Status of Coil Structural Design and Magnetic-Structural Analysis

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Presented by X.R. Wang

Contributors:

ORNL: D. Williamson

UCSD: S. Malang, A.R. Raffray

UW: C. Martin

ARIES Meeting

UC San Diego, San Diego

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Outline

- Report and update EM (Electromagnetic) analysis of the modular coils

- Report magnetic-structural analysis of the structure responses from magnetic forces:
  - -ANSYS solid modelling
  - -ANSYS shell modelling

- Possible structural design for the coil structure

Updates of the ANSYS EM Analysis

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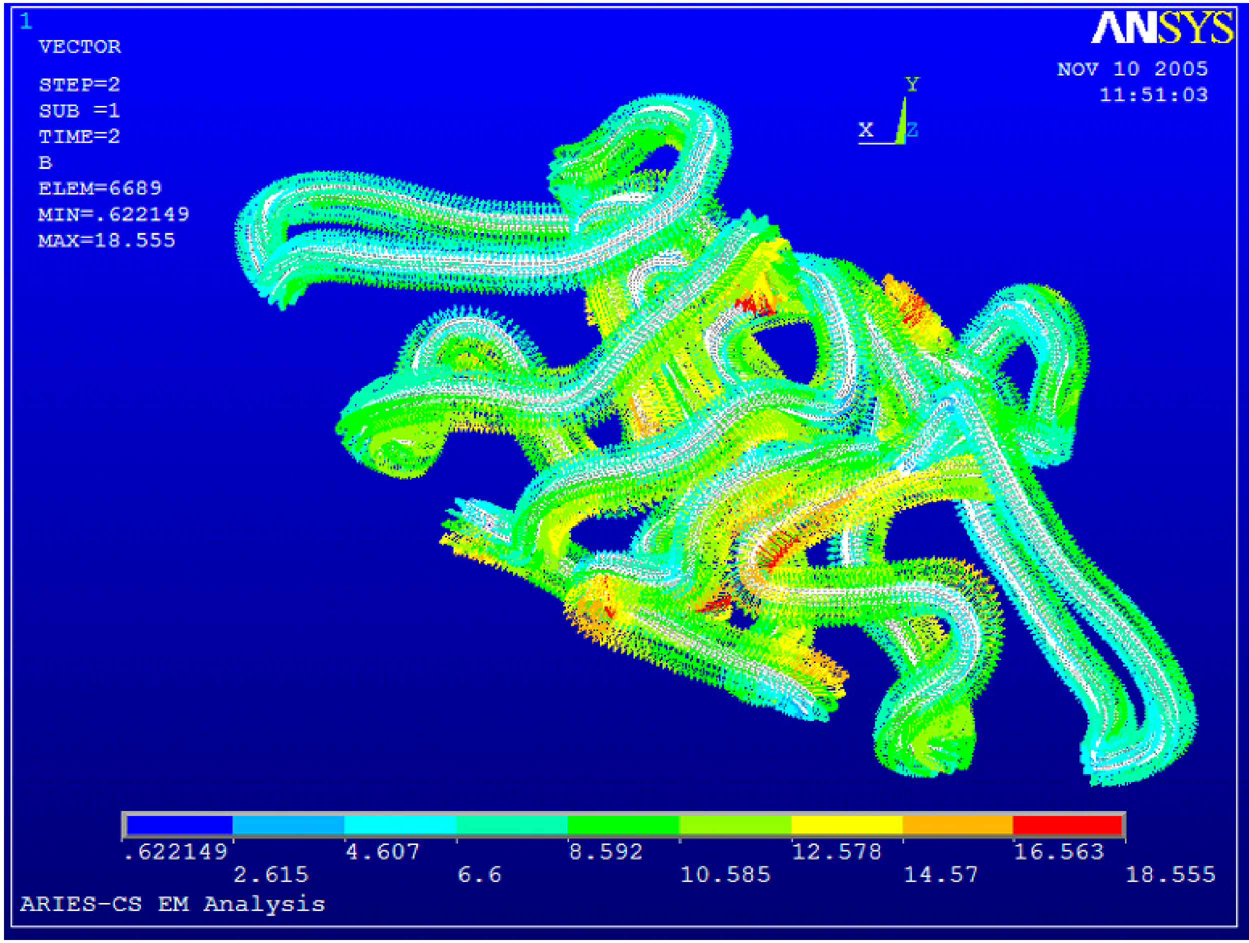
- Geometry of the modular coils are imported from Pro/E CAD modeling.
- The 6 coils are meshed by nearly 30000 Hexahedral elements and 45000 nodes.
- The local maximum magnetic flux density in the modular coils are: B(M1)=13.8T, B(M2)=18.6T, B(M3)=17.1 T.



New Plots Showing the Nodal Forces in the Modular Coils

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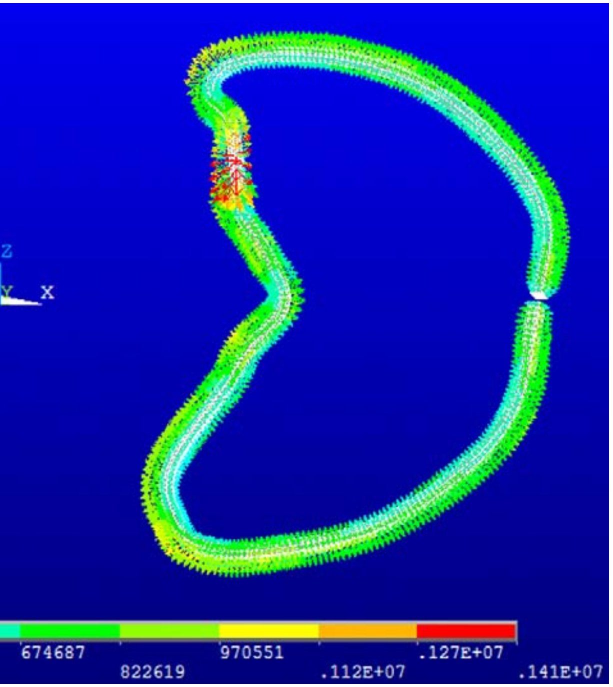
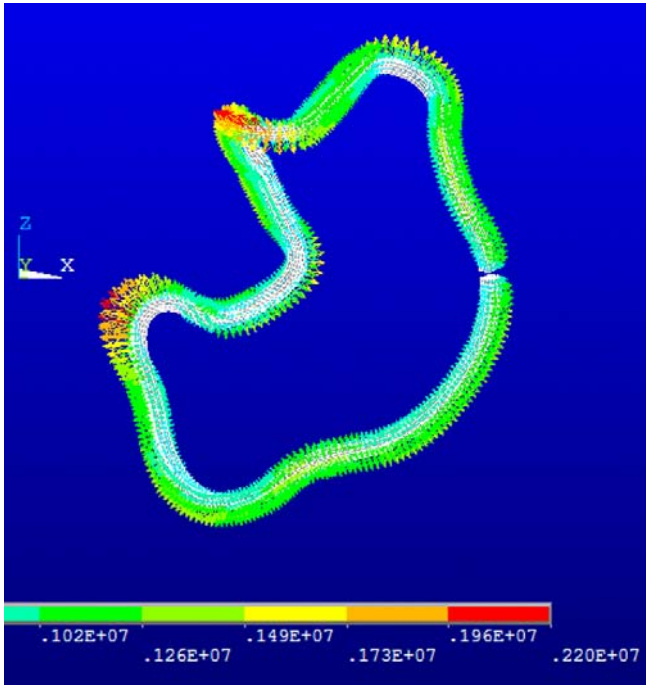
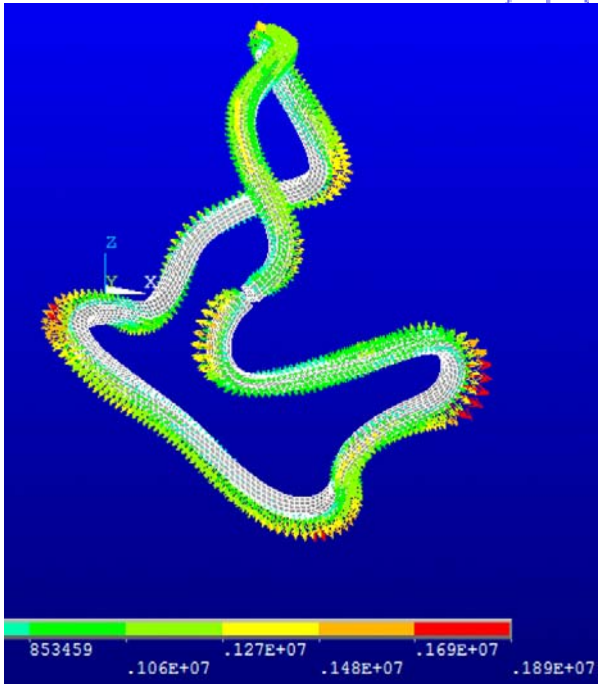


M1



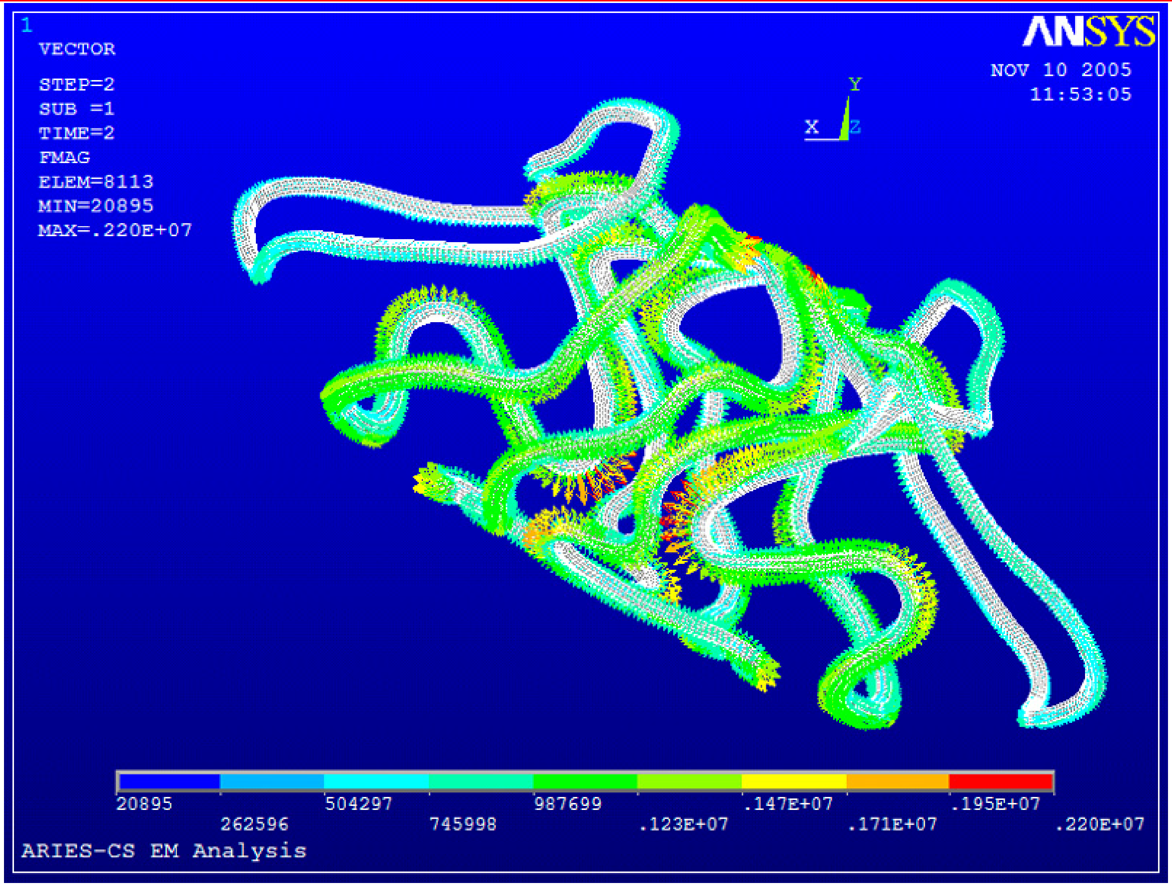
M2



M3

- The maximum magnetic forces are found in the modular coils where there are small bend radiuses of curvatures at winding pack.

Fully Symmetric Magnetic Forces in the Modular Coils Were Found



- The nodal forces vector plot shows a full symmetry for the pair of coils from the top view.

Net Forces in the Modular Coils

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	F_r, MN	F_θ, MN	F_z, MN
M1L	-52.2	-289.2	0.2
M1R	-52.2	289.2	-0.2
M2L	-168.3	-141.3	95.4
M2R	-168.3	141.3	-95.4
M3L	114.5	-65.7	122.9
M3R	114.5	65.7	-122.9
Sum of all 6 coils	-212.0	0	0

EM Results by Different Code: Field in the Modular Coils

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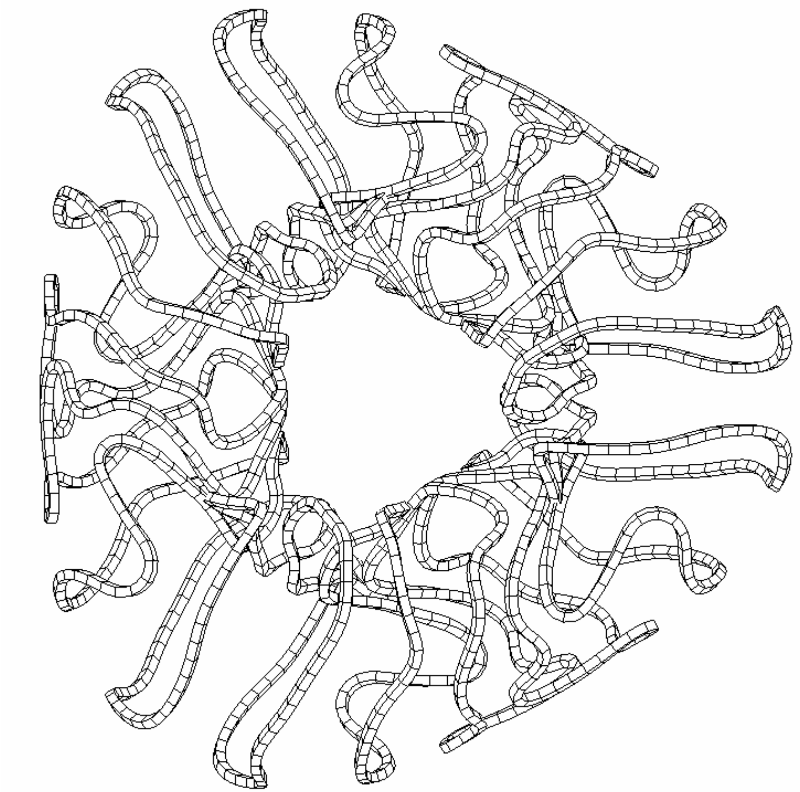


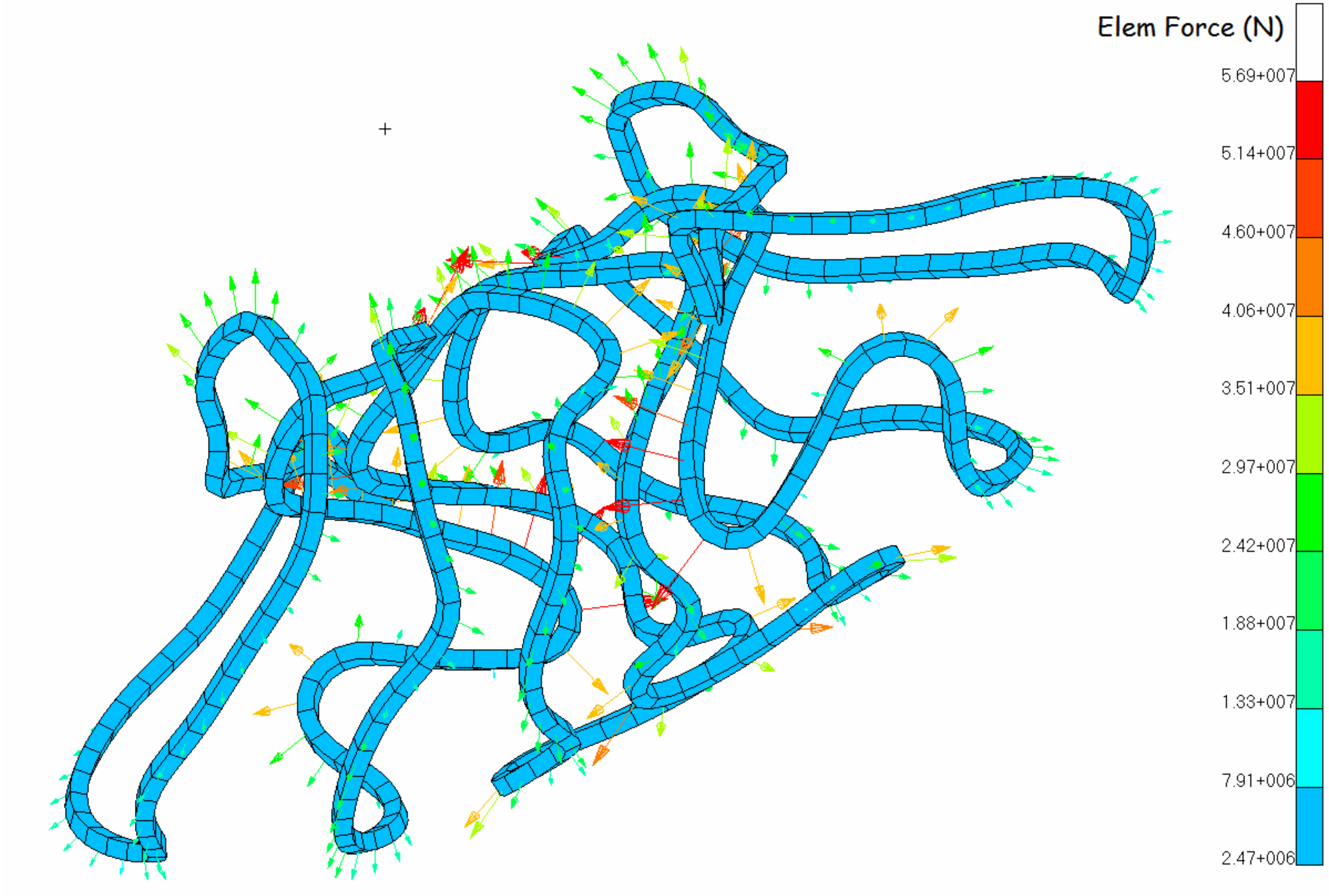
EM ANALYSIS:

✓ MAGFOR calculation using ~1100 20-node elements;

✓ Coil current = 12.2 MA for all coils (revise to 10.1, 12.2, ,12.2);

✓ Maximum field at coil surface = 19.2 T.

EM Results by Different Code: Element Forces in the Modular Coils



EM Results by Different Code: Element Forces in the Modular Coils

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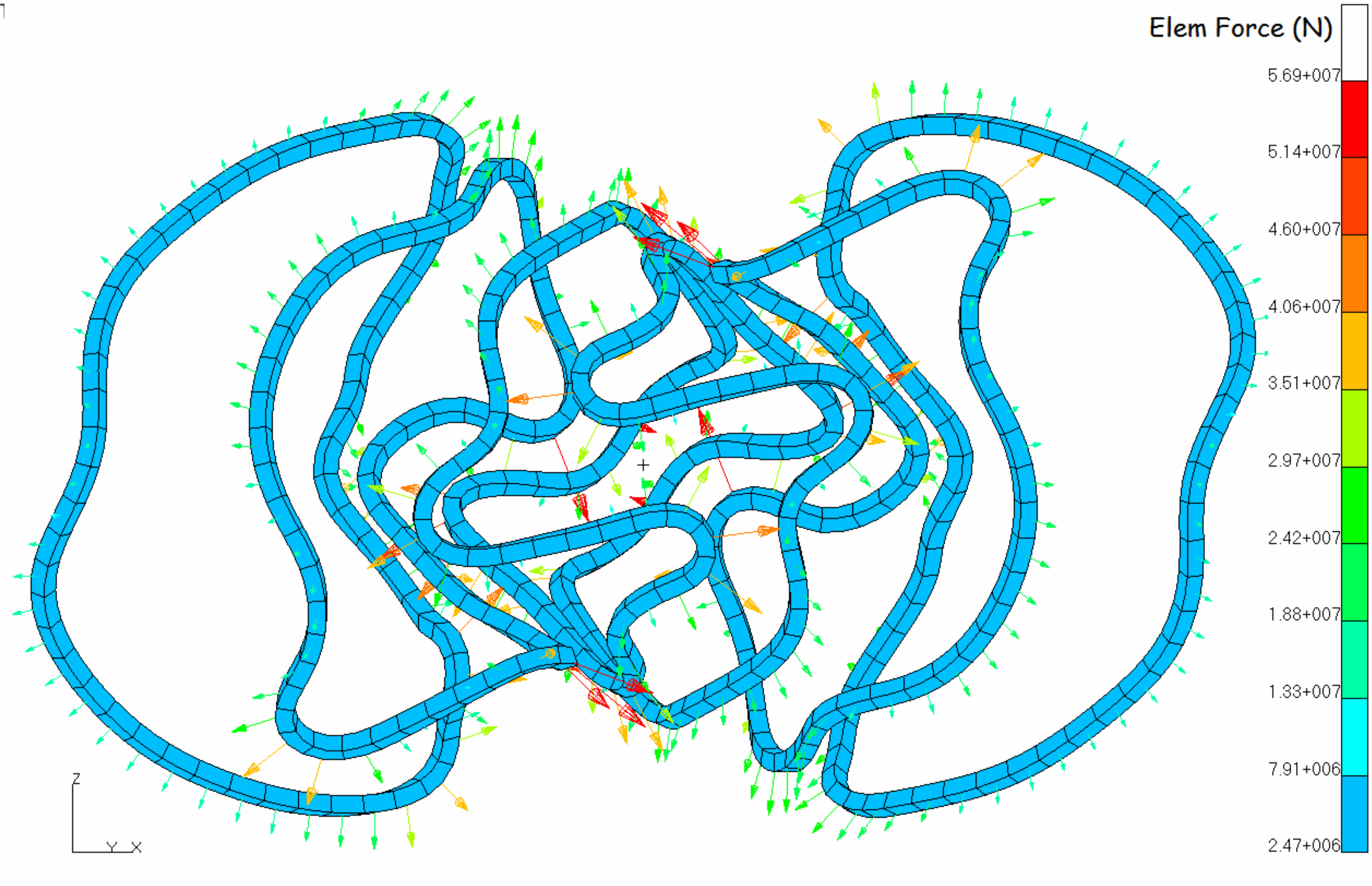

Magnetic-Structural Analysis

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- The structural analysis is to evaluate the structural response form the magnetic forces of the coils and provide guides for designing the coil structure.

- The nodal forces obtained from EM analysis will be applied in the structural model.

- A sequential coupled EM-structural analysis can be adopted in the ANSYS solid structural model, and the nodal force loads in EM analysis can be transferred in the structural model by using the identical nodes and elements.

- It is easy to simulate the openings/penetrations in the structure for the ANSYS solid structural model.

- The ANSYS solid structural model requests large amount of nodes and elements, computer memory, and computing time.

- ANSYS shell structural model uses much less nodes and elements and computer resources, and the thickness of the shell can be easily optimized.

Material Properties Used in ANSYS Structural Modeling

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Material	Incoloy 908
Yield strength	1227 MPa at 4 K
Tensile strength	1892 MPa at 4 K
Modulus of elasticity	1.823×10^{11} MPa at 4K
Poisson's ratio	0.303 at 4K
Design stress	818 MPa at 4 K

- ✓ The design stress is taken as 2/3 of the yield strength at 4 K.

Status of ANSYS Structural Solid Model for the Magnetic-Structural Analysis

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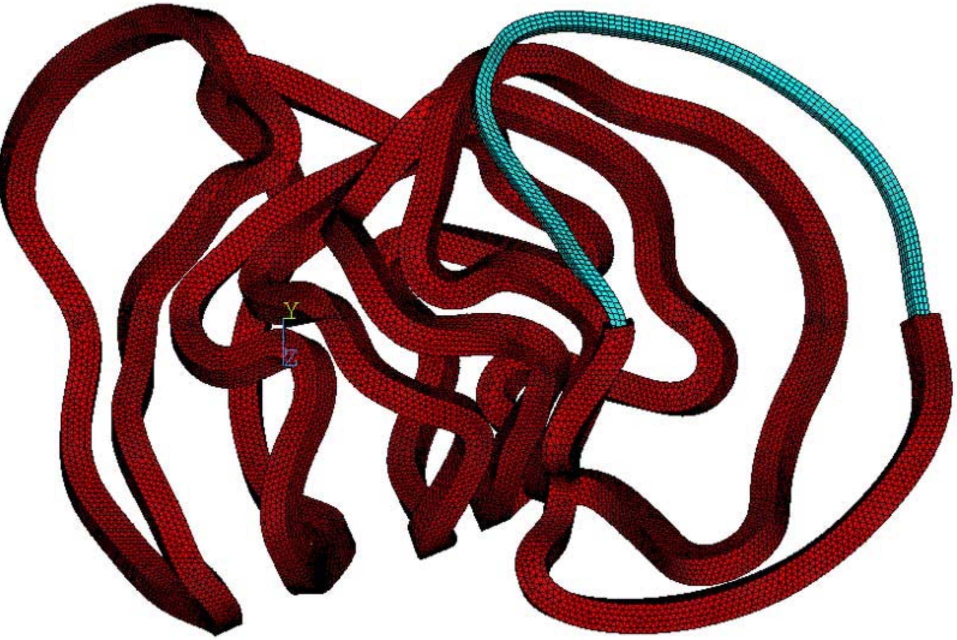

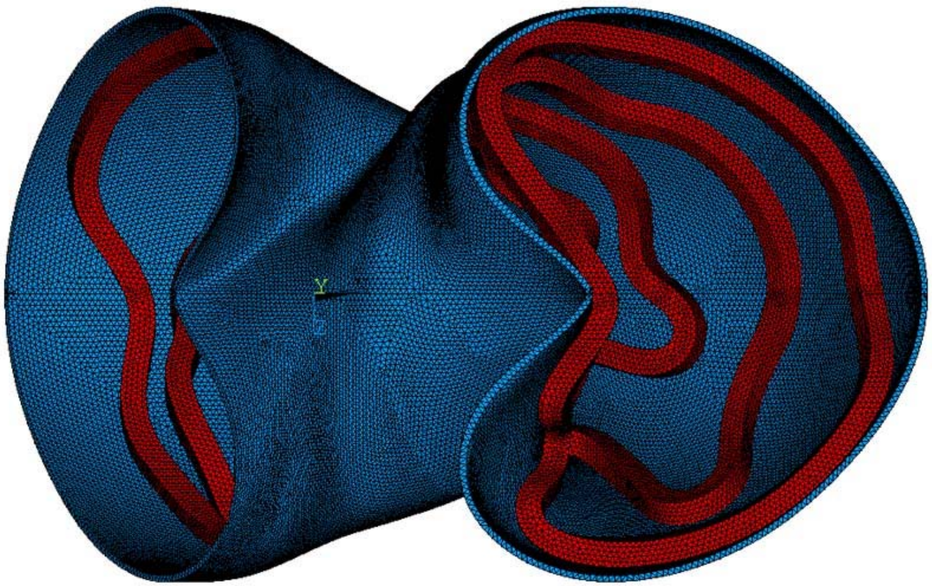

- ANSYS university version has very limited nodes and elements to be used in the solid model.
- ~250,000 nodes for the model plus the contact elements between winding pack and coil case causing the total of DOF exceeds 1.5 million, and requests more computer memory (1 million DOFs need over 1 Gb ram).
- There is not sufficient memory to run this solid model in my computer.

ANSYS Shell Model of the Structural Analysis

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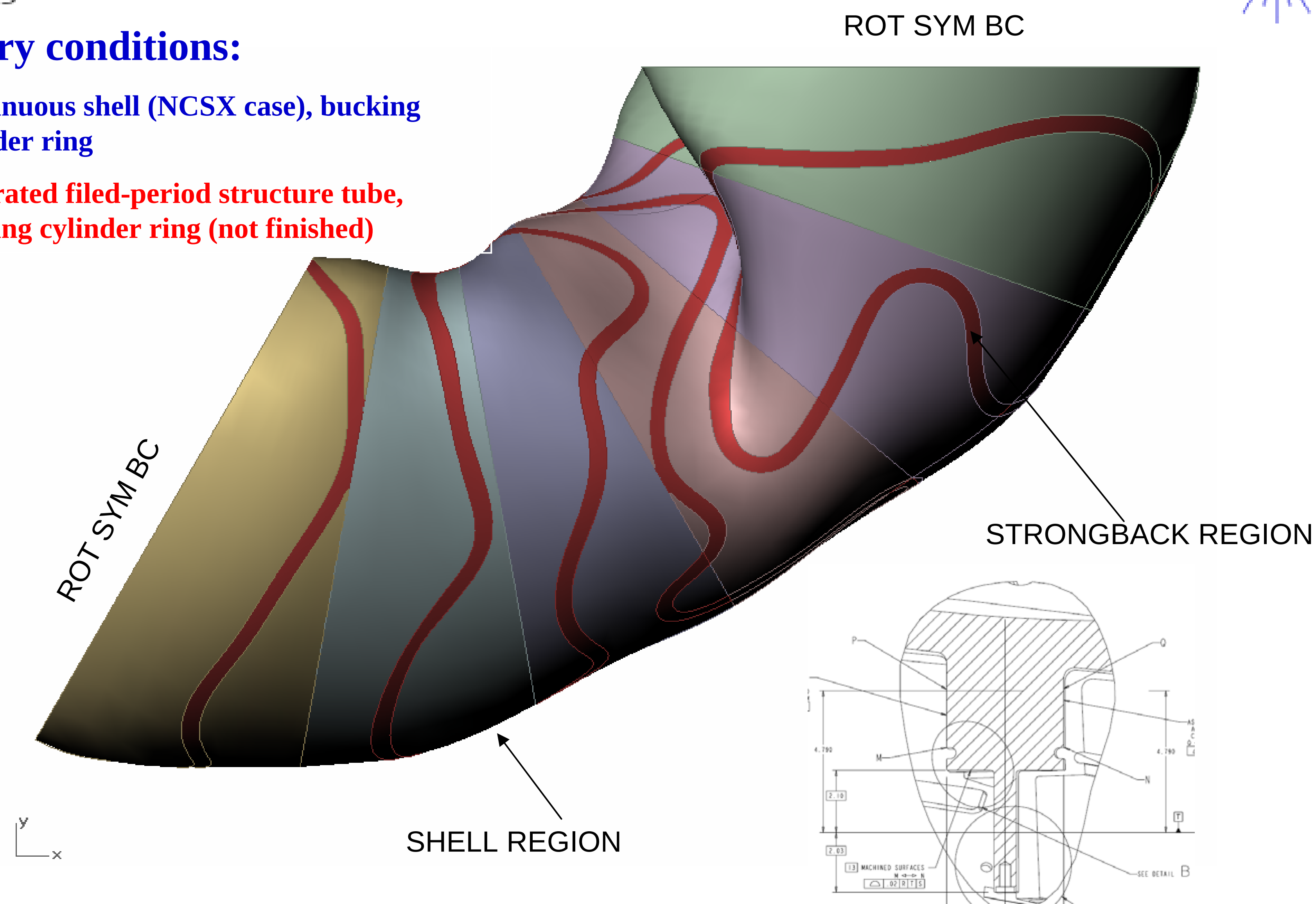
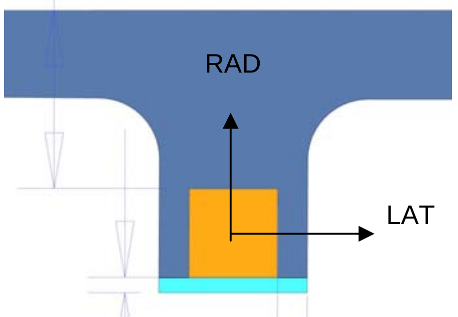
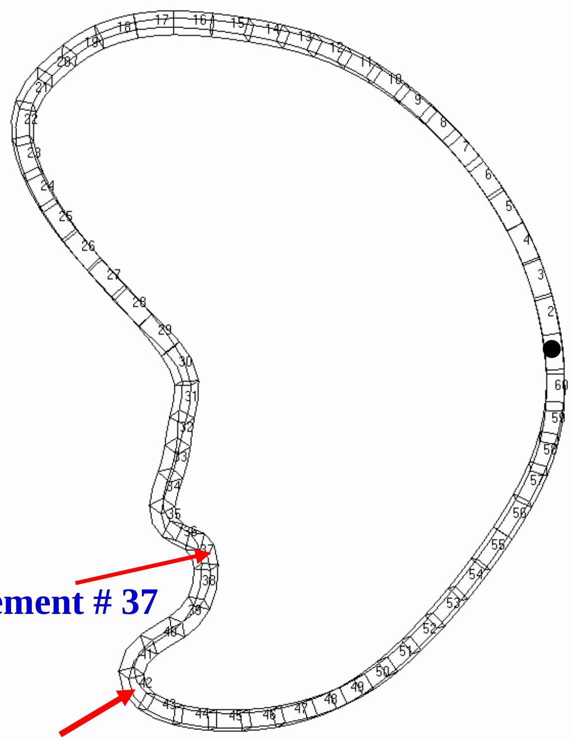
Boundary conditions:

1. Continuous shell (NCSX case), bucking cylinder ring
2. Separated filed-period structure tube, bucking cylinder ring (not finished)



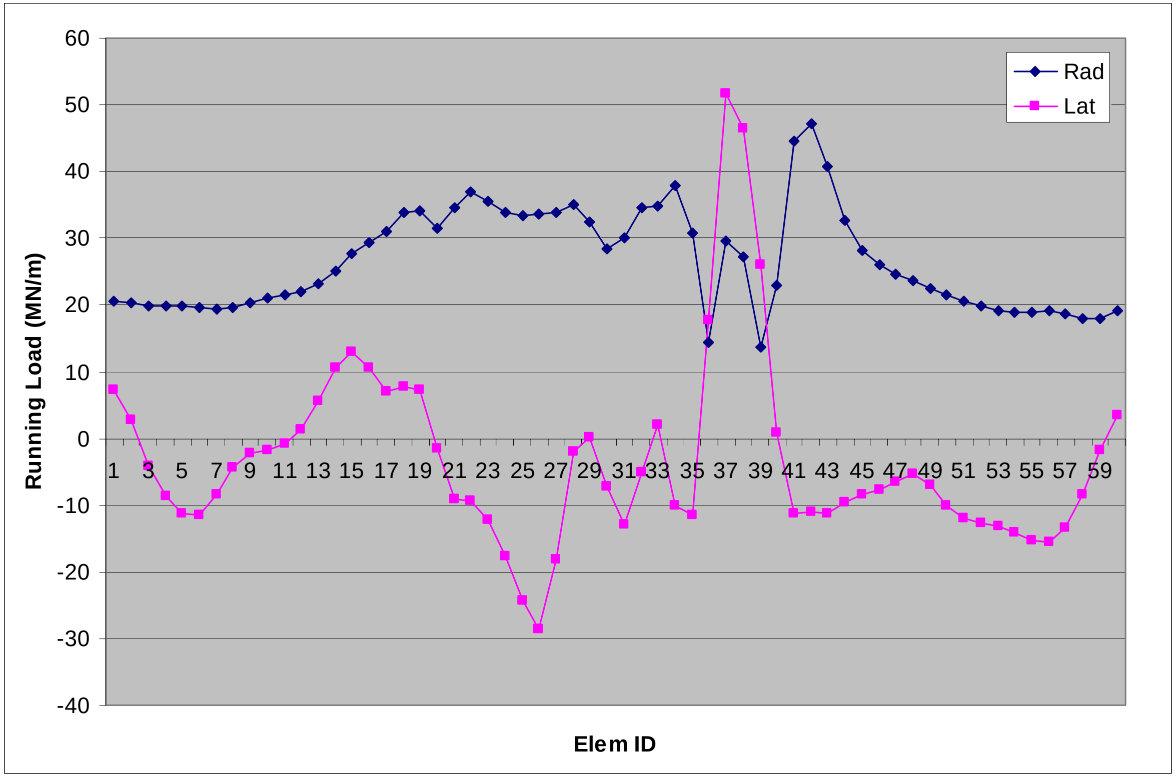
EM Element Force Loads in the Modular Coil M1L





Element # 37

Element # 42



EM Element Force Loads in the Modular Coil M2L

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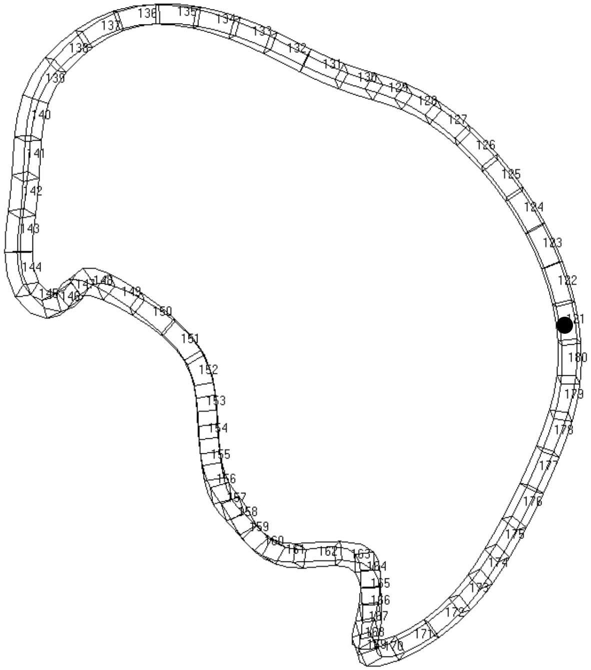
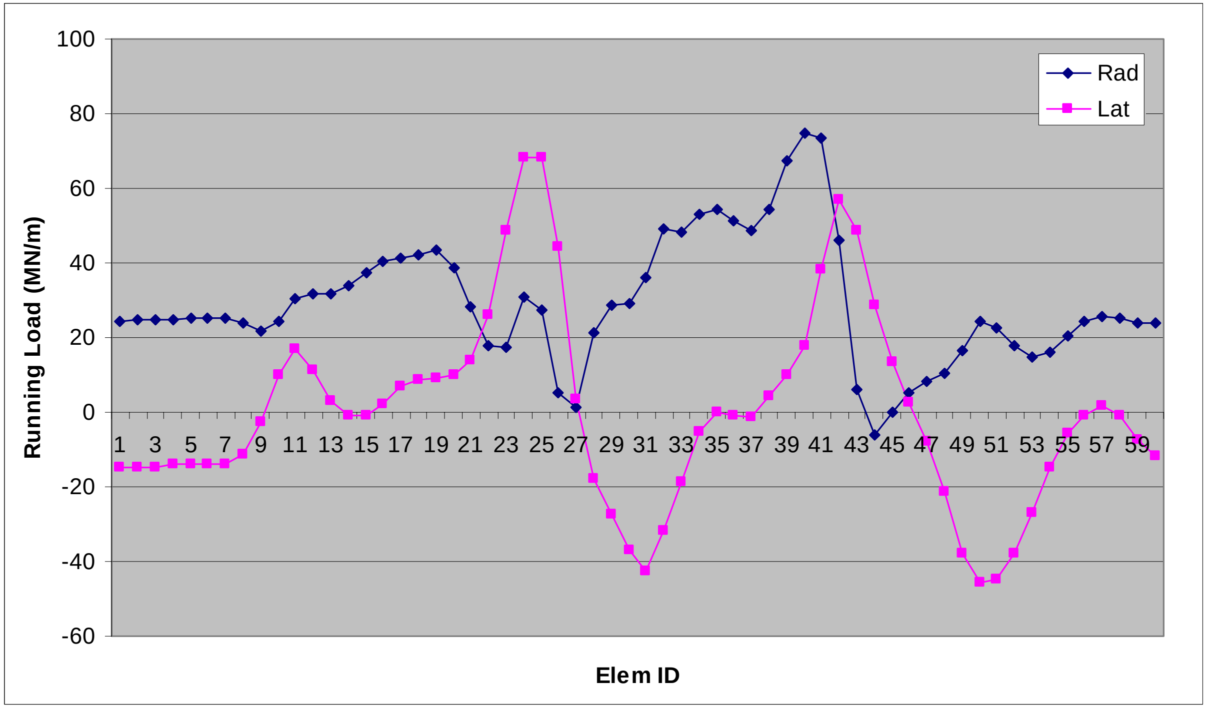
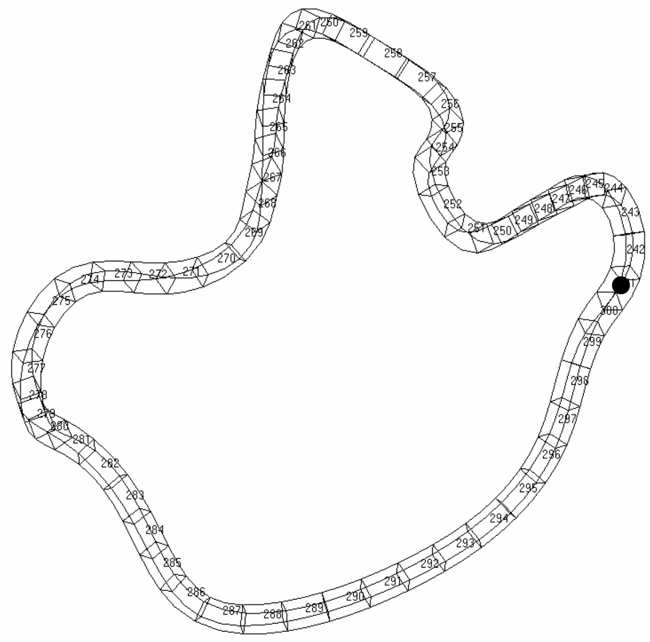
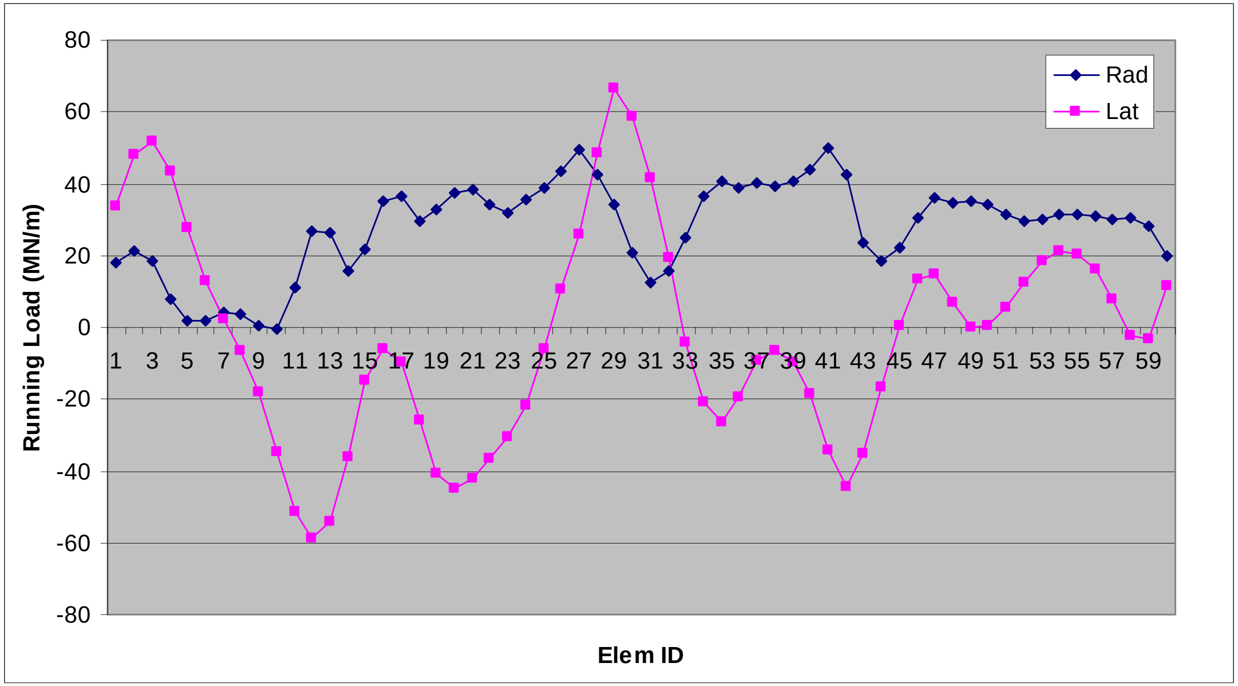


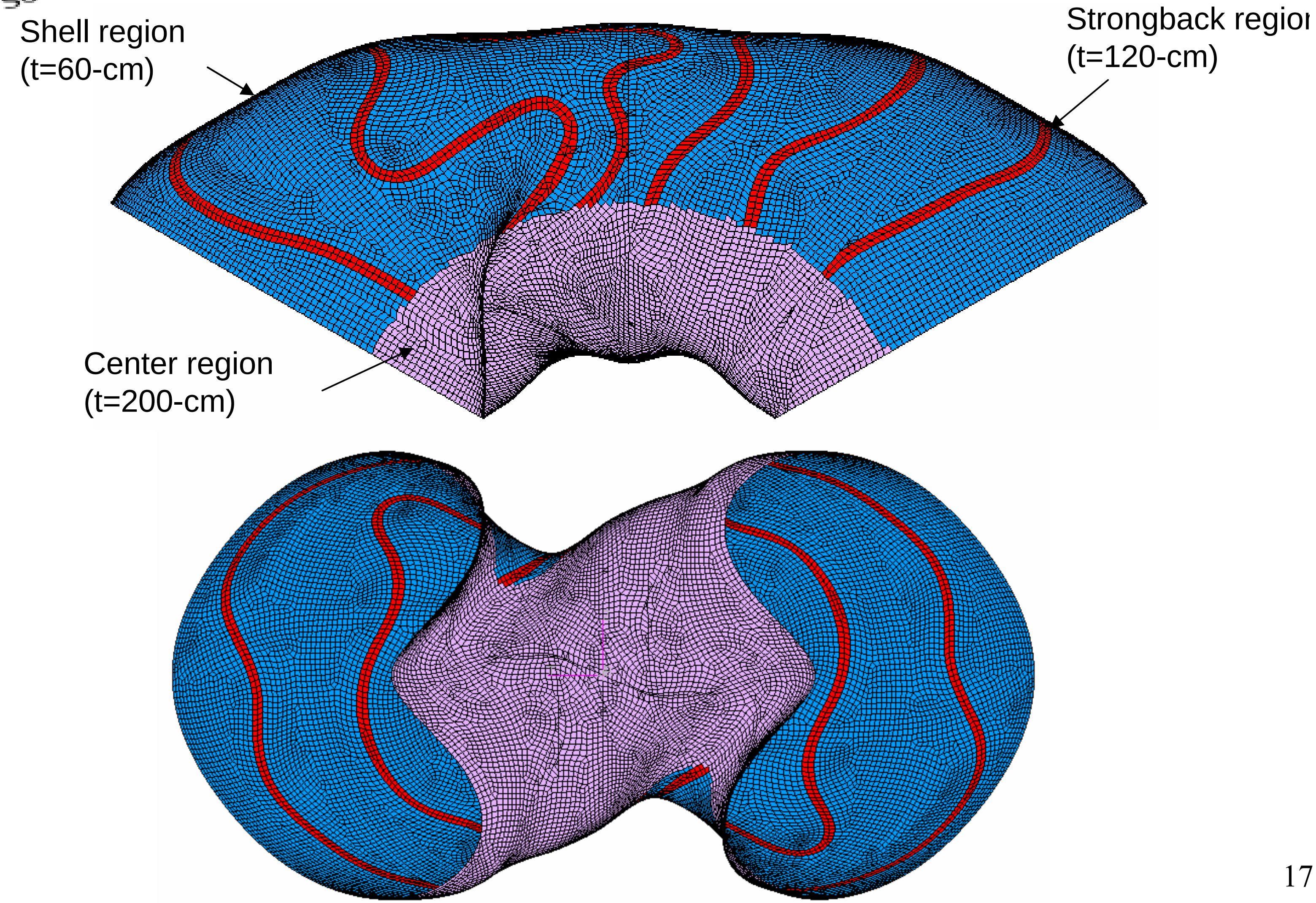


EM Element Force Loads in the Modular Coil M3L

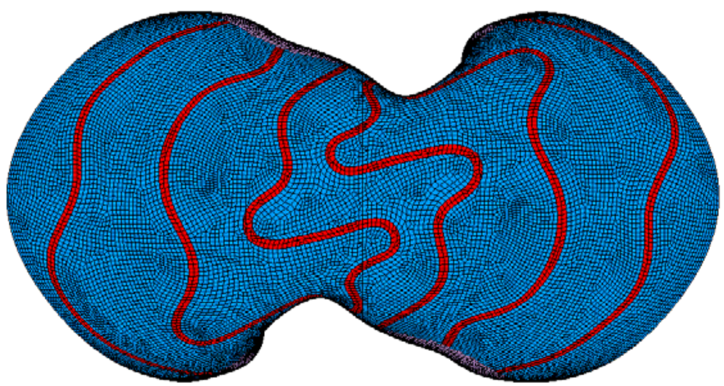


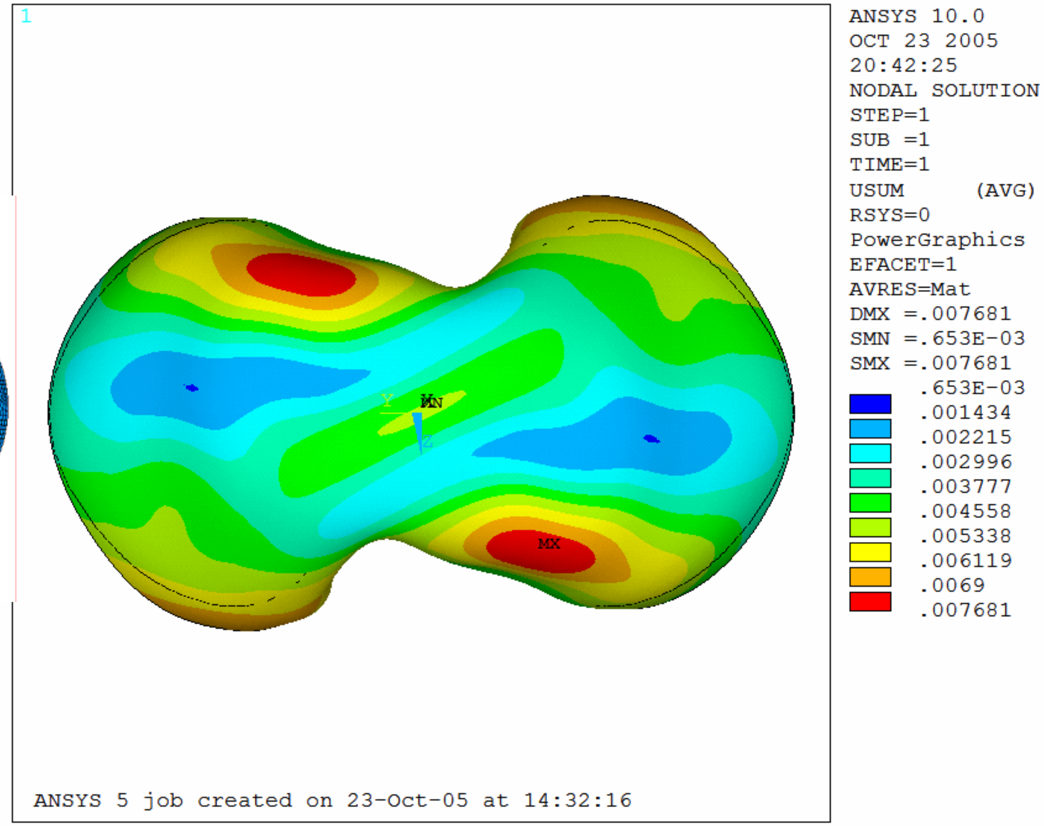


FEA Model and Initial Input Thickness for the Structural Analysis of Coil Structure



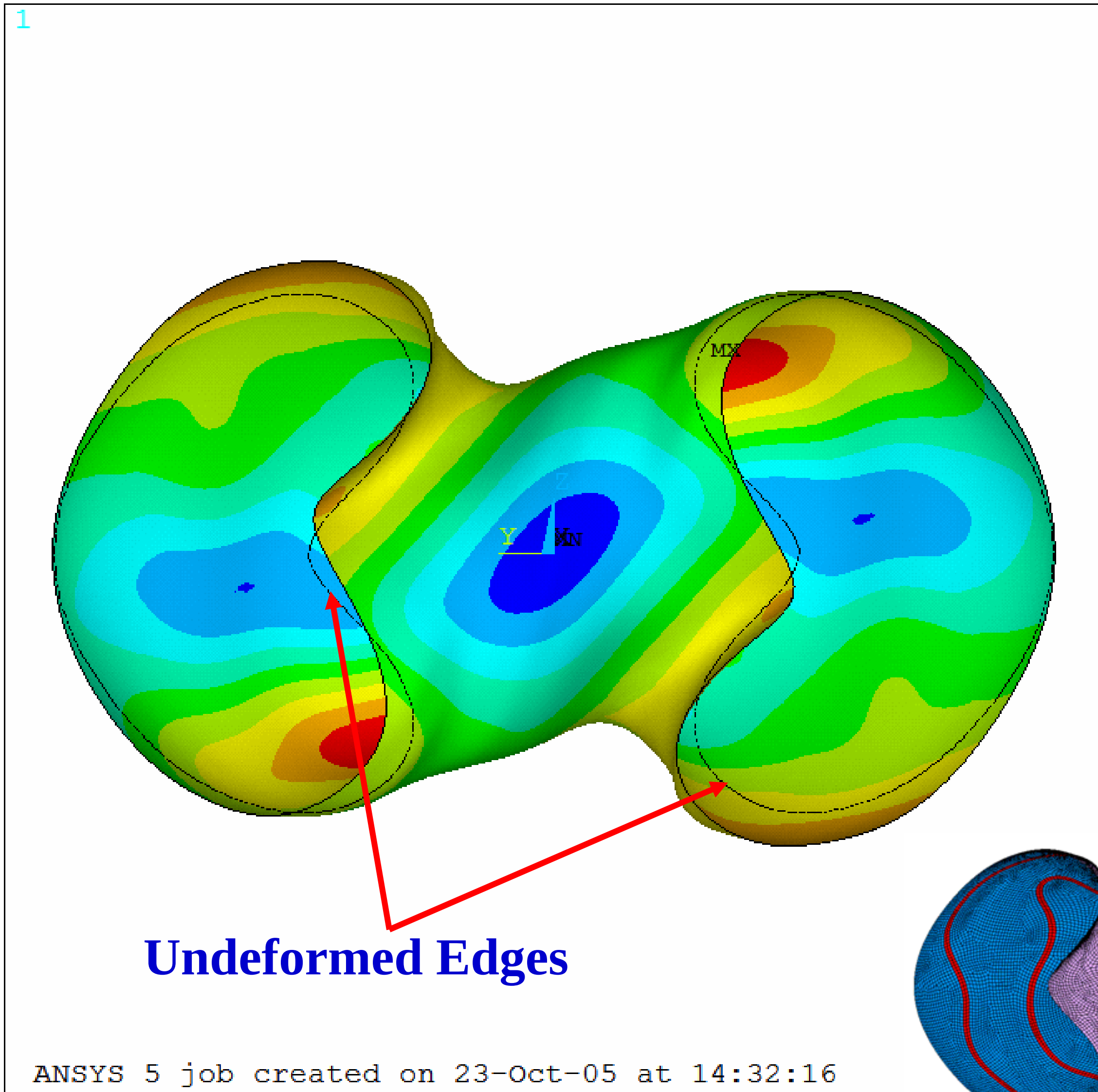
Displacement Based on the Initial Thickness

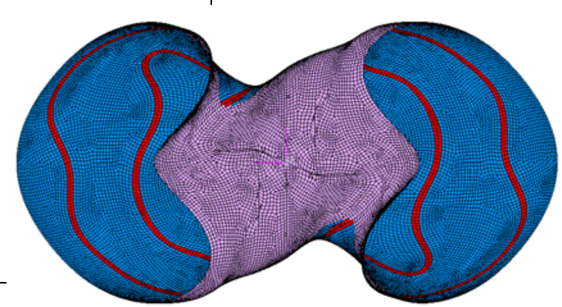




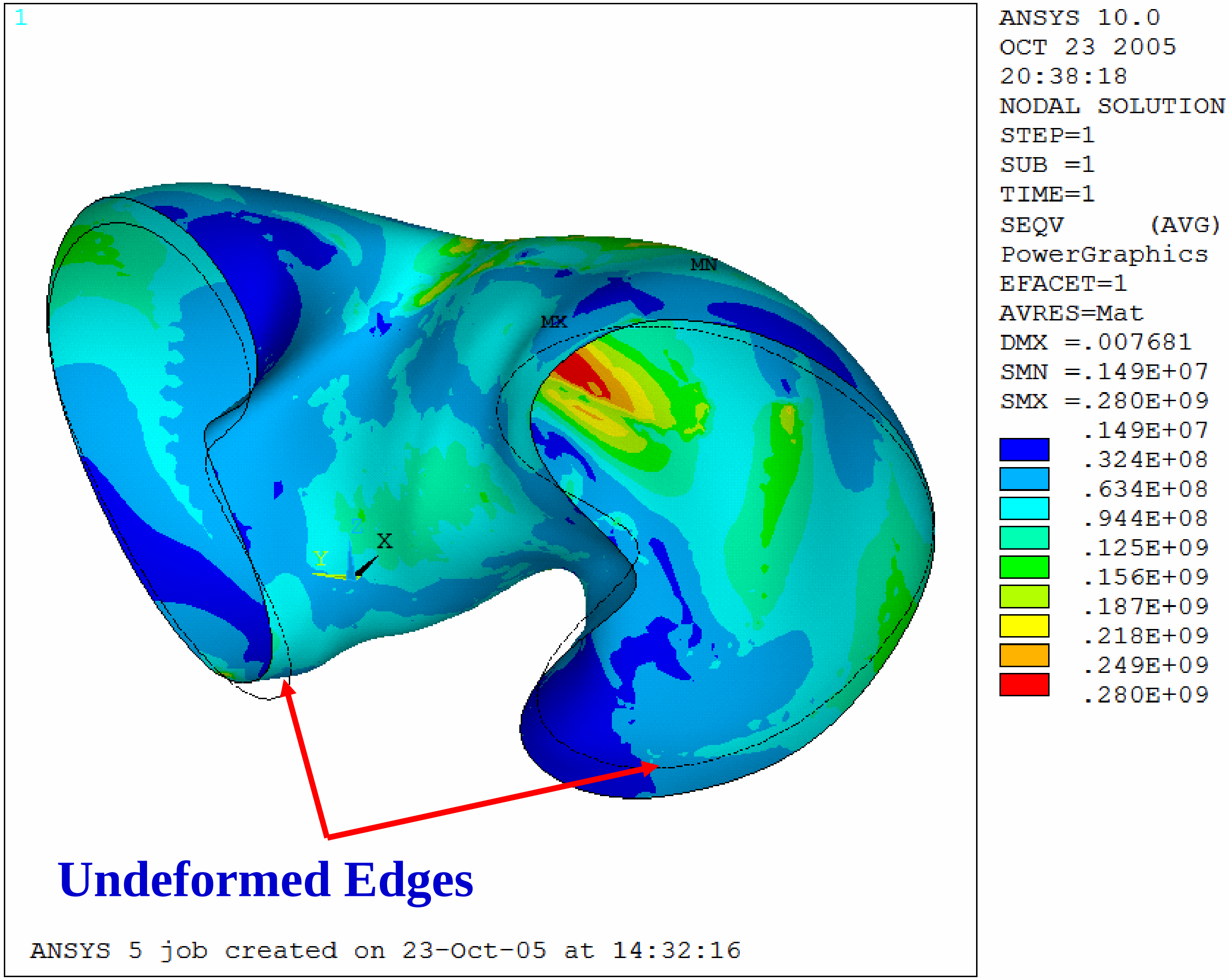
✓Support at midplane to check symmetric response.

Displacement Based on the Initial Thickness

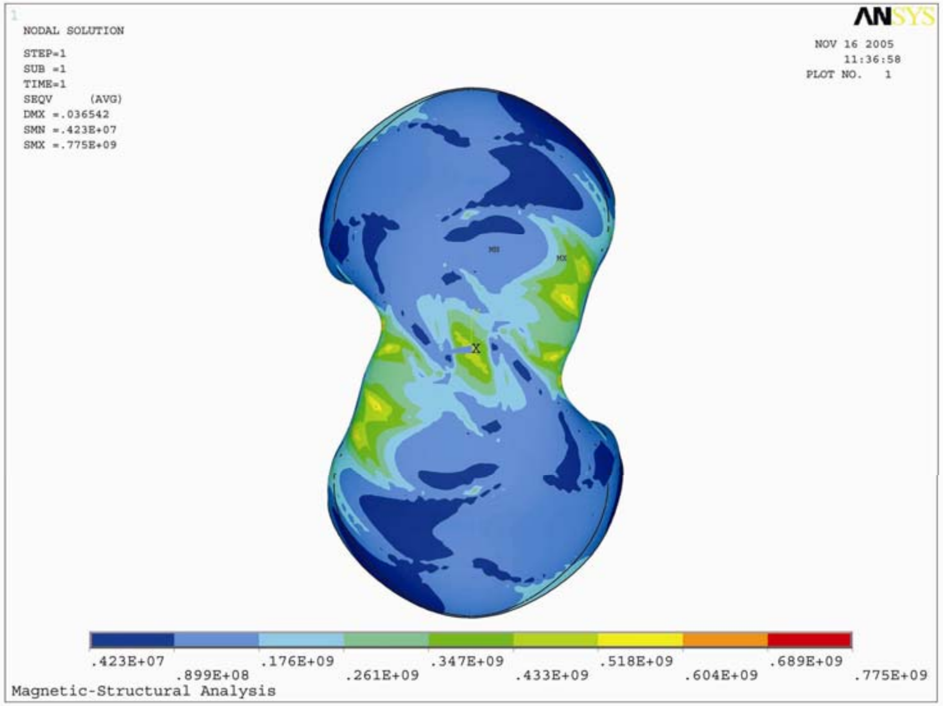


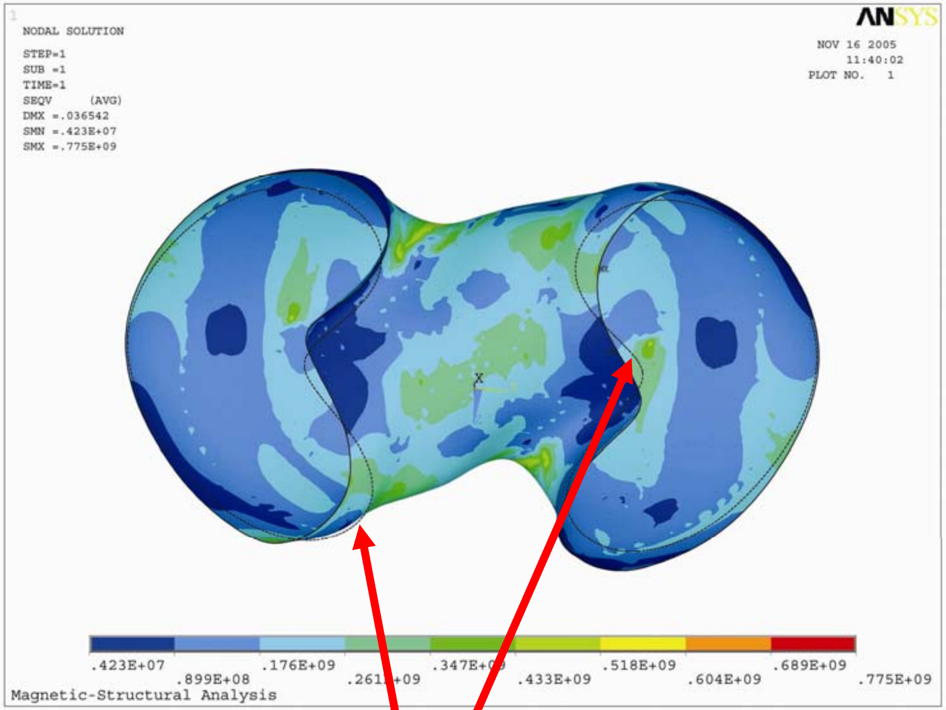


Stresses of the Coil Structure Based on the Initial Thickness of the Shell, Strongback and Center Regions



Example of the Stress for Optimized Thickness of the Intercoil Shell, Strongback and Center Regions





Undeformed Edges

Example of the Displacement for Optimized Thickness of the Intercoil Shell, Strongback and Center Regions

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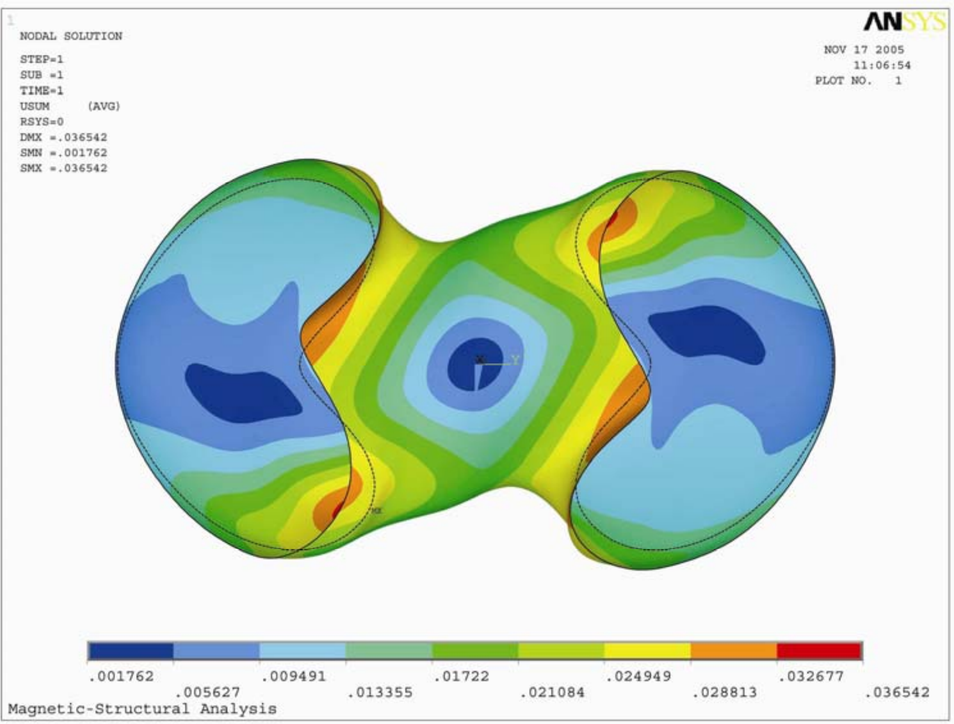
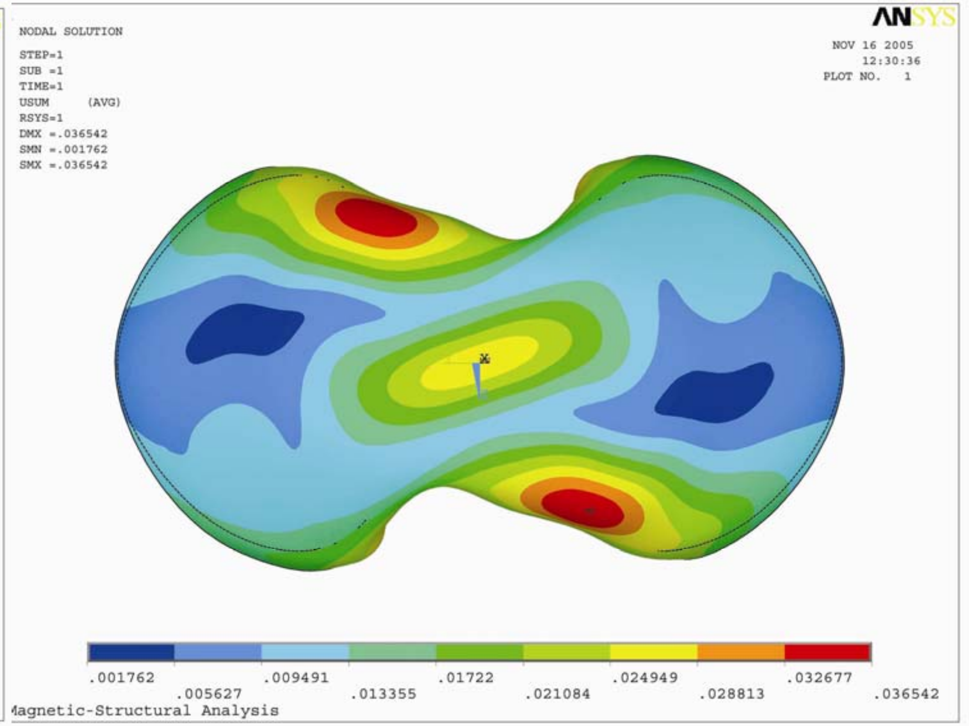


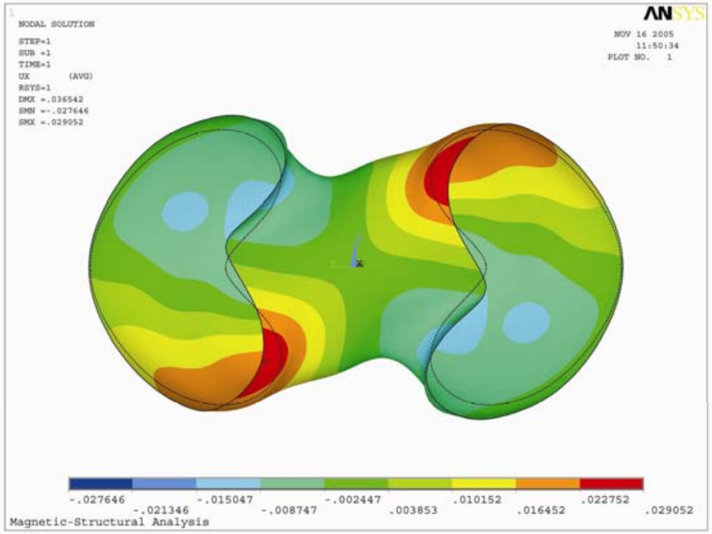


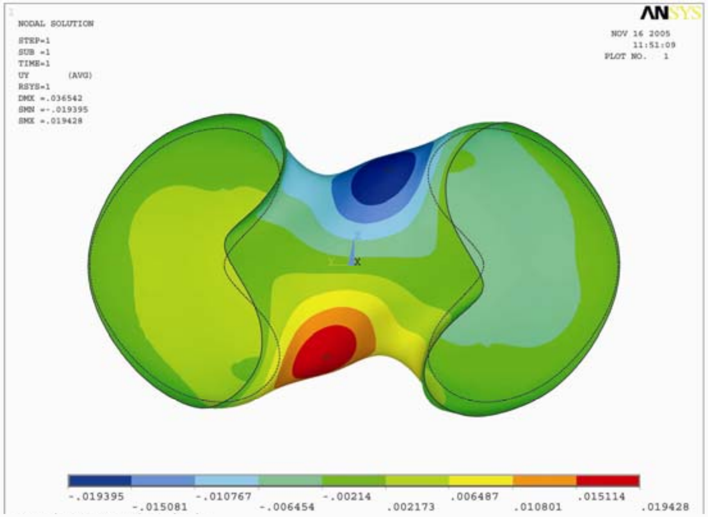
✓**Max. Displacement Vector Sum=3.65 cm**

To reduce the displacement, it may need to increase the side thickness at the both ends, gussets or racetrack beam may be helpful.

<u>What is the design limit of the displacement for the coil design?</u>

Example of the Displacement for Optimized Thickness of the Intercoil Shell, Strongback and Center Regions

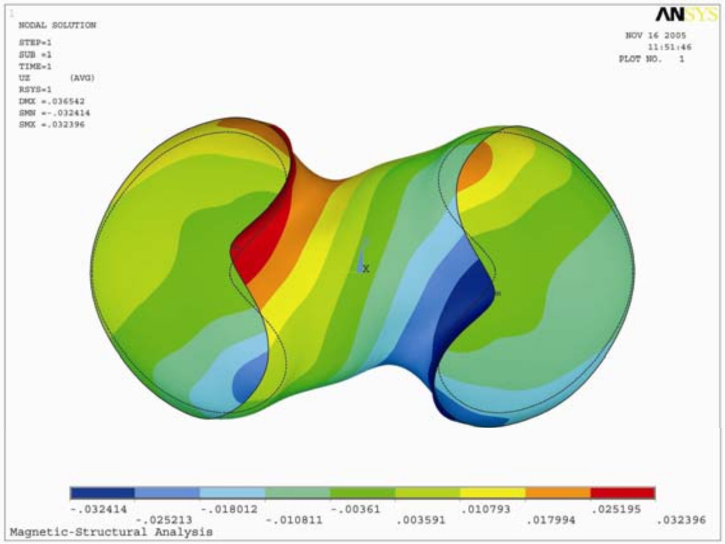




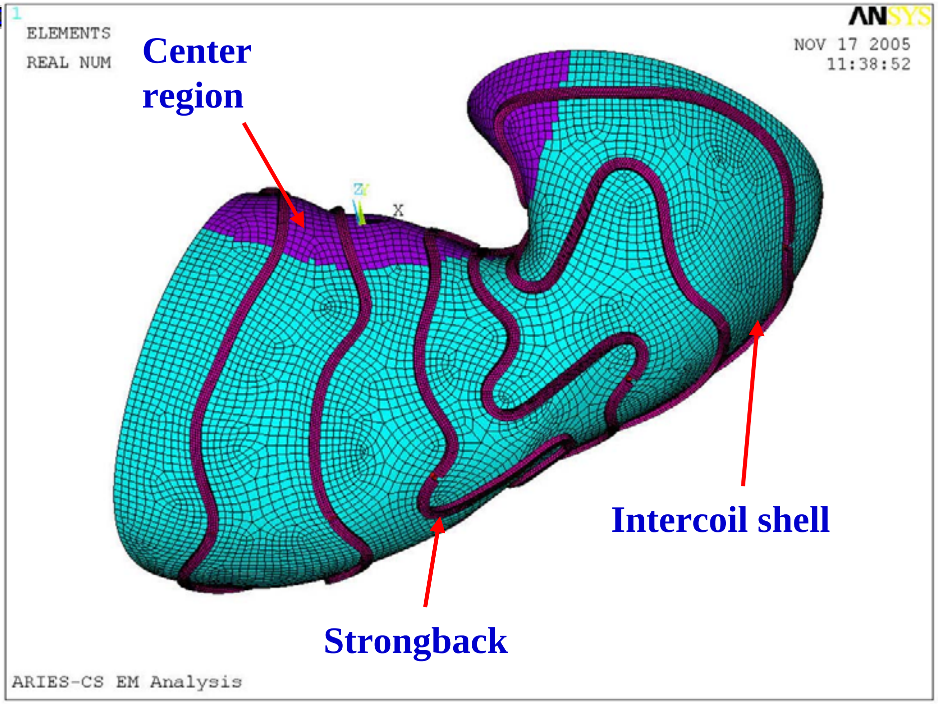
Max. Ux=2.91 cm

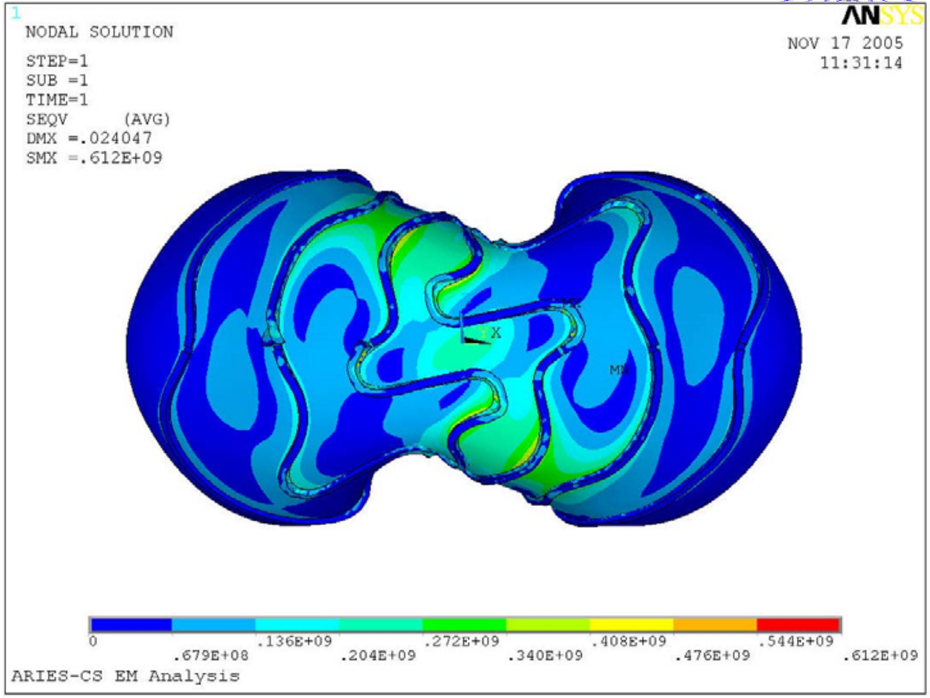
Max. Uy=1.94 cm

Max. Uz=3.24 cm



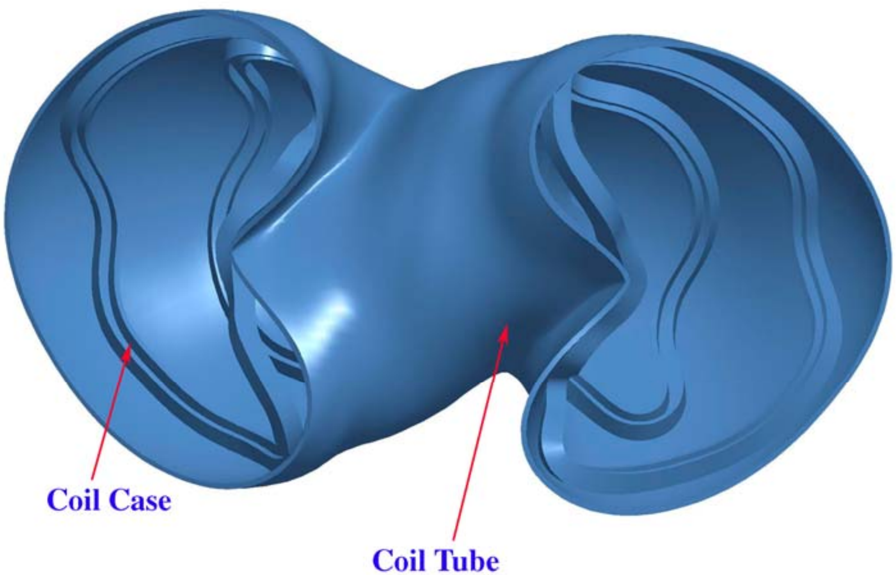
Status of the ANSYS Solid Model Plus Shell Model for the Magnetic-Structural Analysis

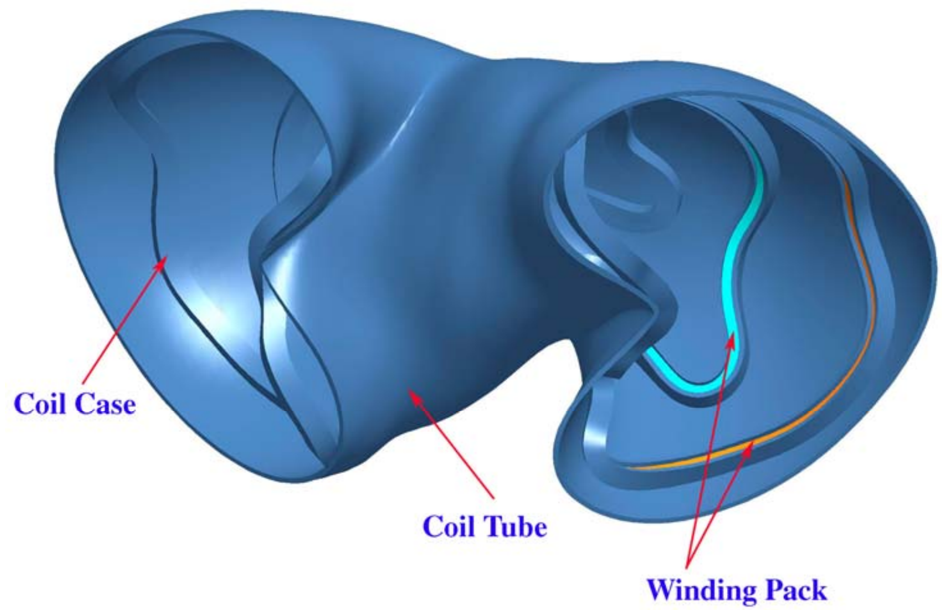


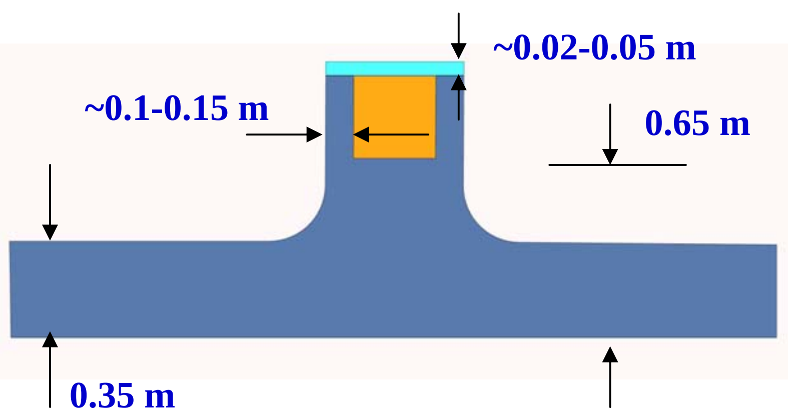


- Continuous tube structure and bucking cylinder
- Solid element type for the winding pack, and shell element type for the intercoil structure, strongback, and bucking cylinder.
- Assumed thickness: Intercoil shell=0.35 m, Strongback=0.35 m, Bucking cylinder=0.65 m
- Max. Displacement vector sum=2.4 cm, Max. stress=612 MPa
- Need further work to confirm this results.

Possible Coil Structural Design for One Tube Segment (1)

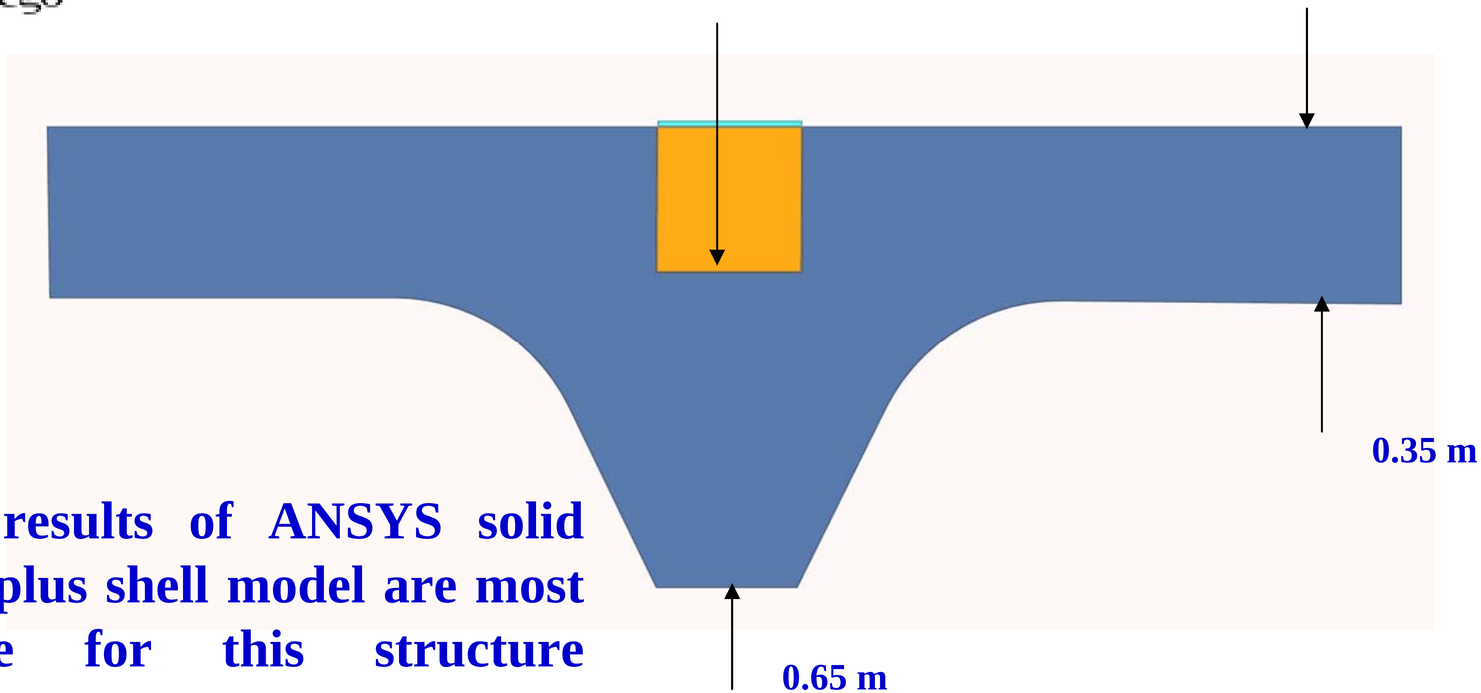






- ✓Coil tube (Intercoil shell) is about ~0.35 m;
- ✓Strongback is about ~0.65m;
- ✓ Bucking cylinder ring is ~0.85 m.

Possible Coil Structural Design for One Segment (2)



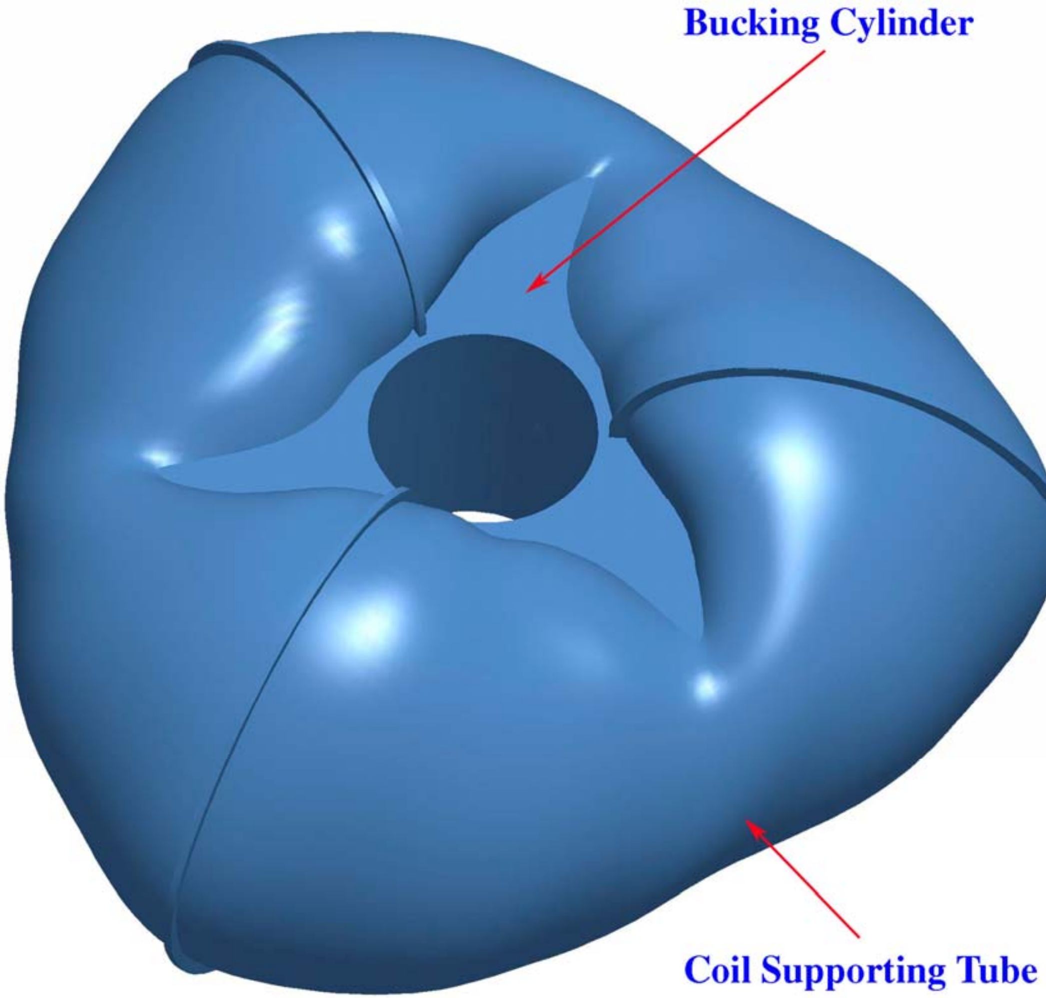
✓The results of ANSYS solid model plus shell model are most suitable for this structure design.

✓Coil tube (Intercoil shell) is about ~0.35 m;

✓Strongback is about ~0.65m;

✓ Bucking cylinder ring is ~0.65 m.

Possible Coil Structural Design For Full Field-Period: Bolted the Three Tube Segments Together



Possible Coil Structural Design for Full Field-Peroid: Separated Tube Segments

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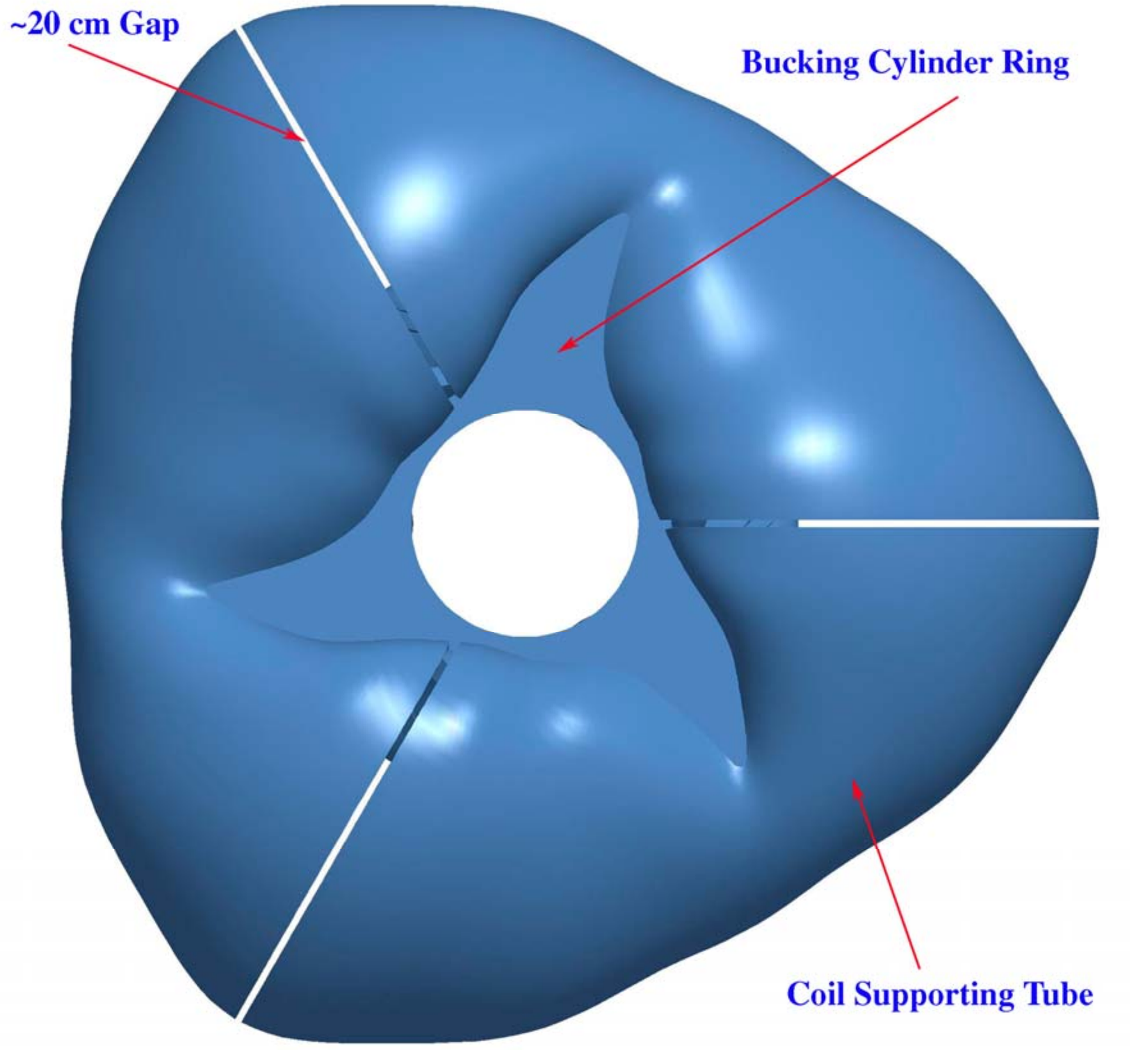

Do not have the structural results for this case, yet.

Lesson from the NCSX Coil Structure Design

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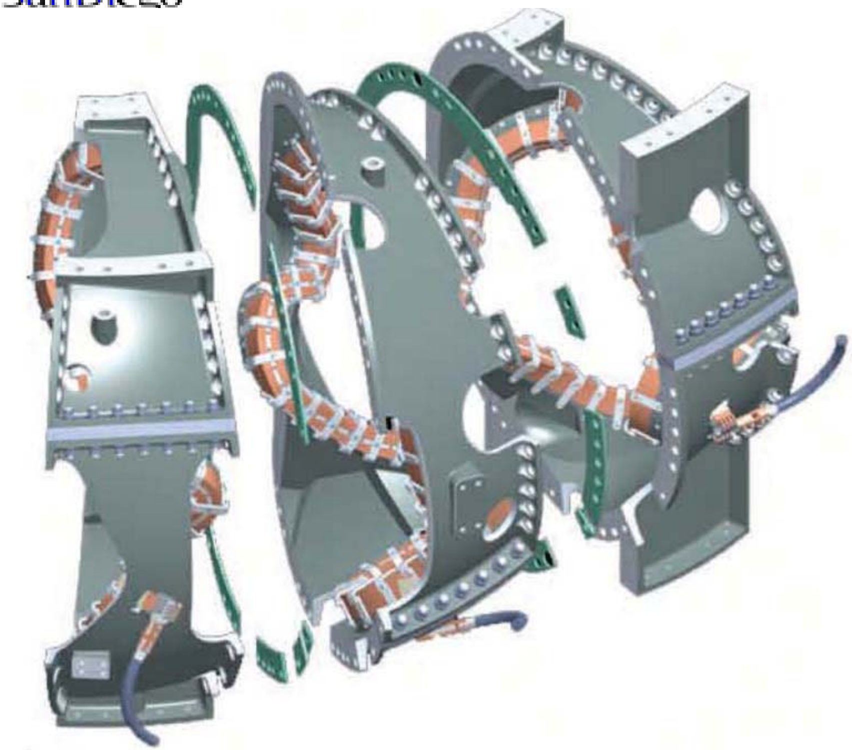

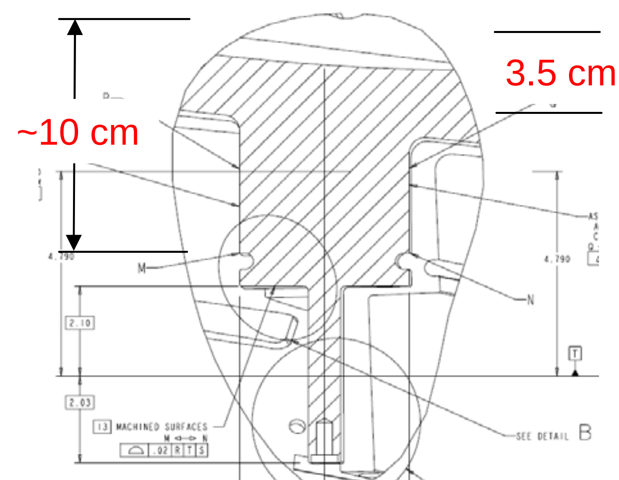

- ➢The modular coils are supported by the integral winding form and shell structure.
- ➢There are 18 shell segments bolted together to make a continuous shell structure.

Summary

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- The maximum magnetic flux densities were found in the modular coils where there are small bend radius of curvatures at the winding pack.
- The results of EM analysis show that both the net vertical and toroidal forces of the 6 modular coils inside one field-period are zero, and there is only the net centering force with a magnitude of 201 MN.
- Two different approaches of the EM Analysis show very good agreements.
- The thickness of the intercoil shell, the strongback and the bucking cylinder are about 0.35 m, 0.65 m and 0.85 m, respectively based on the continuous coil tube design.
- Three tube segments (one segment each field-period) can be either bolted together (like the NCSX) or separated . This needs the ANSYS runs to confirm the separated case.