Status of Coil Structural Design and Magnetic-Structural Analysis

Presented by X.R. Wang

Contributors:

UCSD: S. Malang, A.R. Raffray

UW: C. Martin

ARIES Meeting

UC San Diego, San Diego

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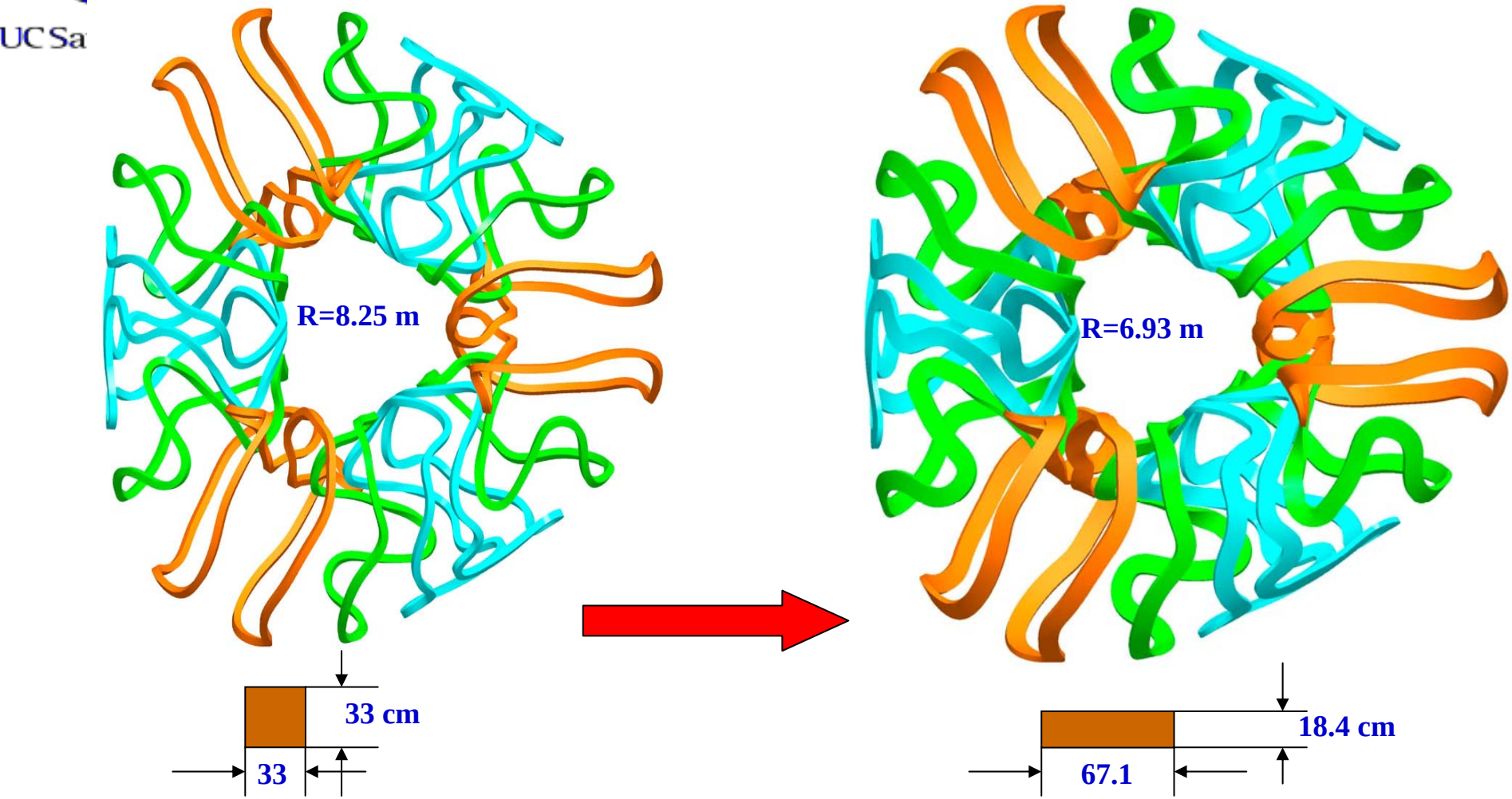
Outline

- Report and update EM (Electromagnetic) analysis based on the ARE coils

- Report magnetic-structural analysis of the structure responses from magnetic forces:
  - -ANSYS shell modelling
  - -Possible coil structural design

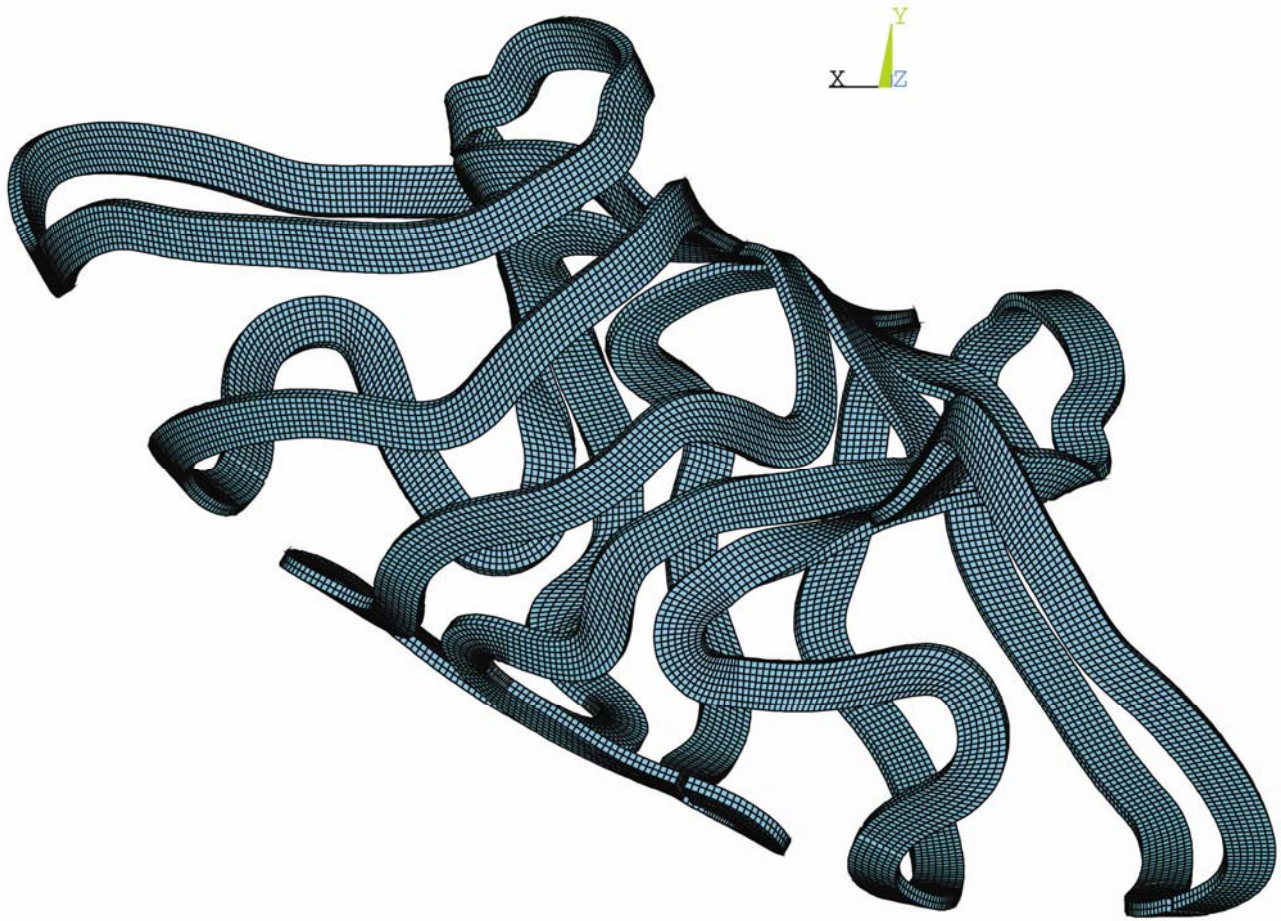
- Summary

Update the ANSYS EM Model to the ARE Coils



- Previous coil design, R=8.15 m, cross section of winding pack is 33 x 33 cm.
- ARE coils, R=6.93 m, cross section of winding pack is ~18.4 cm x 67.1 cm.

ANSYS FEA Element Model



- The 6 coils are meshed by nearly 188000 Hexahedral elements (SOLID5).

Results of the ANSYS EM Analysis

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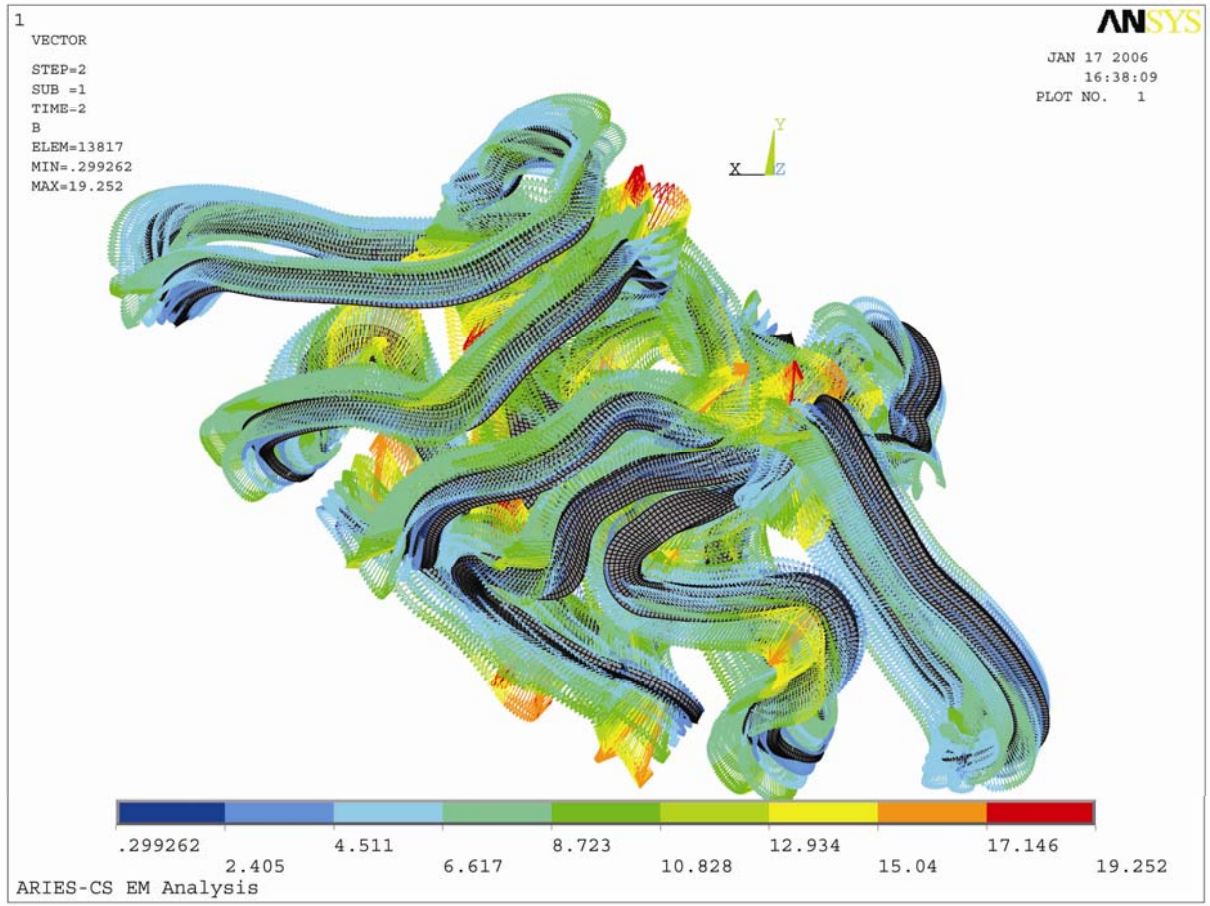
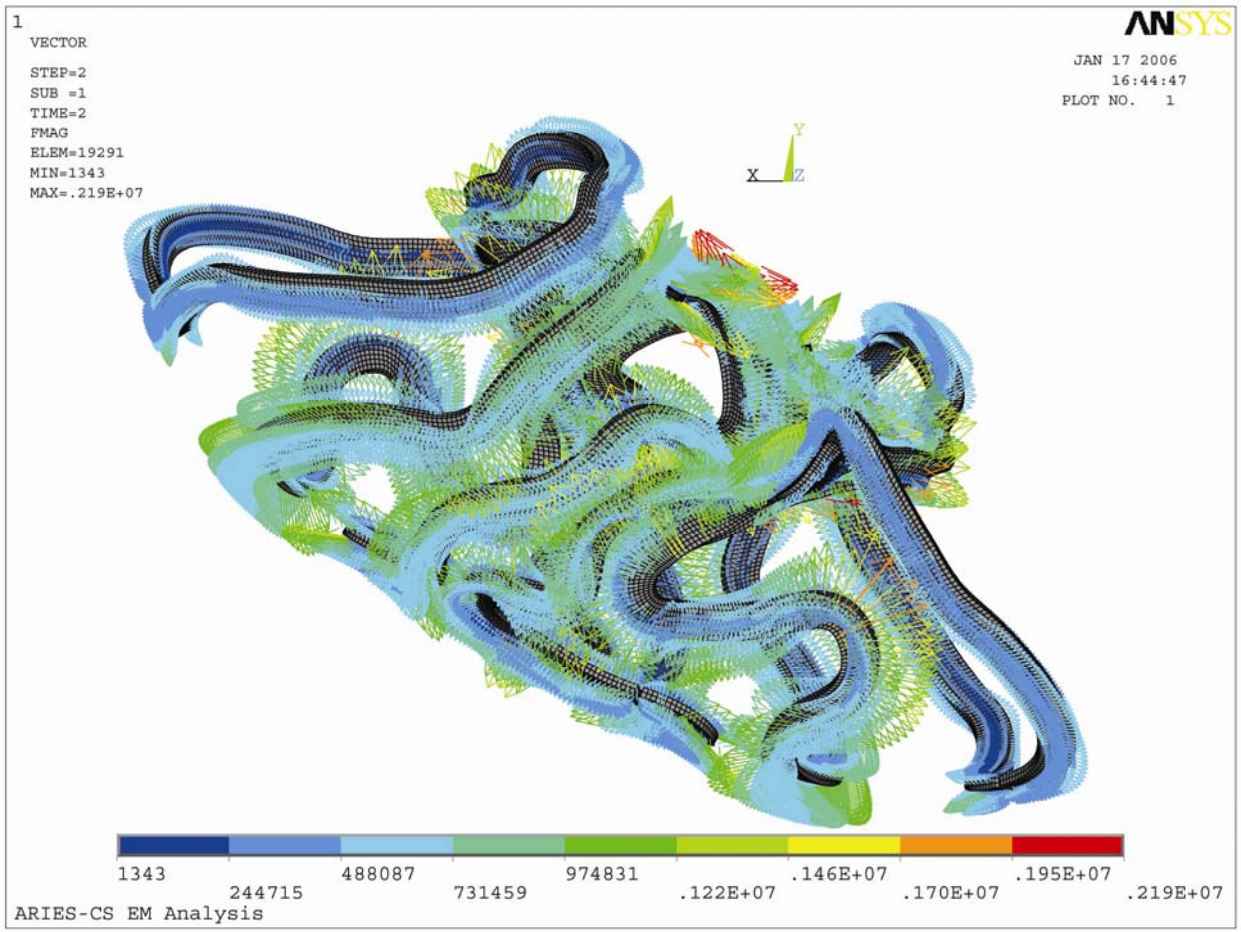
- Currents are revised
  I(M1)=10.61 MA
  I(M2)=13.34 MA
  I(M3)=12.91 MA

- The local maximum magnetic flux density in the modular coils are:

  B(M1)=14.6T,
  B(M2)=19.3T,
  B(M3)=18.5T.

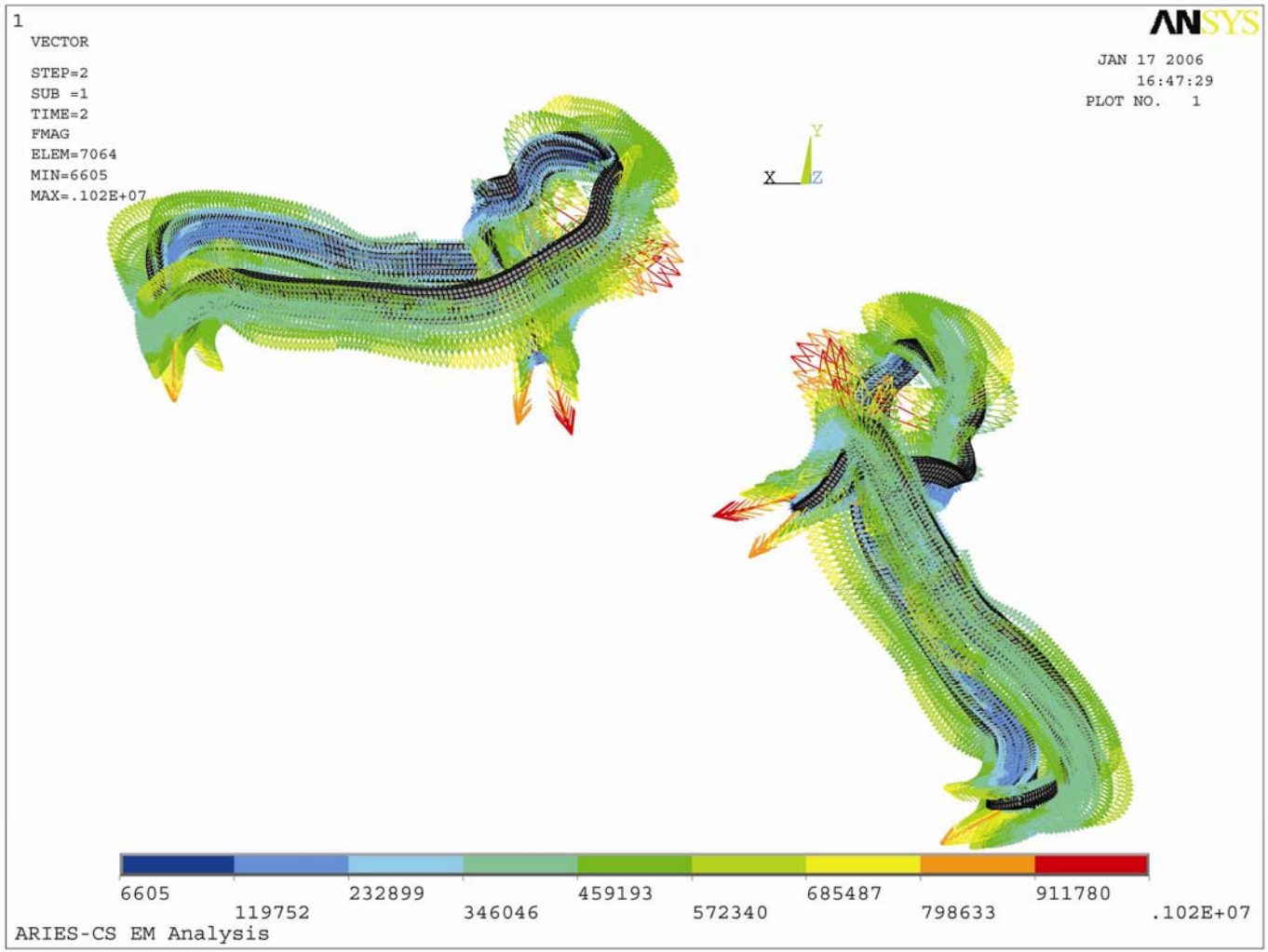


Fully Symmetric Magnetic Forces in One Field-Period Coils Were Found

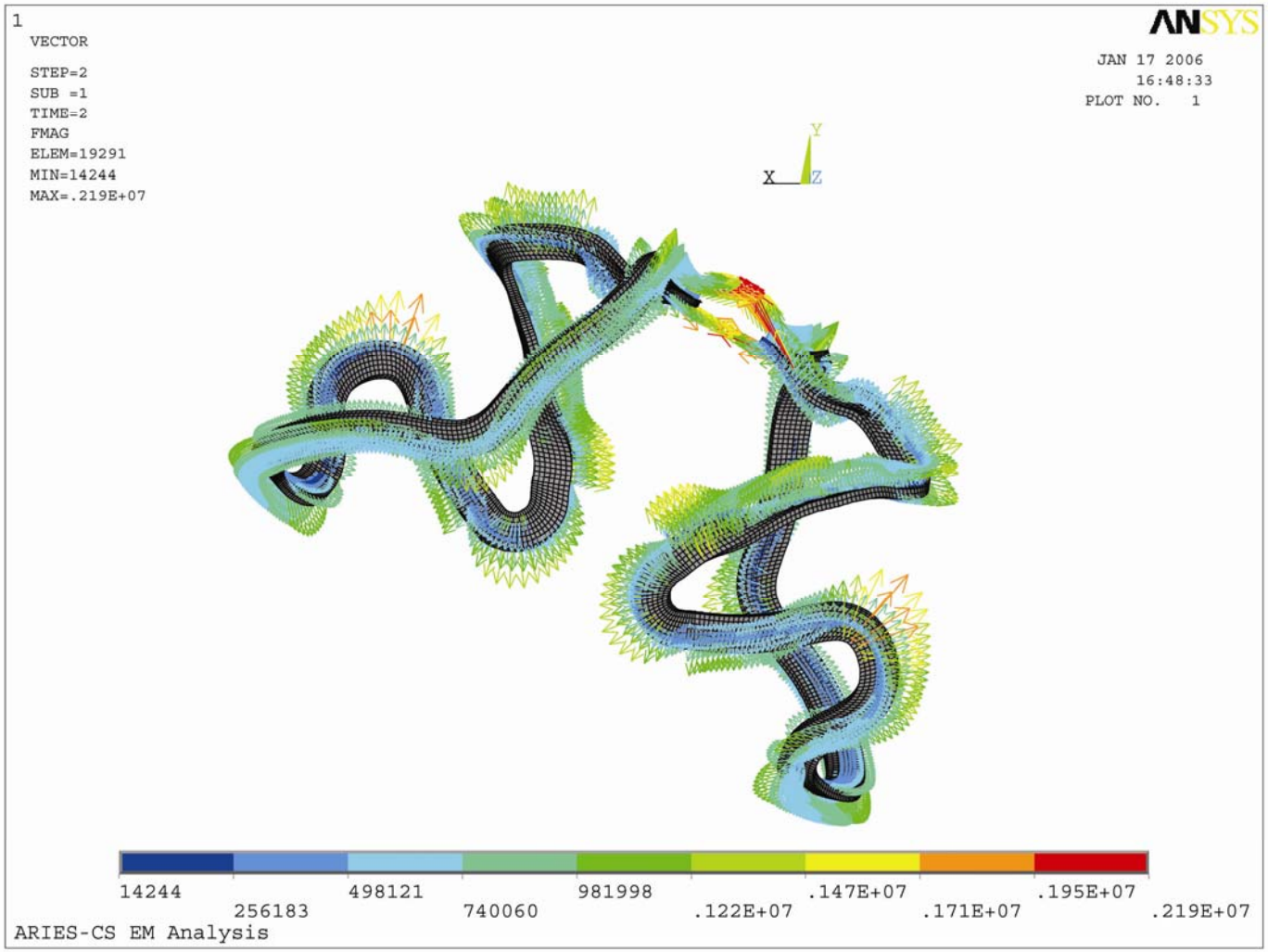


- The nodal force vector plot shows a full symmetry for among the 6 coils, and the maximum nodal force is about 2.2 MN.

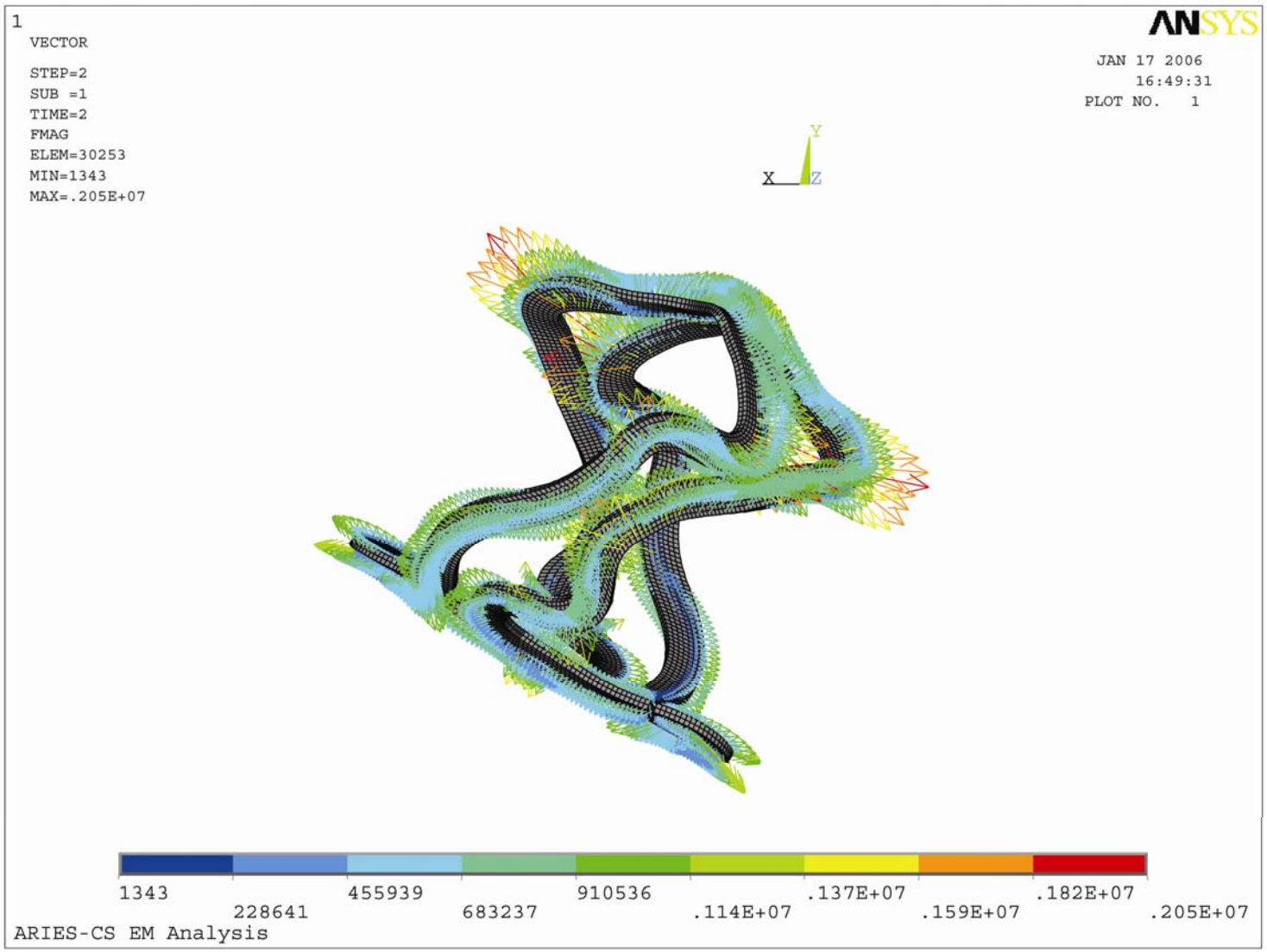
Plots Showing Symmetric Nodal Forces in One Pair of Coils(M1)



Plots Showing Symmetric Nodal Forces in One Pair of Coils(M2)



Plots Showing Symmetric Nodal Forces in One Pair of Coils(M3)



Net Forces in the Modular Coils

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	F_r, MN	F_θ, MN	F_z, MN
M1L	-58.5	377.2	22.6
M1R	-58.5	-377.2	-22.6
M2L	-257.3	178.5	-150.7
M2R	-257.3	-178.5	150.7
M3L	143.2	51.1	-141.7
M3R	143.2	-51.1	141.7
Sum of all 6 coils	-345.2	0	0

Material Properties Used in ANSYS Structural Modeling

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
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.

ANSYS Shell Model of the Structural Analysis

Two cases have been explored, and both cases do not have bucking cylinder at the center of the supporting tube.

Case 1:

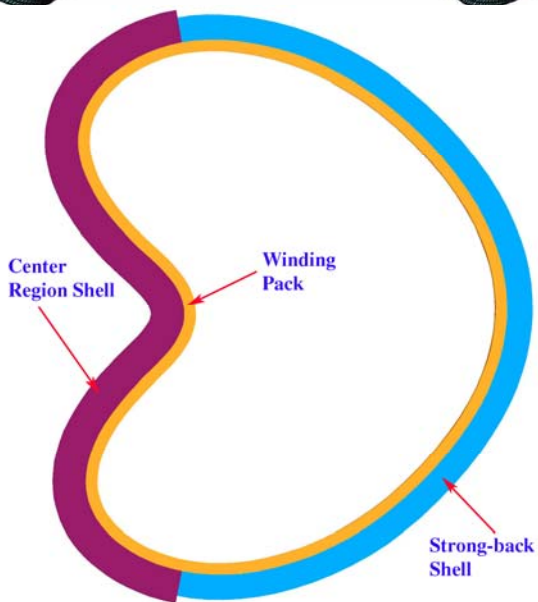
- **The coil supporting tube includes the inter-coil shell , strong-back shell at the outboard, and center region shell at the inboard.**
- **Rotational boundary conditions are applied at the both end of the supporting tube.**

Case 2:

- **The coil supporting tube has the inter-coil and strong-back shells at the inboard and outboard of the supporting tube. There is no center region shell at the inboard.**
- **Rotational boundary conditions are applied at the both end of the supporting tube.**

FEA Model and Assumed Thickness for the Case 1

✓The assumed thickness is based on optimization of previous case (R=8.25 m)



Example Stresses of the Coil Structure Based on the Case 1

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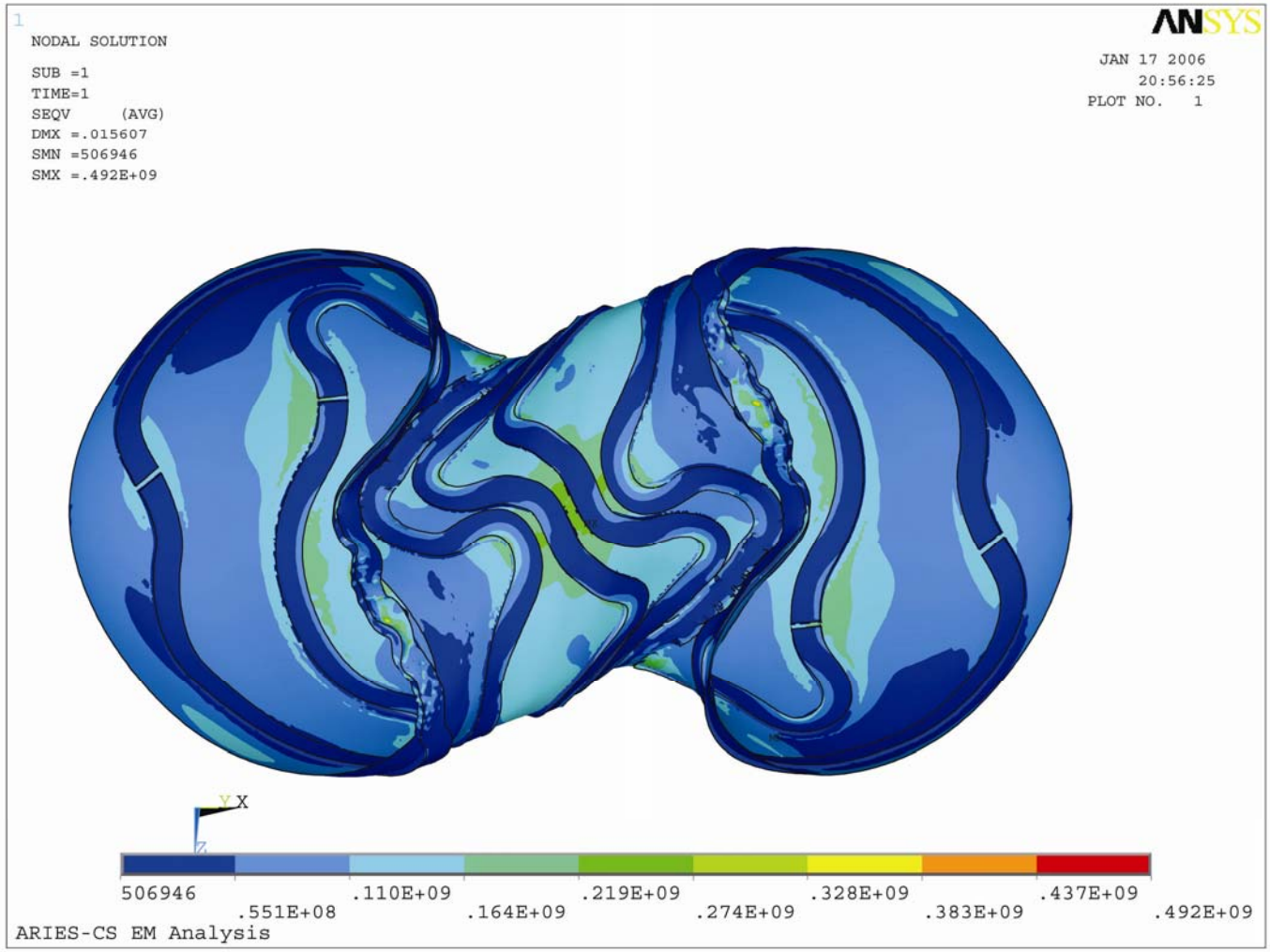
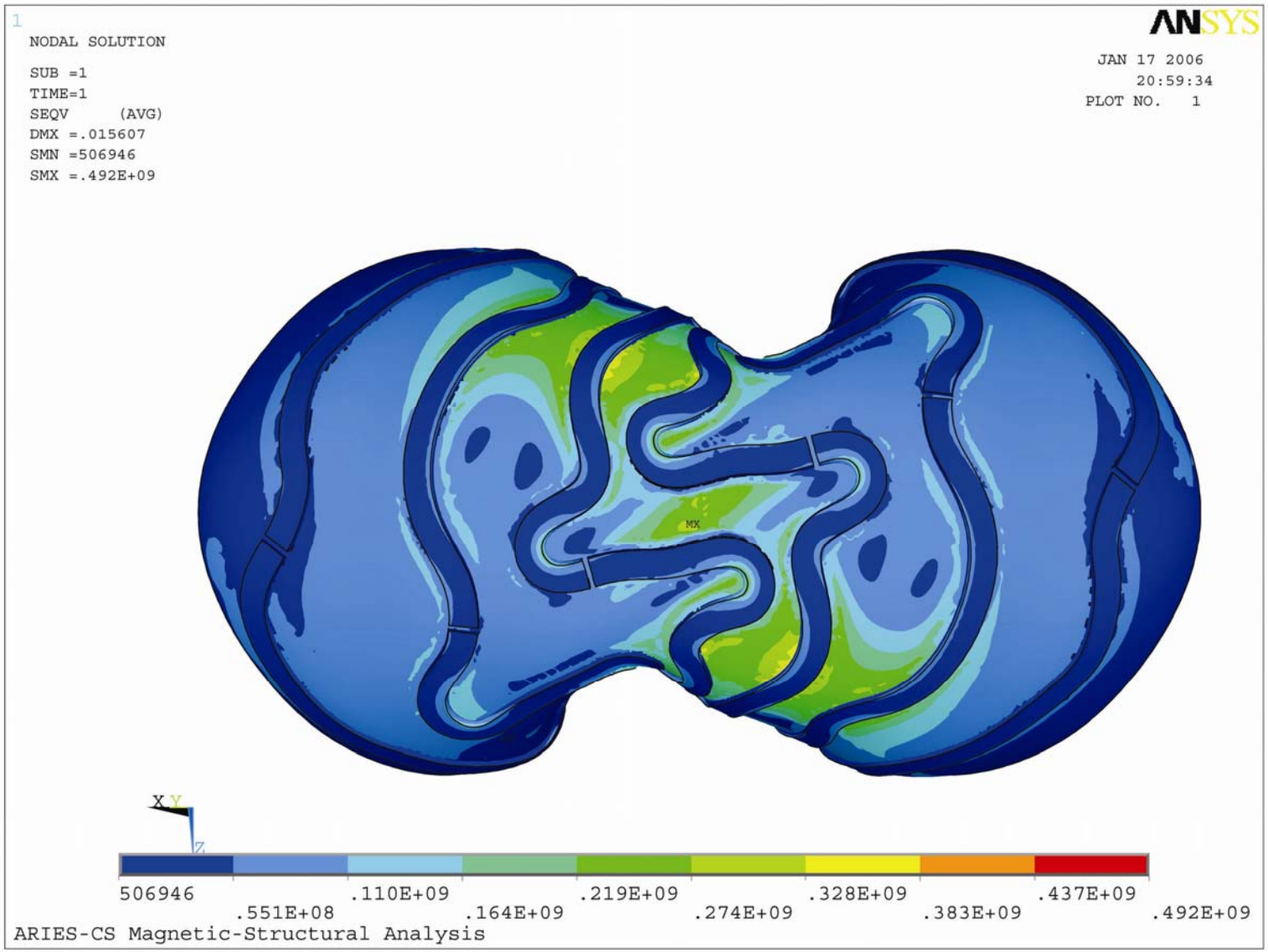
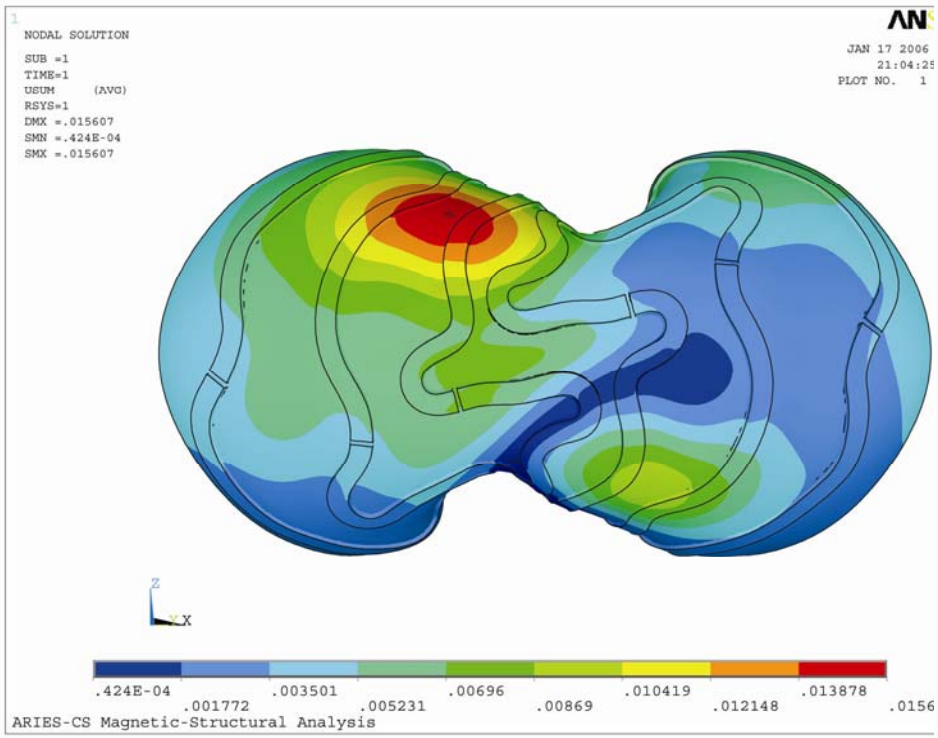
- The maximum stress is about 492 MPa, and it is well below the stress design limit of 818 MPa.

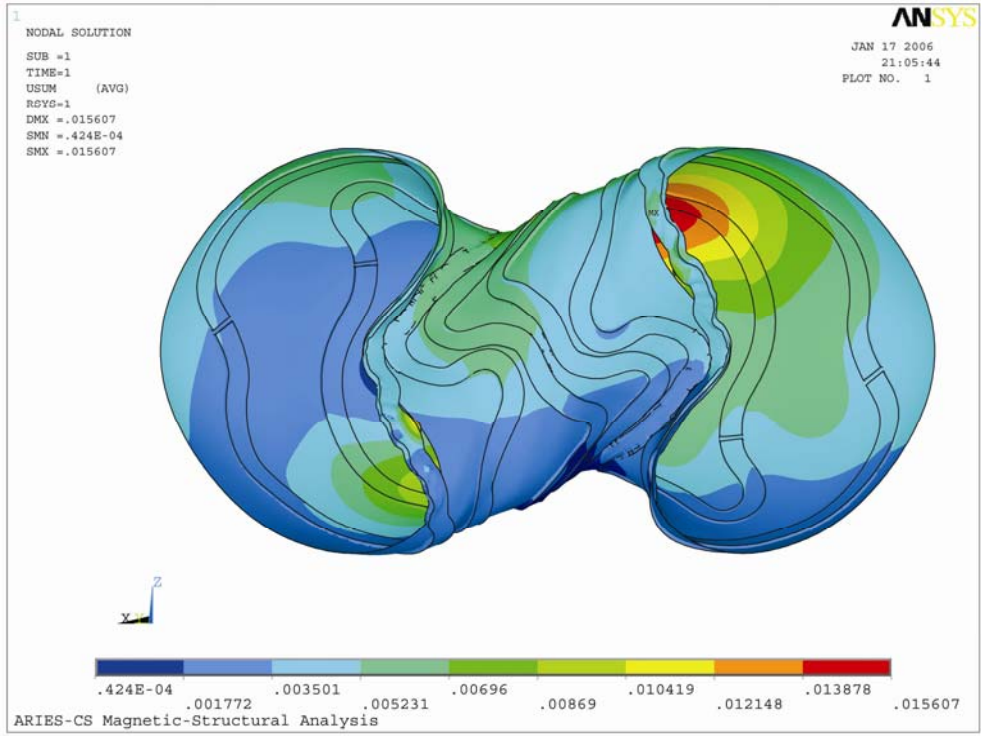


Example Stresses of the Coil Structure Based on the Case 1



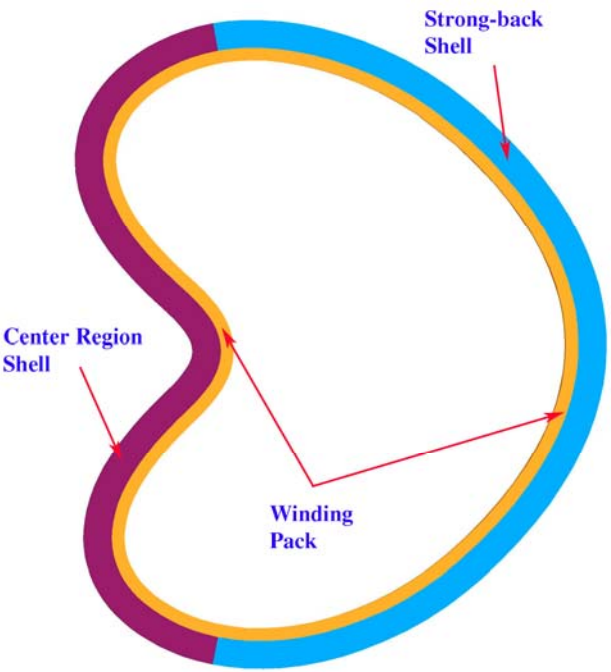
Example Displacement Vector Sum Based on the Case 1





- The displacement vector sum is about 1.56 cm for the case 1.

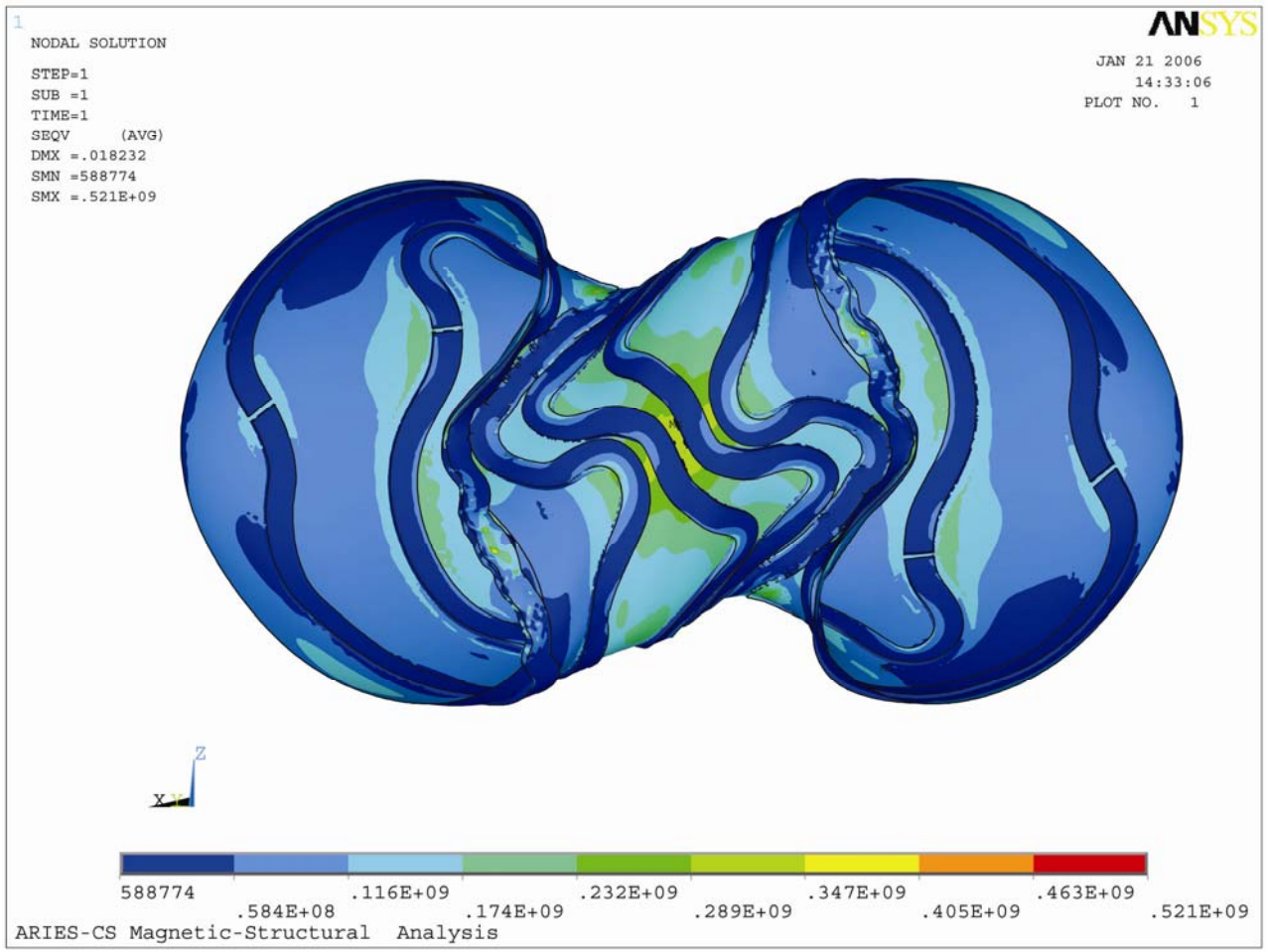
Example Results of Making Center Region Shell Thinner (Case 1)



Center region shell ~0.65 m

Strong-back shell ~0.65 m

Inter-coil shell ~0.35 m



- The displacement vector sum increases from 1.56 cm to 1.82 cm.
- The stress goes up from 492 MPa to 521 MPa.

FEA Model with Assumed Thickness for the Case 2

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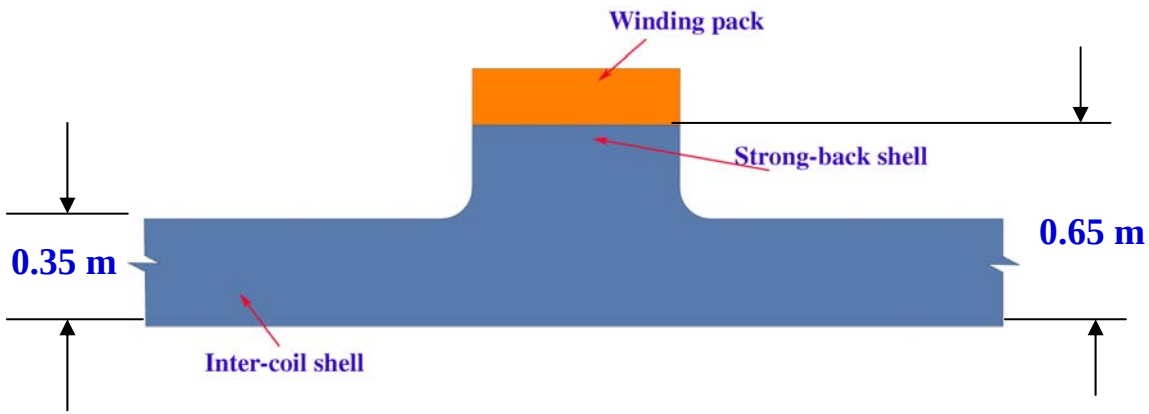
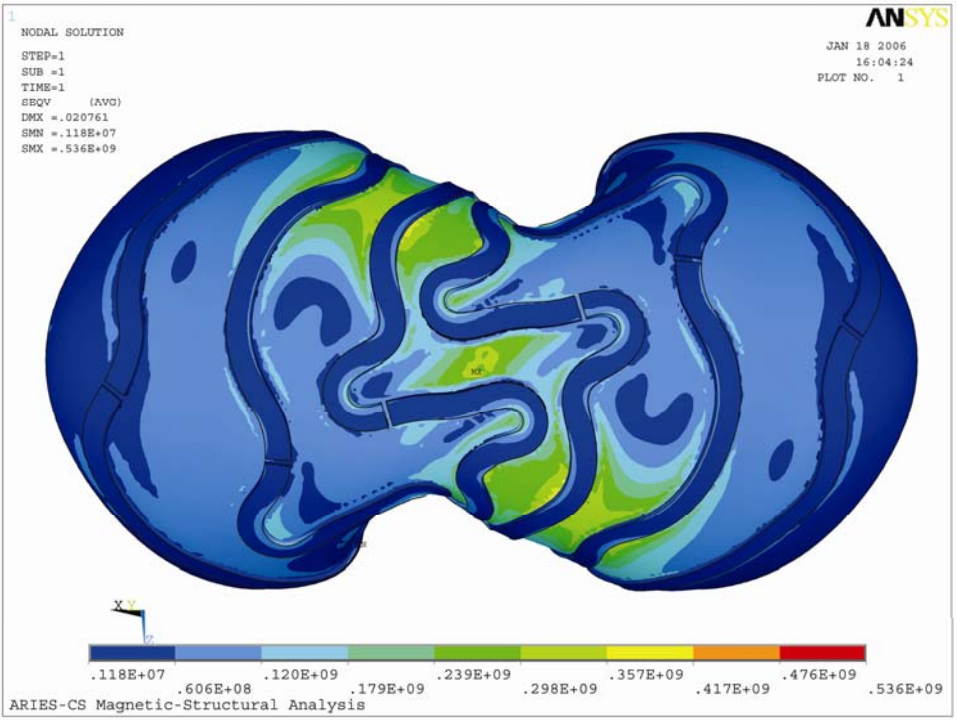
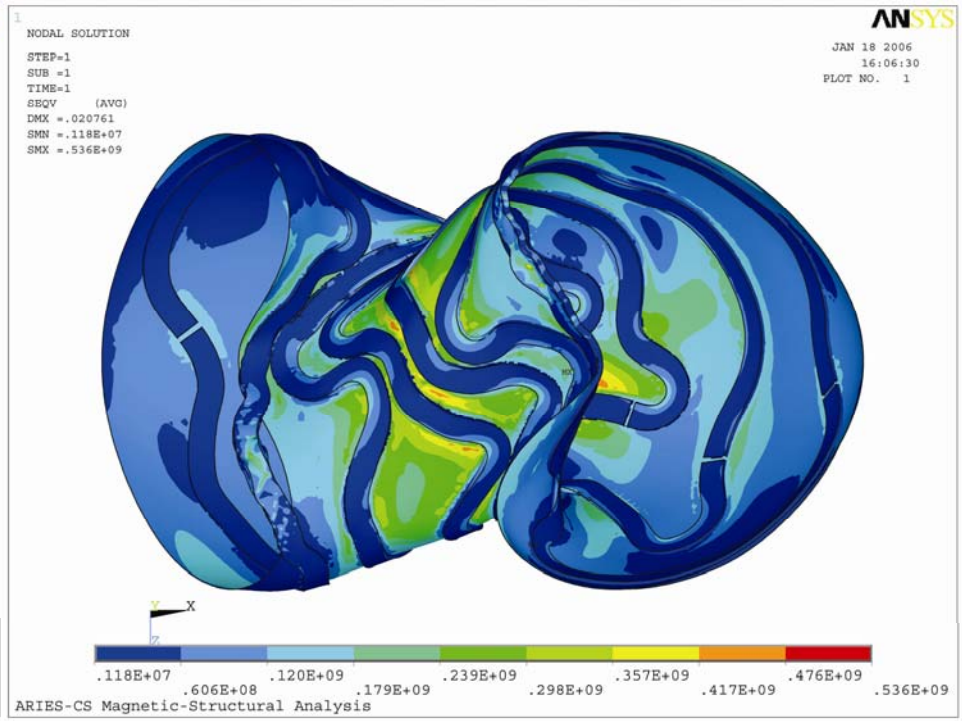
Inter-coil shell

Strong-back shell



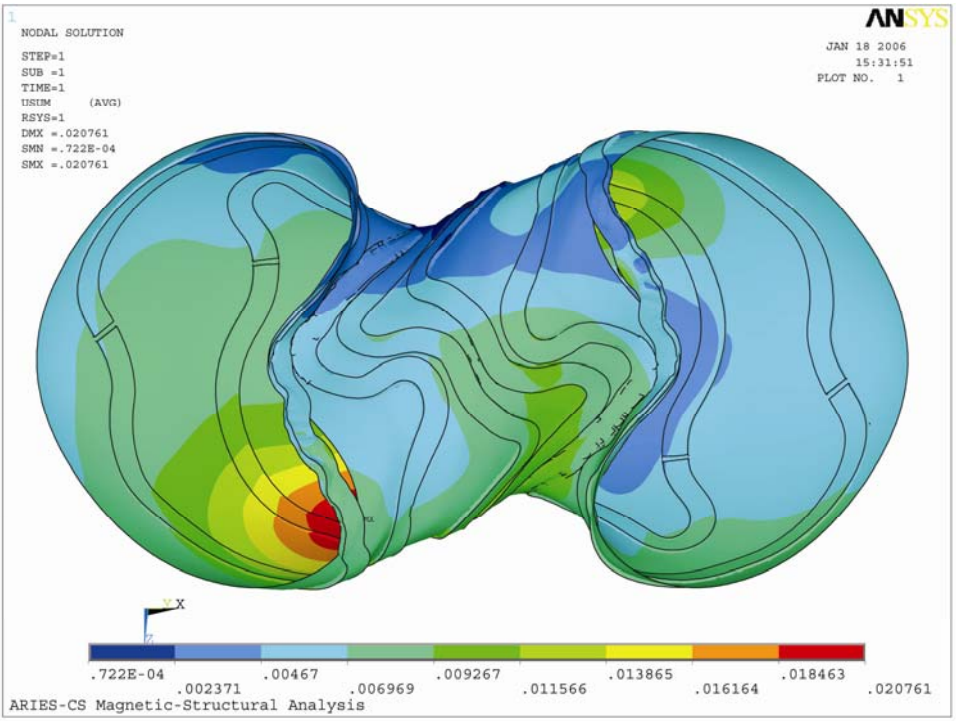
Example Stresses of the Coil Structure Based on the Case 2

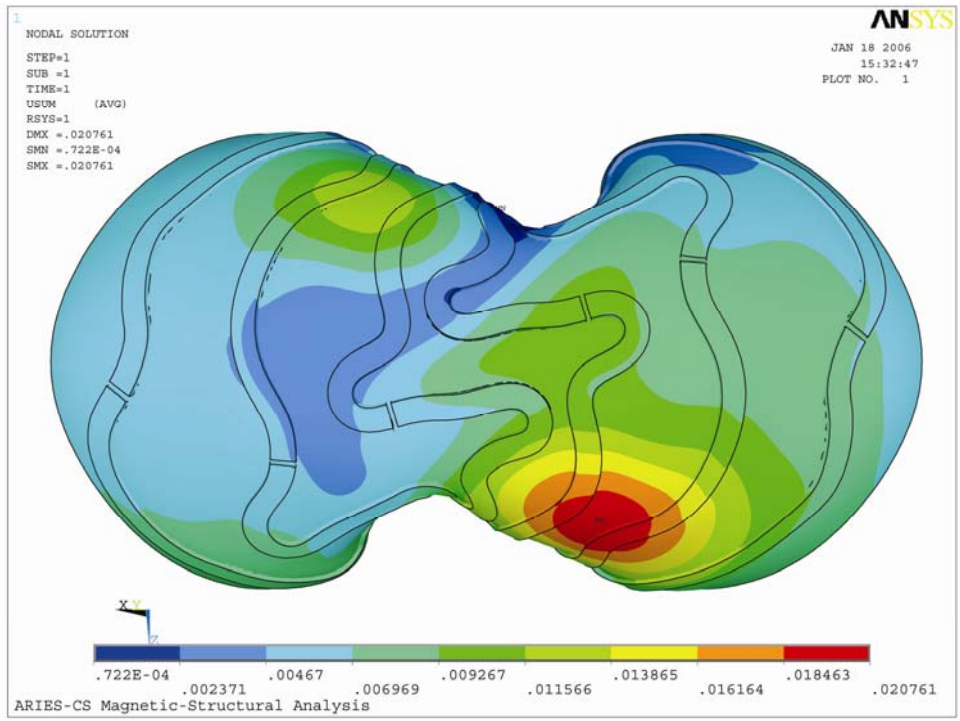




- **The maximum stress is about 536 MPa (429 MPa for the case 1).**

Example Displacement Vector Sum Based on the Case 2





- The displacement vector sum is about 2.08 cm (1.56 cm for the case 1).

Summary

- The maximum magnetic flux densities B=19.3 T 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 345 MN.

- There is no bucking cylinder required at the center of the coil supporting tube, and the supporting tubes between field periods need to be connected.

- An ANSYS solid modeling will be needed to confirm the results of shell modeling.