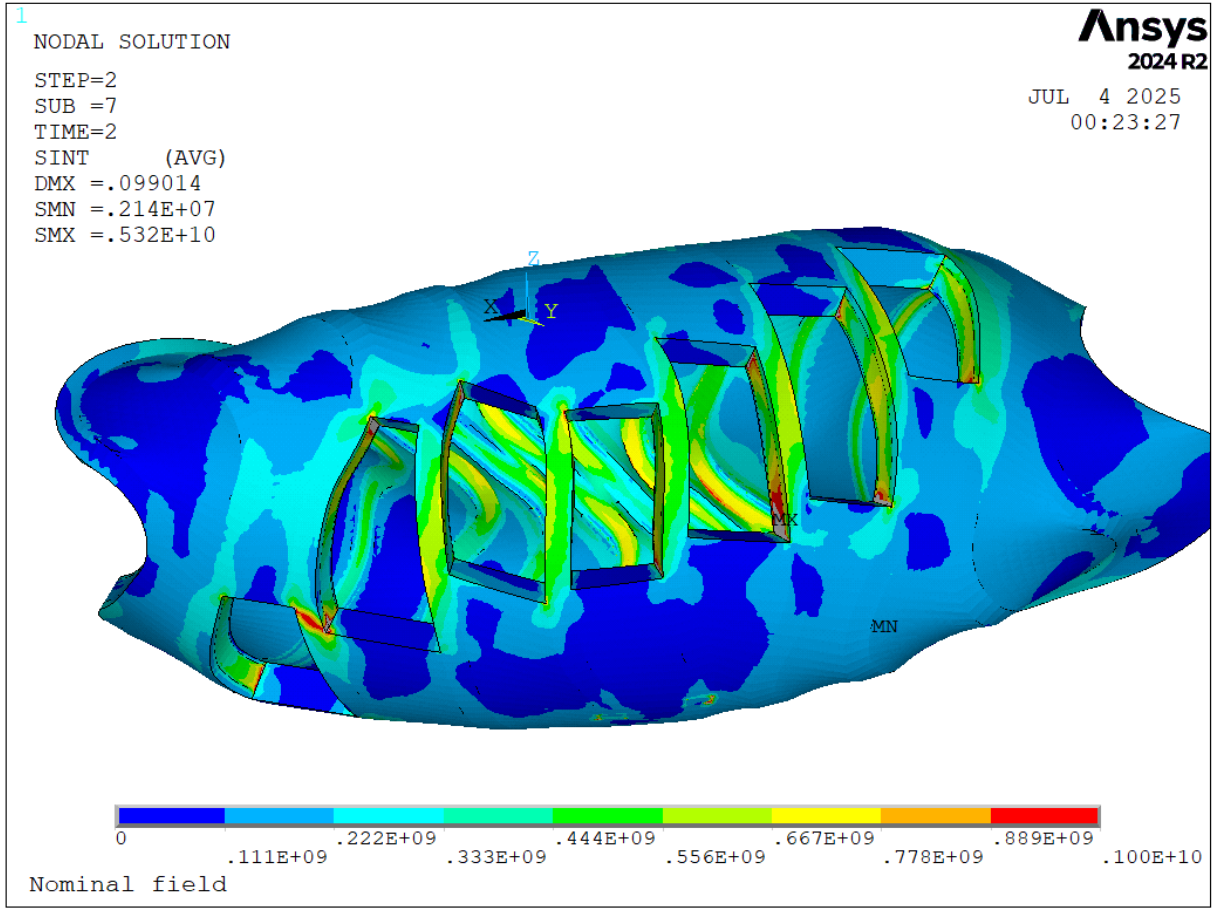


Hook's Law

Quantity	Value
Maximum Stress (yield strength 1GPa)	1.23 GPa
#Nodes with stress values above 1GPa (yield strength)	393 (0.08%)
#Nodes with stress values above 867MPa	1460 (0.3%)

Maximum longitudinal strain lower than 0.2%

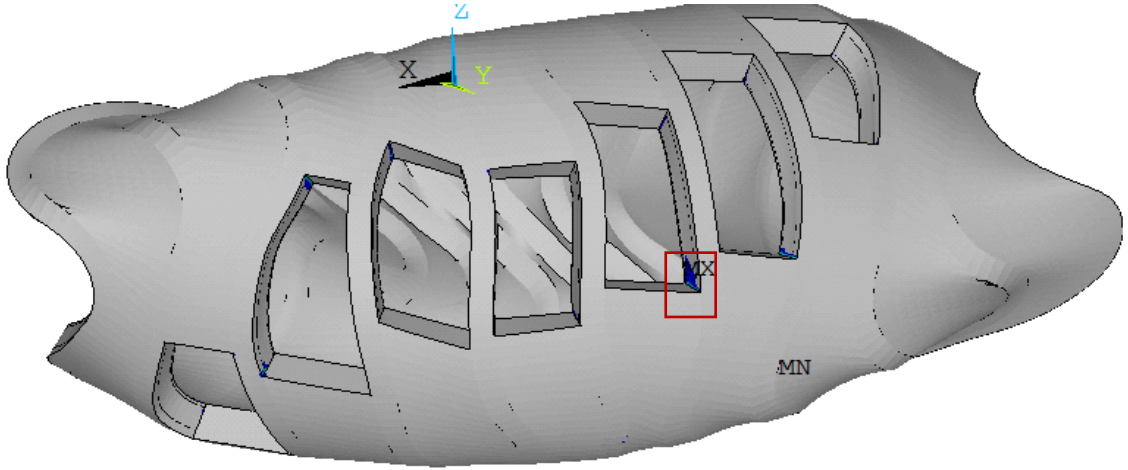
Helias Mechanical Analysis – Ports (Stress intensity <= 1GPa)

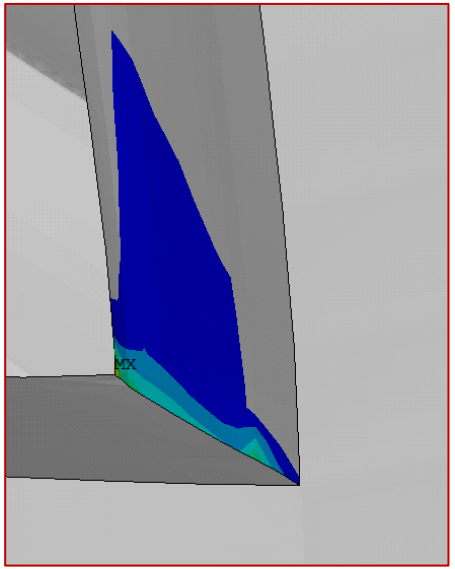


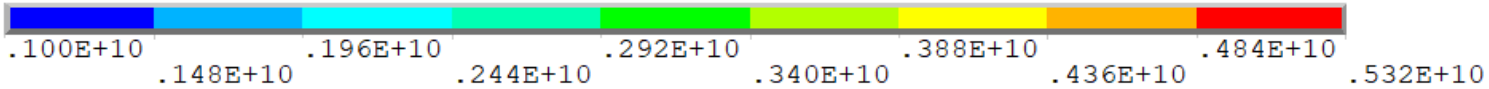
Daniel Biek

Helias Mechanical Analysis – Ports (Stress intensity > 1GPa)

Daniel Biek

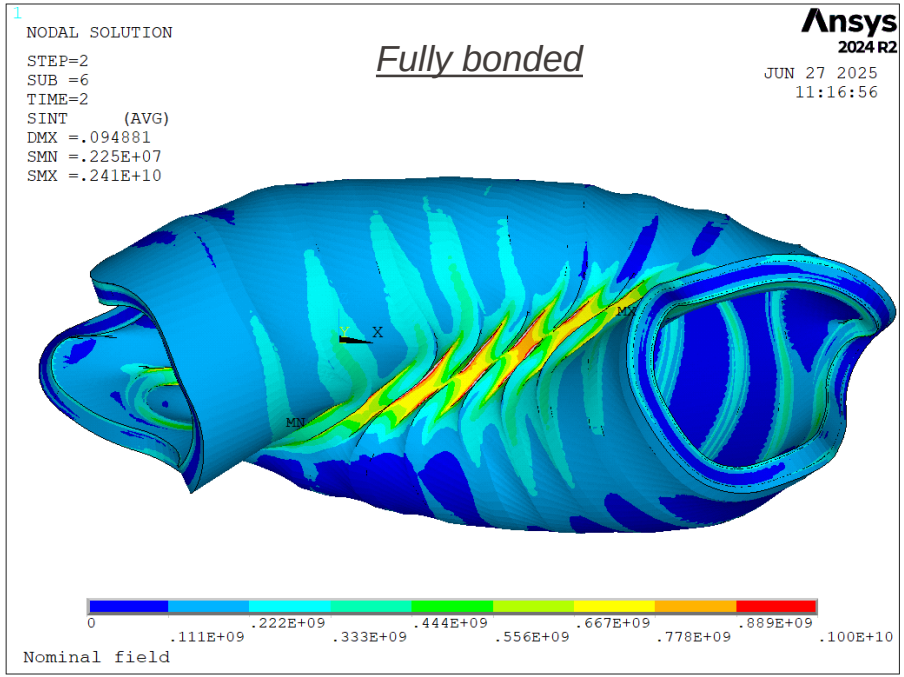


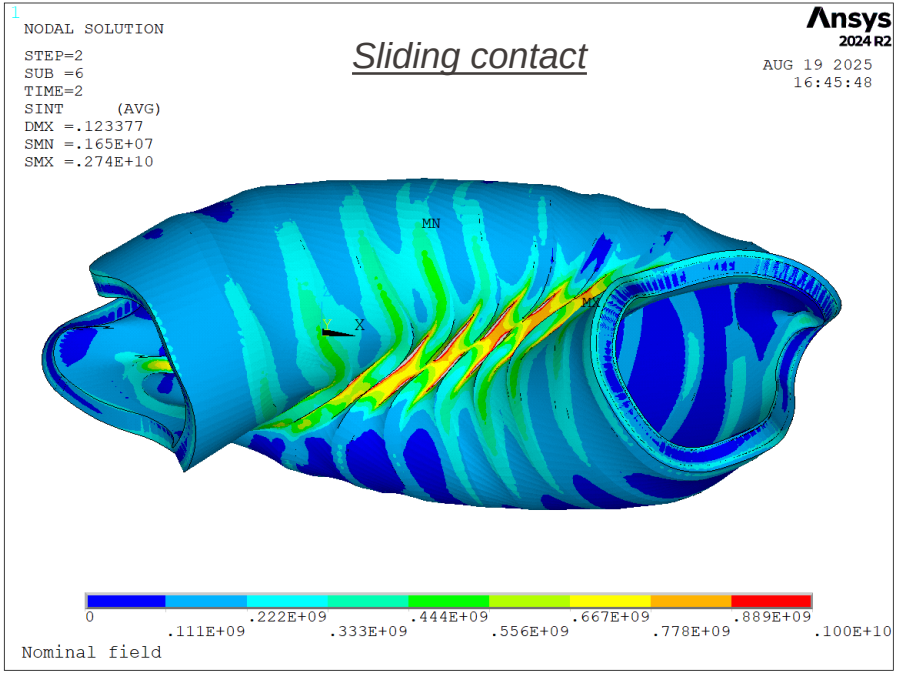




Comparison – Stress intensity

Daniel Biek

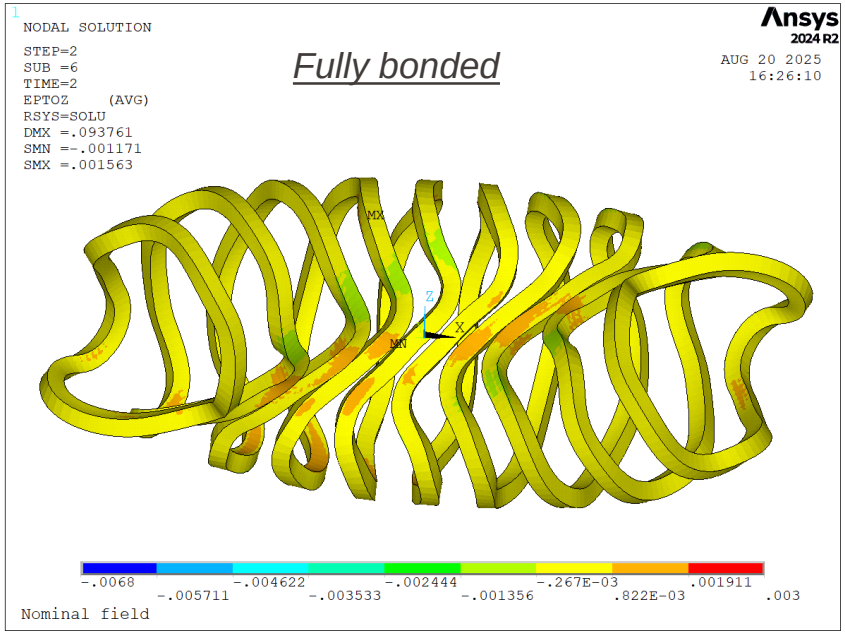


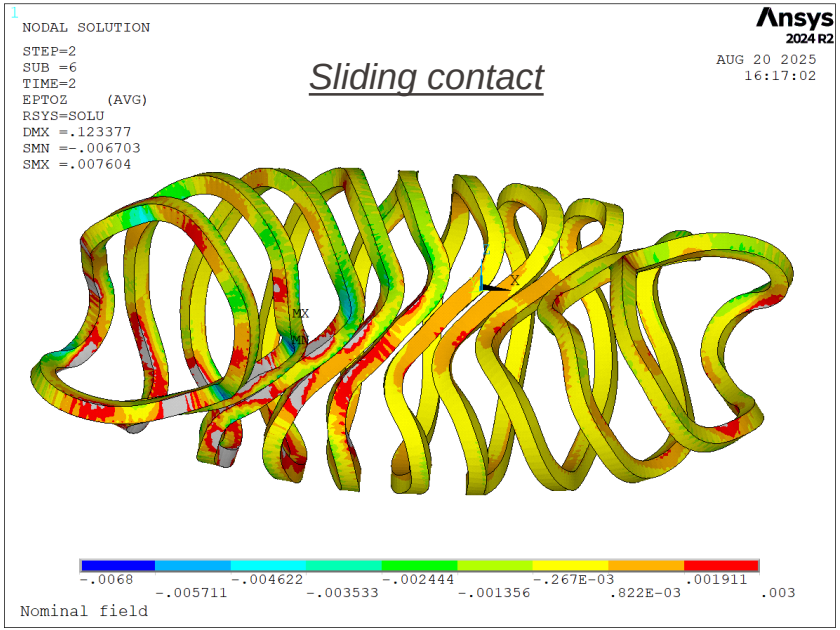


Stress intensity (Pa) from 0 to 1GPa (yield strength at 4.2K)

Comparison – Longitudnal Strain

Daniel Biek



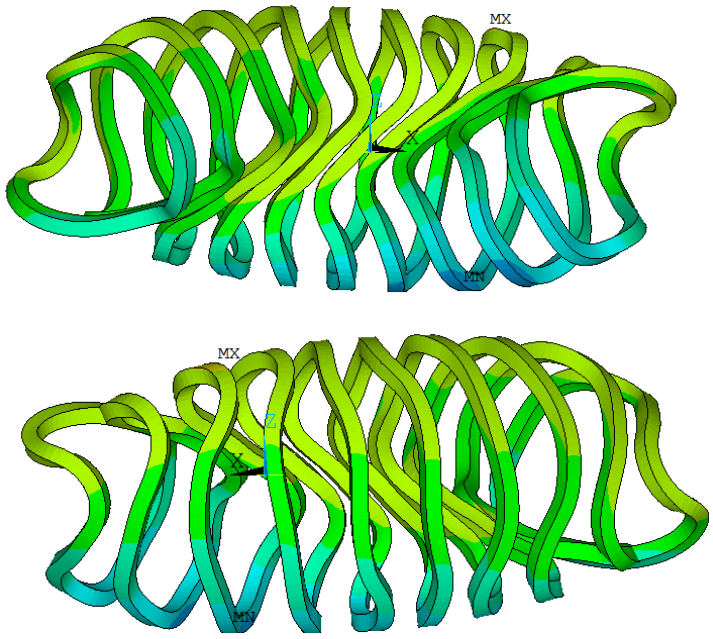


Comparison – Displacement – coil

Daniel Biek

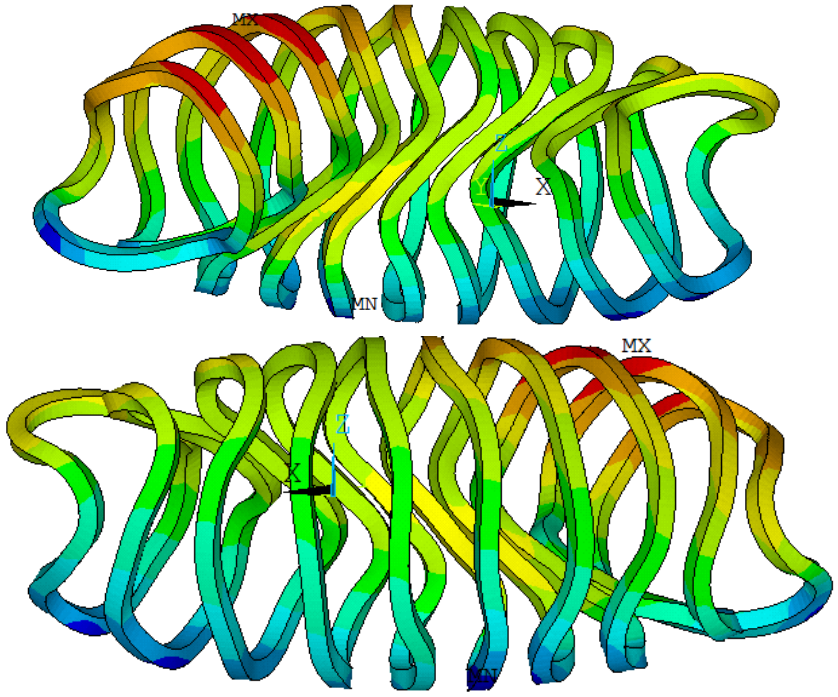
DMX =.094881
SMN =.048248
SMX =.094881

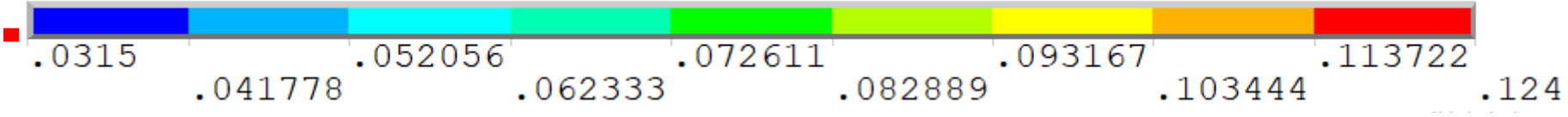
Fully bonded



Sliding contact

DMX =.123377
SMN =.031558
SMX =.123377





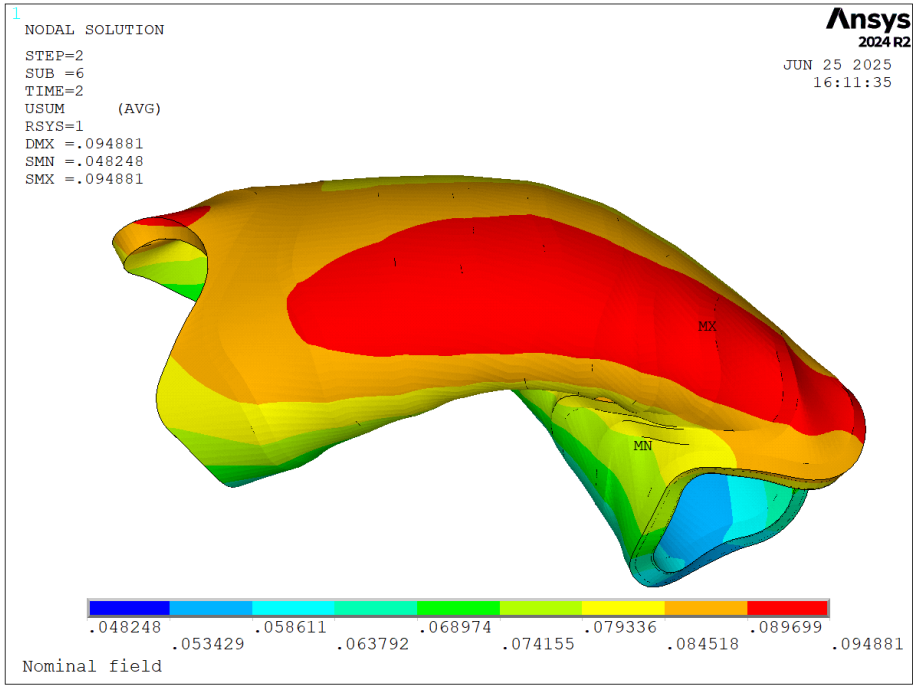
Summary

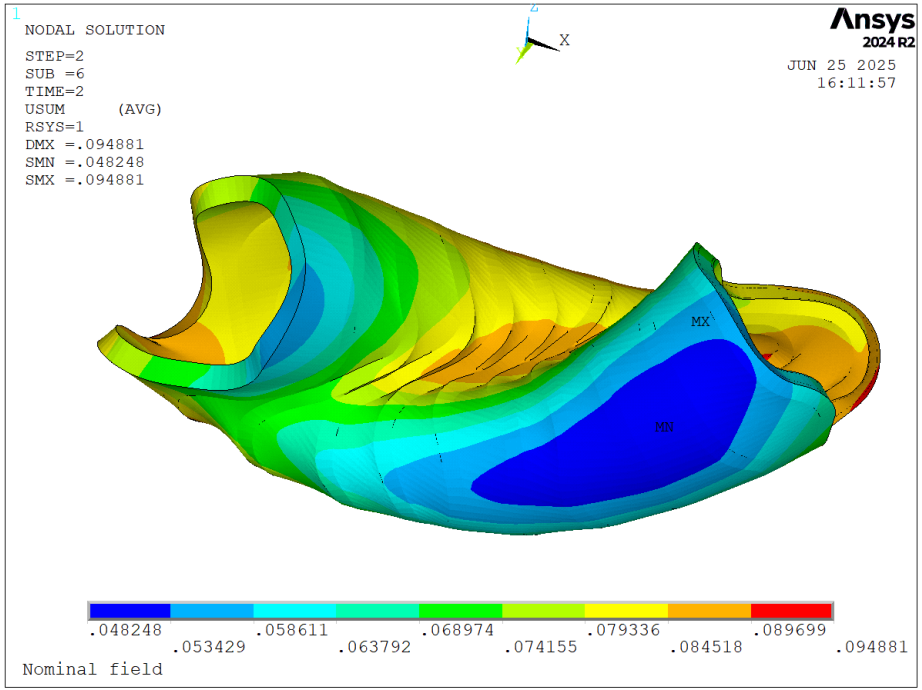
- Stress exceeds stress limit only in localized regions (edges, sharp transitions)
  - Possible countermeasures: Central ring, rounding of edges
- Strain is within reversible range (fully bonded case) of Nb3Sn
- Including ports leads to localized high stress in the corner -> chamfers
- Fully bonded vs. Sliding Contact
  - Stress is similar
  - Strain is higher in the sliding contact due to higher displacements
- Possible measures to increase structural integrity would be adding a central support ring
- Paper about the whole workflow is published [1]
- Next steps: Application to a new configuration + HTS design

[1]: D. Biek et al. 'A Parametric Workflow for the Design of High-Field Magnets for Optimized Stellarators', IEEE Trans. Appl. Supercond., pp. 1–6, 2025, doi: 10.1109/TASC.2025.3646598.

Mechanical Analysis – Displacement

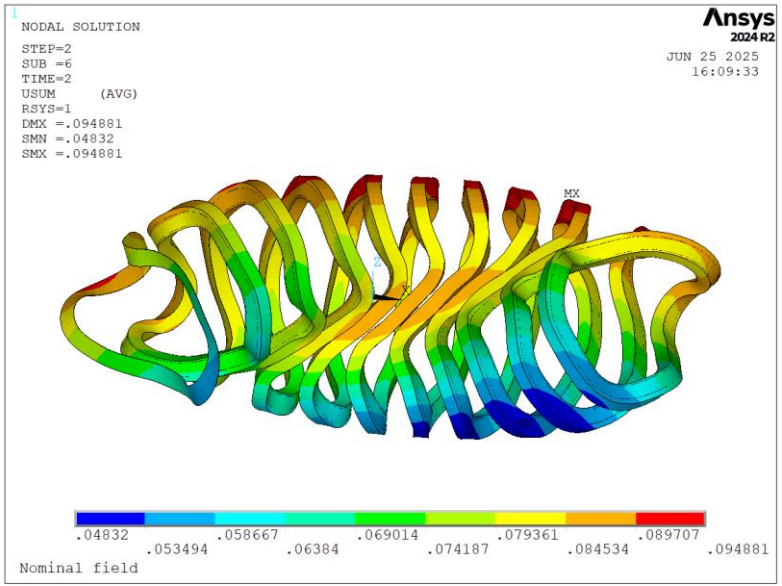
Daniel Biek

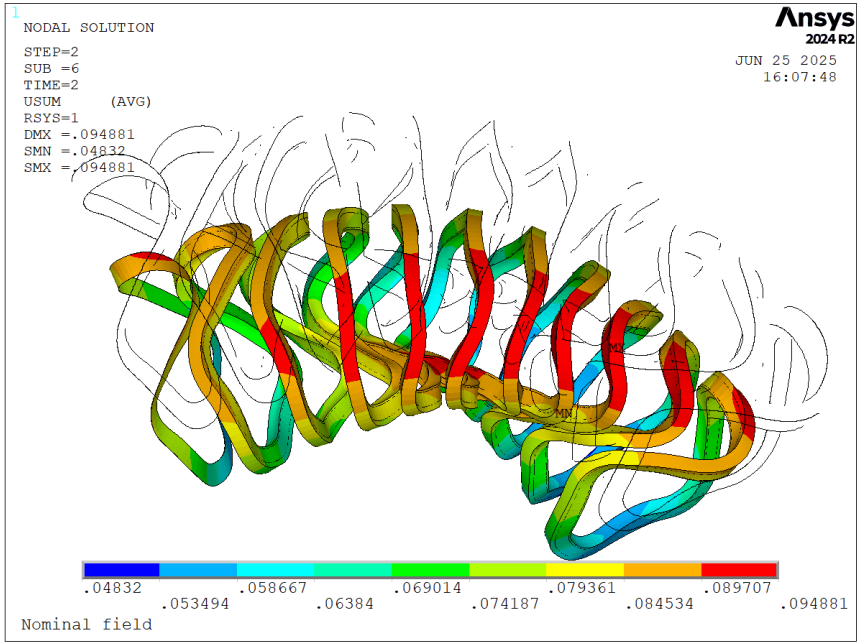




Mechanical Analysis – Displacement – Coil Case

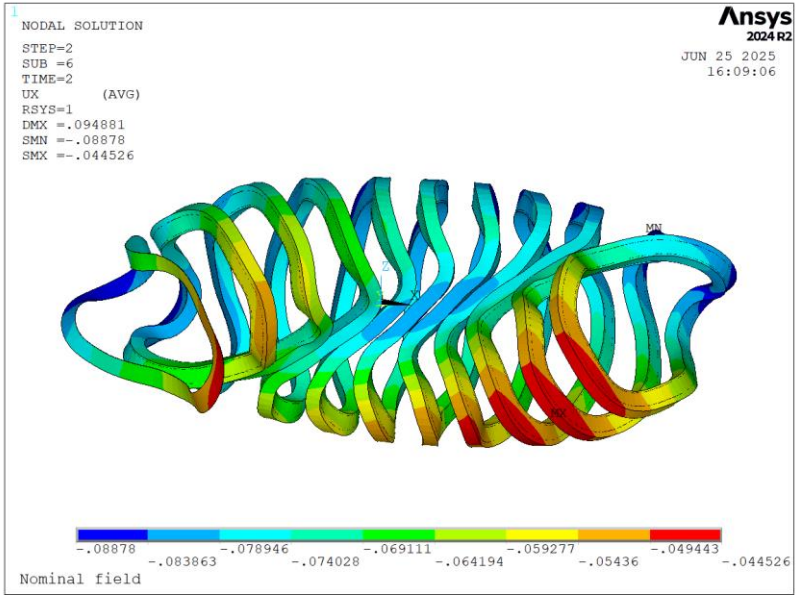
Daniel Biek

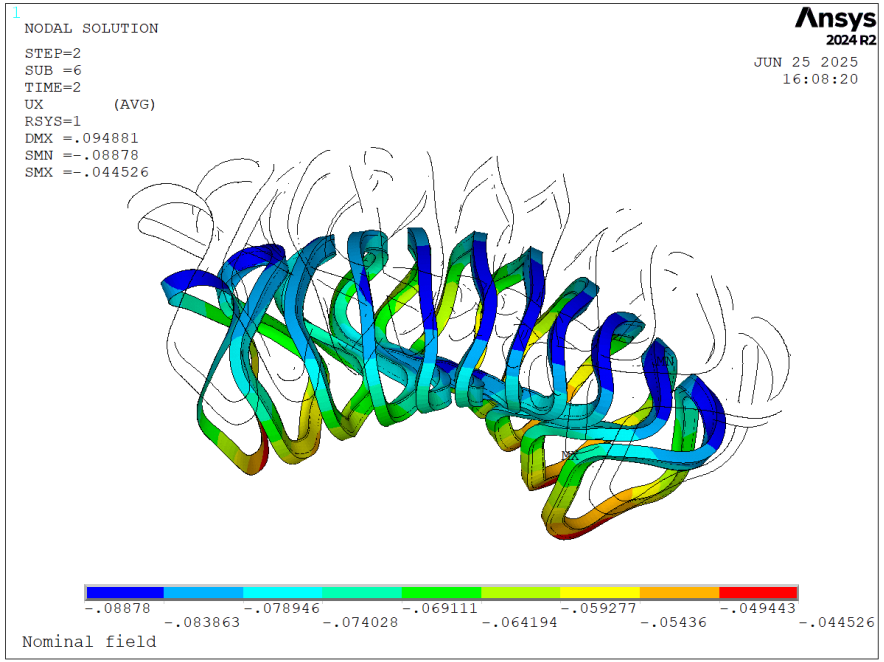




Mechanical Analysis – Radial Displacement – Coil Case

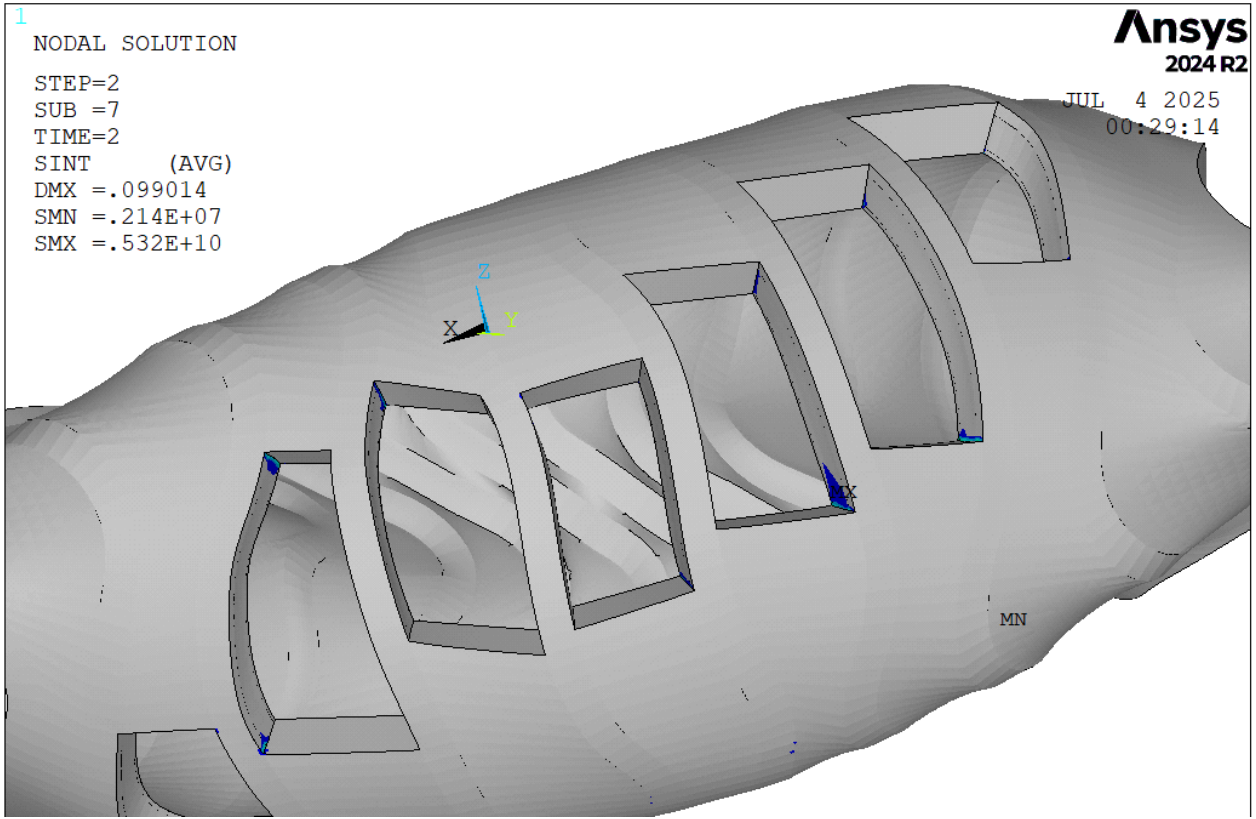
Daniel Biek





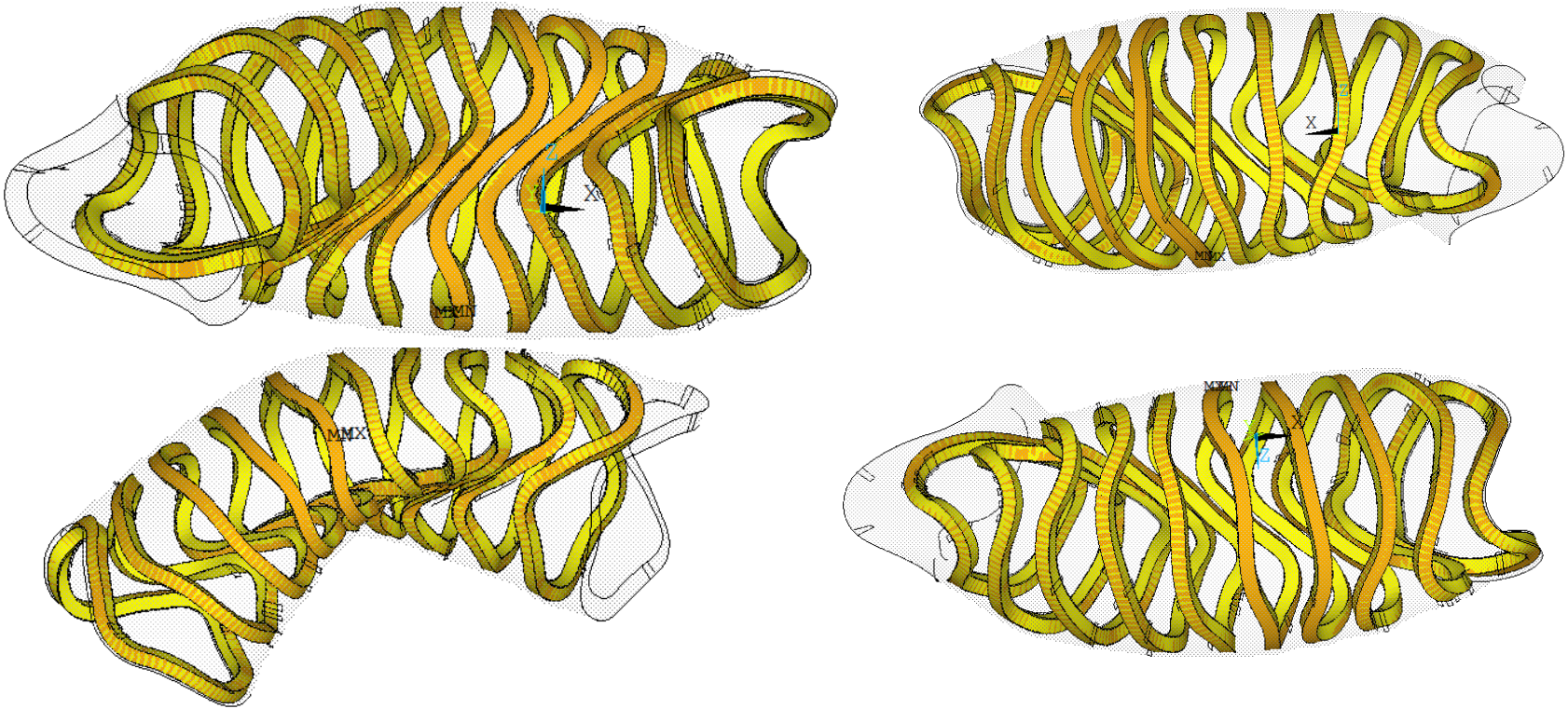
Helias Mechanical Analysis – Ports (Stress intensity > 1GPa)

Daniel Biek



Daniel Biek

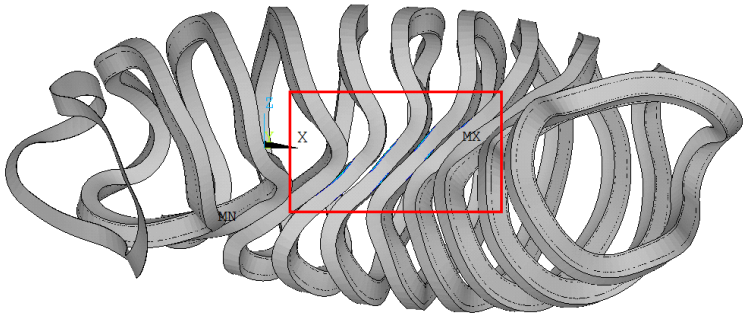
Contact – Sliding model

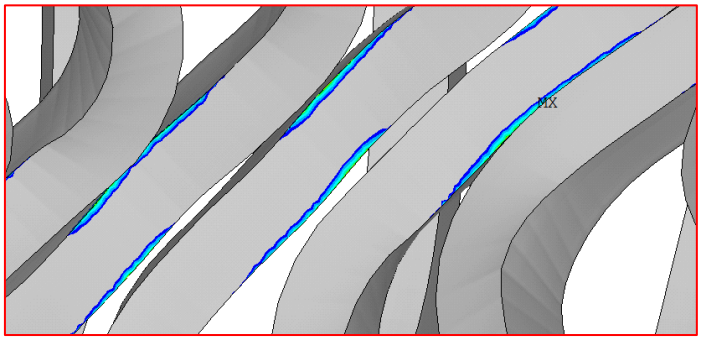


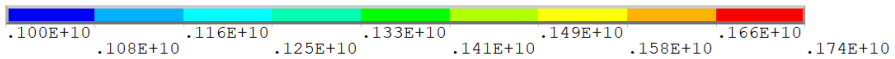
Daniel Biek

Mechanical Analysis – Stress intensity > 1GPa

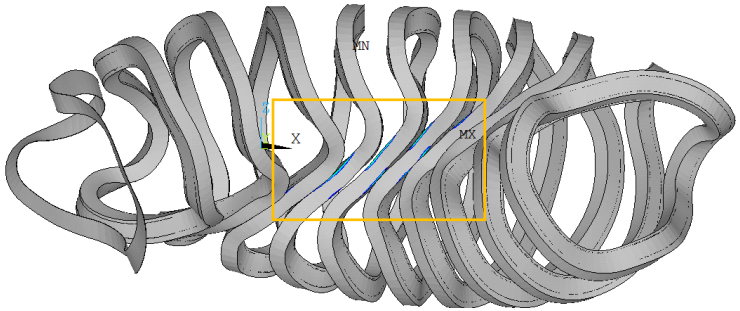
Fully bonded

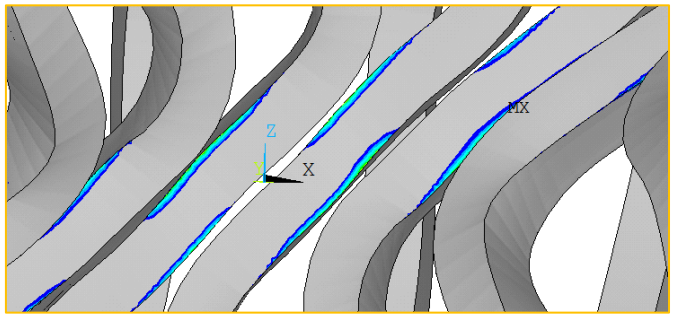


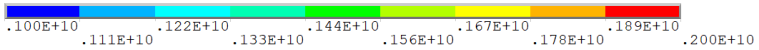




Sliding contact

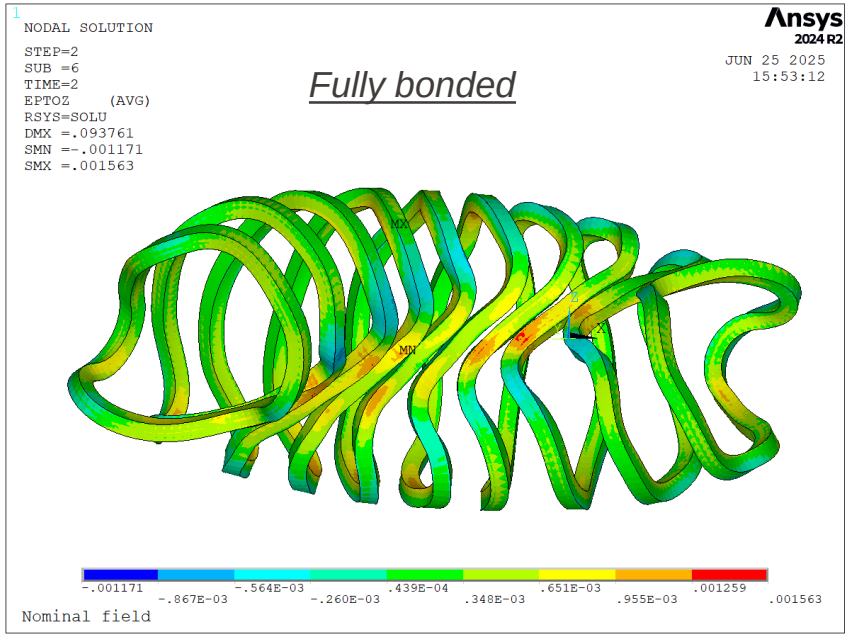


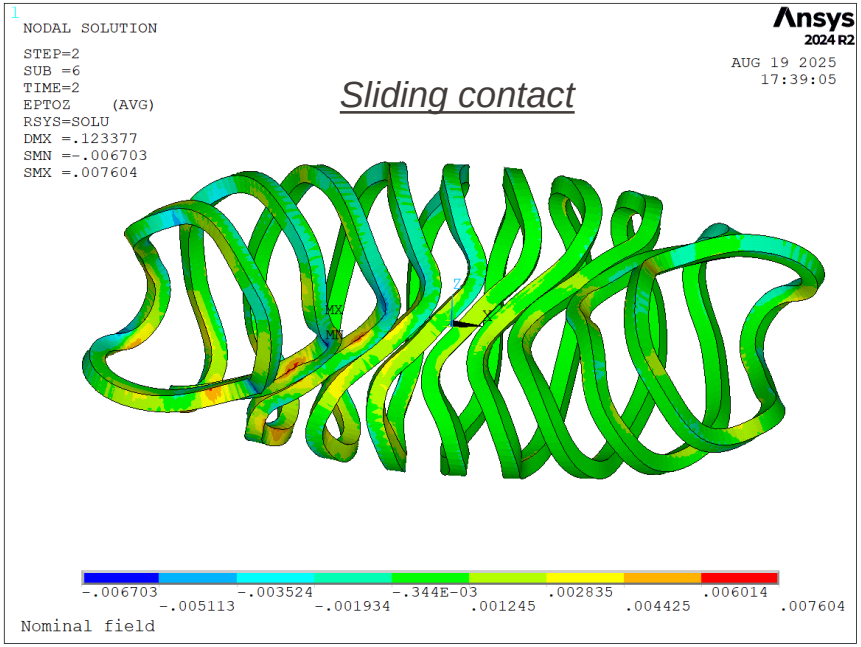




Daniel Biek

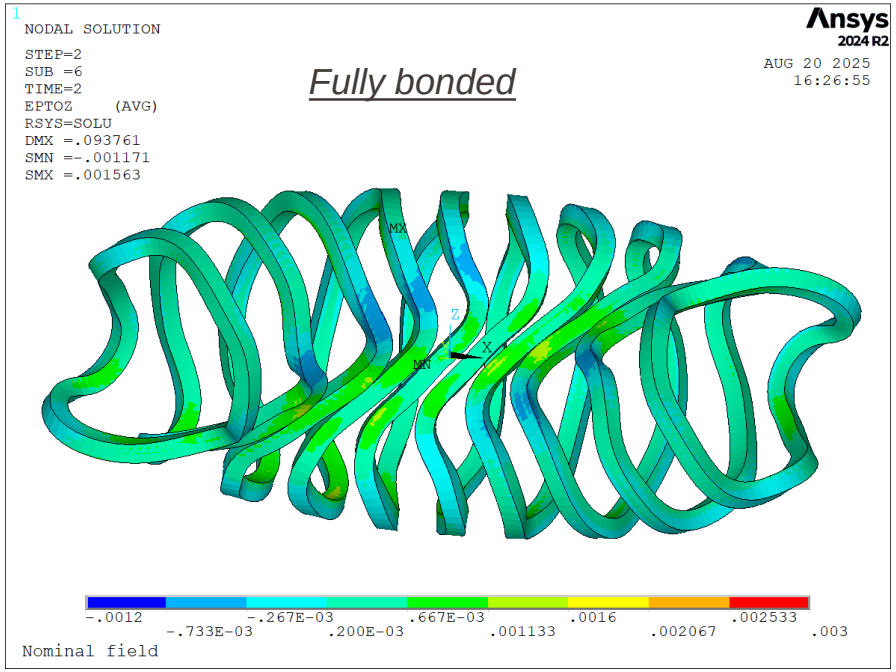
Comparison – Longitudnal Strain

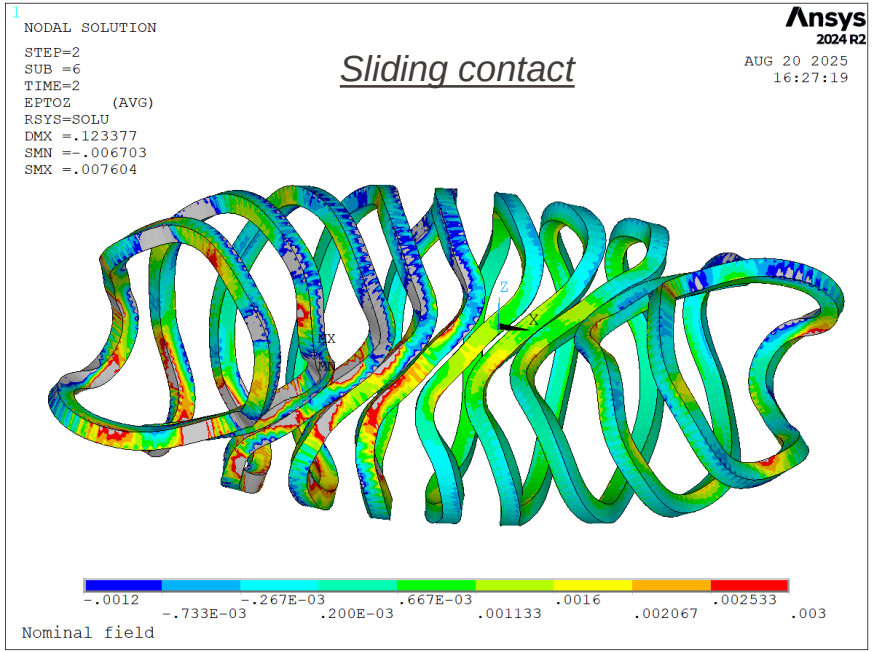




Daniel Biek

Comparison – Longitudnal Strain



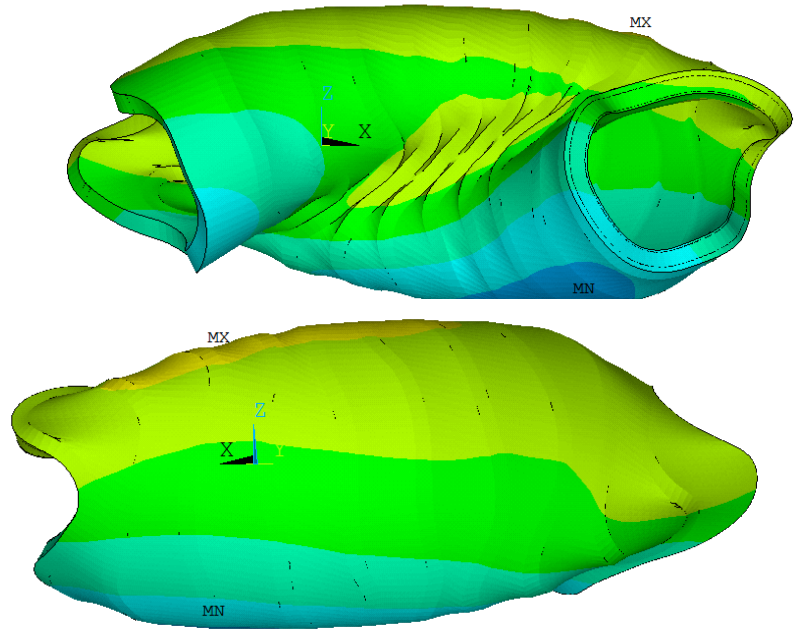


Comparison – Displacement

Daniel Biek

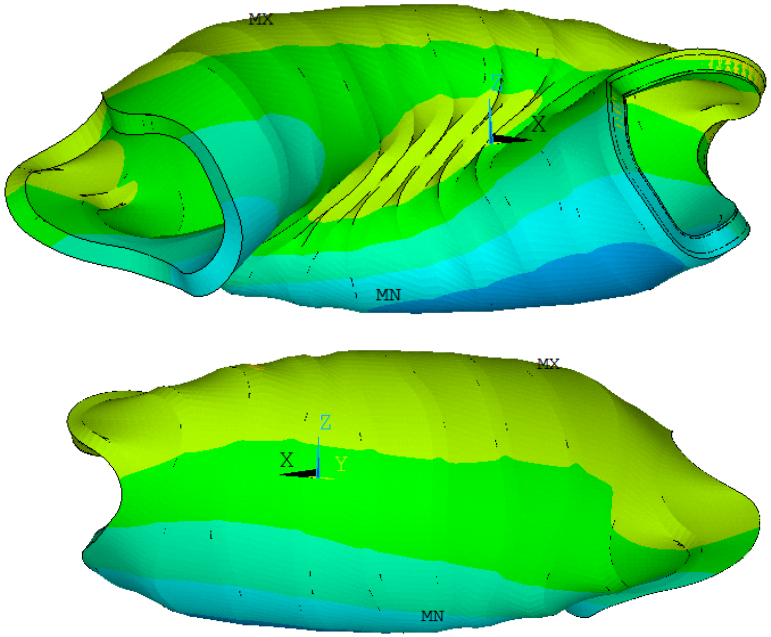
DMX =.094881
SMN =.048248
SMX =.094881

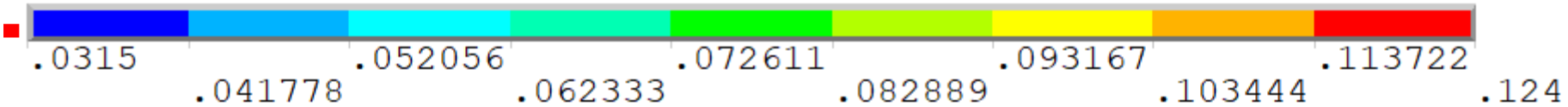
Fully bonded



Sliding contact

DMX =.123377
SMN =.031558
SMX =.123377





Comparison – Stress in the coil

Daniel Biek

Fully bonded

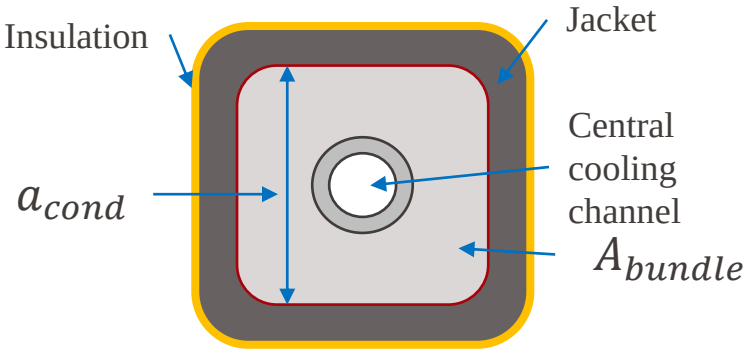
Quantity	Value
Maximum Stress (yield strength 1GPa)	1.23 GPa
#Nodes with stress values above 1GPa (yield strength)	393 (0.08%)
#Nodes with stress values above 867MPa	1460 (0.3%)

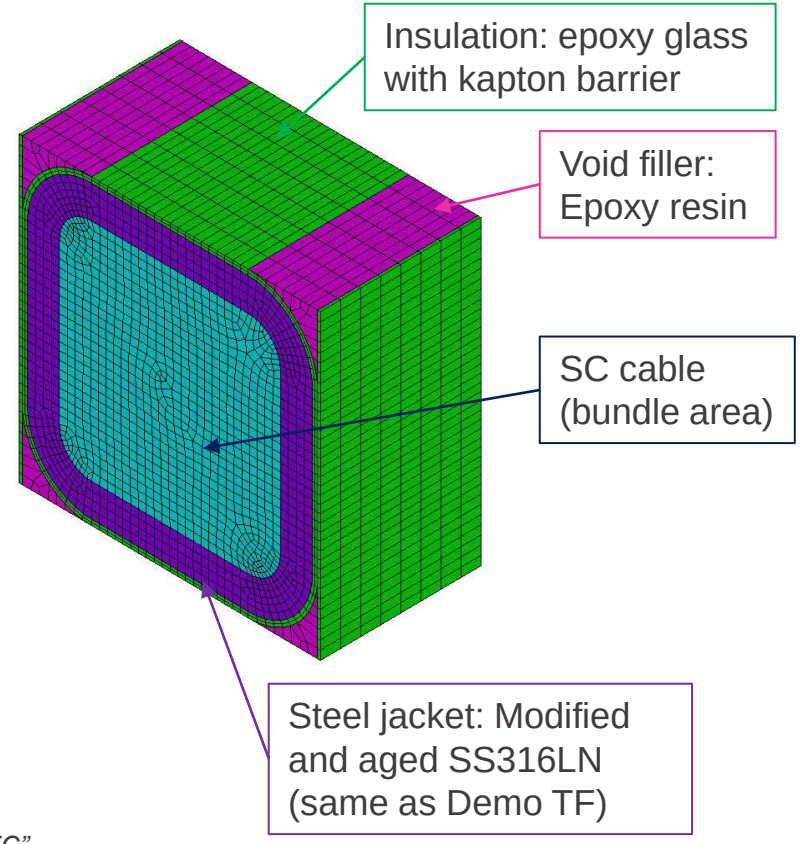
Sliding contact

Quantity	Value
Maximum Stress (yield strength 1GPa)	1.81 GPa
#Nodes with stress values above 1GPa (yield strength)	598 (0.12%)
#Nodes with stress values above 867MPa	1674 (0.34%)

Smeared Properties

- Started with calculating the smeared properties of the conductor
- Using the material references from EuroFusion reports [1]
- Periodic boundary condition





[1]: *F. Nunio et al.; "Reference basis for mechanical & thermal analysis of TFC"*

Smeared properties – Results

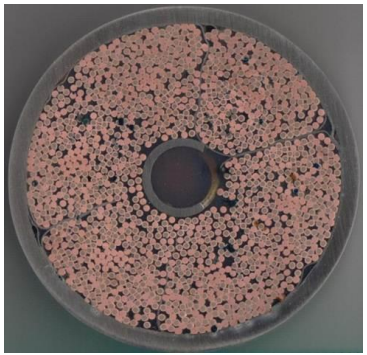
Daniel Biek

Young modulus (GPa)			Shear modulus (GPa)			Poisson's ratio			Thermal expansion coefficient $\left(\frac{\mu m}{m \cdot K}\right)$		
E_x	E_y	E_z	G_{xy}	G_{yz}	G_{xz}	ν_{xy}	ν_{yz}	ν_{xz}	α_{xy}	α_{yz}	α_{xz}
20.28	21.03	70.79	1.56	14.37	14.06	0.43	0.09	0.09	14.54	14.53	10.43

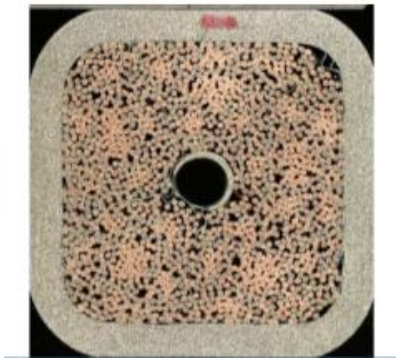
- Direct input to the mechanical simulation
- Validated by analytical calculations

Summary

- In Katheder the mass flow rate is higher as in other one
- However, the difference is not as high as for example in Federica's case
- So generally, Katheder also works for my conductor



ITER



CEA

SPC

- The void distribution in the last one is more systematic, whereas the others is more random

-> Katheder should be used for CICCs my "systematic" voids -> HTS conductors

Daniel Biek

Summary – Comparison

- The BBL and LB leads to almost similar results
- Katheder leads for the same void fraction to a higher mass flow rate due to the dependence on the wetted perimeter
  - Lowering the wetted perimeter reduces the mass flow rate
  - Higher mass flow rate -> lower operating temperature
- BBL and LB are independent of the definition of the wetted perimeter and hydraulic diameter and to change the mass flow rate on parameter would be the void fraction
- The new heat transfer coefficient has almost no influence on the result
- The friction factor correlation for a spiral reduces the mass flow rate and therefore leads to higher operating temperature (lower ΔT)
- The temperature are still quite similar
- Further investigation needed for the quench analysis