Coil Structural Design and Magnetic-Structural Analysis

UC San Diego

Presented by X.R. Wang

Contributors:

UCSD: S. Malang, A.R. Raffray

UW: C. Martin

ARIES Meeting

UW, Madison

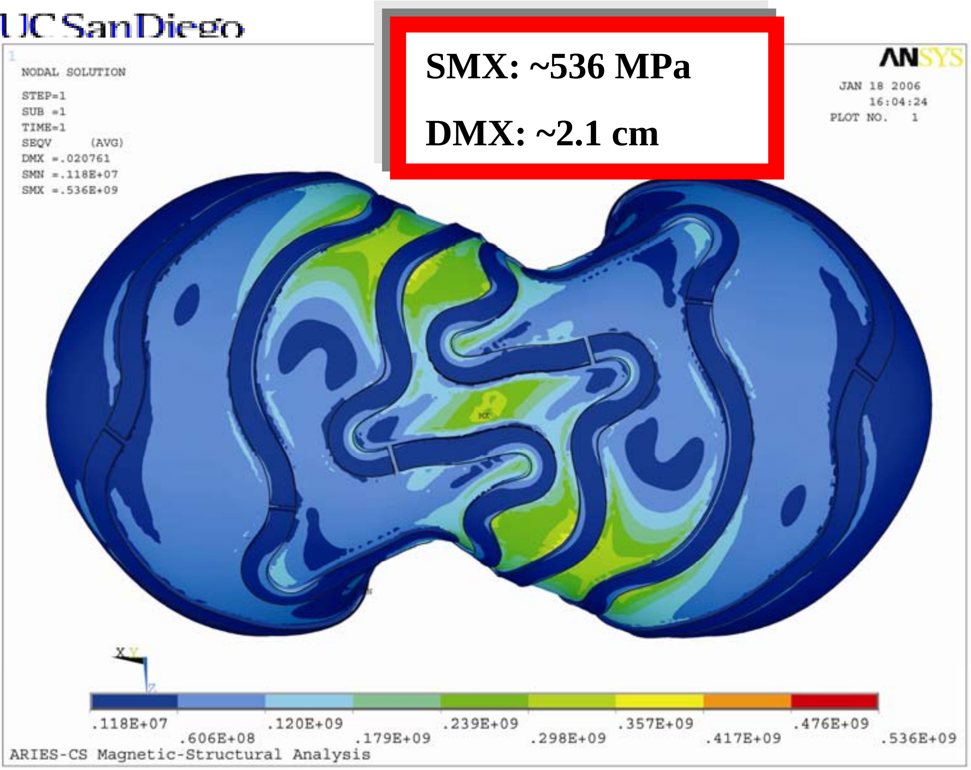
April 27-28, 2006

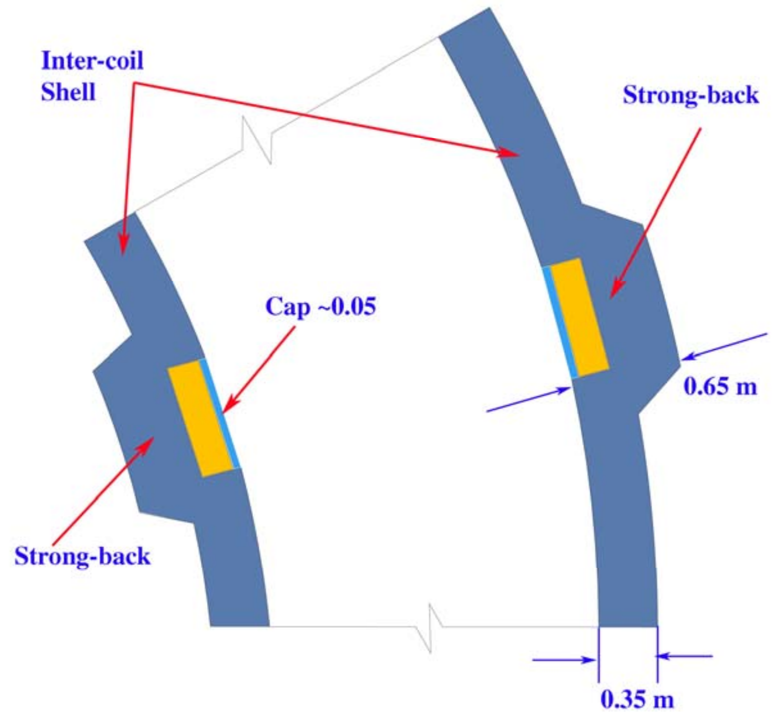
Outline

- Coil structural design definition based on previous ANSYS shell modelling.
- 3D solid modelling of the magnetic-structural analysis:
  - -Finite element model for structure analysis
  - -Max. stress in the coil supporting structure
  - -Max. stress in the modular coils
- Summary
- Future work

Definition of the Coil Structural Design

UC San Diego





- Based on results of parametric analysis with ANSYS shell modeling, the thickness of the coil tube and strong-back were initially decided to be 0.35 m for the inter-coil structure, and 0.65 m for the strong-back, respectively.
- There are three segments of the coil supporting tube (one segment per field-period) bolted together to make a continuous structure ring.

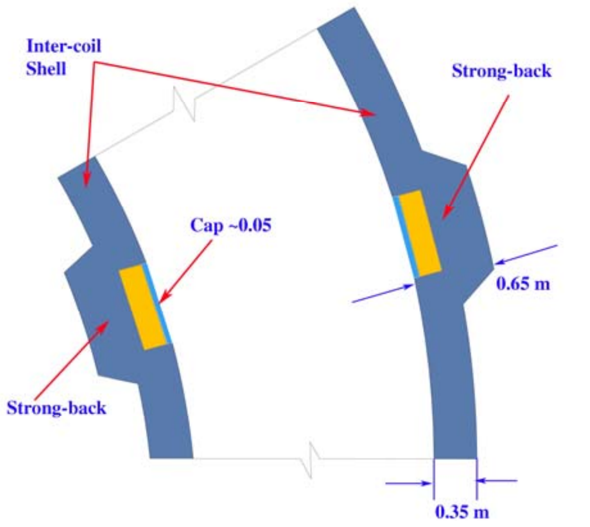
Why ANSYS Solid Modeling for Magnetic-Structural Analysis?

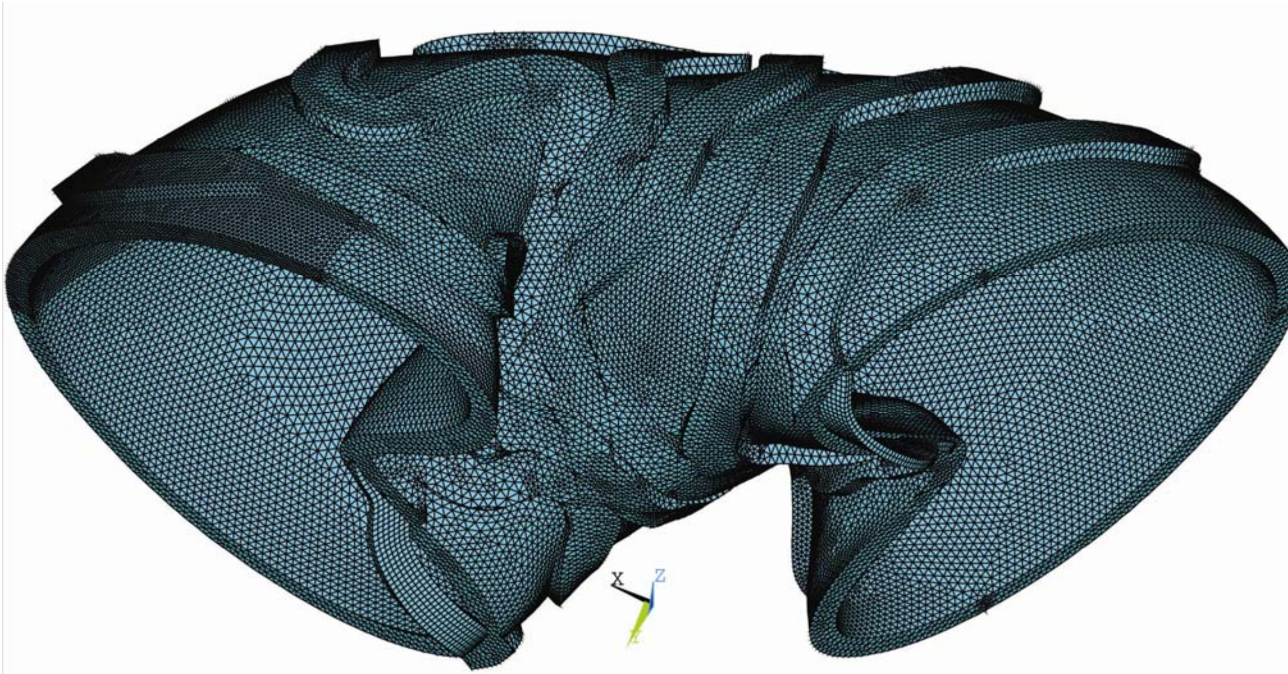
UC San Diego

- Shell elements in magnetic-structural model are really 2-D plane elements used to model the mid-plane of ***thin structures***.
  - ✓ 3-D Structures with thin layer are ideal structures for shell element application.
  - ✓ There is an enormous time saving when shell elements are used in place of 3-D solid elements.
  - ✓ Shell thickness can be used as a parameter optimization.
  - ✓ ***Results of shell modeling for a thick structure may not be accurate.***

- Solid structural elements are capable of modeling any general 3-D structure.
  - ✓ They have the advantage of directness, for example, boundary conditions on forces and displacements can be more realistically treated.
  - ✓ Solid element mesh visually looks like the physical system.
  - ✓ They are good for verification of final design stage.
  - ✓ ***Mesh preparation effort and computing time are big disadvantage for solid modeling, and any modification for the solid model, such as changing the thickness of shell, will cause to re-create the model from the beginning.***

Finite Element Model for Magnetic-Structural Analysis

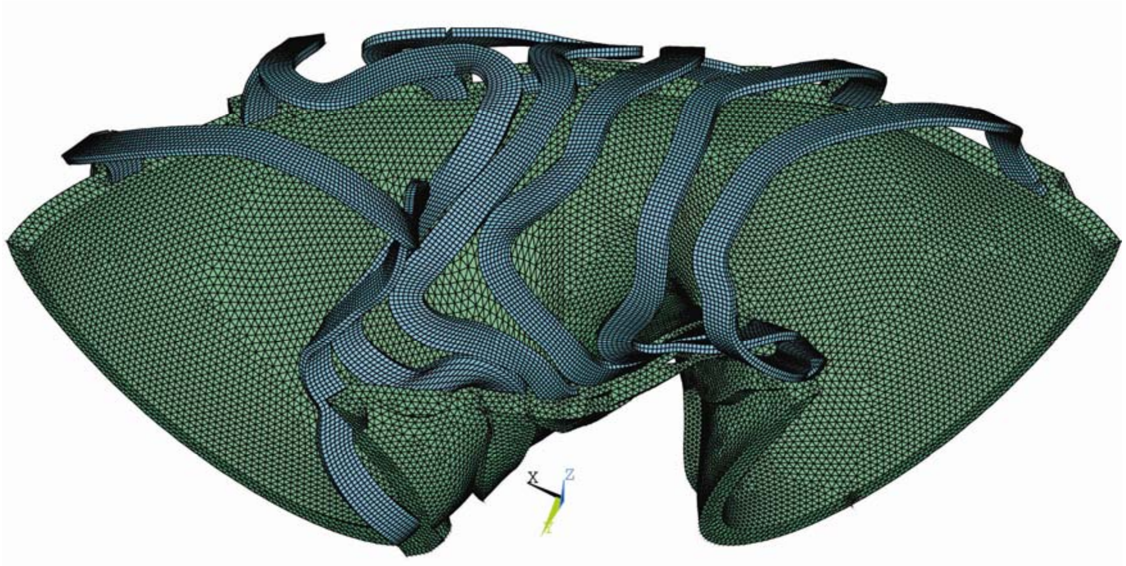




- The modular coils and coil supporting tube are imported from Pro/E generated files to provide an accurate shape and representation
- The element model consists of 6 modular coils and one sector coil supporting tube (one field-period).
- There are ~188,000 elements (SLOID5) for EM model, and 712,000 elements (SOLID45) for structural model.

Finite Element Model for Magnetic-Structural Analysis (Cont.)

UC San Diego



- The modular coils are assumed to be tied together with the grooves in the coil supporting tube.
- Cyclic symmetry boundary conditions are applied at the both ends of the coil supporting tube (at the -60-degree and 60-degree sections) because of threefold cyclic symmetry presented for both the structural and loading.
- Two nodes located at bottom side of the coil tube are constrained to simulate the constraints from the machine support structure.
- EM loads obtained from the EM analysis will be applied as nodal force in the subsequent stress analysis by using identical nodal points and elements.

Material Properties for the Coil Supporting Structure*

Material	Incoloy 908
Yield strength	1227 MPa at 4 K
Tensile strength	1892 MPa at 4 K
Modulus of elasticity	1.823 x 10^{11} MPa at 4K
Elongation	28.5% 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.

***L. Bromberg, Material Properties for the Conductor.**

Material Properties for the Winding Pack

UC San Diego

- There are no many accurate data available for winding pack because of the difficulty calculating the composite material properties of the modular coils. The data used in the NCSX engineering analysis were based on test results.

- Composition of winding pack based on assumption of 14 T magnet*:

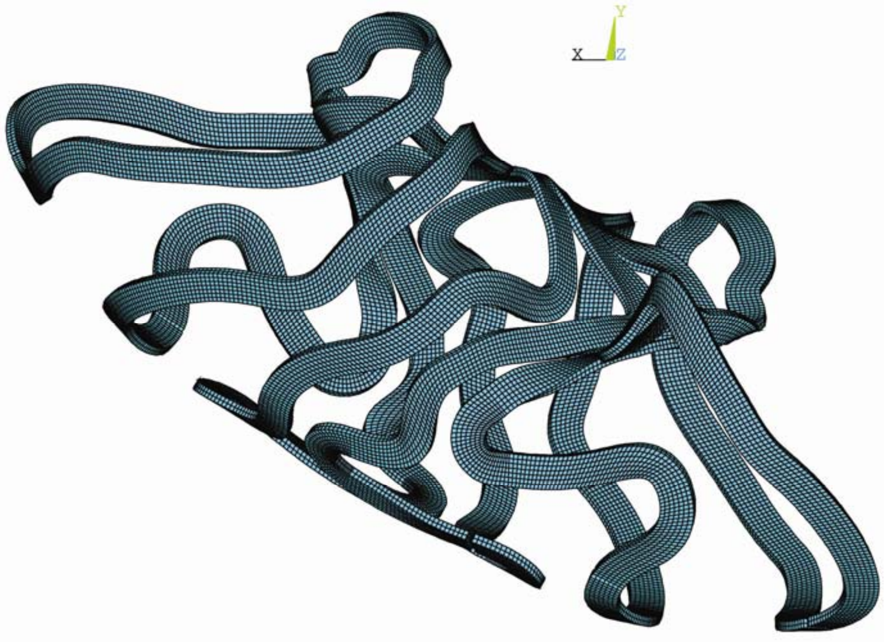
	Fraction (volume)
Inconel	18.5%
Copper	48.2%
SC	12.8%
Insulation	10.0%

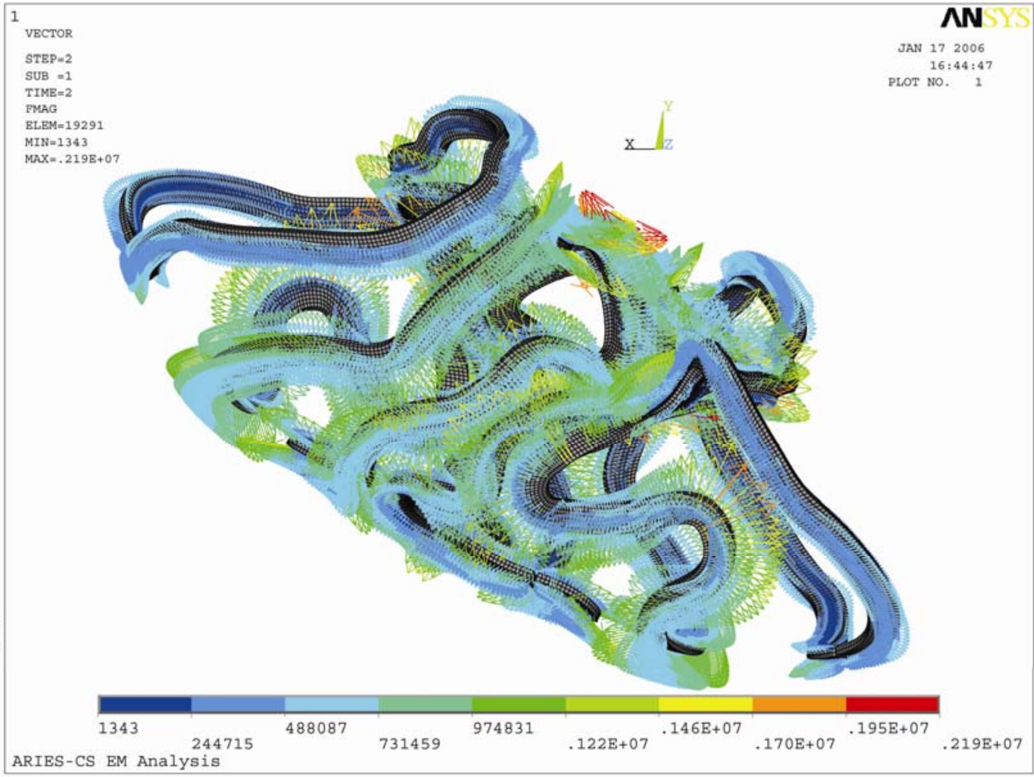
- Average material property for the winding pack is assumed*:
  - ✓ Young's Modulus in the direction of the conductor, E~34 GPa
  - ✓ Young's Modulus in the direction normal to the conductor, E~17 GPa
  - ✓ Poisson's ratio based on the composition of winding pack, 0.3

***L. Bromberg, Material Properties for the Conductor.**

Magnetic Forces from EM Modeling

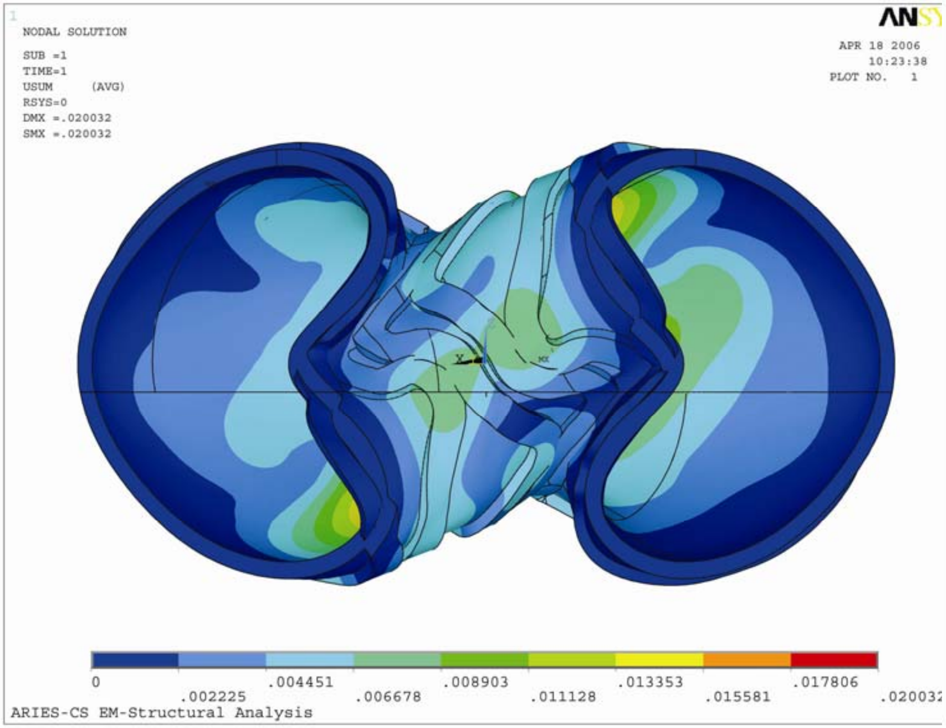
UC San Diego

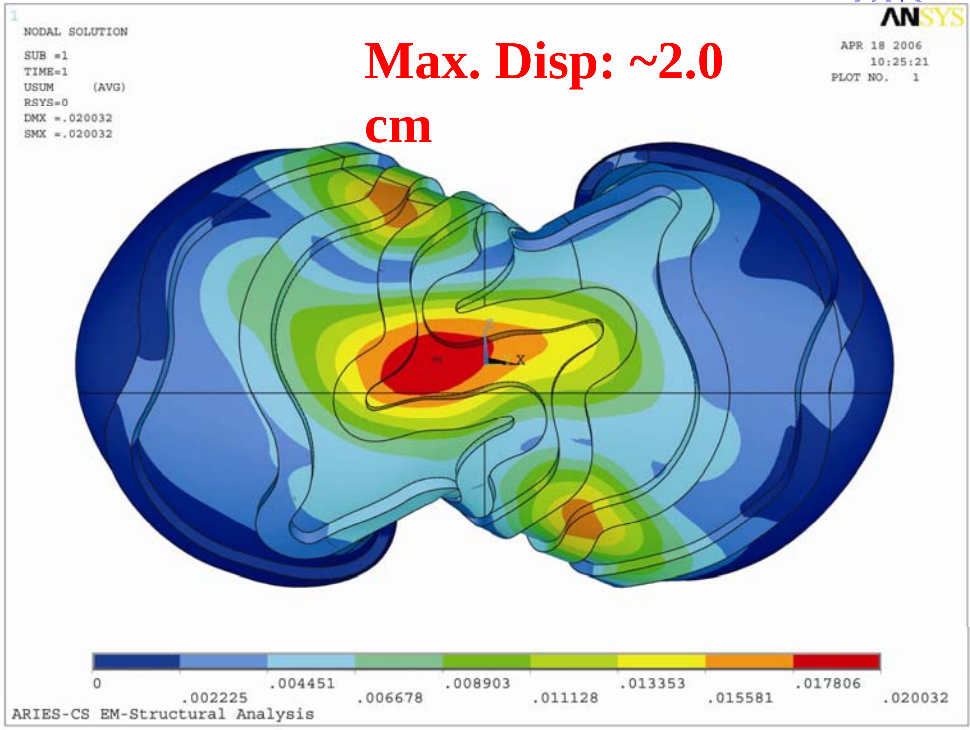




- The maximum nodal forces are found in the modular coils where there are small bend radiuses of curvatures.
- The nodal forces will be transferred into structural model node by node.

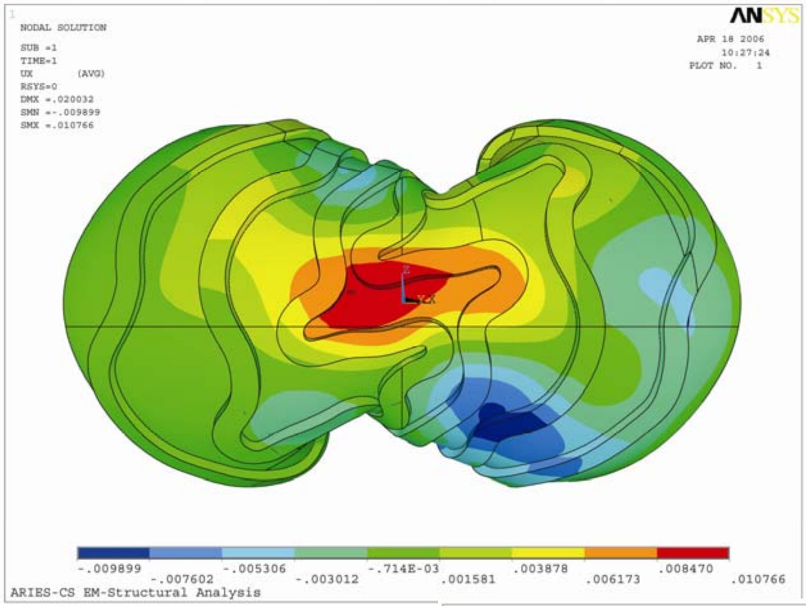
Max. Displacement of the Coil Structure

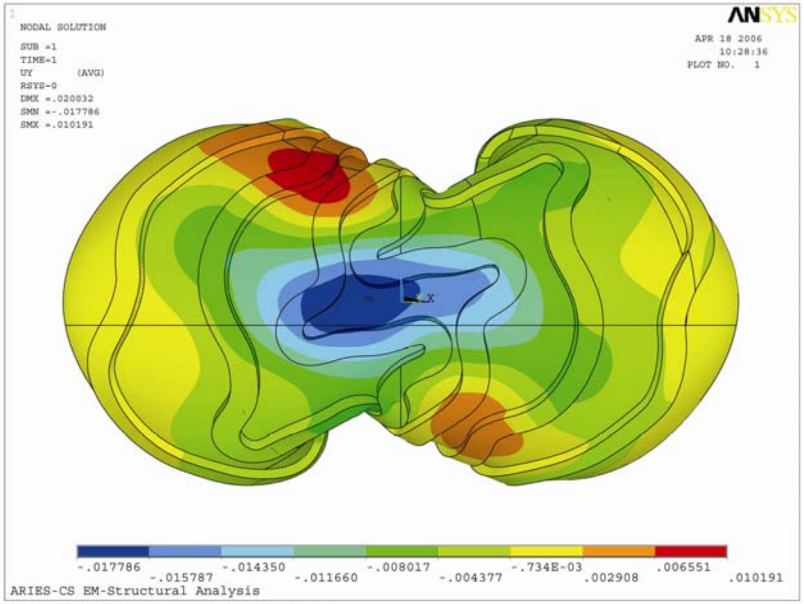




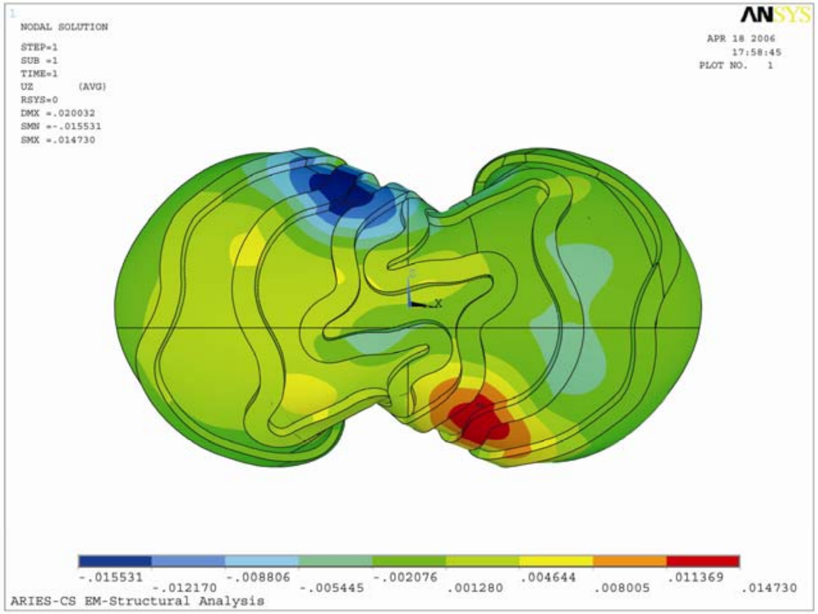
- The results indicate the maximum displacement of 2.0 cm at the outboard of the coil supporting tube.
- Contour shows a good symmetry because of the symmetric structure and EM loadings.

Max. Displacement Components of the Coil Structure





Ux=1.07 cm



Uy=1.02 cm

Uz=1.47 cm

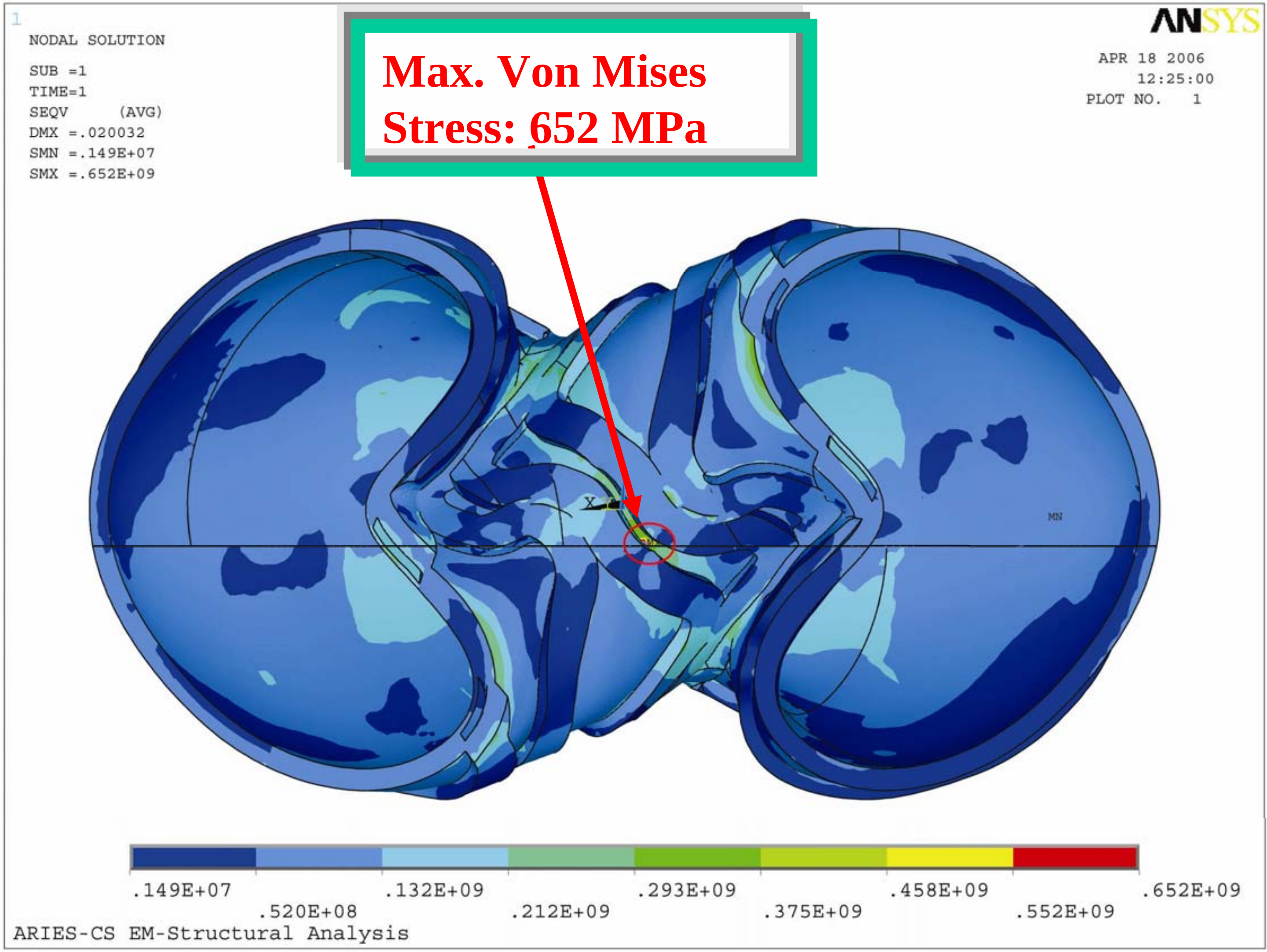
Max. Von Mises Stress of the Coil Structure

UC San Diego

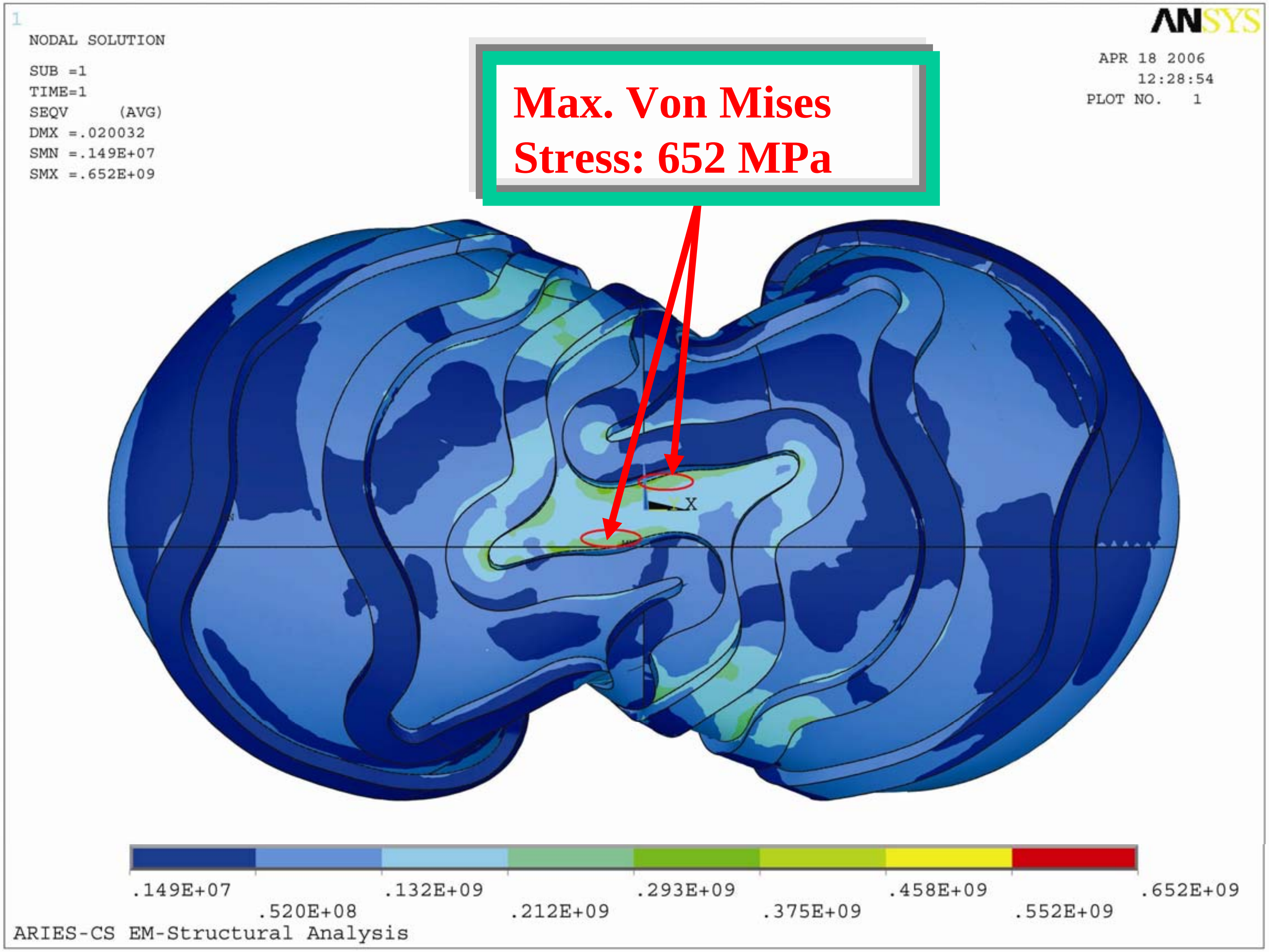
✓The Max. Von Mises stress of 652 MPa is found at inboard side of the coil supporting tube.

✓The Max. stress occurs locally at very small region only.

✓Most regions of the coil supporting tube including the inter-coil structure shell and strong-back are in a low stress level.

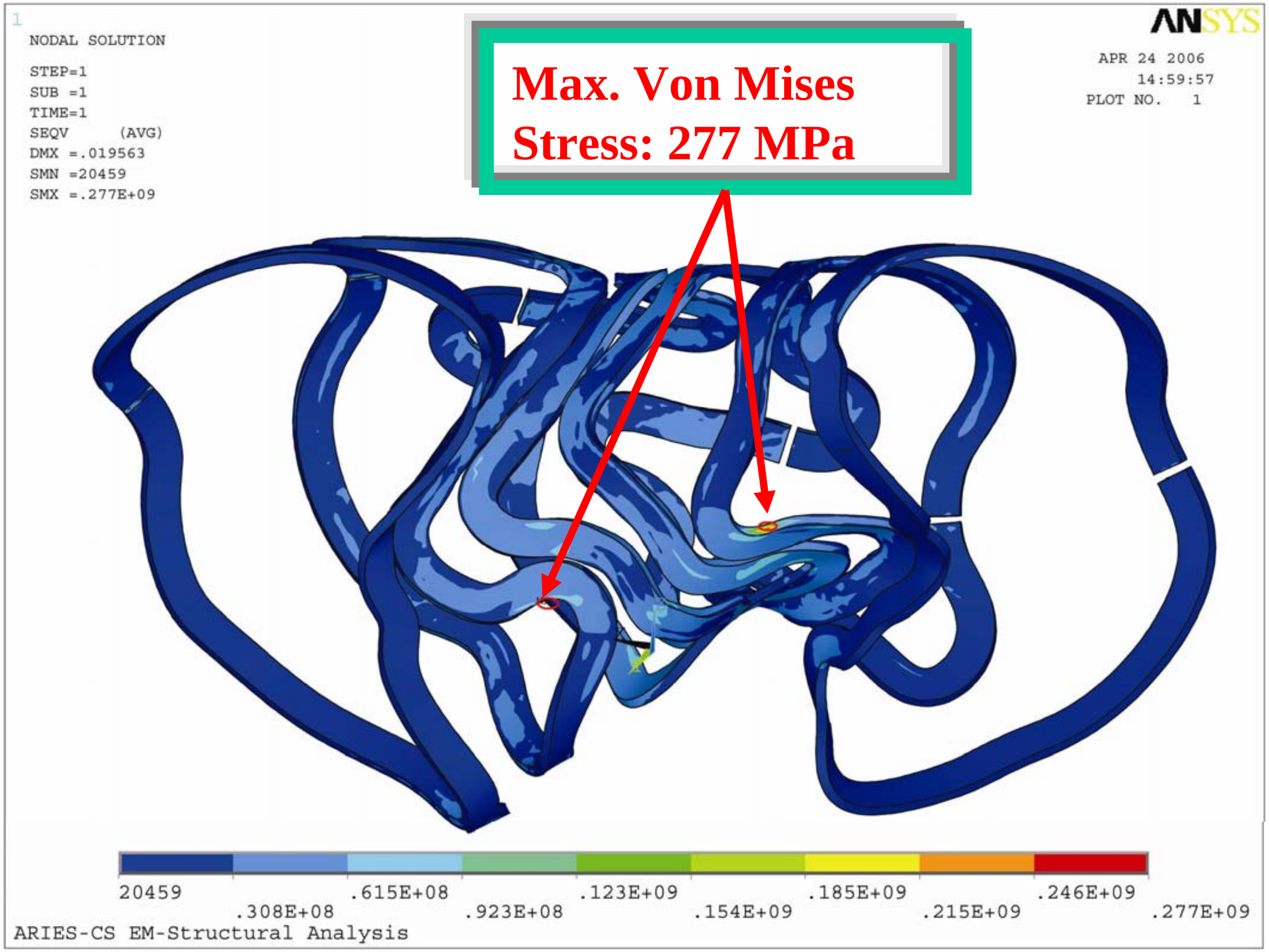


Max. Von Mises Stress of the Coil Structure



Max. Von Mises Stress of the Modular Coils

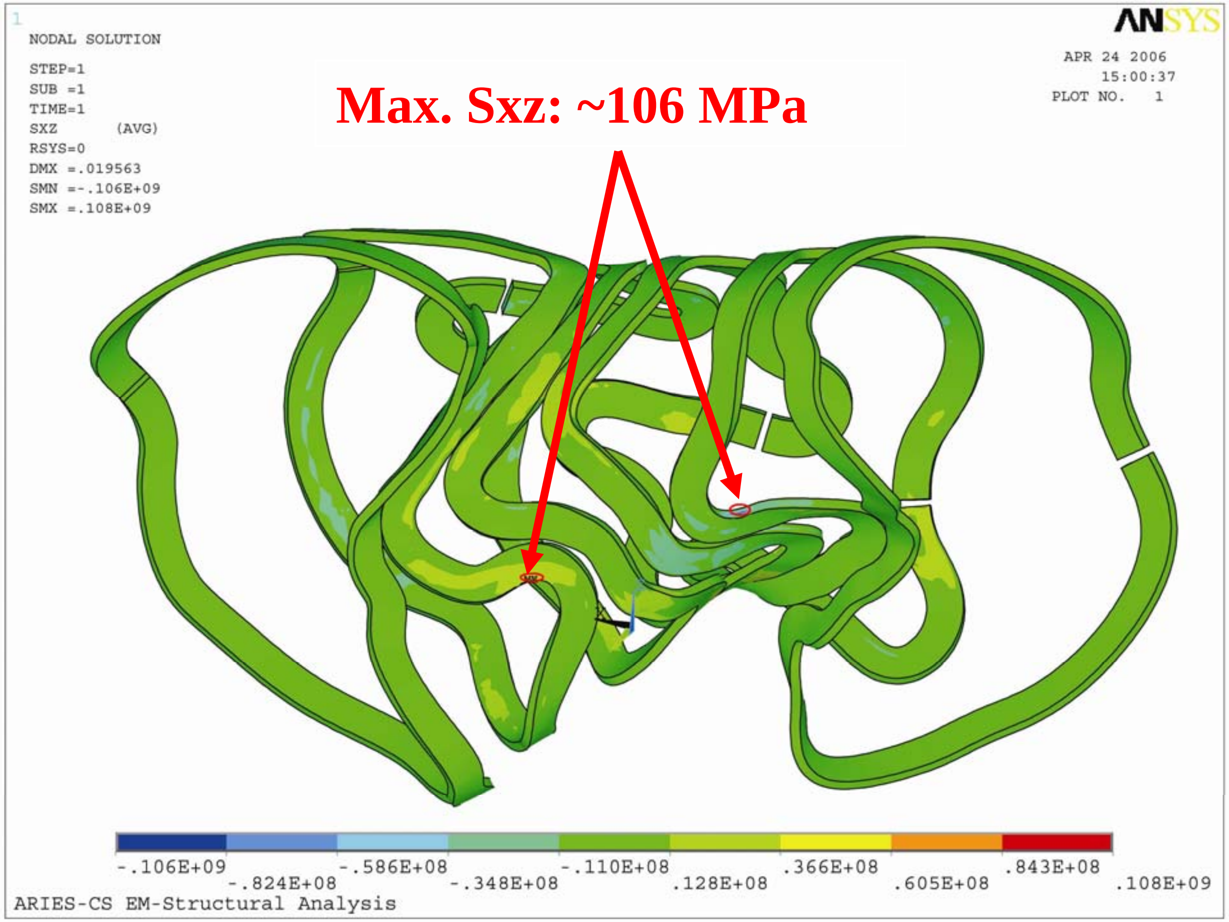
- The Max. Von Mises stress in the modular coils is ~277 MPa, and it locates in very small regions.
- The most regions of the modular coils are below 100 MPa.



Max. Shear Stress in the Modular Coil

UC San Diego

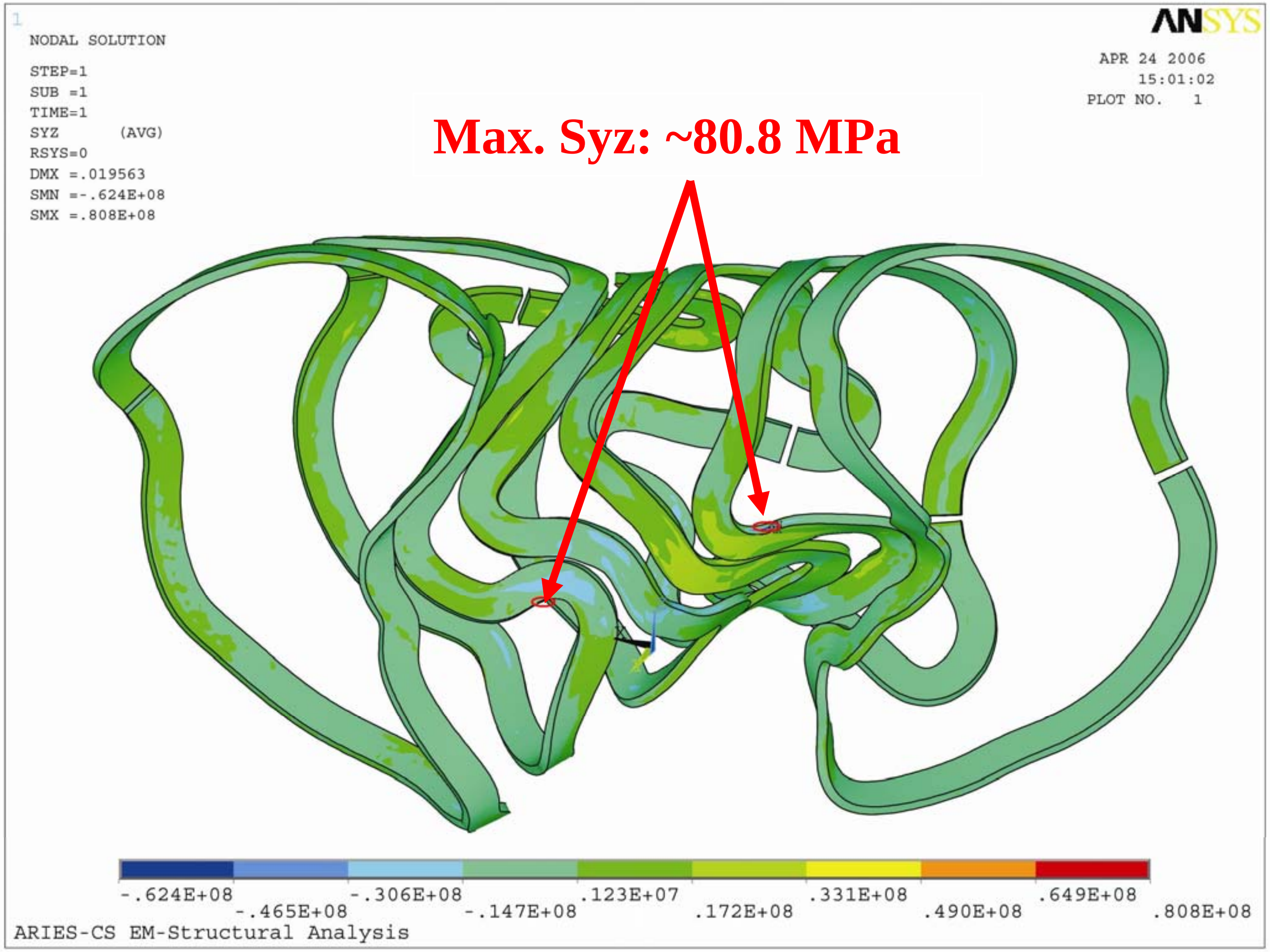
- ***Shear stress is a critical parameter for insulation system of the winding pack.***
- ***Excessive shear stresses would lead to the structural failure of the insulation system.***
- Max. Sxz~108 MPa.
- The peak shear stress is found at inboard side of the coil #2, and it occurs locally.
- Most regions of the coils are below 35 MPa.



Max. Shear Stress in the Modular Coil

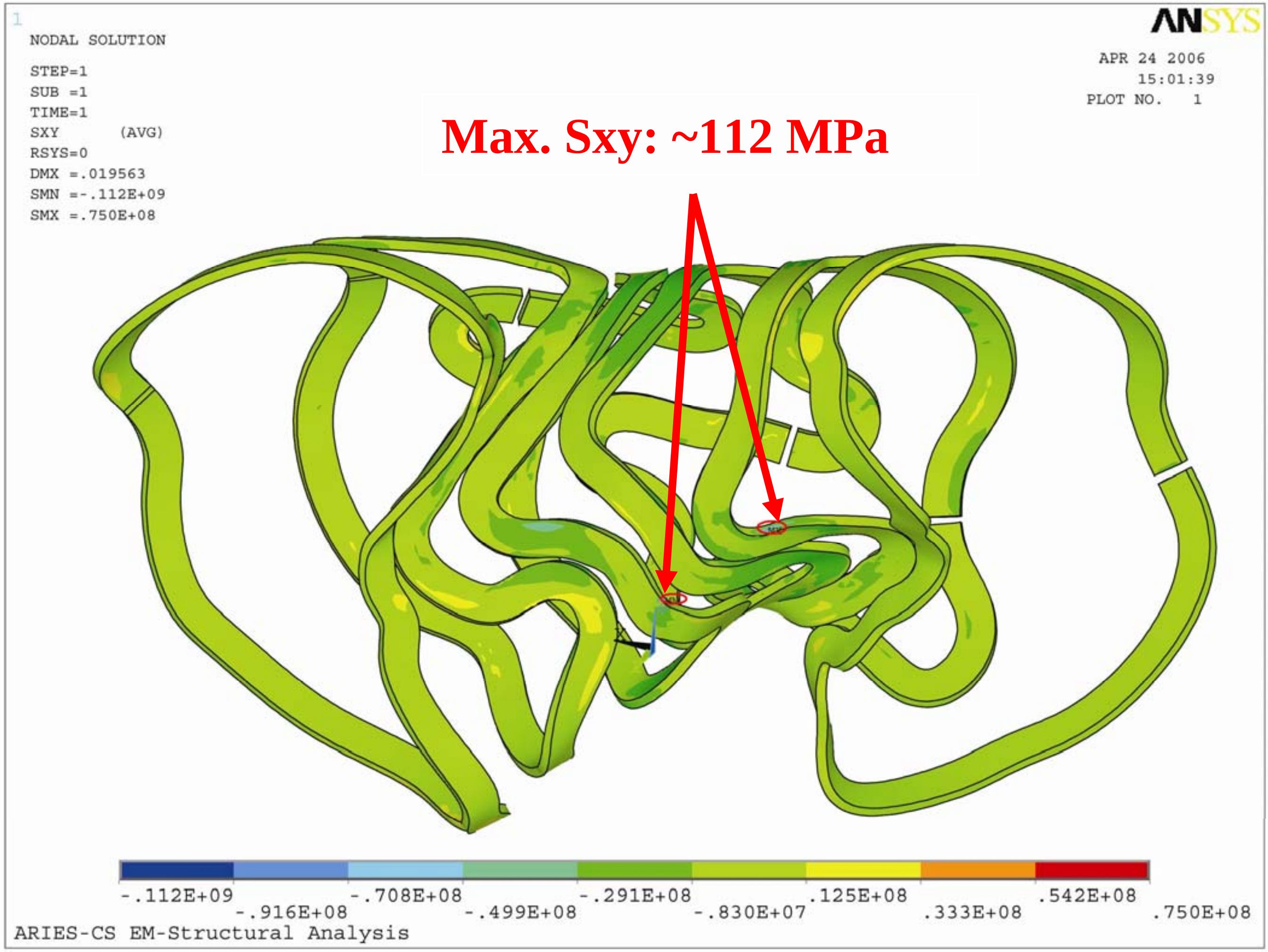
UC San Diego

- Max. Syz~80.8 MPa.
- The peak shear stress is found at inboard side of the coil #2, and it occurs locally.
- Most regions of the coils are below 30 MPa.

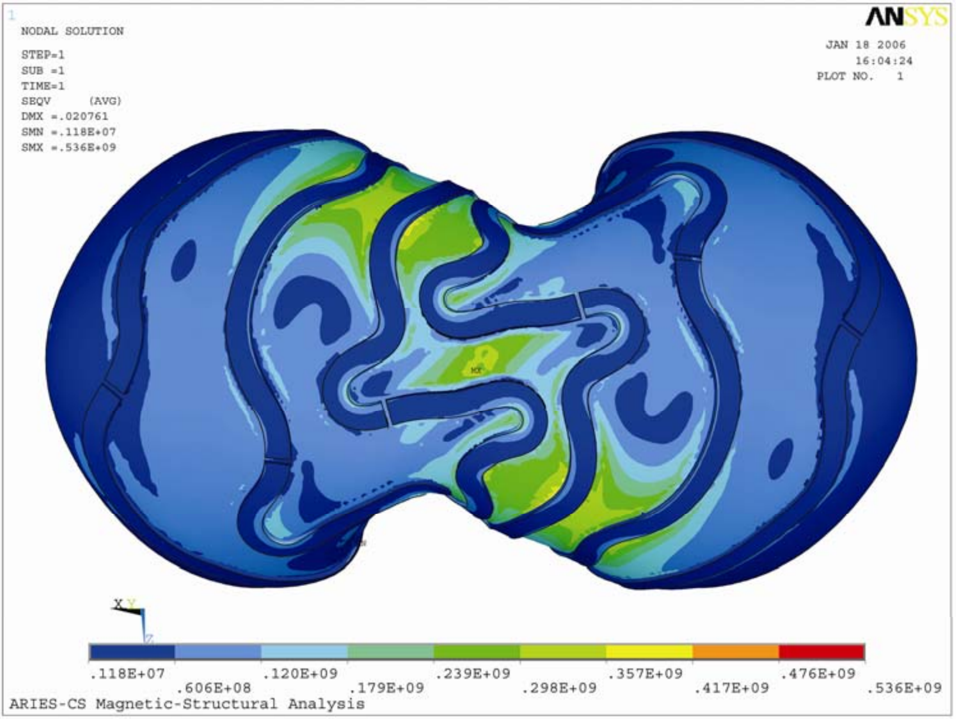


Max. Shear Stress in the Modular Coil

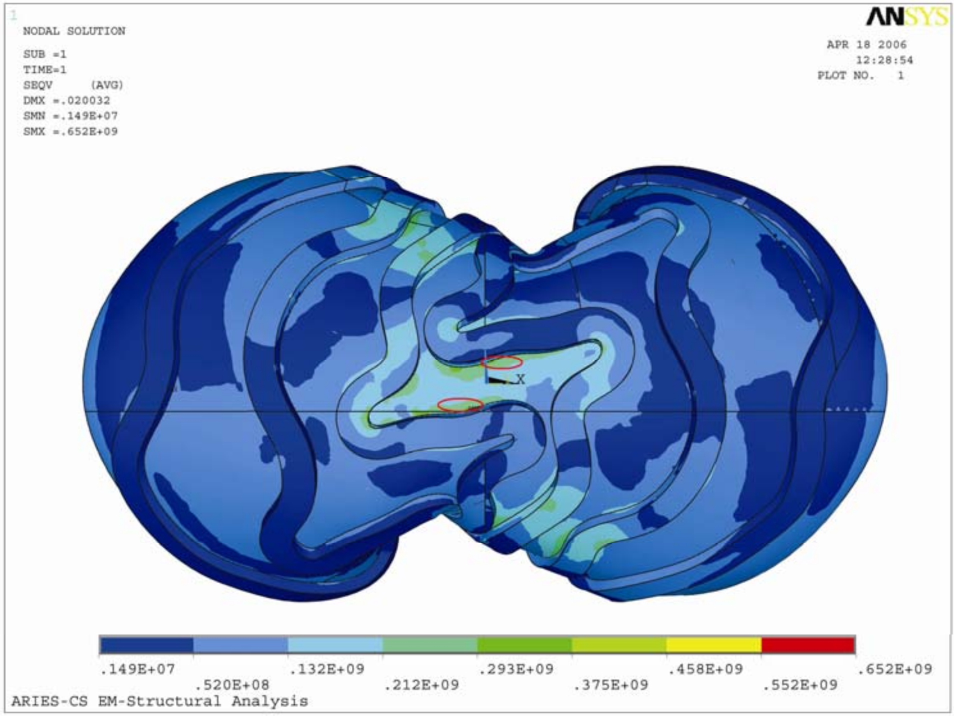
- Max. Sxy~112 MPa.
- The peak shear stress is found at inboard side of the coil #2 and coil #3, and it occurs locally.
- Most of the coils are below 30 MPa.



Results Comparison Between the Shell and Solid Modeling



Shell Model



Solid Model

- The peak Von Mises stress is ~ *536 MPa*; max. displacement is ~*2.08 cm* for the shell modeling.
- The peak Von Mises stress is ~ *652 MPa*; max displacement is *2.0 cm* for the solid modeling.

Summary

UC San Diego

- An extensive ANSYS solid modeling has been performed to confirm the results of parametric studies by using ANSYS shell modeling.

- The results of 3D solid modeling show a low stress level mainly. The peak stresses in the inter-coil shell is ~652 MPa, which occurs locally in a very small region only.

- The local peak stresses on the inter-coil shell is below the allowable design stress limit (~818 MPa), and it can be reduced by locally adding material in that region.

Future Work

UC San Diego

- Cut the inter-coil shell at the regions where the stress is very low.
- To do the magnetic-structural analysis with the openings needs to create a new ANSYS model.
- It needs lot of effort to prepare for a FEA model.
- Team makes decision if the stress will be re-checked after the cuts being made.