Design and Simulation of Nb_3Sn Accelerator Magnets at LBNL

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Acknowledgement to Dan Cheng, Paolo Ferracin, Ray Hafalia and Soren Prestemon

2D Coil Cross-section

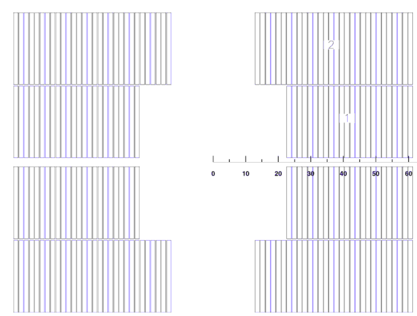
Analytical approach

Coil dimensions: Width of coil, number of layers, type of geometry

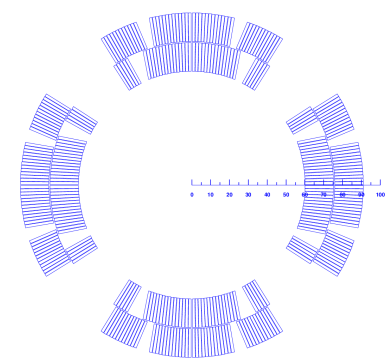
2D coil cross-section without iron or with infinite permeability

ROXIE* 2D
+
In-house program

-Modeling of the cable
- strand
- keystone angle
- insulation thickness



HD2 cross-section



LARP HQ cross-section

***R**outine for the **O**ptimization of magnet **X**-sections, **I**nverse field calculation and coil **E**nd design

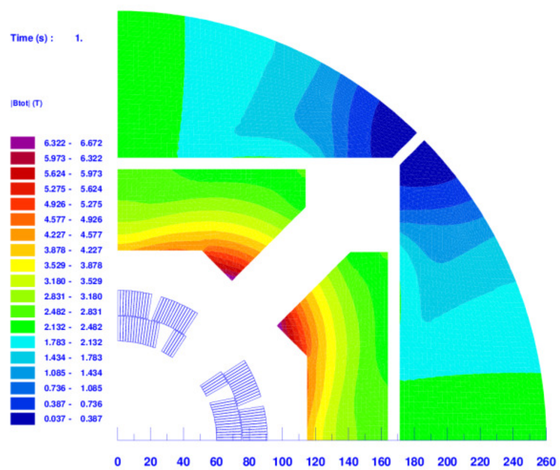
2D Modeling

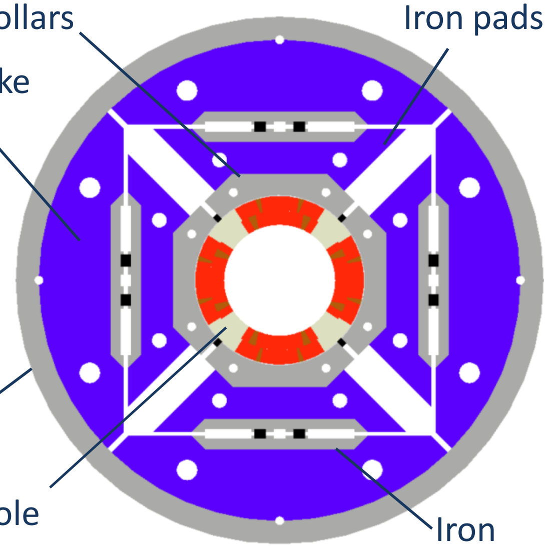
- **2D magnetic analysis (ROXIE, Opera)**

- **ANSYS 2D magnetic analysis**
  - ⇒ Lorentz forces

-**ANSYS 2D Mechanical analysis**
  - ⇒ Frictionless
  - ⇒ Friction

-**Iterations**
- Coil cross-section: mechanical magnetic coupling
- iron saturation





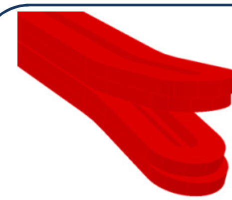
3D coil-end design and end parts design

BEND

- Input: 2D cross-section
- Design of the pole piece
- Design of the metallic end-parts

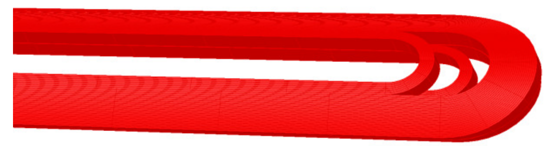
⟷

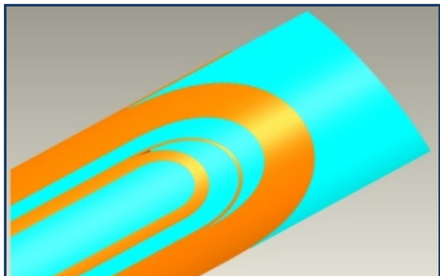
Opera 3D



Block design

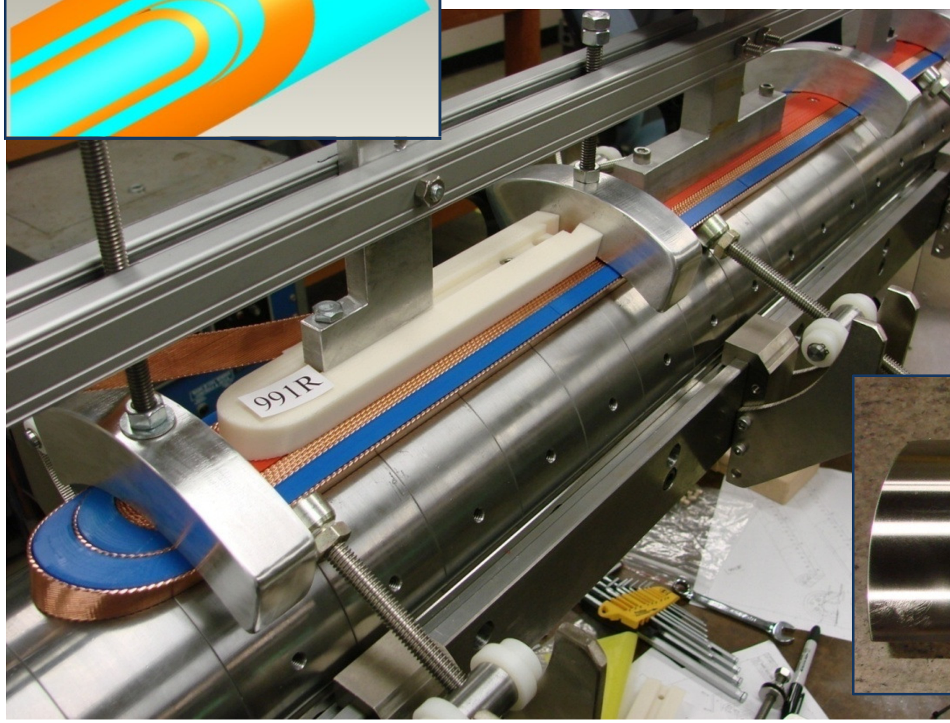
Cos3θ design





CAD

Rapid Prototyping parts



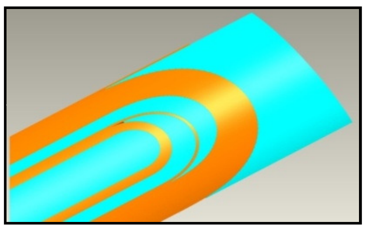
Pole and End parts fabrication

3D Coil Modeling: Cos nθ magnets

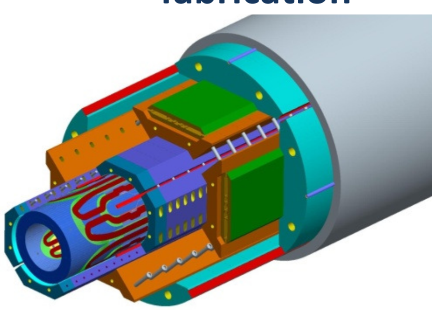
BEND

Turn by turn coil model
Block model

CAD

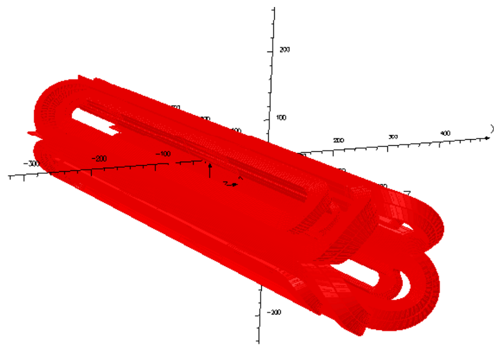


End parts and island fabrication



Turn by turn coil model
Refined coil model

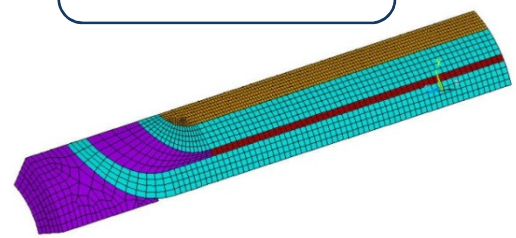
VF Opera 3D

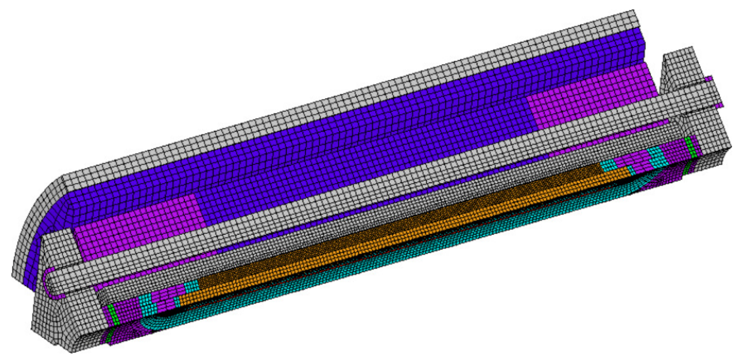


End optimization and peak field management (length of yoke)

Block coil model

ANSYS 3D





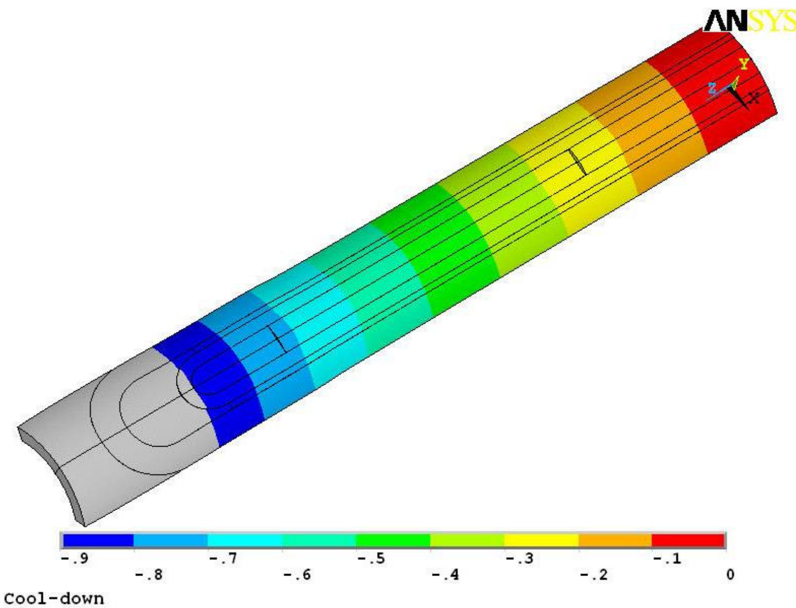
3D Mechanical Analysis

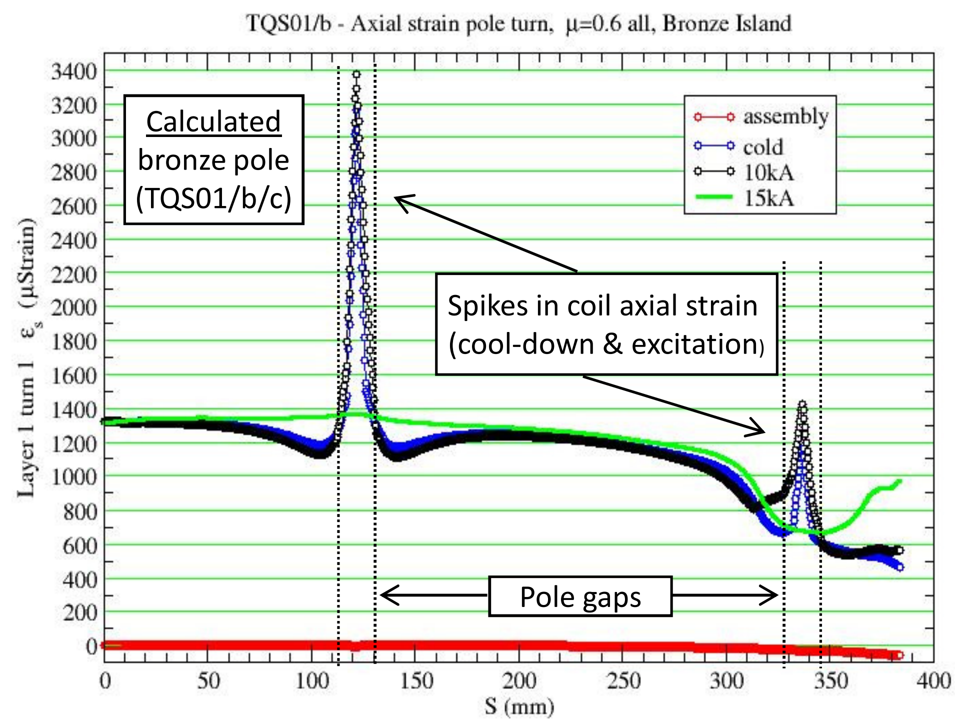
3D Mechanical Analysis, a tool…

To design

To understand magnet performances…

Case of a quadrupole with bronze pole
For fabrication reasons => gaps in pole





After cool-down, pole and coil in tension
⇒ Gap opening
⇒ High tension in the coil
⇒ correlation with quench location during magnet test

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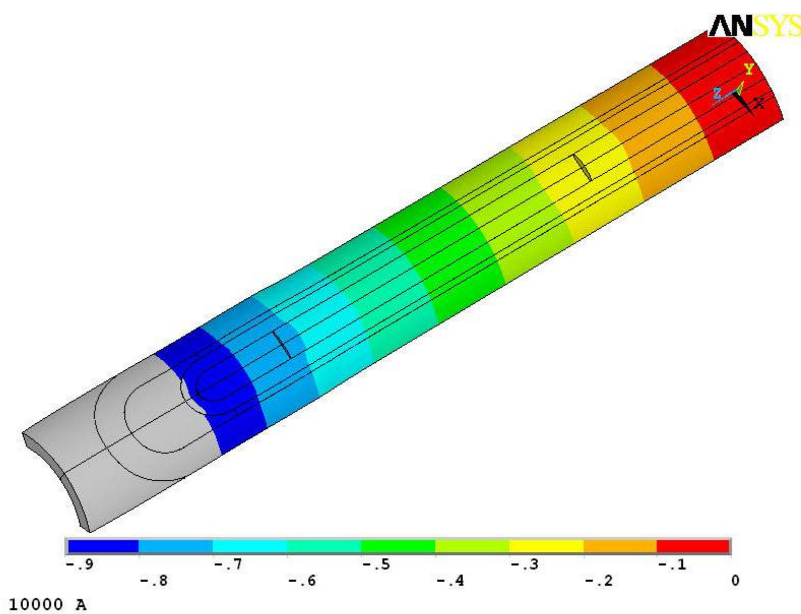

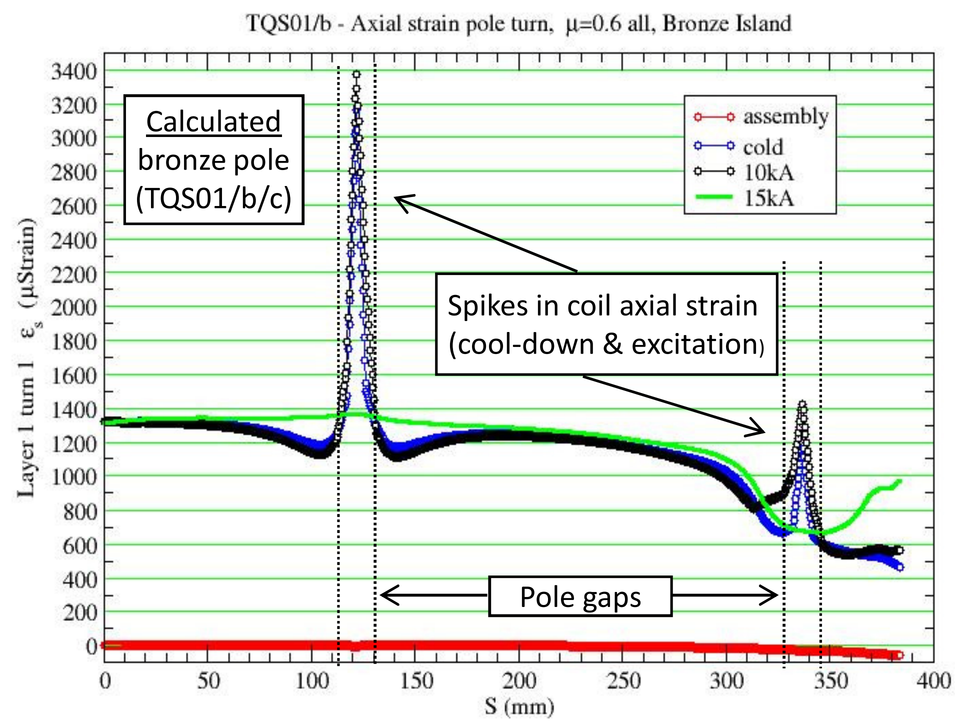

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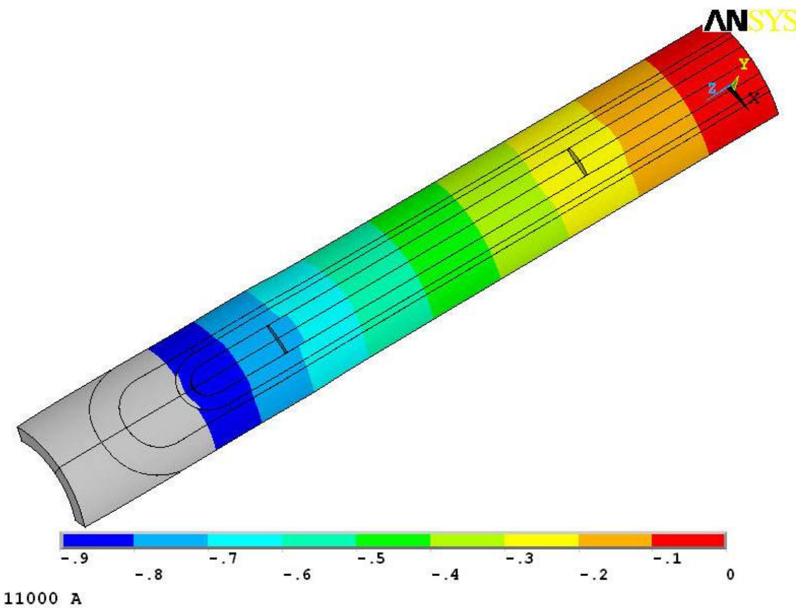

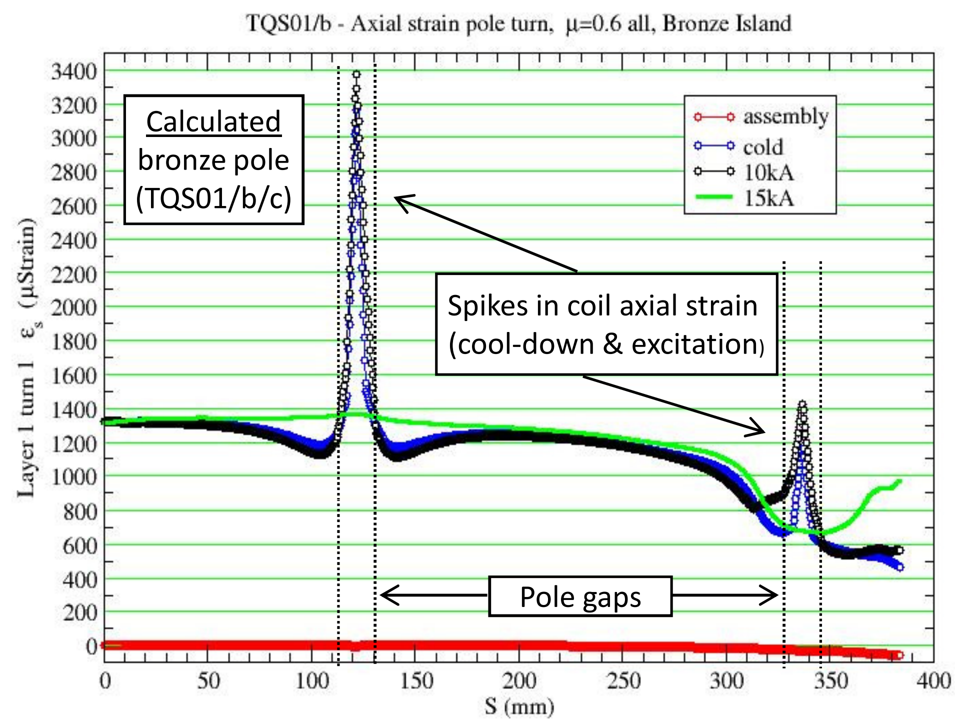

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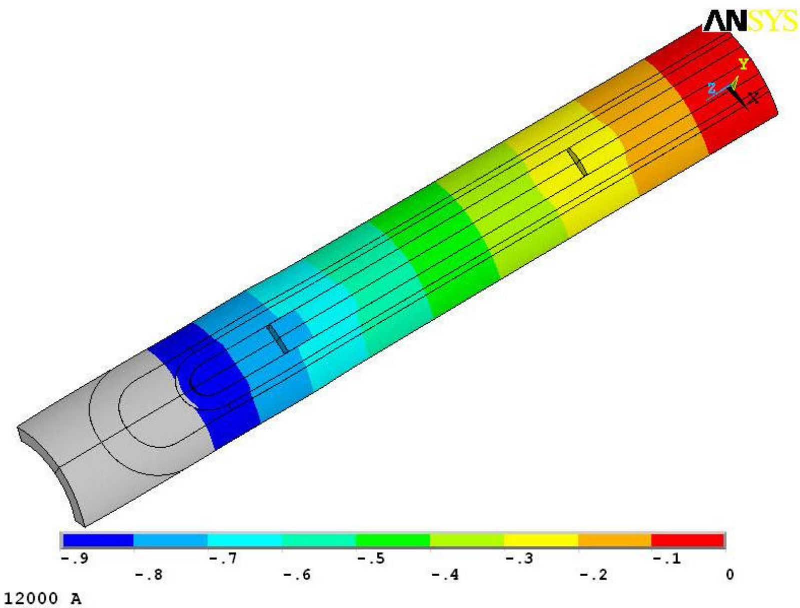

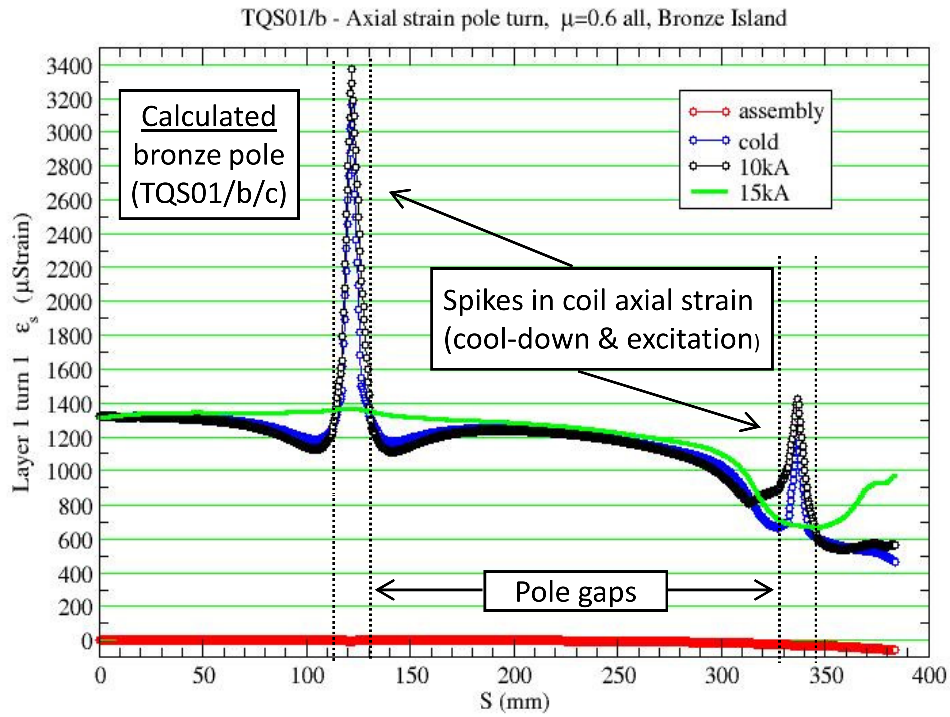

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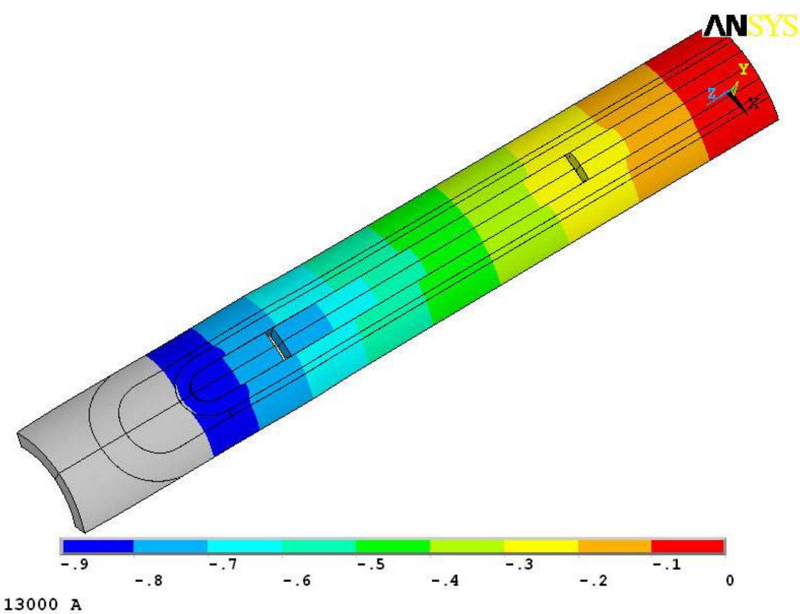

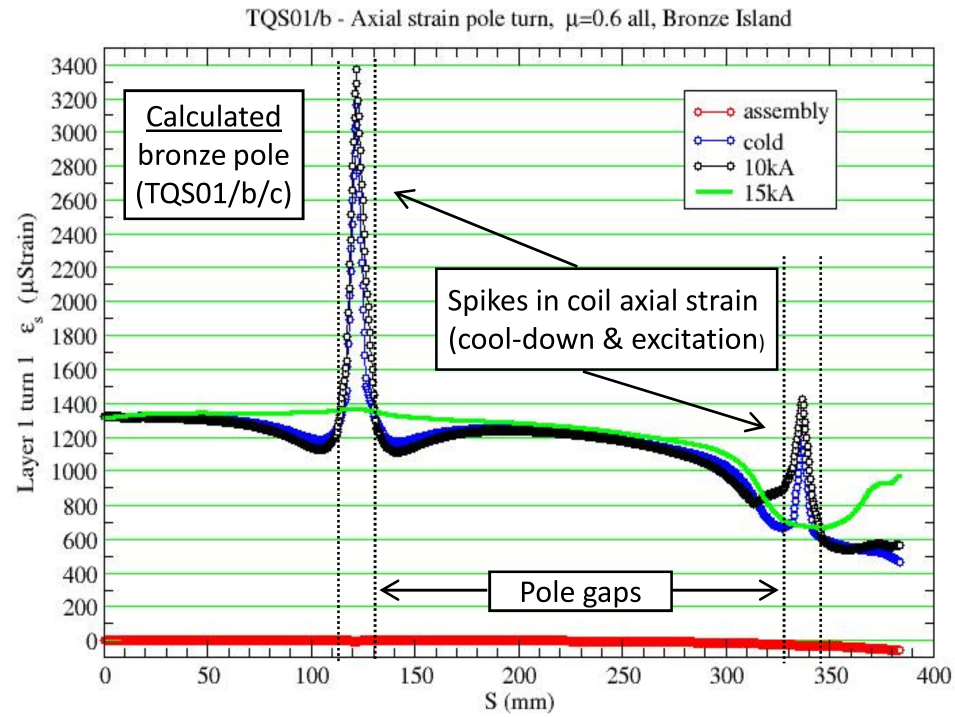

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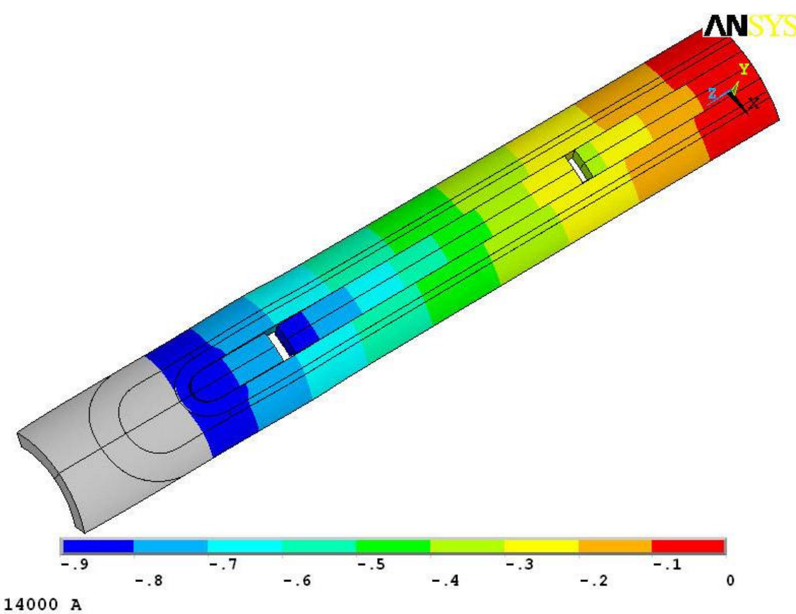

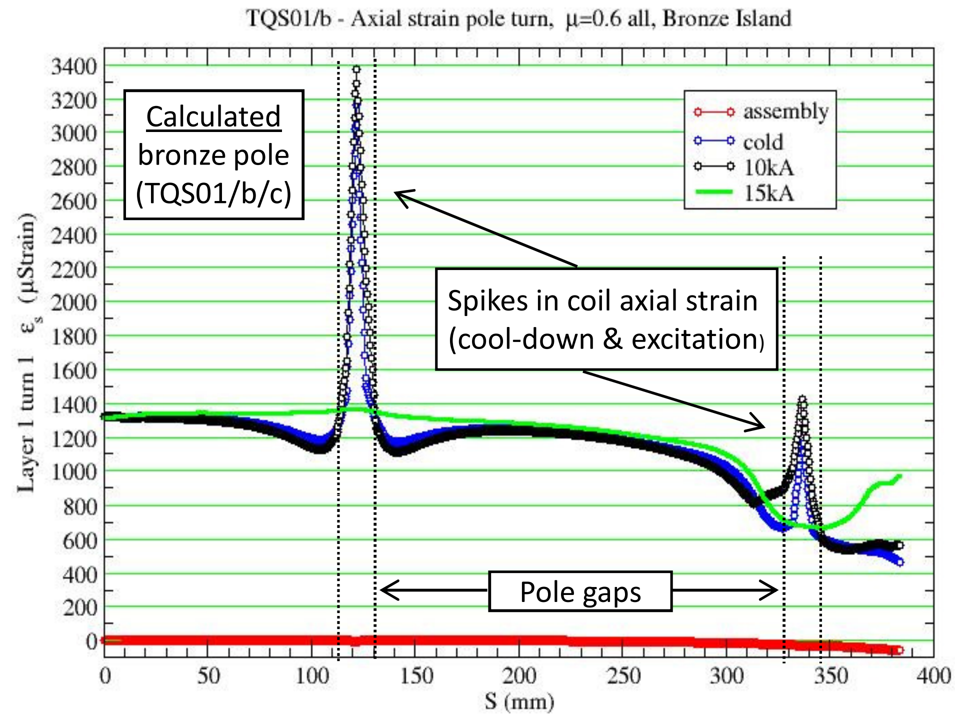

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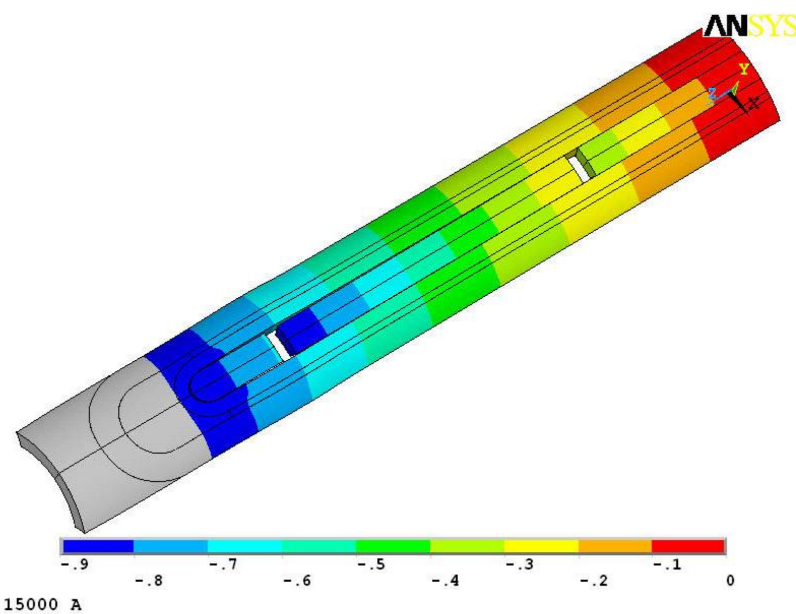

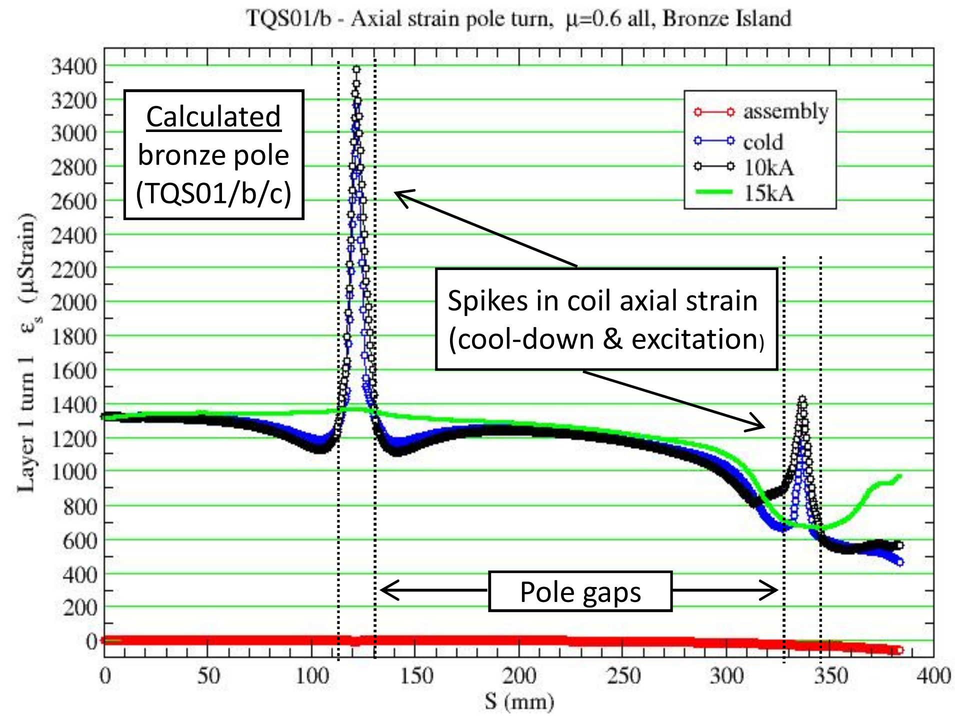

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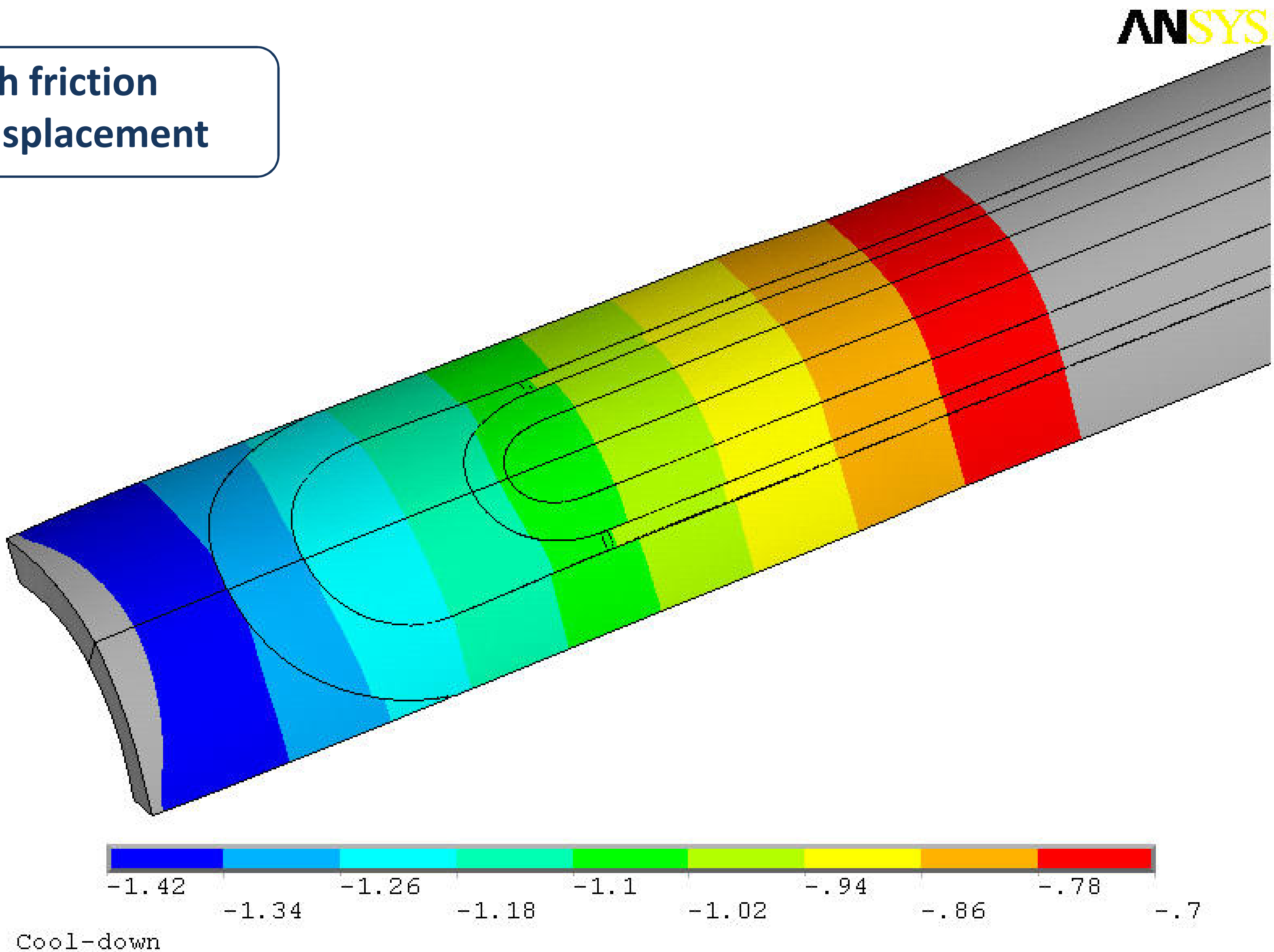
Situation in the end

With friction
Pole displacement



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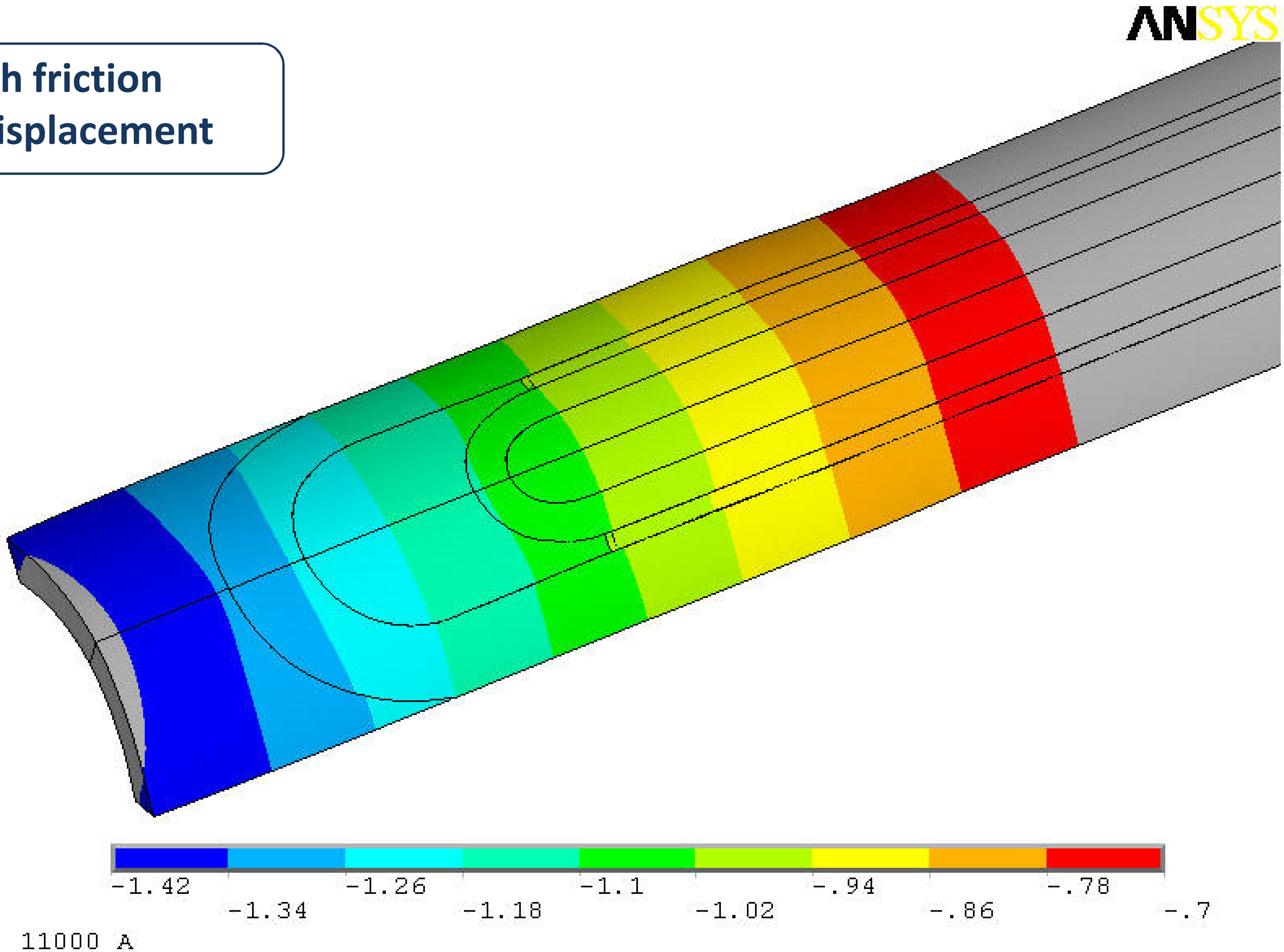

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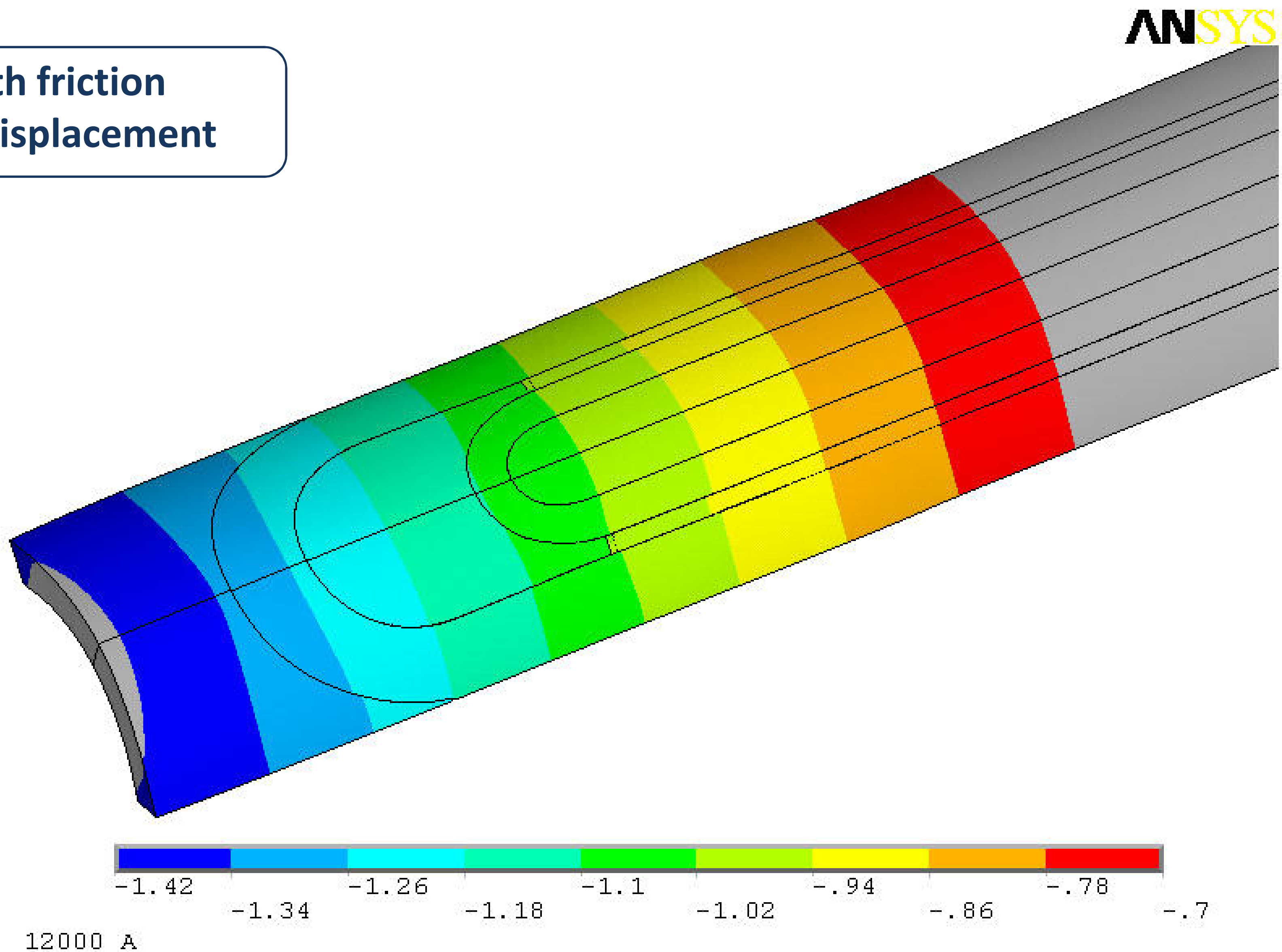

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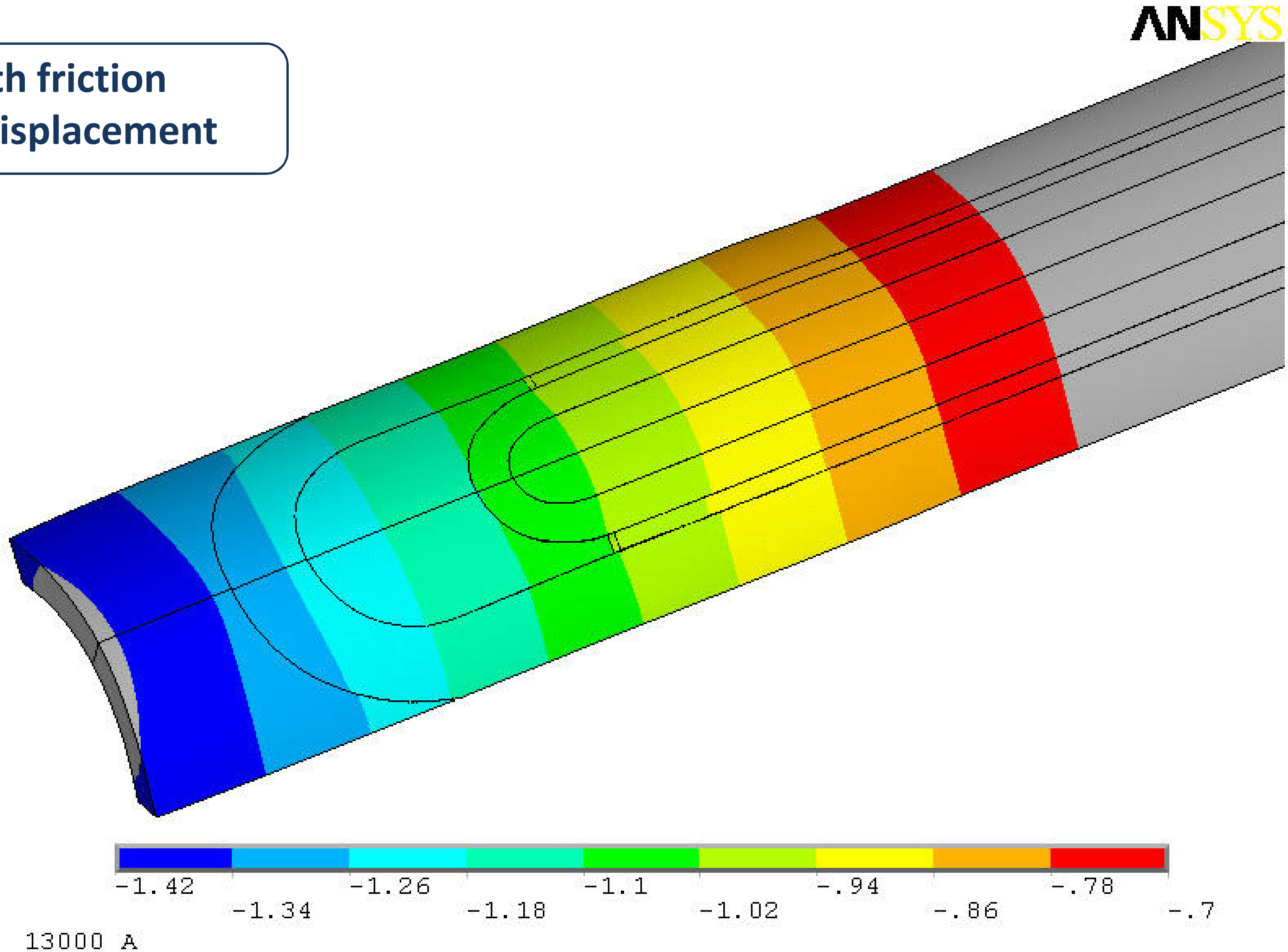

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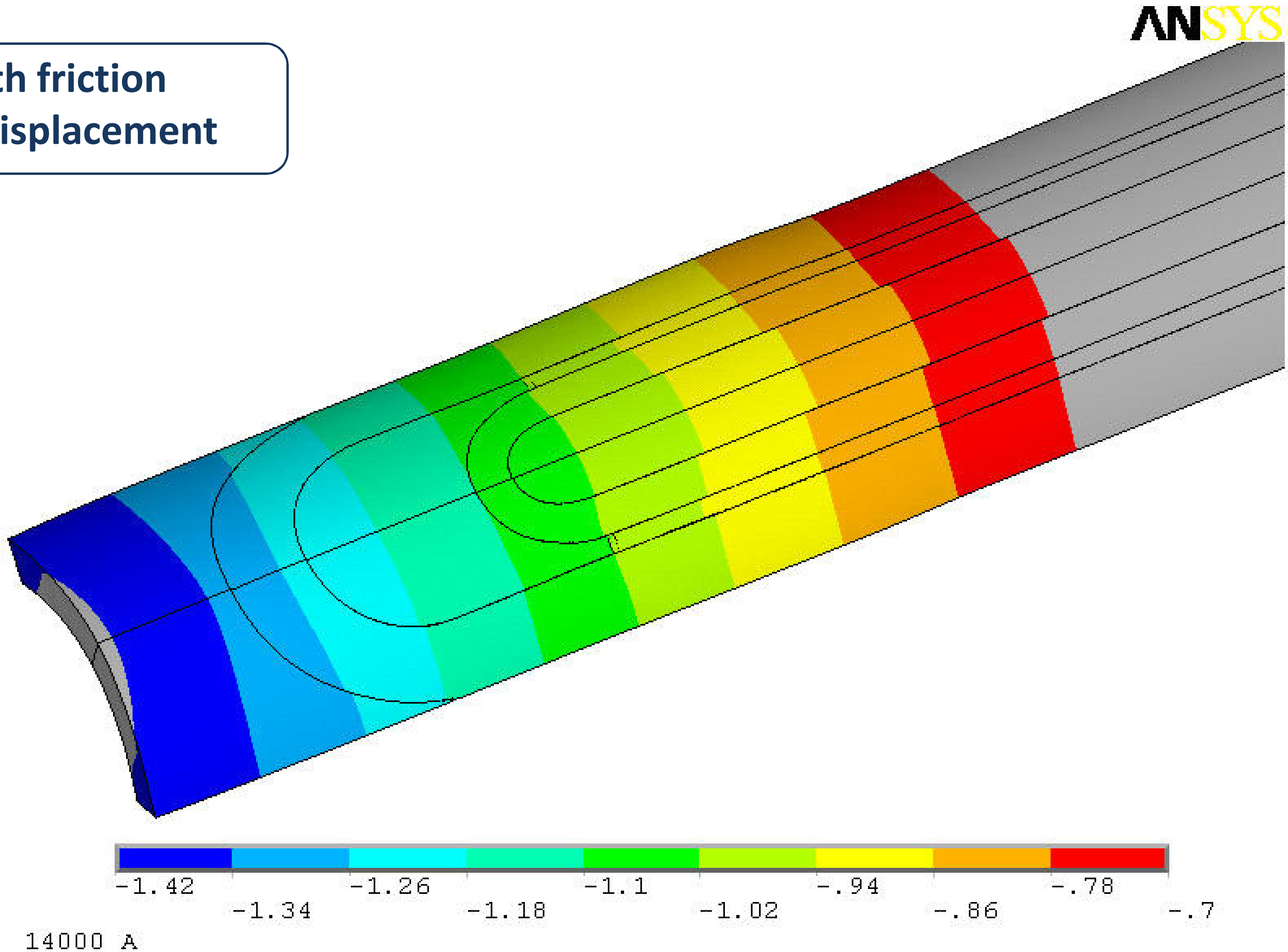

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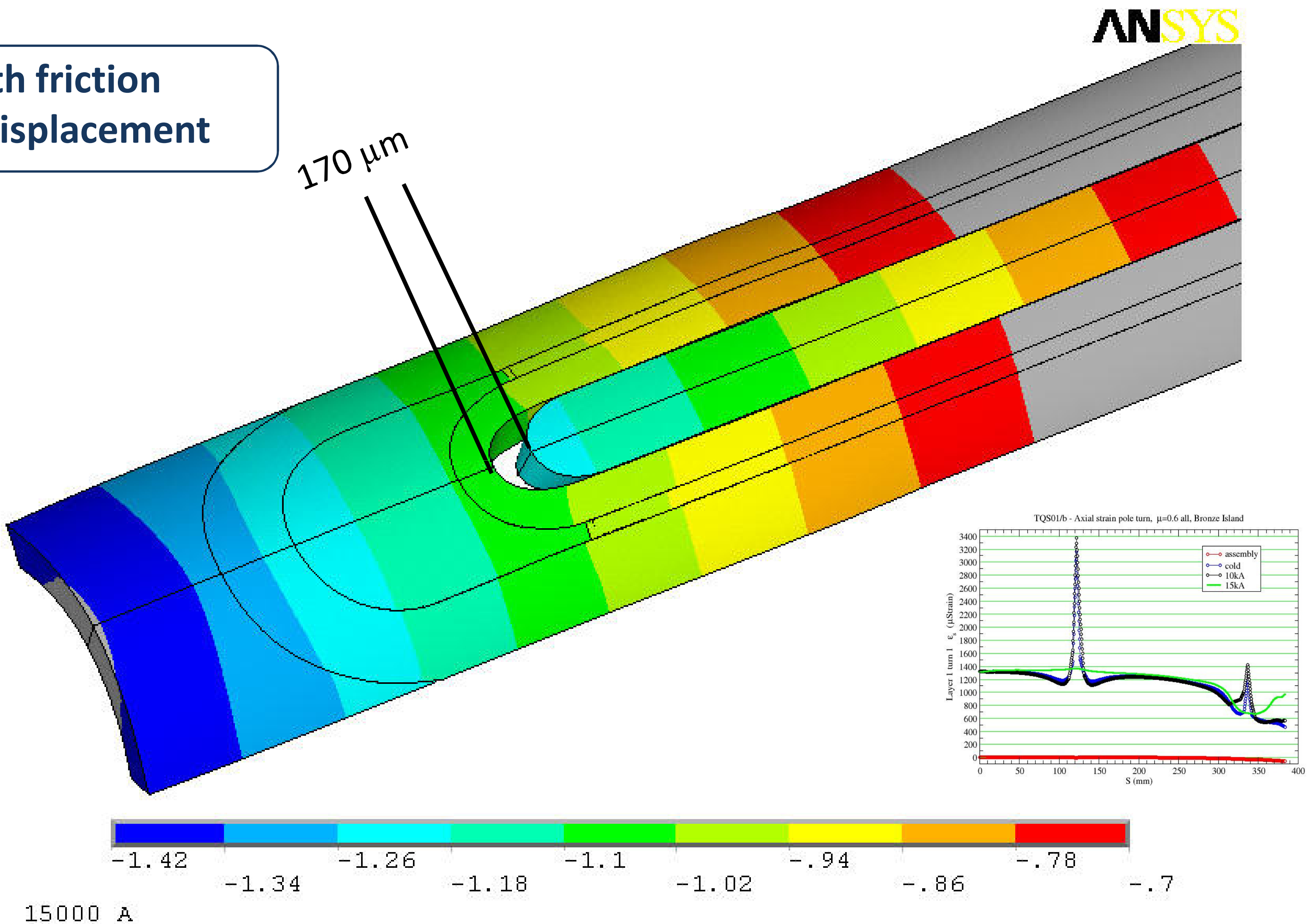


3D Mechanical Analysis, a tool…

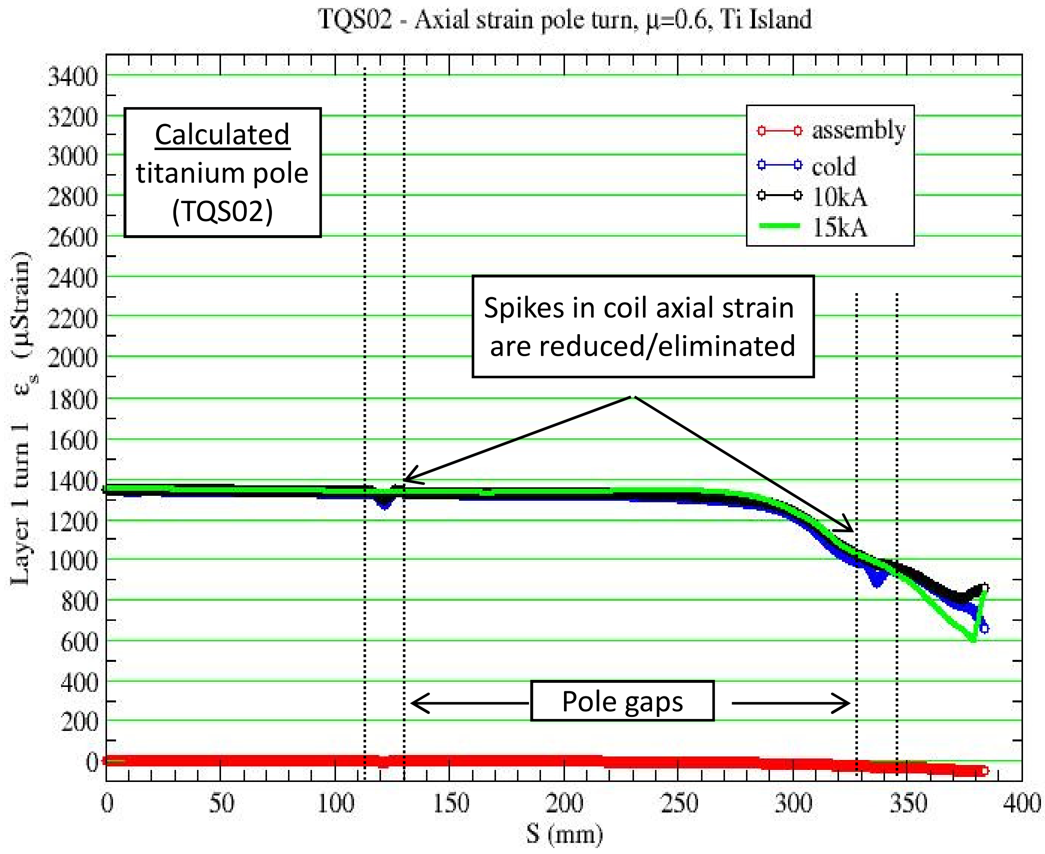
… and improve magnet design / coil fabrication

Choice of Titanium pole

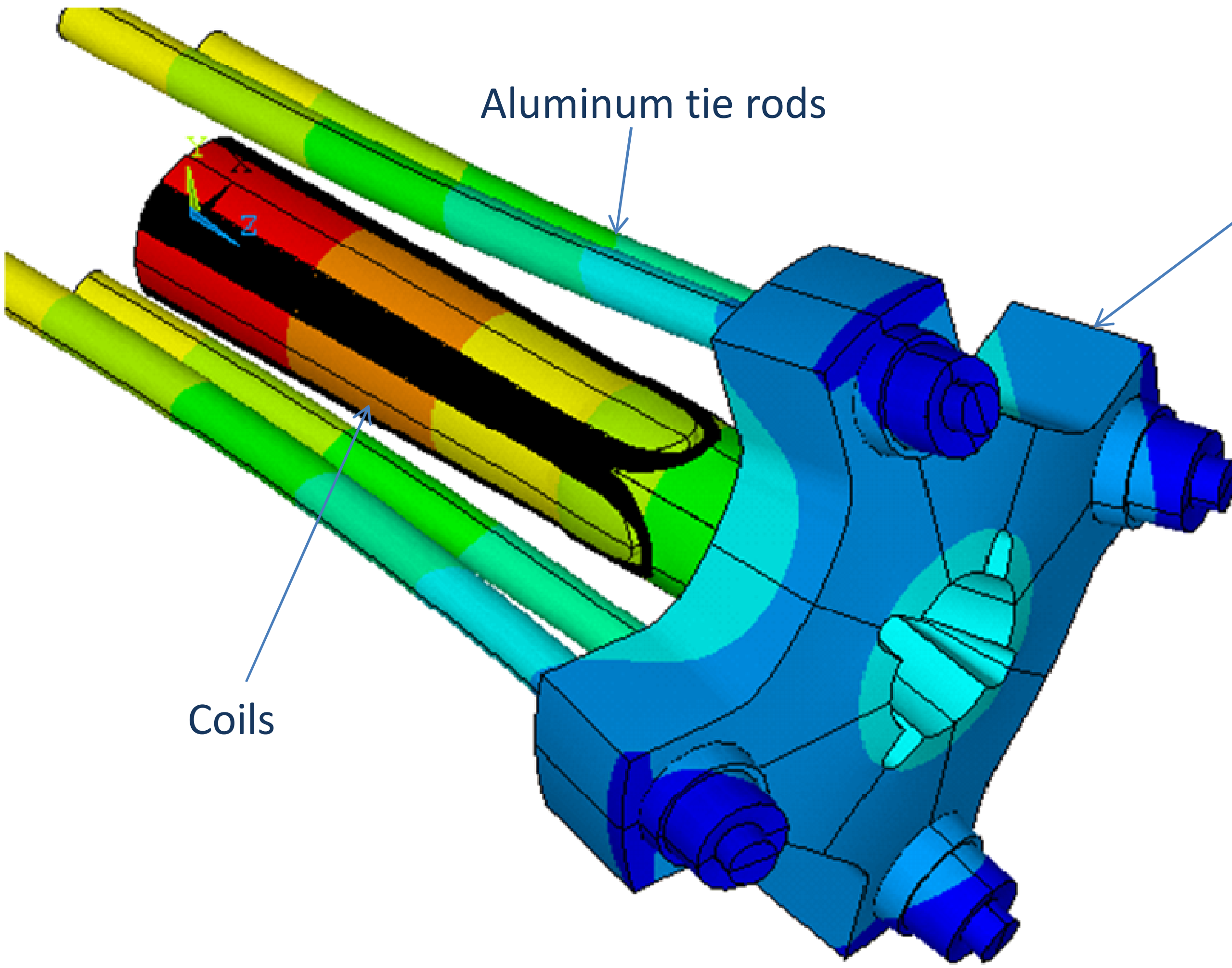
⇒ pole in compression

⇒ eliminate stress concentration at the pole cut

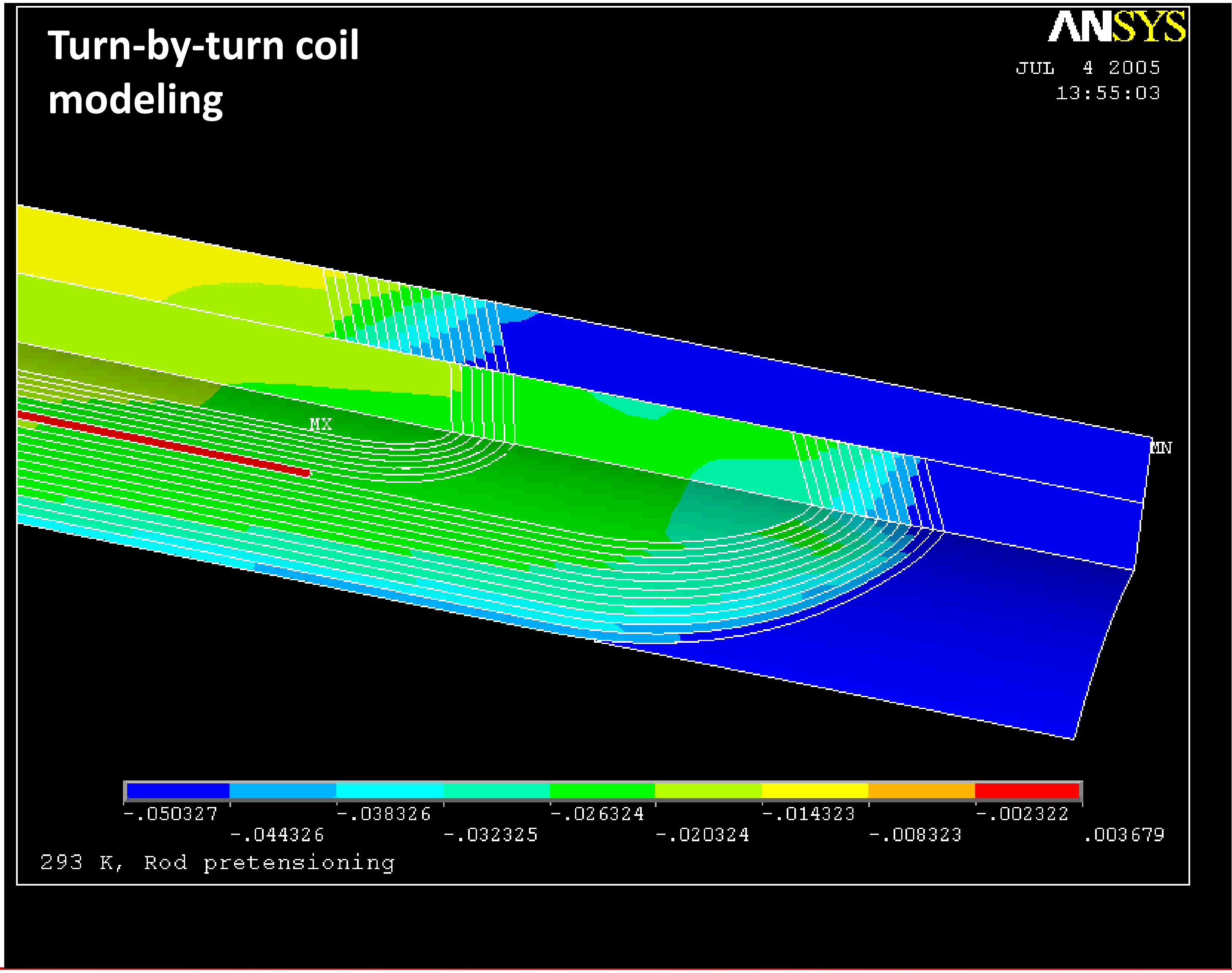
⇒ improvement of the coil fabrication (no need of gap)



Choice of the axial loading



No friction, low axial loading



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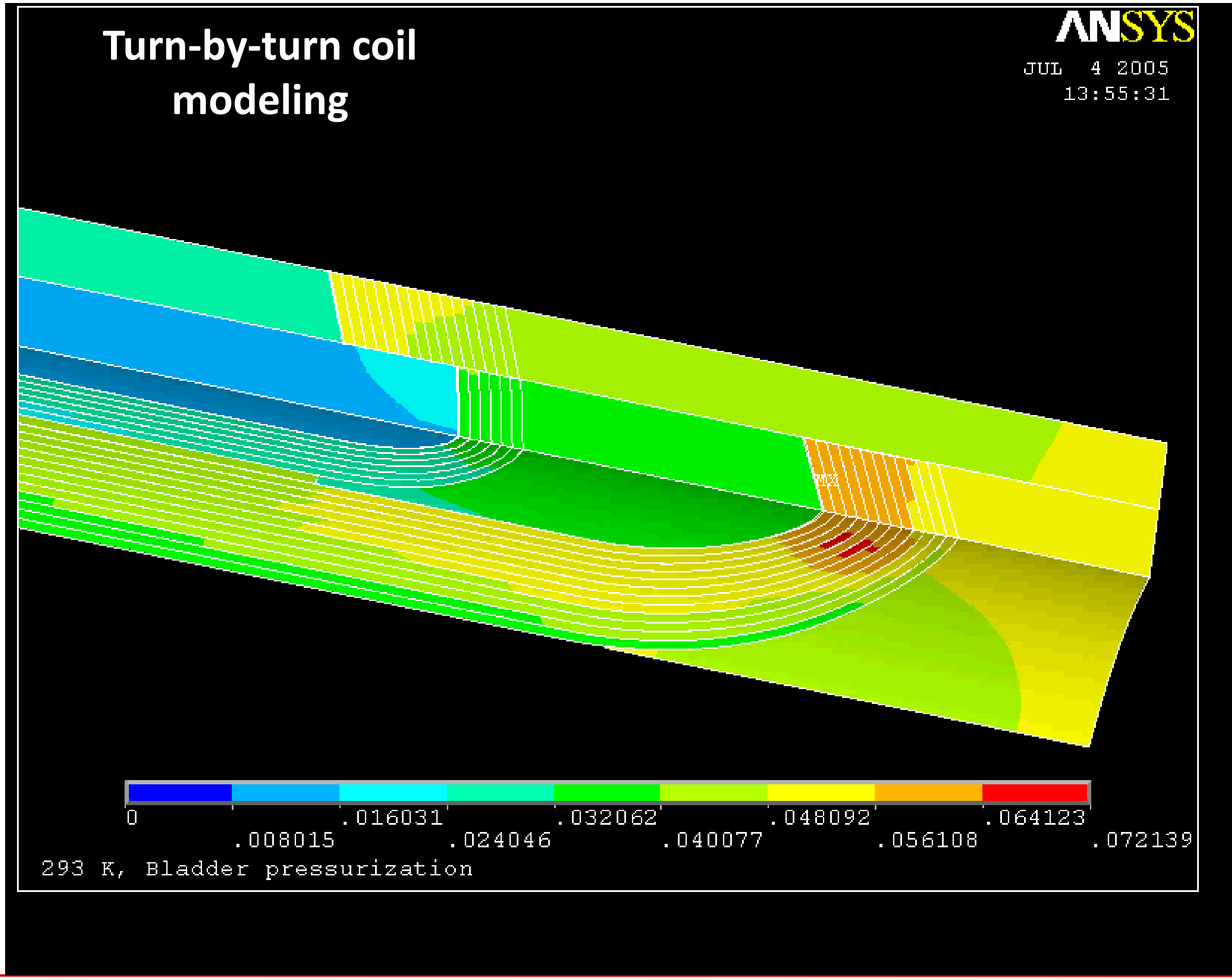

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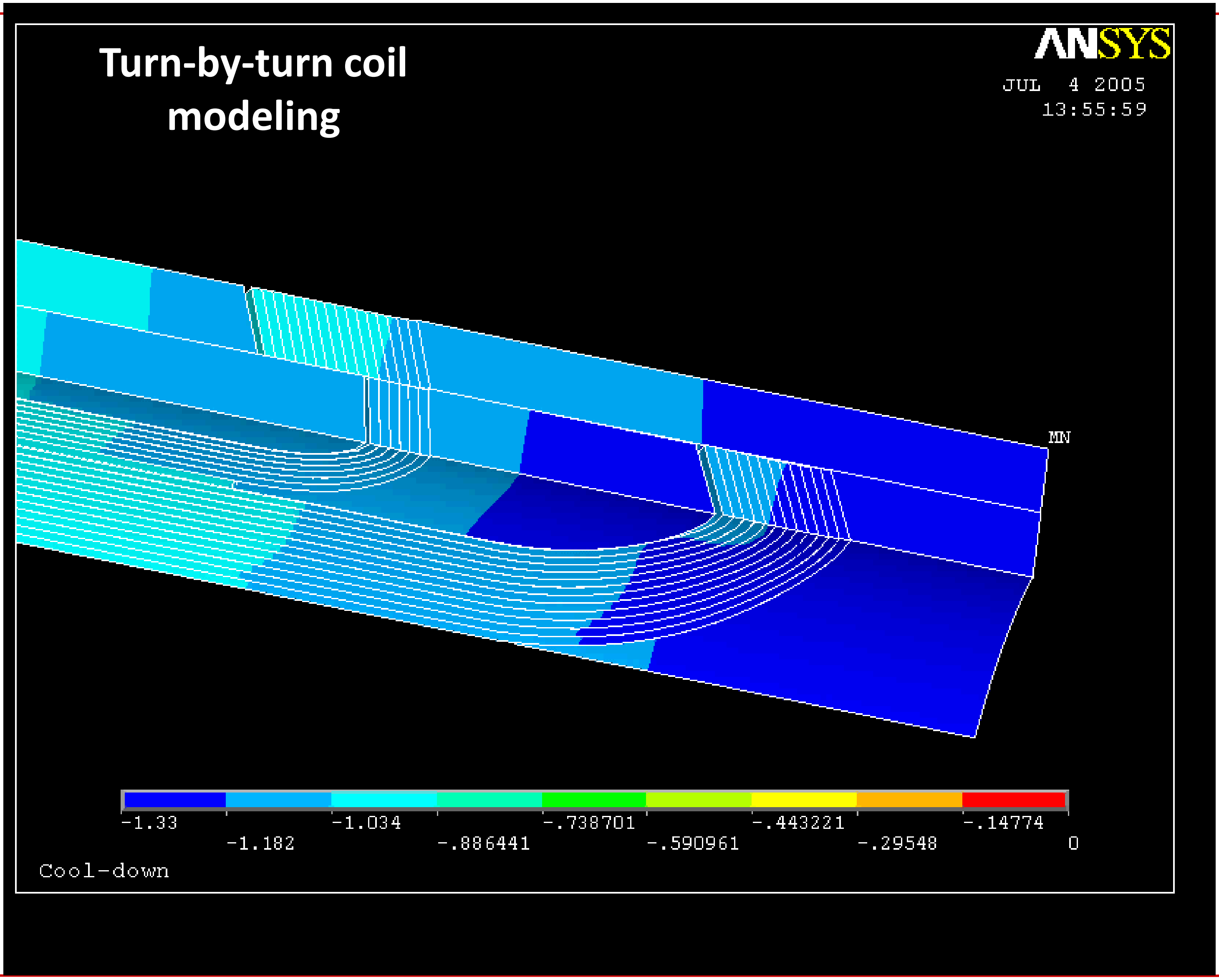

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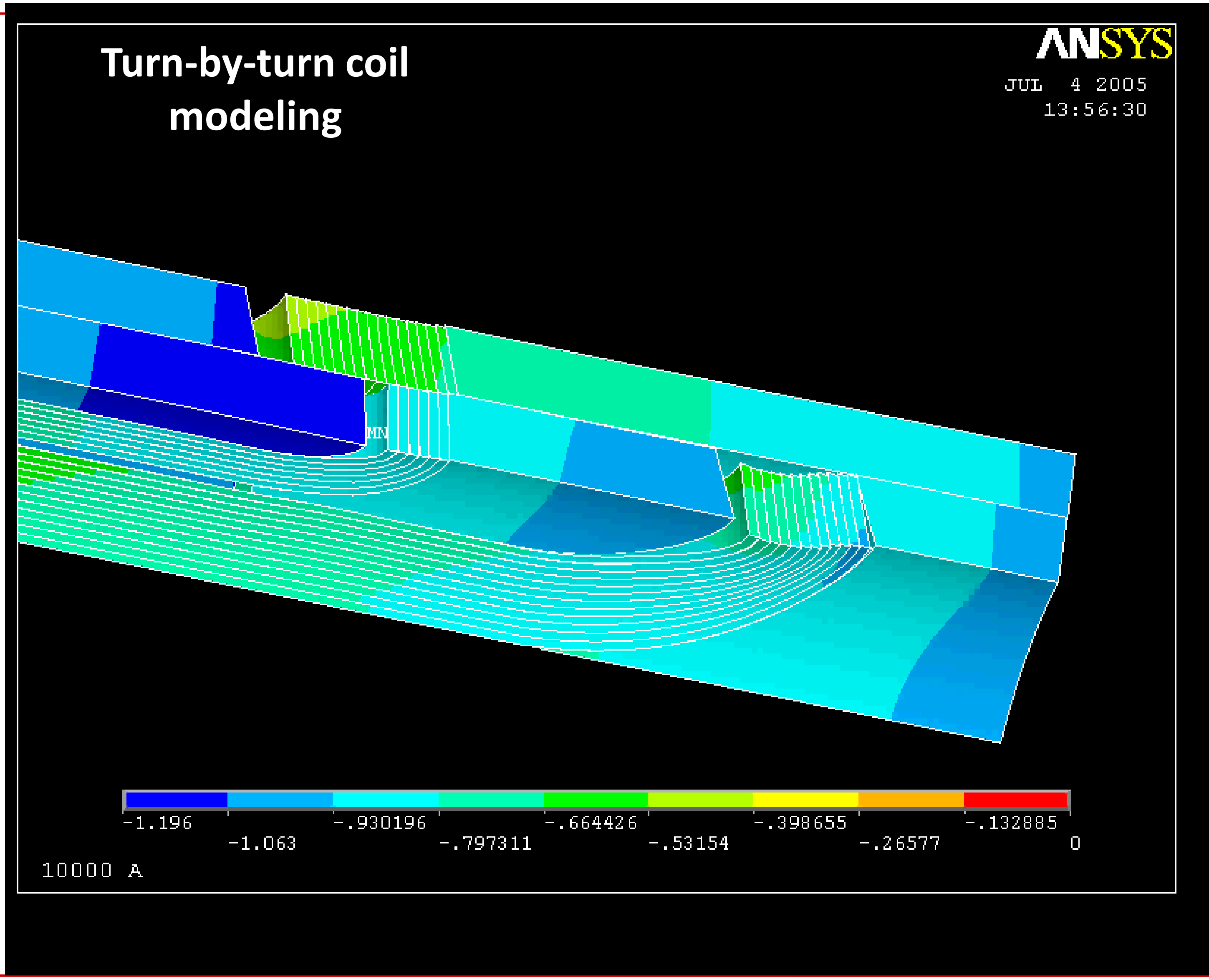

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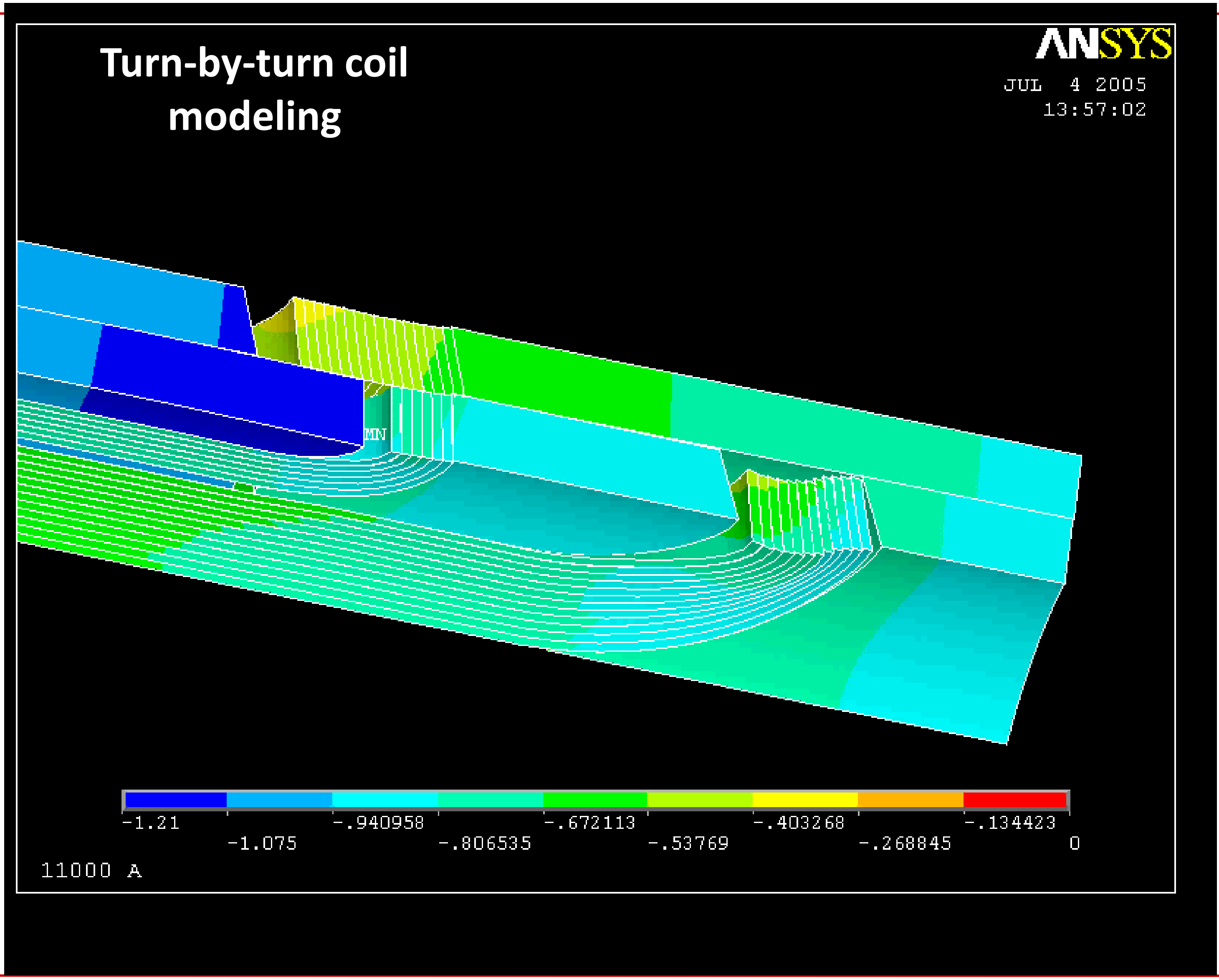

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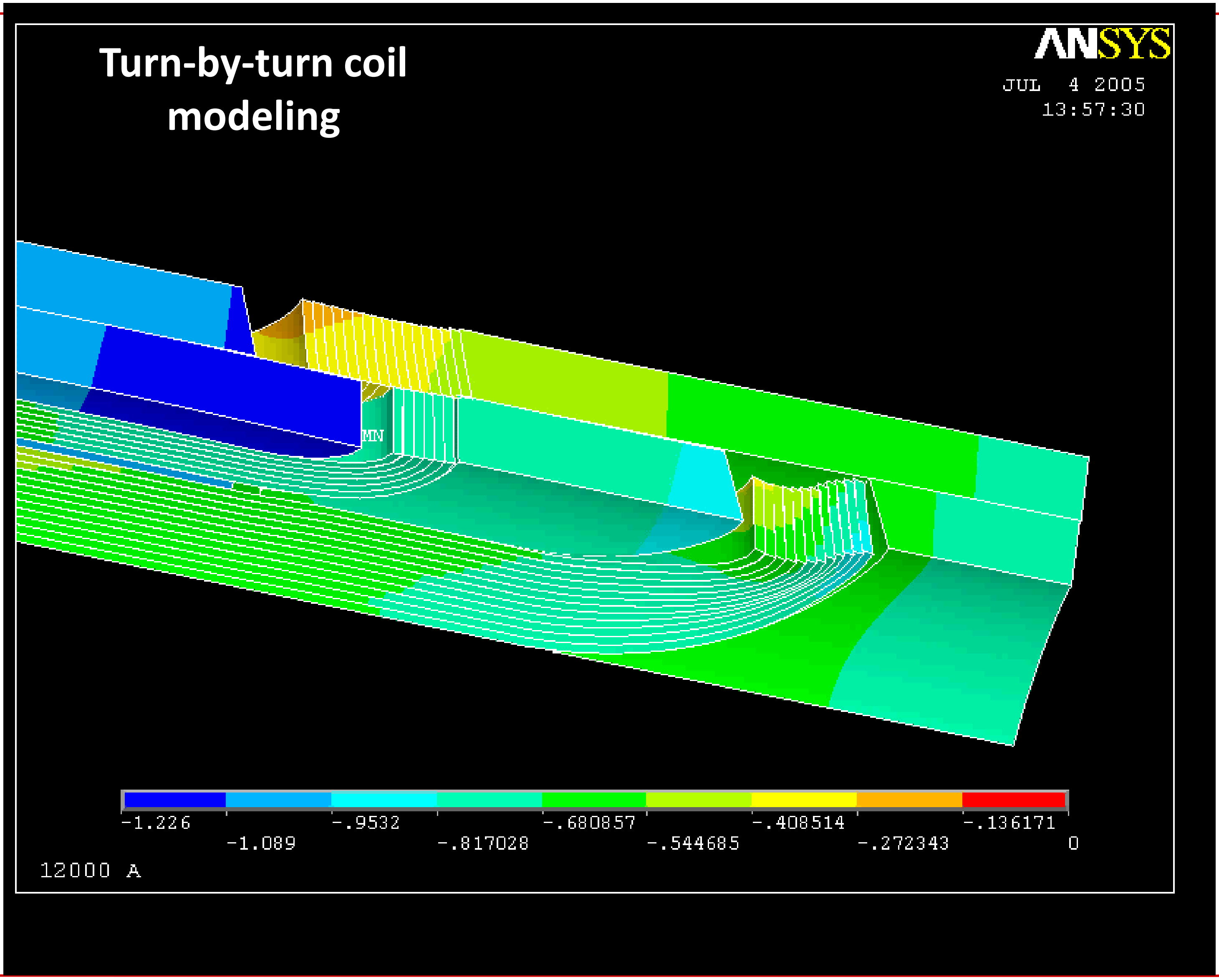

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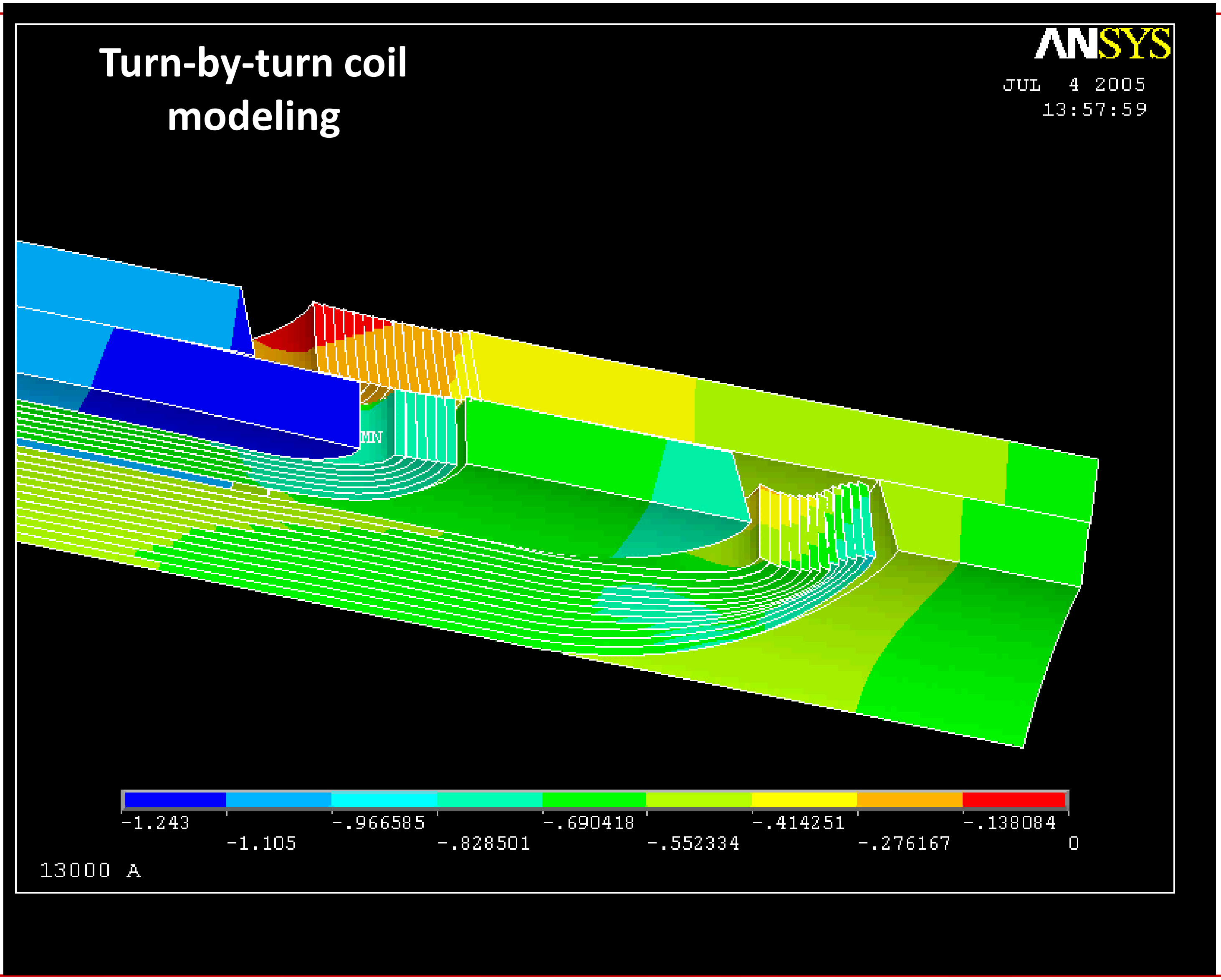

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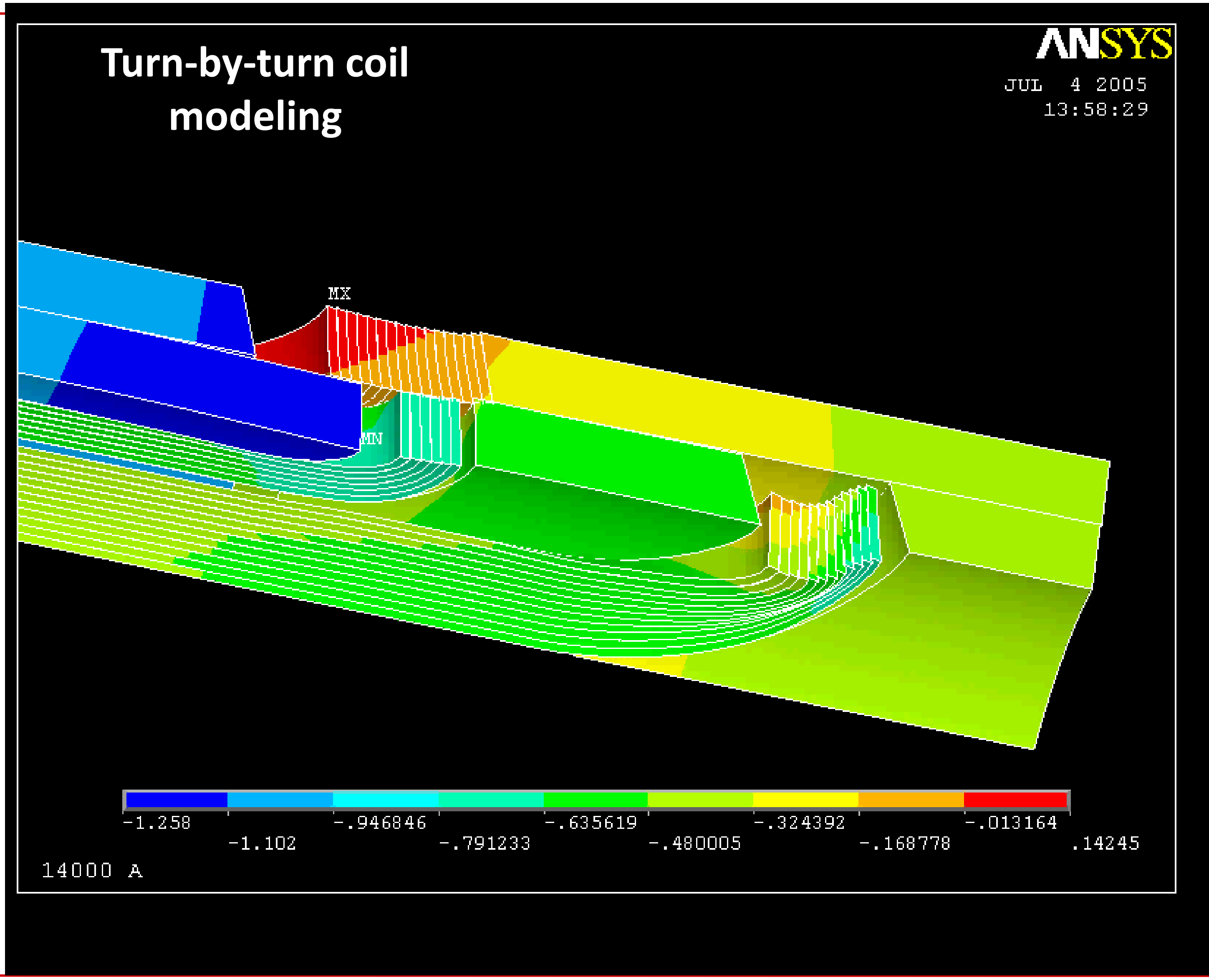

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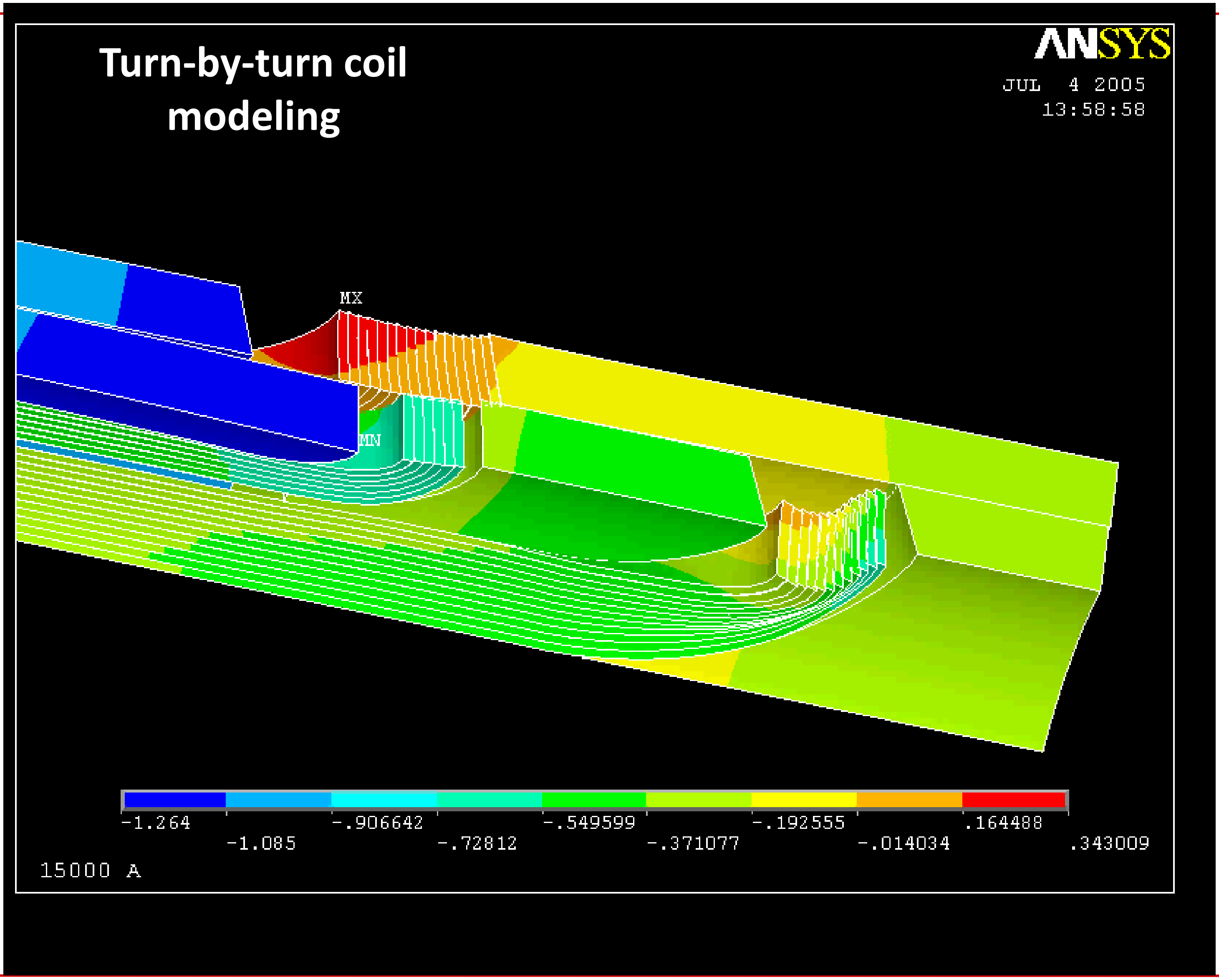
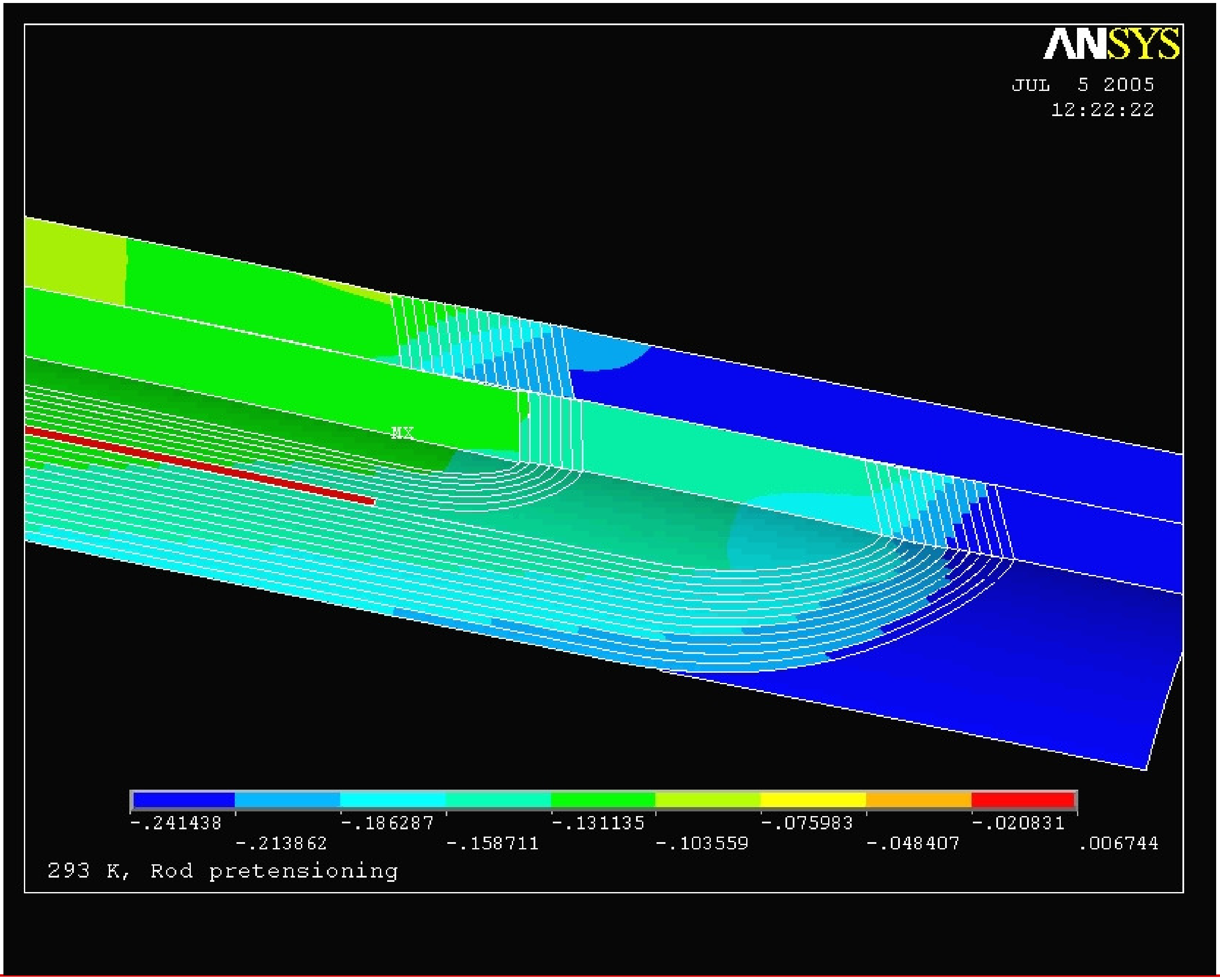


No friction, full axial support



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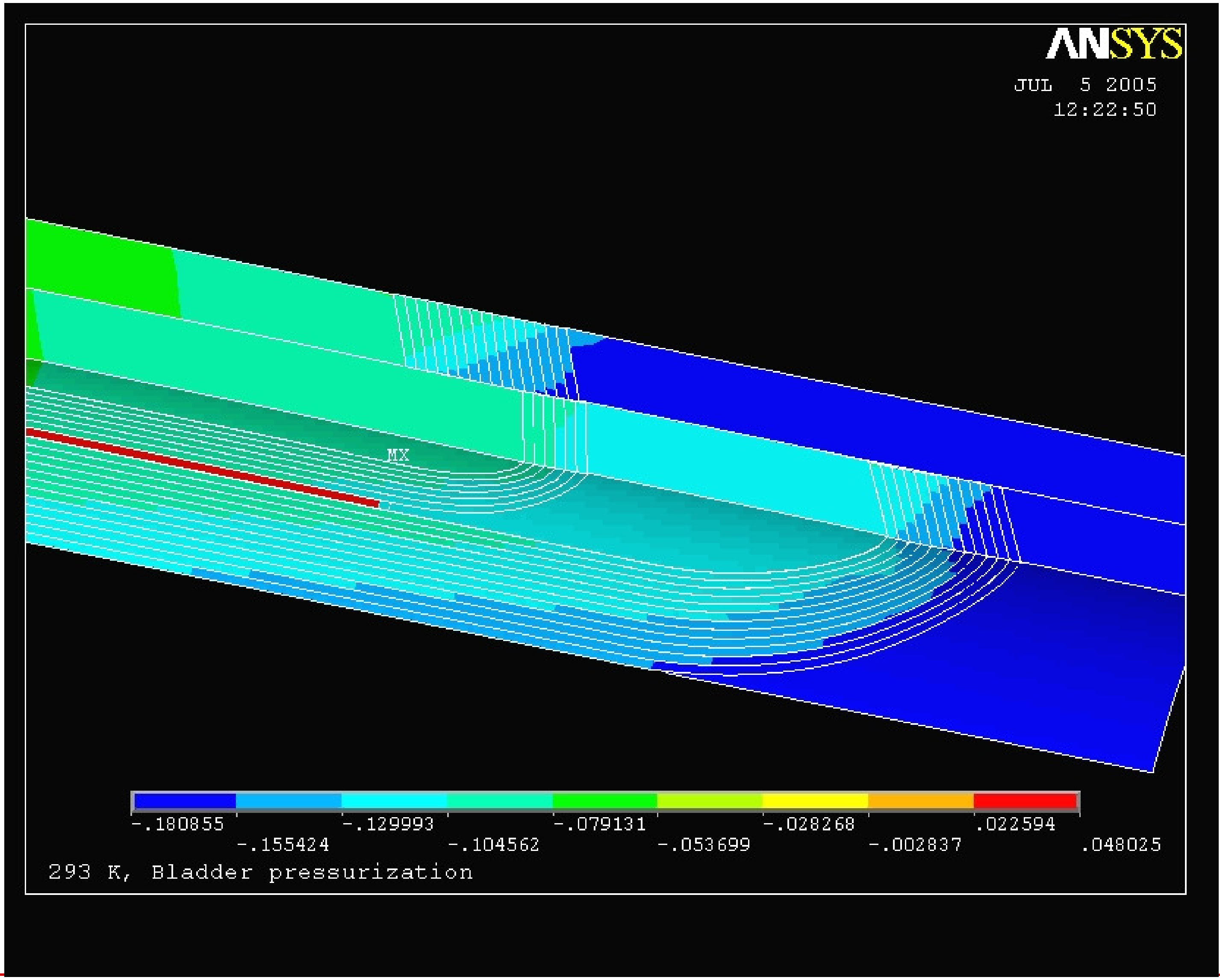

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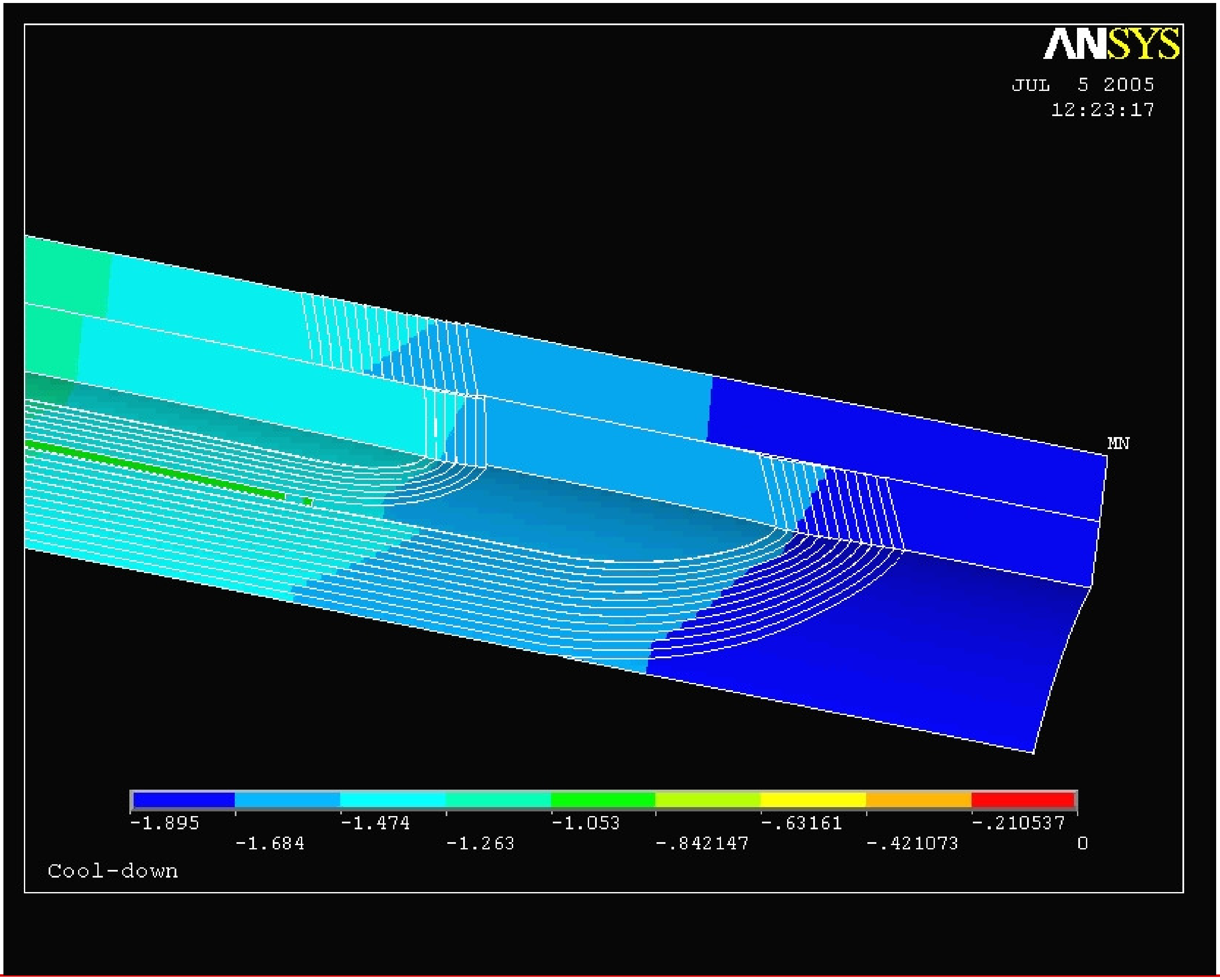

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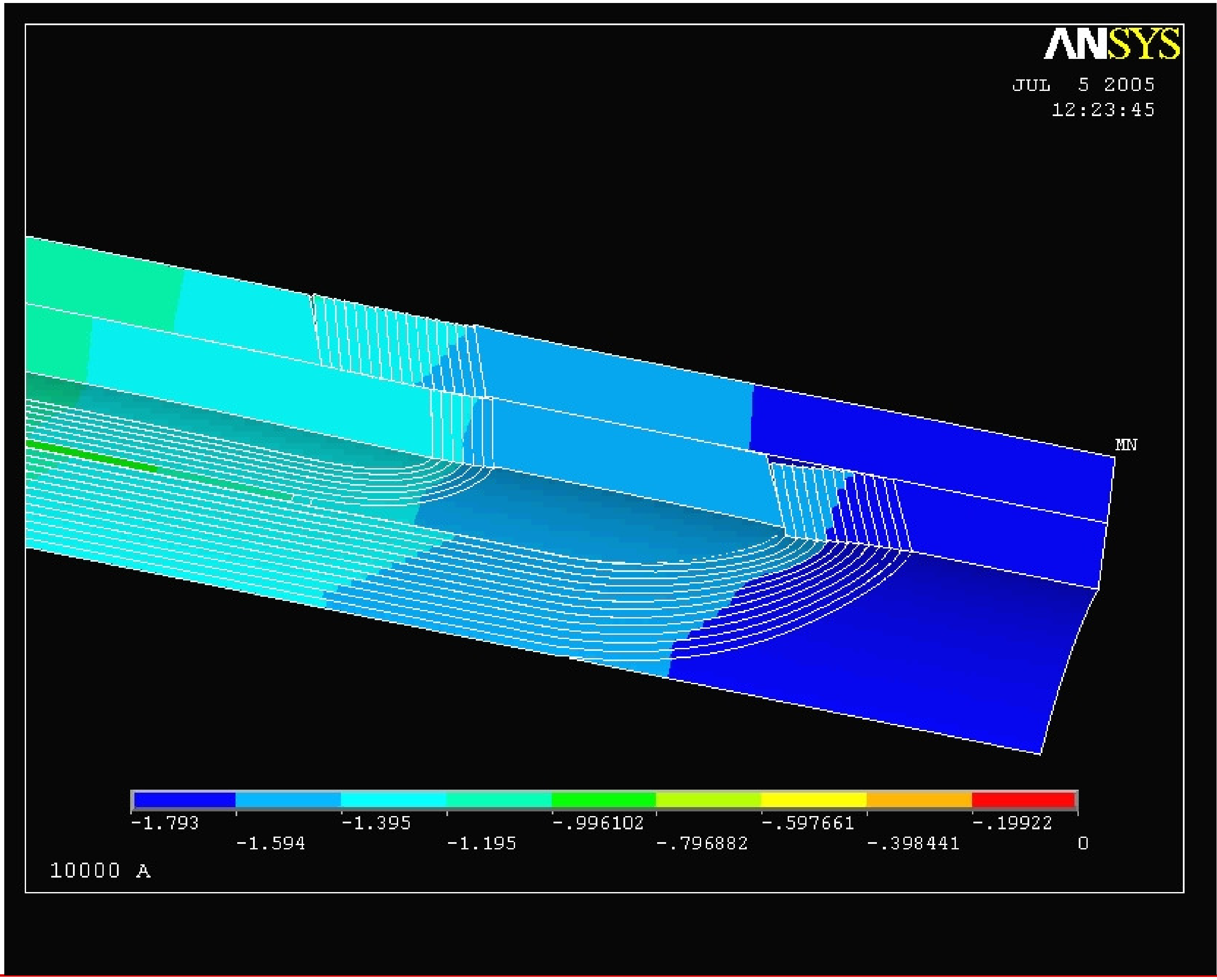

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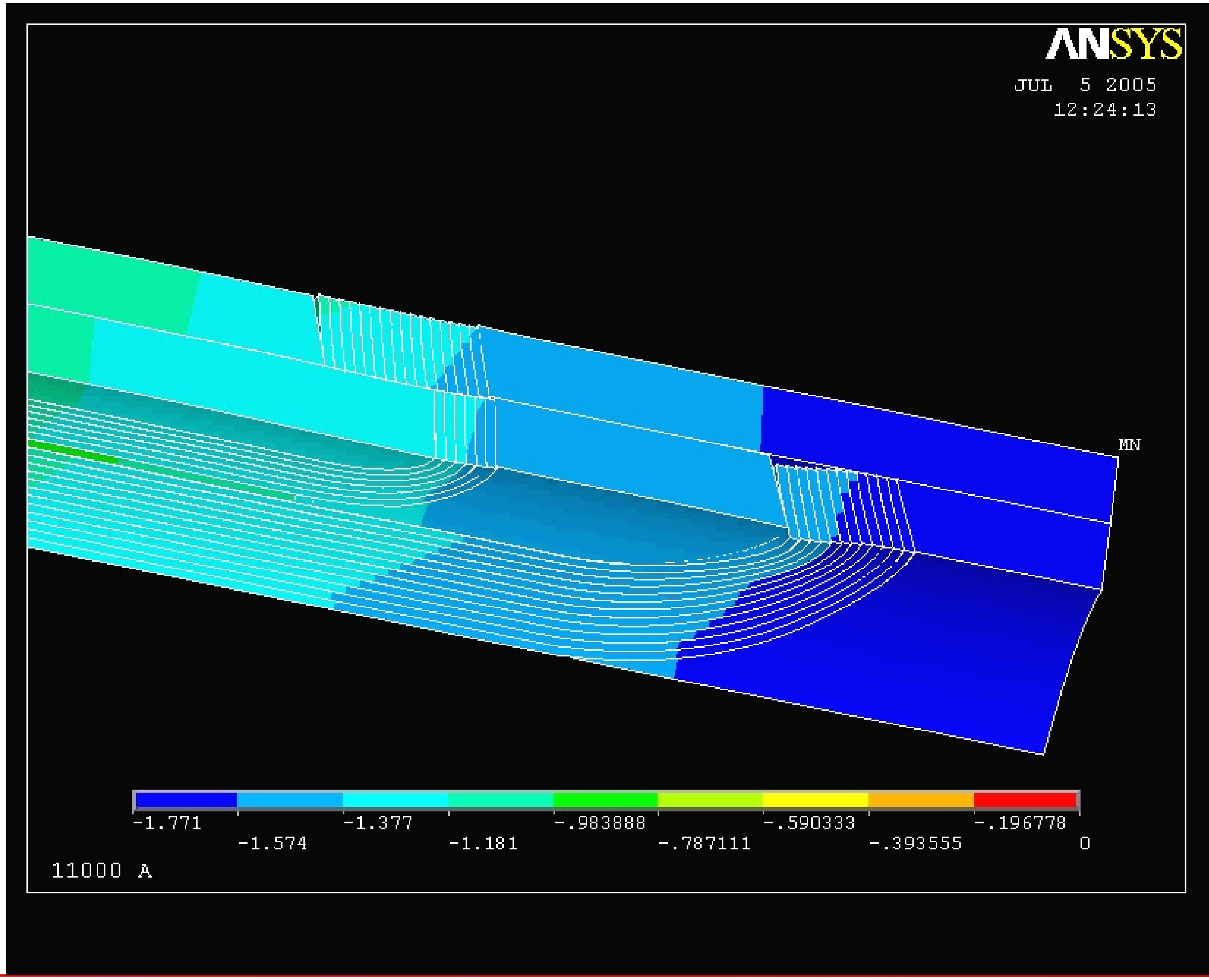

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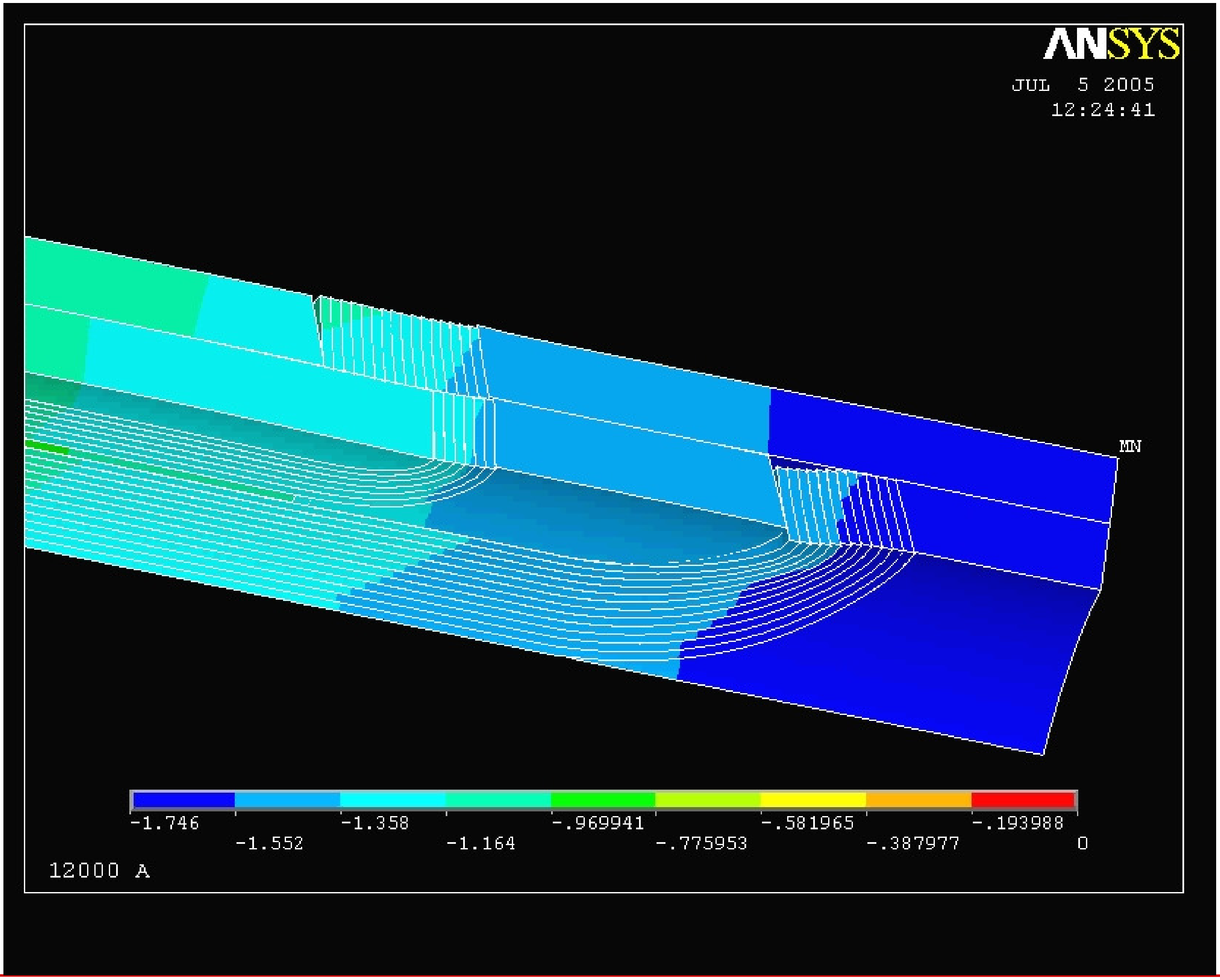

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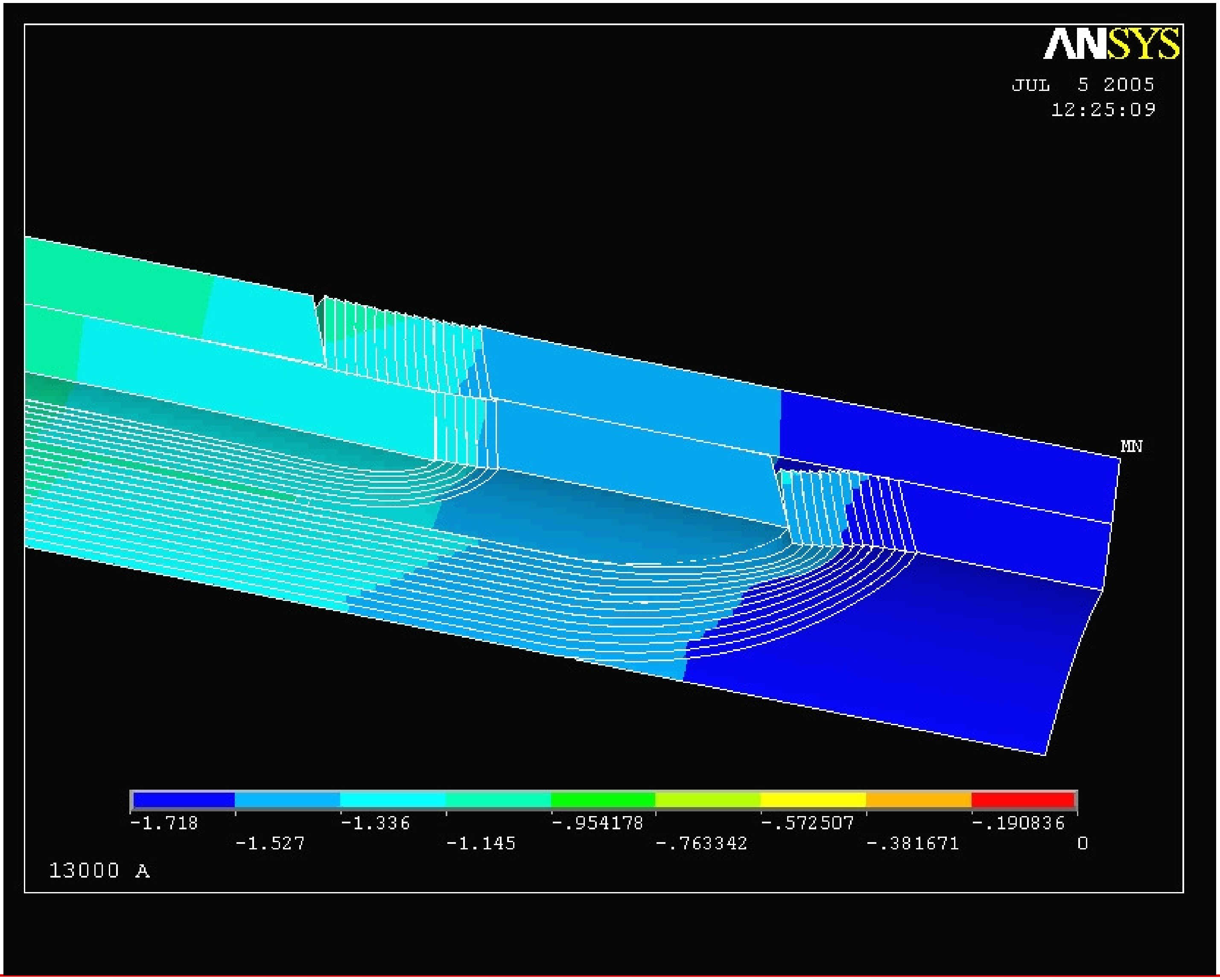

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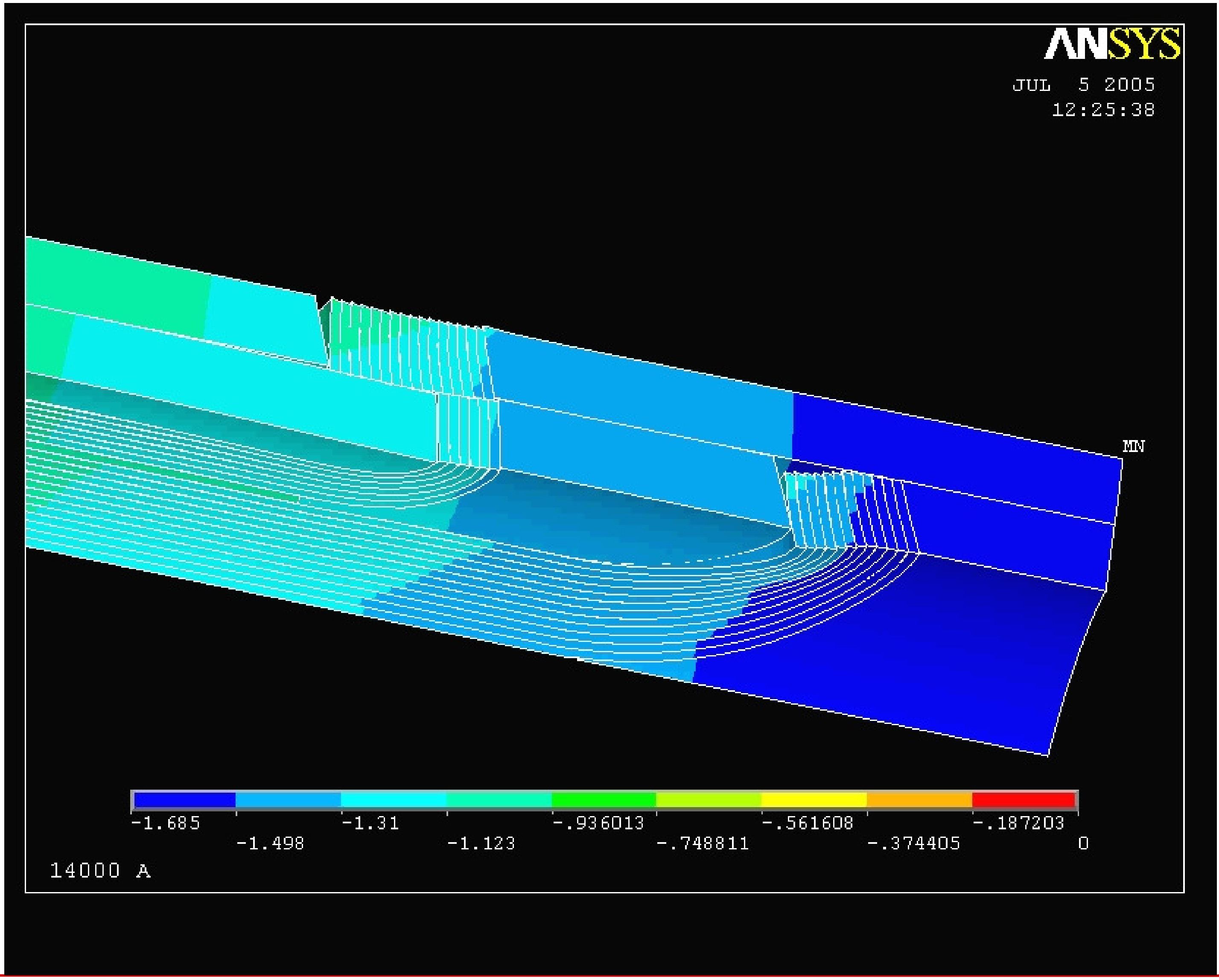

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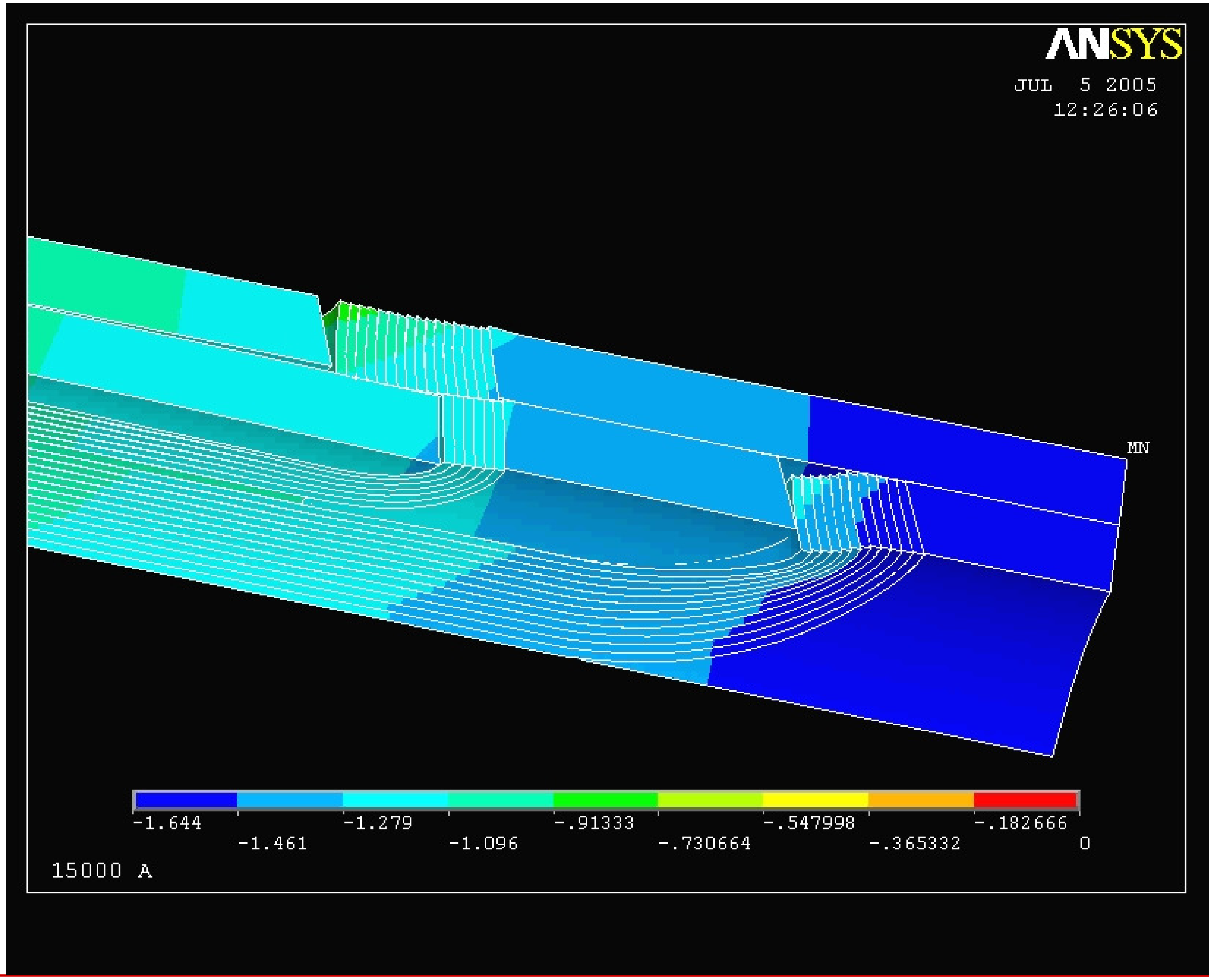
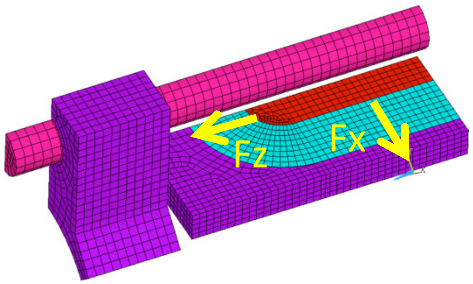
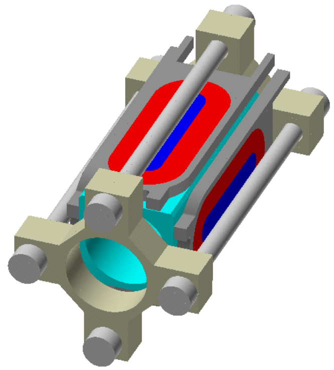
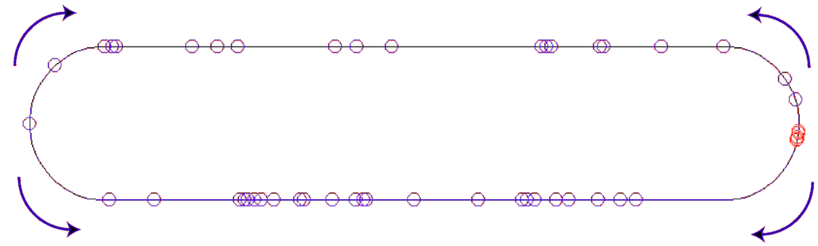


Axial Support in Racetrack

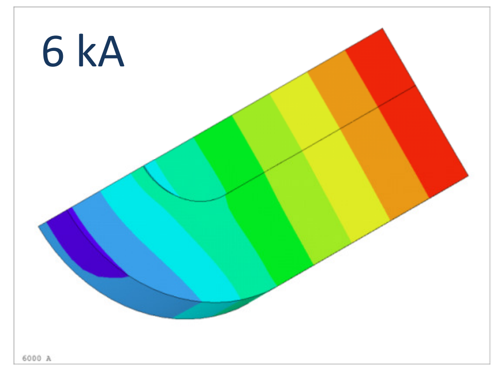


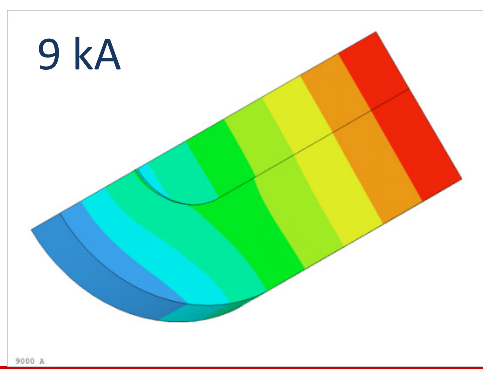


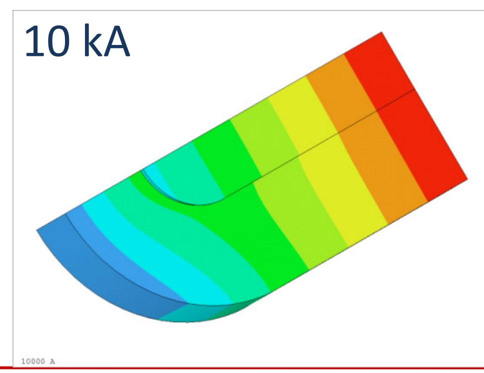


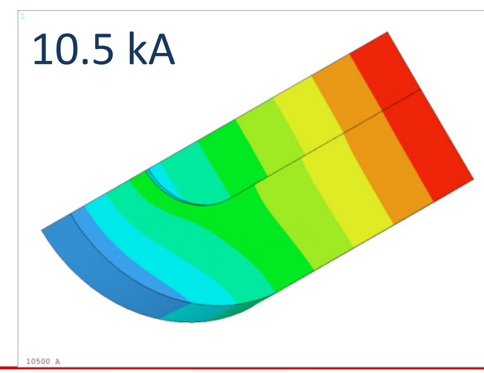
Measurements:
- All quenches in the innermost turn
- Trend from end to central segments

Finite element model:
- Gaps in the ends
- Sliding in the straight section



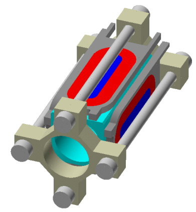






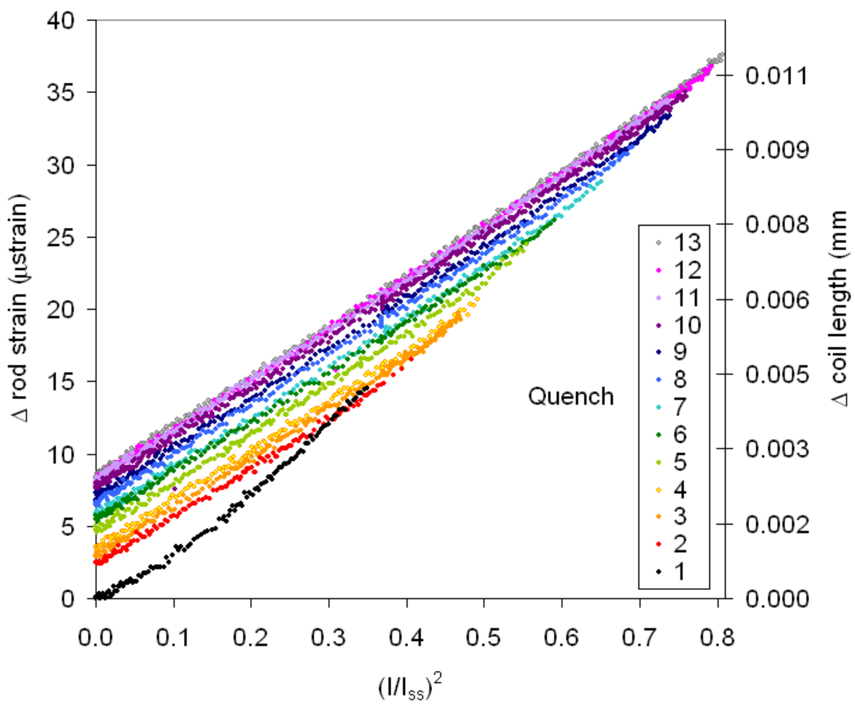
Example of Ratcheting

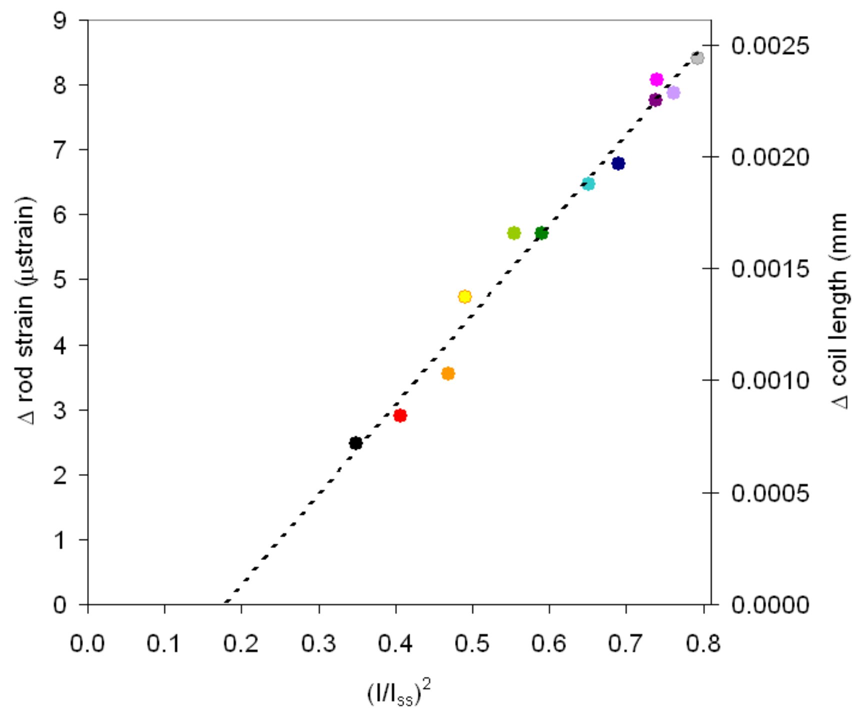
Measurements of rods response during excitation

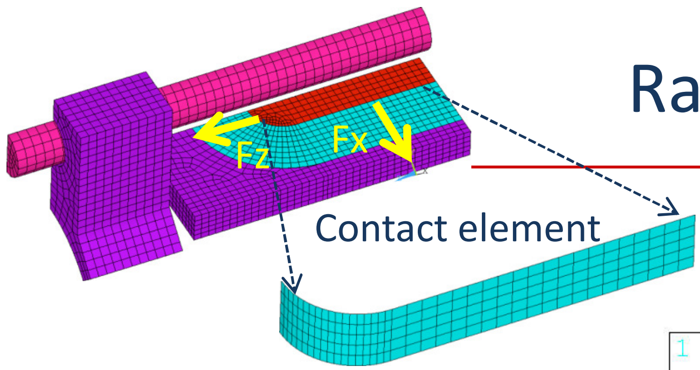


Variation of rod strain and coil length during excitation

Ratcheting of rod strain and coil length during excitation





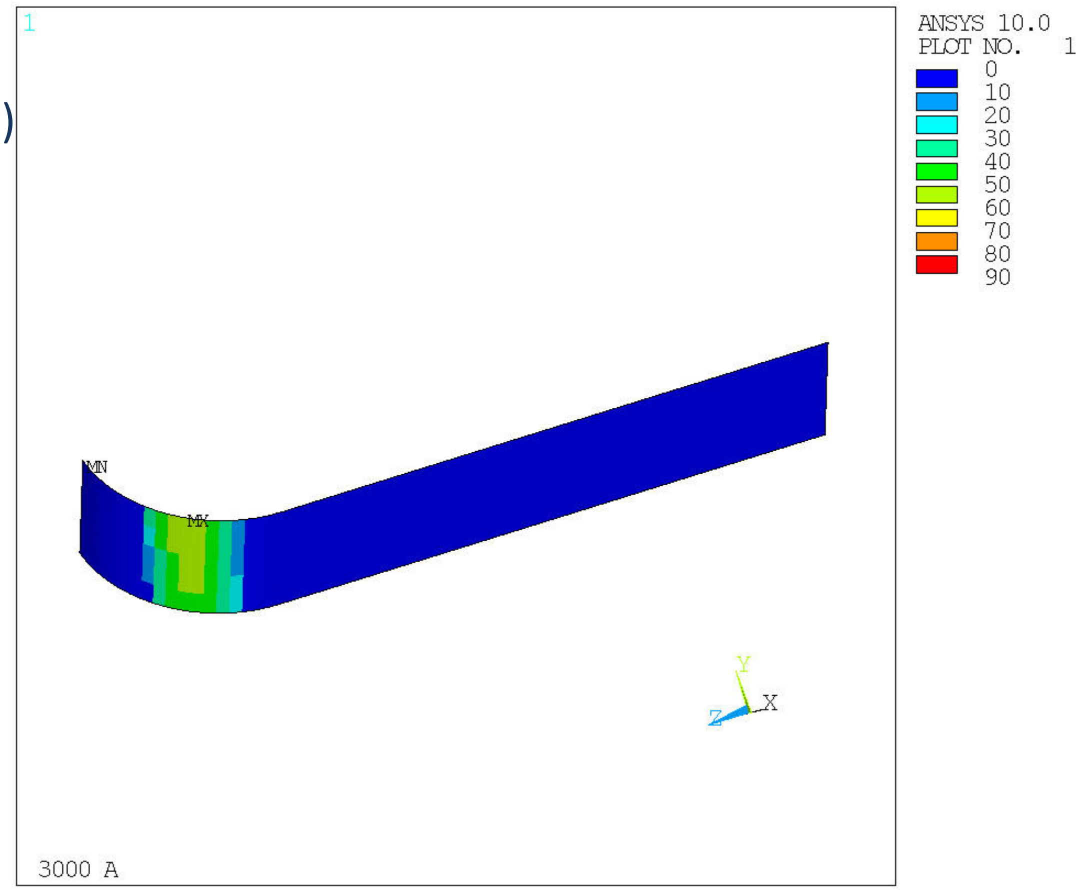


Ratcheting: Modeling

The model simulates a non-conservative system:

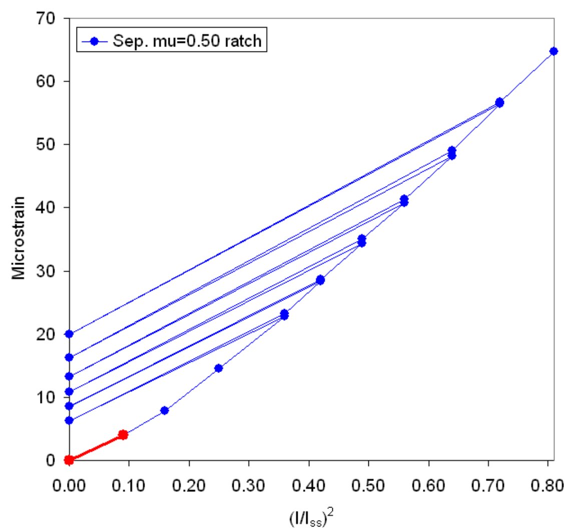
=> Energy is dissipated by sliding friction

E dissipation from 0 to 3kA (J/m2)



Results of the analysis :

Path dependent



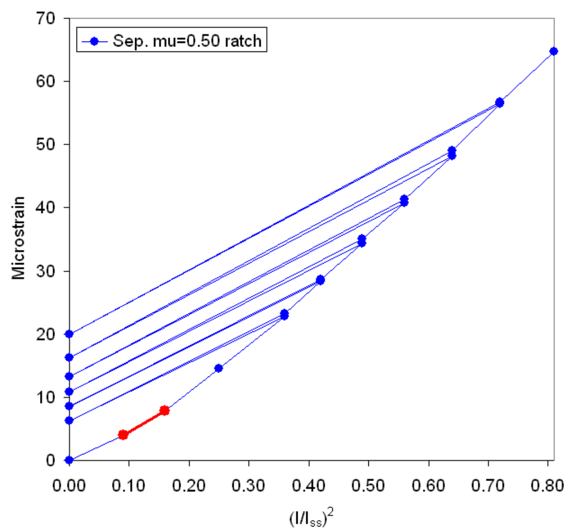
Ratcheting: Modeling

The model simulates a non-conservative system:

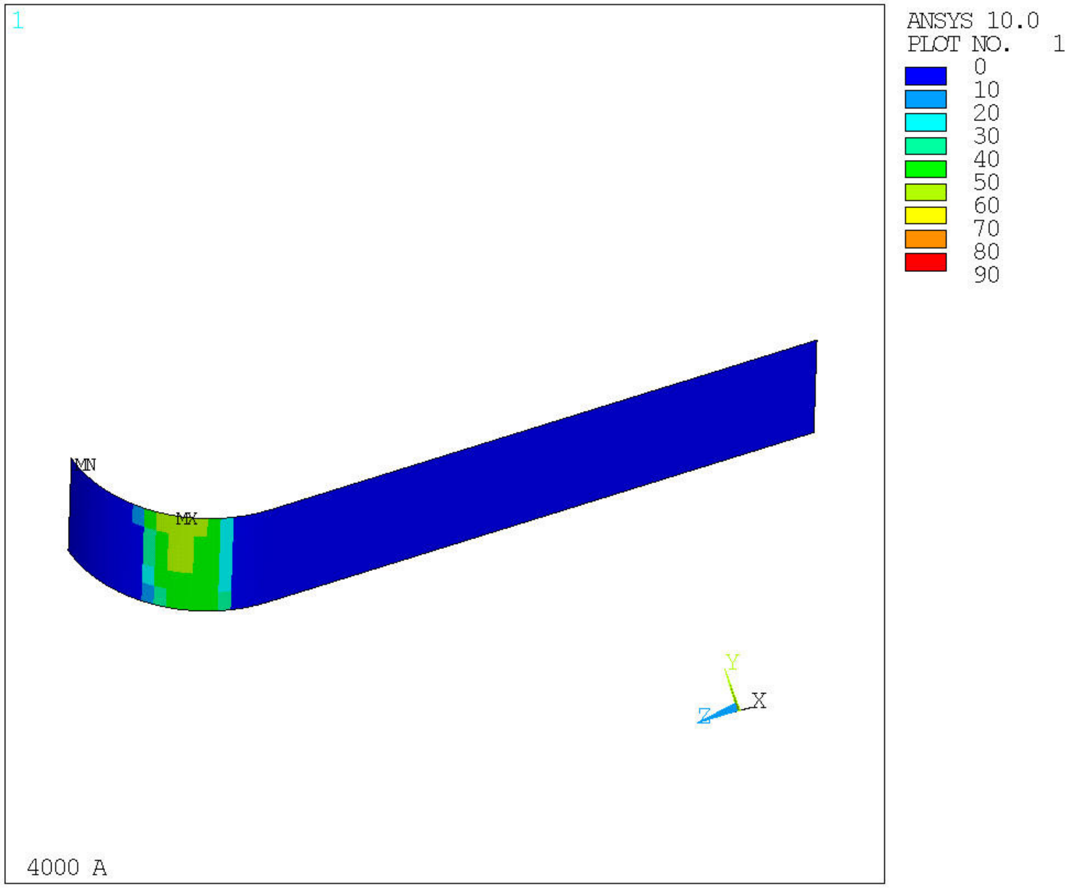
=> Energy is dissipated by sliding friction

Results of the analysis :

Path dependent



E dissipation from 3 to 4kA (J/m2)



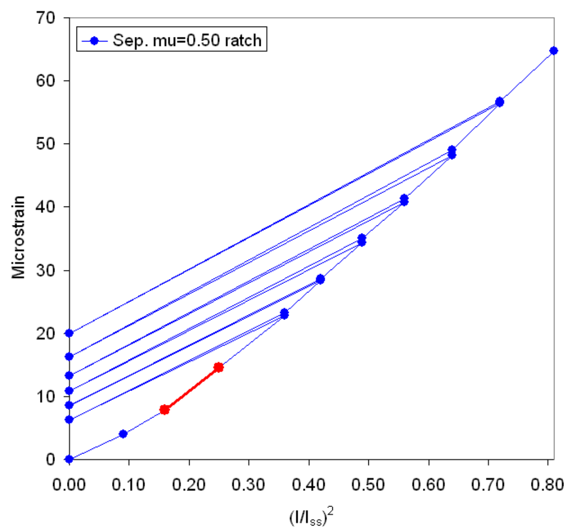
Ratcheting: Modeling

The model simulates a non-conservative system:

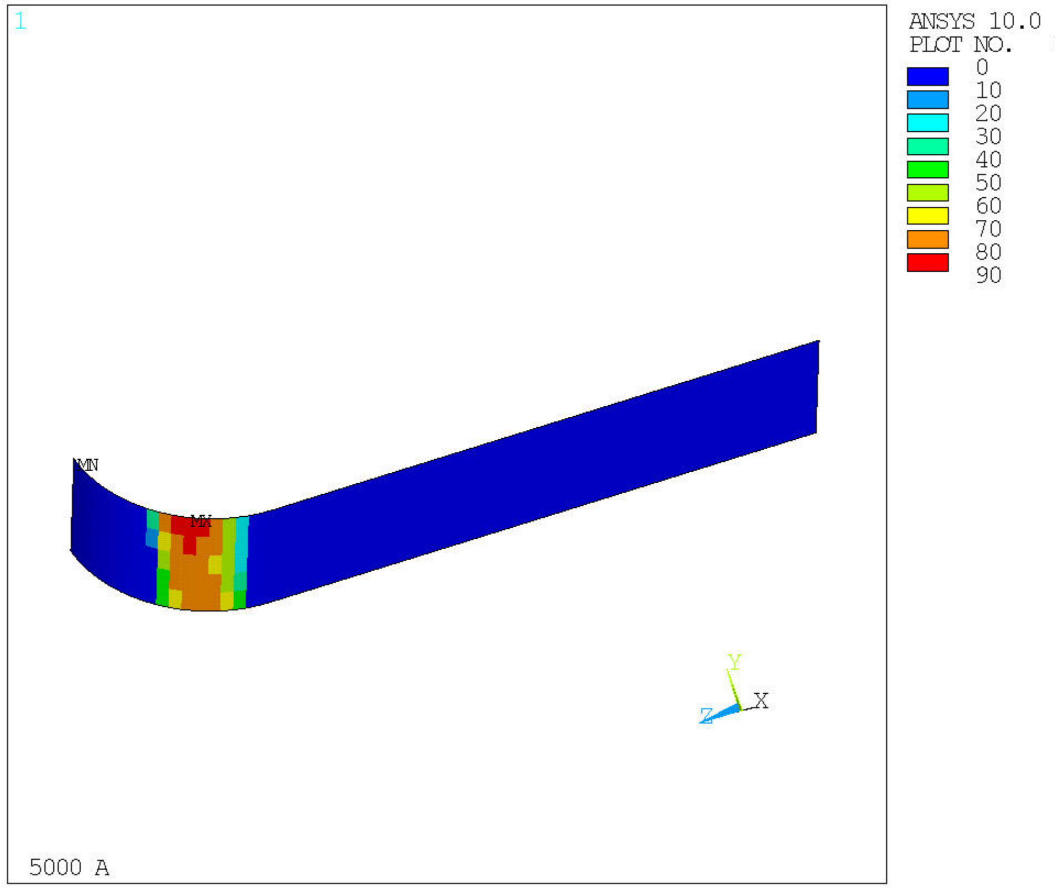
=> Energy is dissipated by sliding friction

Results of the analysis :

Path dependent



E dissipation from 4 to 5kA (J/m2)



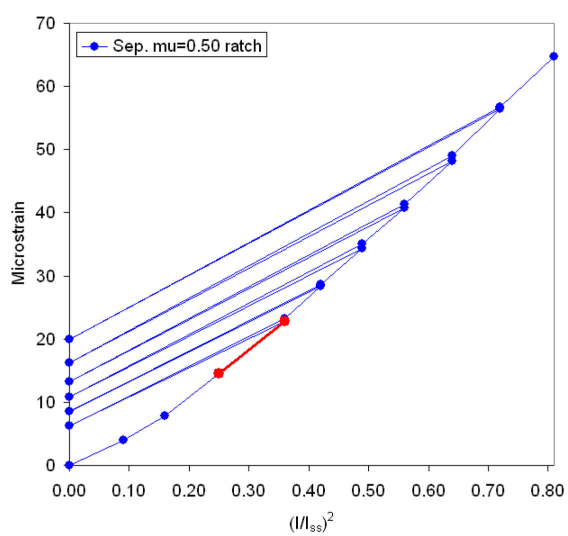
Ratcheting: Modeling

The model simulates a non-conservative system:

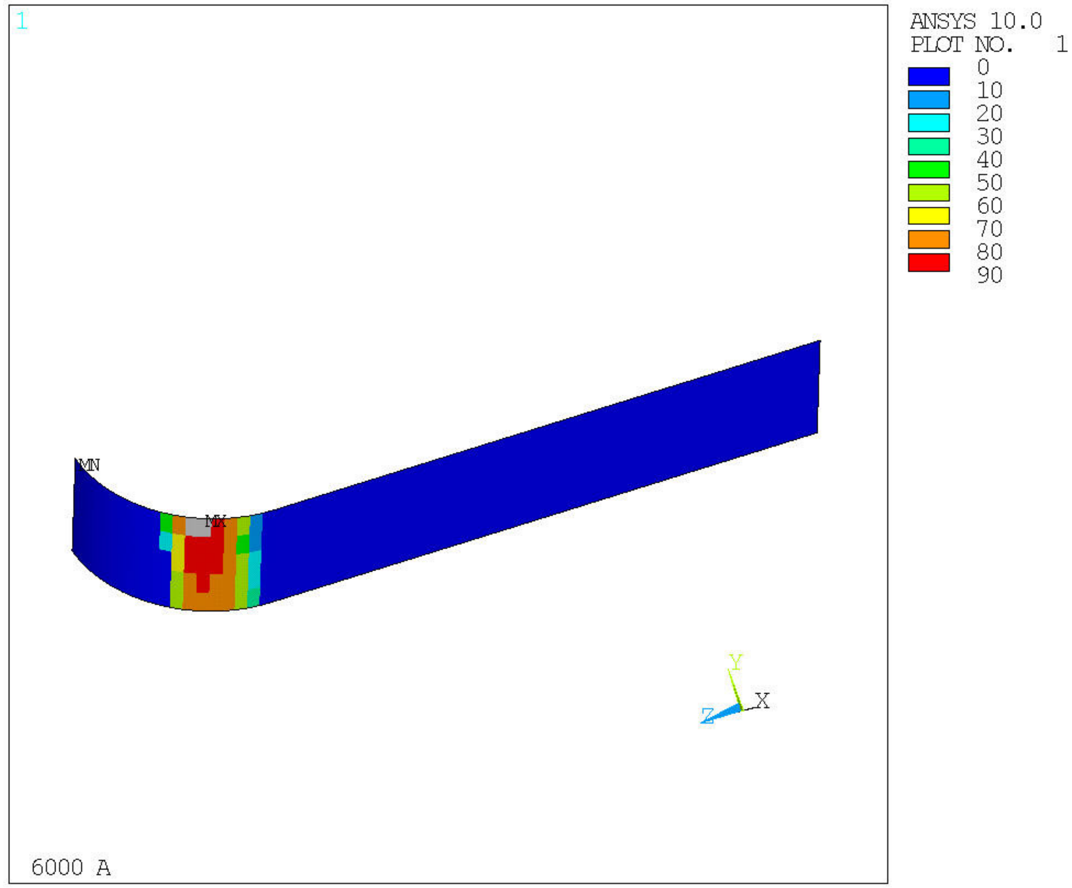
=> Energy is dissipated by sliding friction

Results of the analysis :

Path dependent



E dissipation from 5 to 6kA (J/m2)



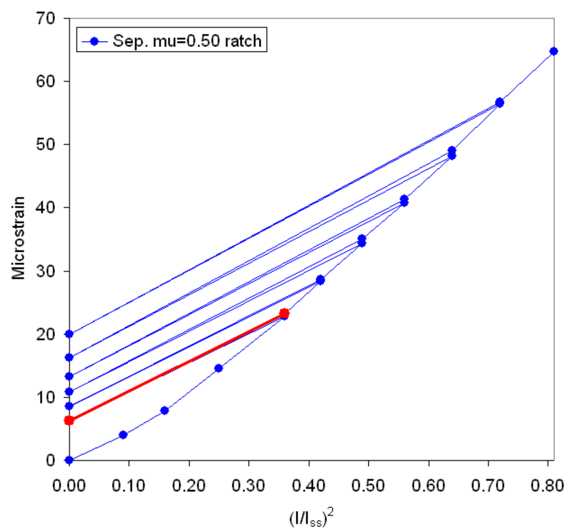
Ratcheting: Modeling

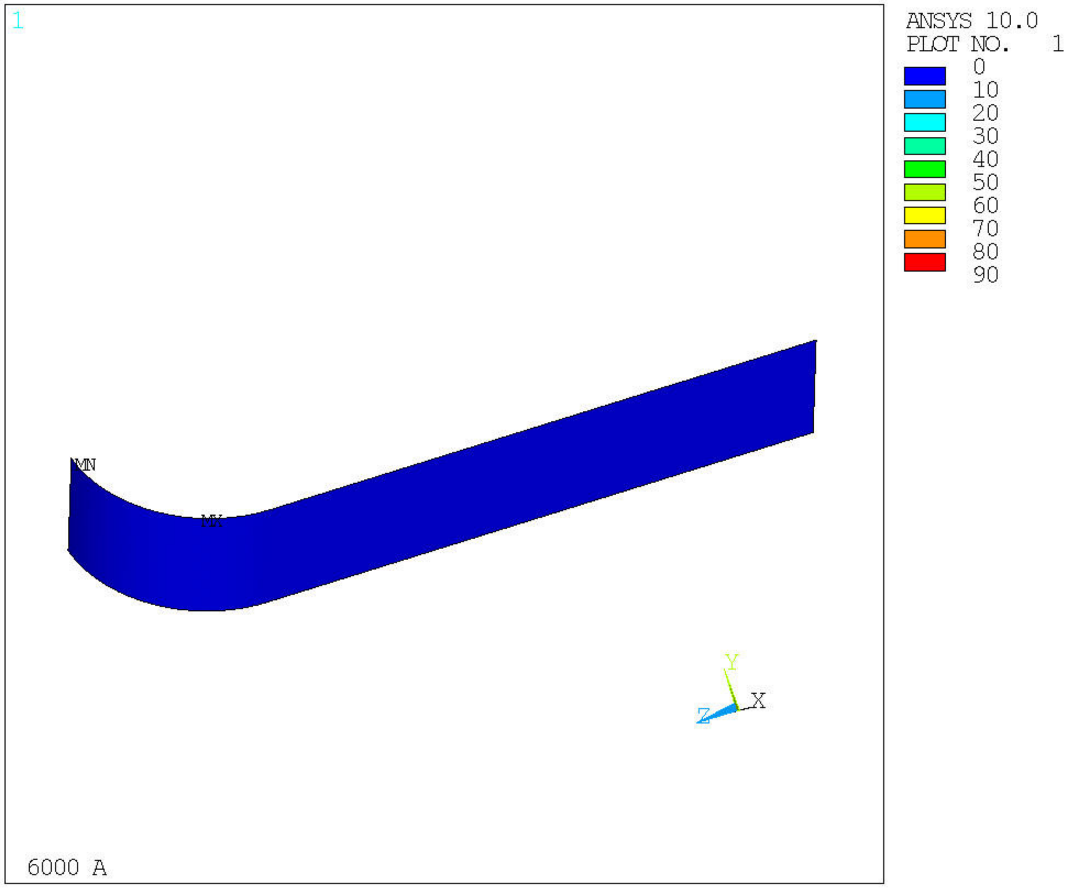
The model simulates a non-conservative system:

=> Energy is dissipated by sliding friction

E dissipation from 0 to 6 kA (J/m2)

Results of the analysis :
Path dependent





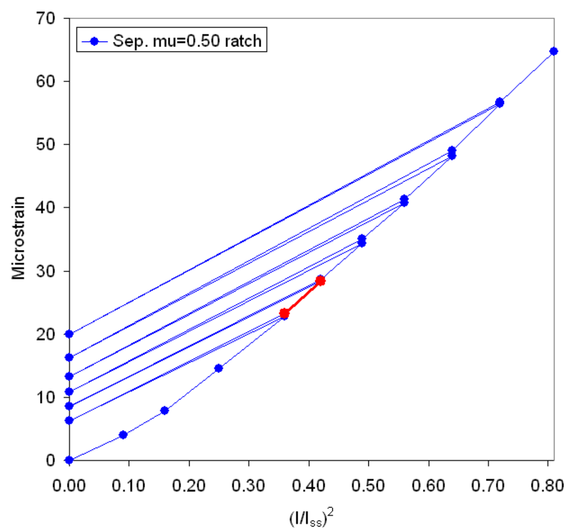
Ratcheting: Modeling

The model simulates a non-conservative system:

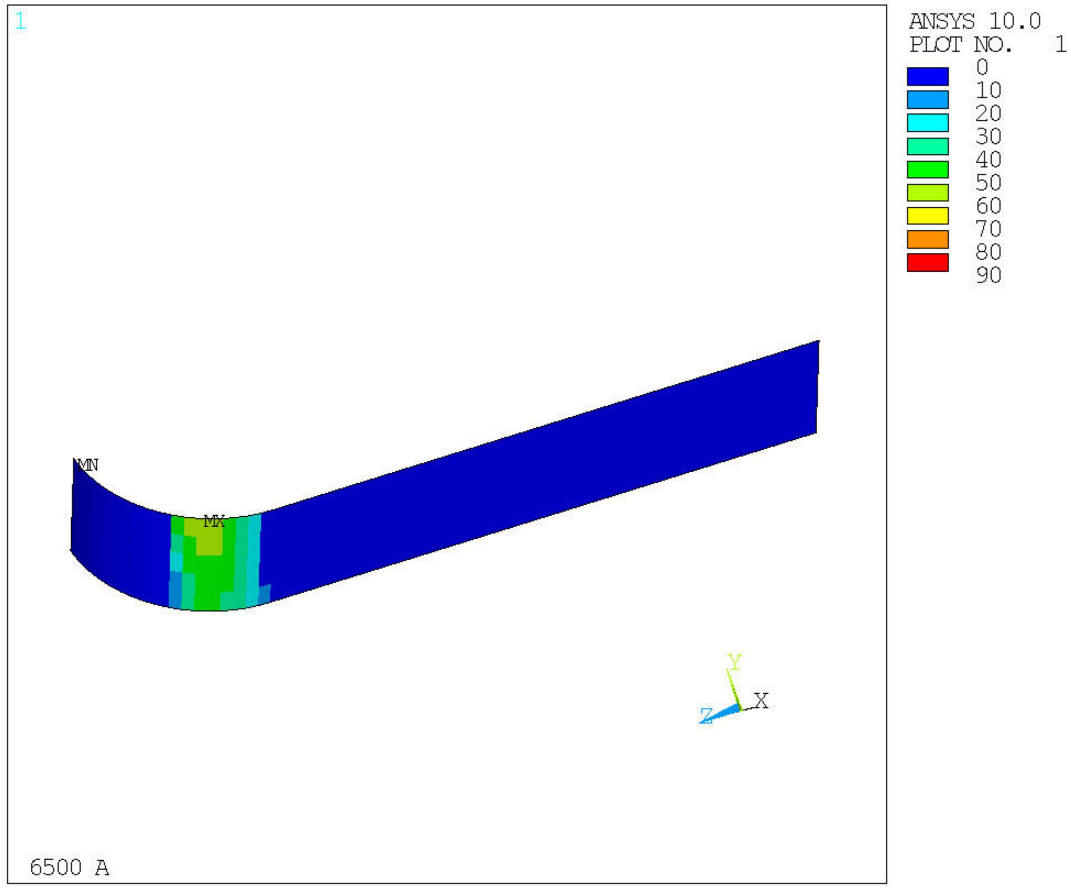
=> Energy is dissipated by sliding friction

Results of the analysis :

Path dependent



E dissipation from 6 to 6.5kA (J/m2)



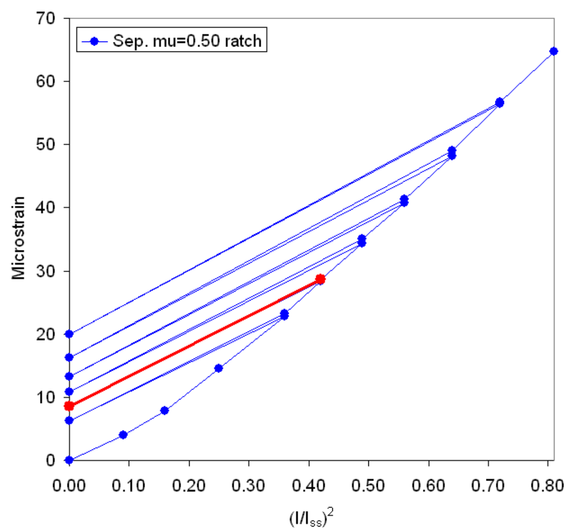
Ratcheting: Modeling

The model simulates a non-conservative system:

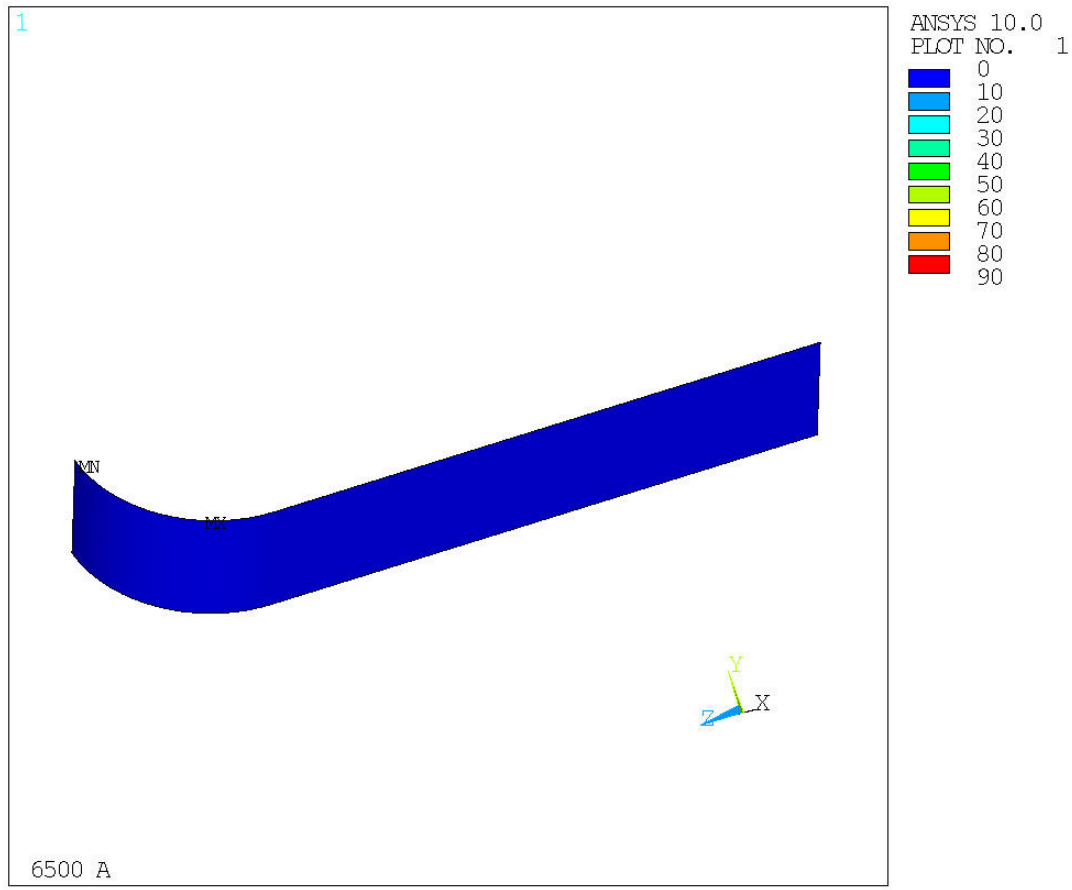
=> Energy is dissipated by sliding friction

Results of the analysis :

Path dependent



E dissipation from 0 to 6.5kA (J/m2)



Ratcheting: Modeling

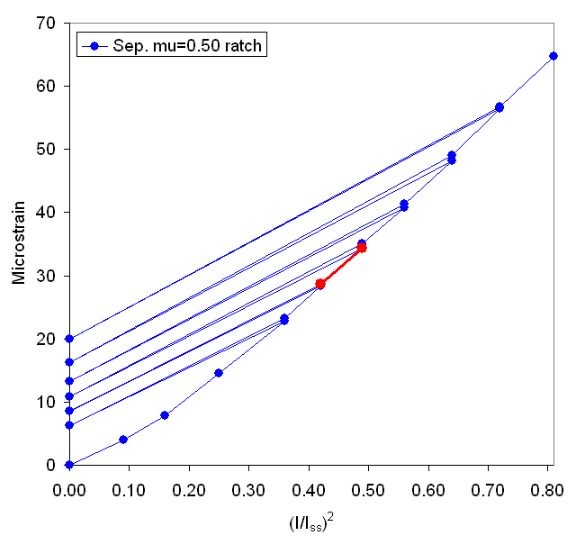
The model simulates a non-conservative system:

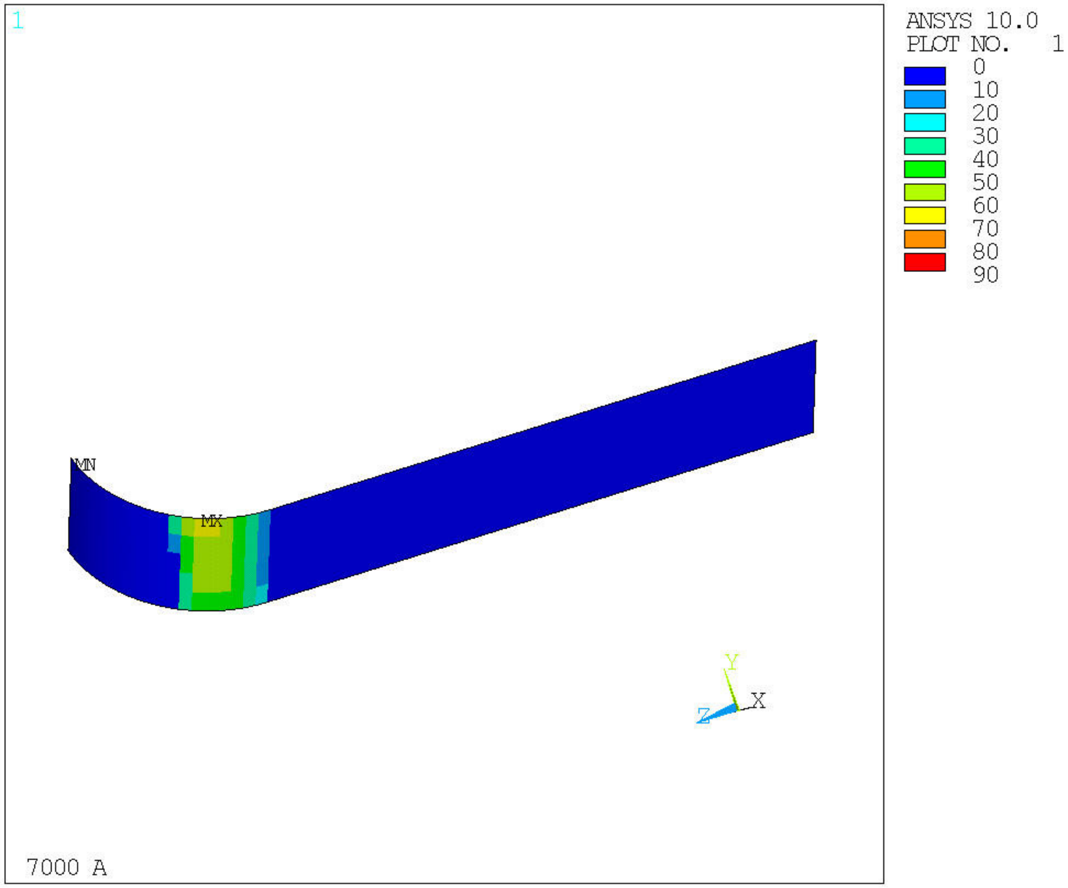
=> Energy is dissipated by sliding friction

E dissipation from 6.5 to 7kA (J/m2)

Results of the analysis :

Path dependent





Ratcheting: Modeling

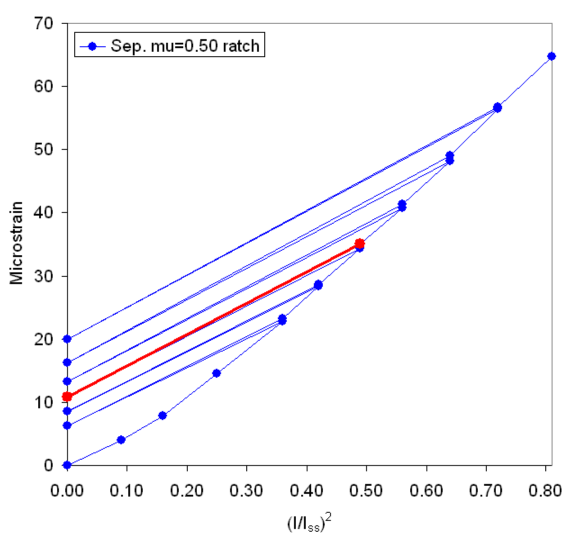
The model simulates a non-conservative system:

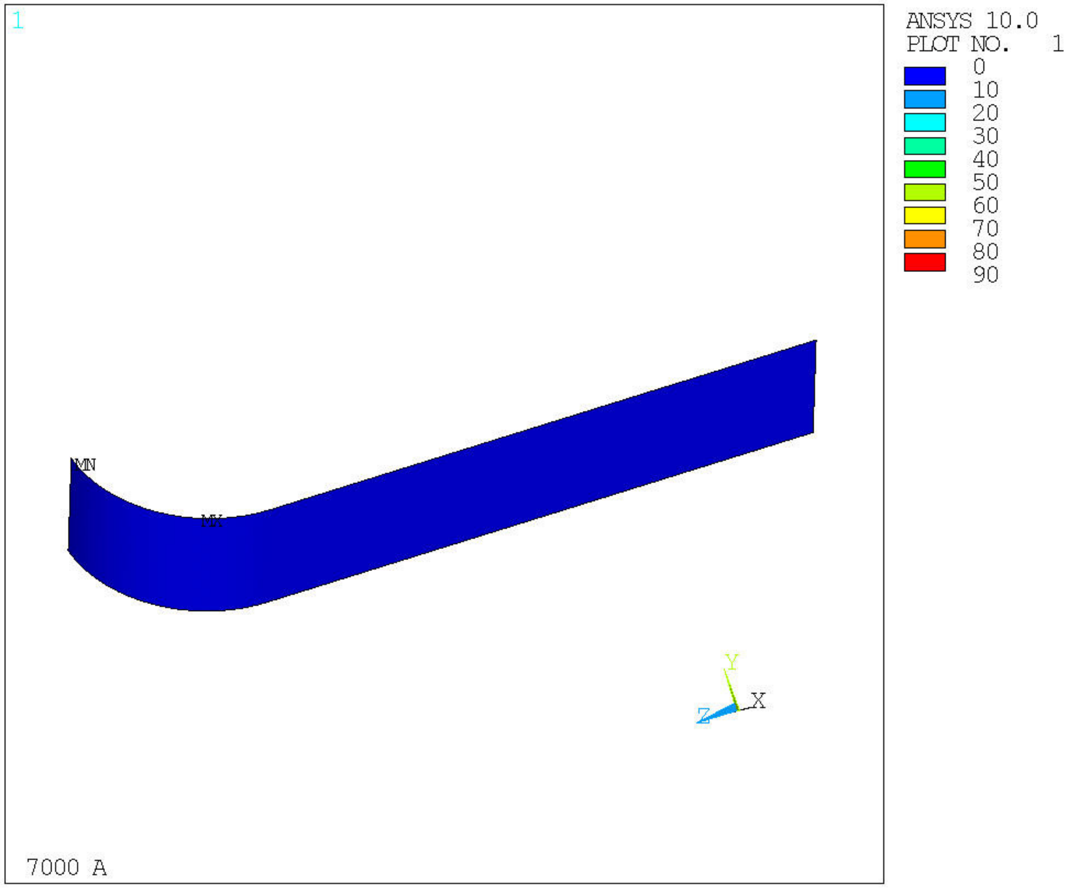
=> Energy is dissipated by sliding friction

E dissipation from 0 to 7kA (J/m2)

Results of the analysis :

Path dependent





Ratcheting: Modeling

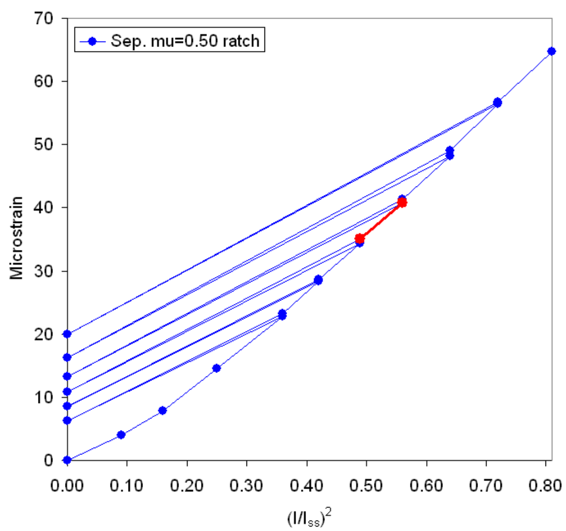
The model simulates a non-conservative system:

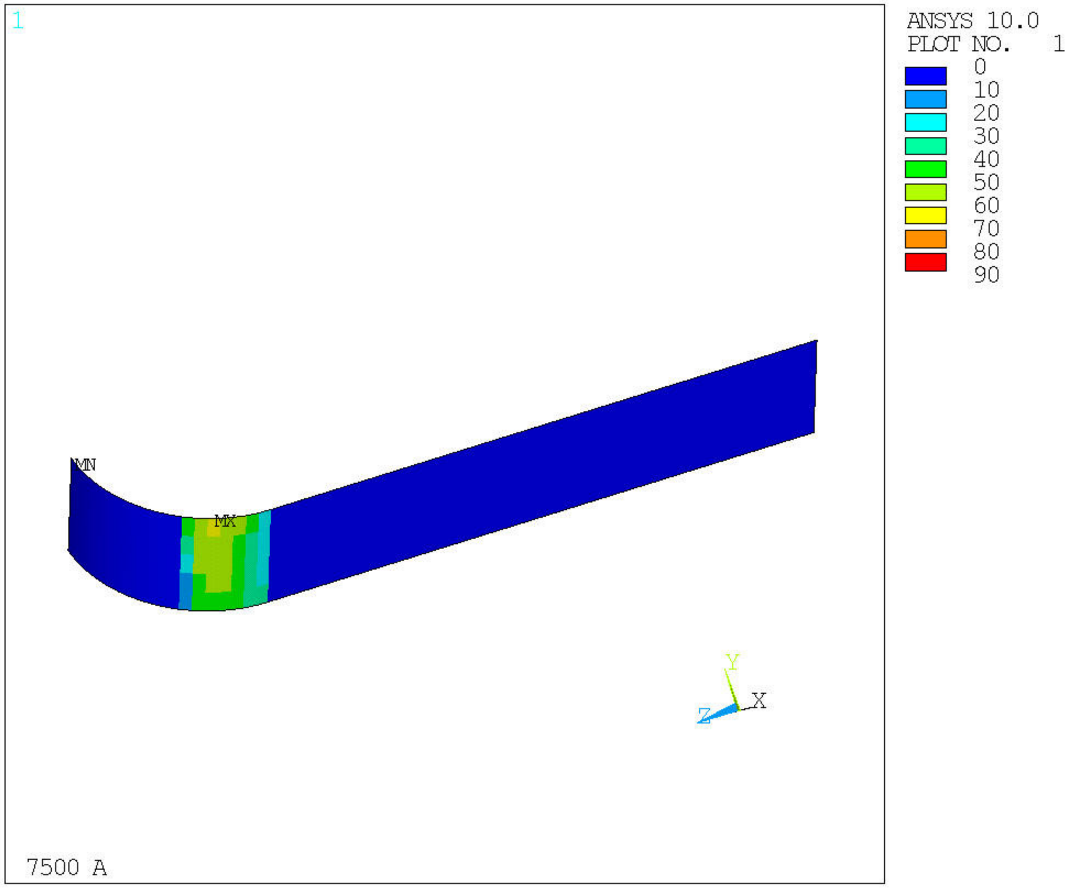
=> Energy is dissipated by sliding friction

E dissipation from 7 to 7.5kA (J/m2)

Results of the analysis :

Path dependent





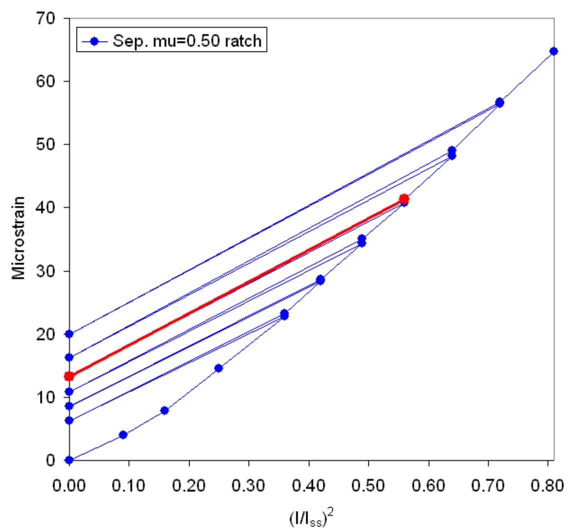
Ratcheting: Modeling

The model simulates a non-conservative system:

=> Energy is dissipated by sliding friction

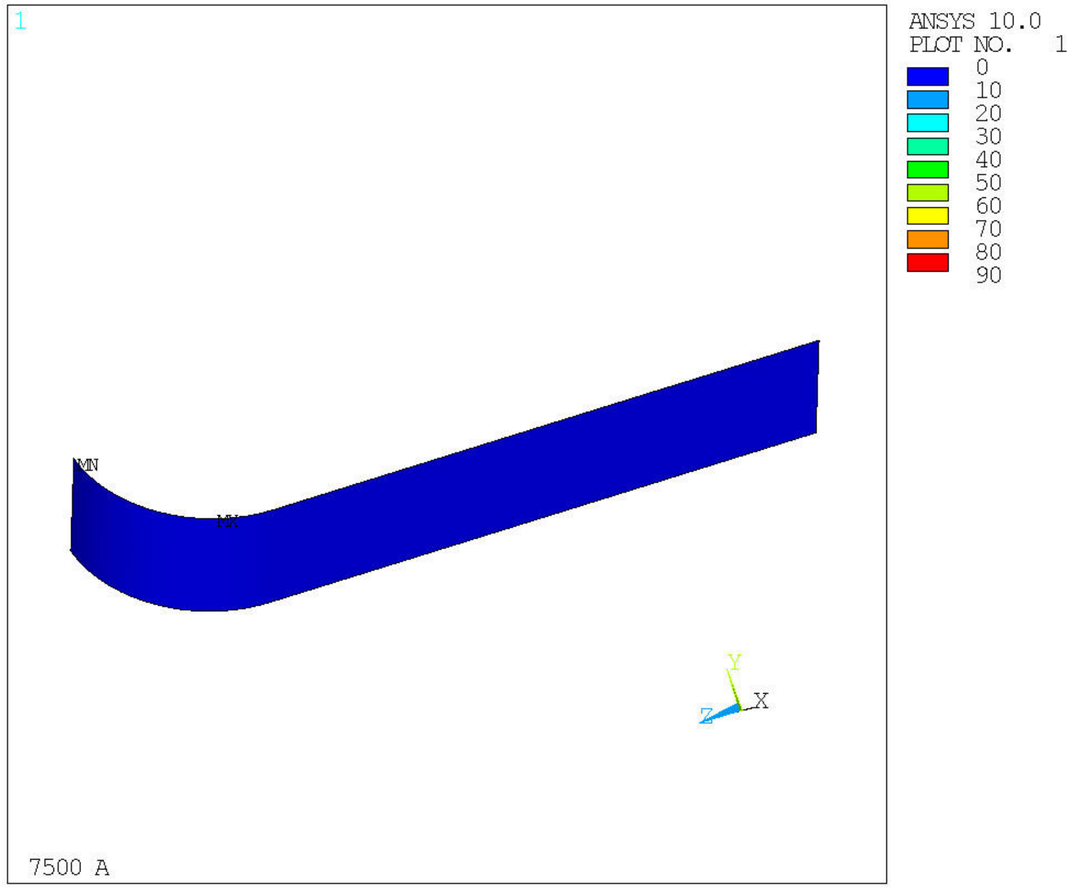
Results of the analysis :

Path dependent



E dissipation from 0 to 7.5kA

(J/m2)



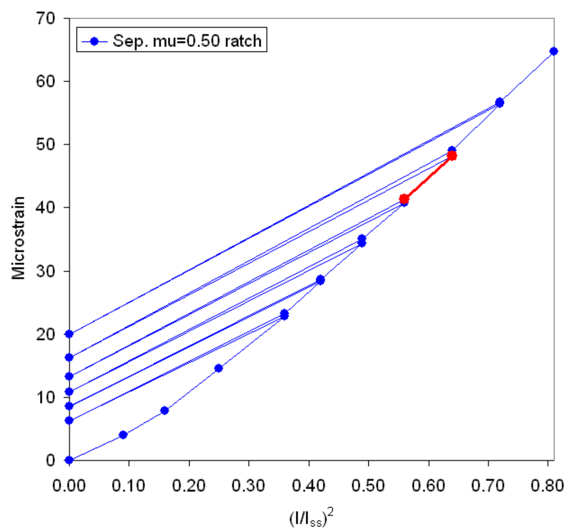
Ratcheting: Modeling

The model simulates a non-conservative system:

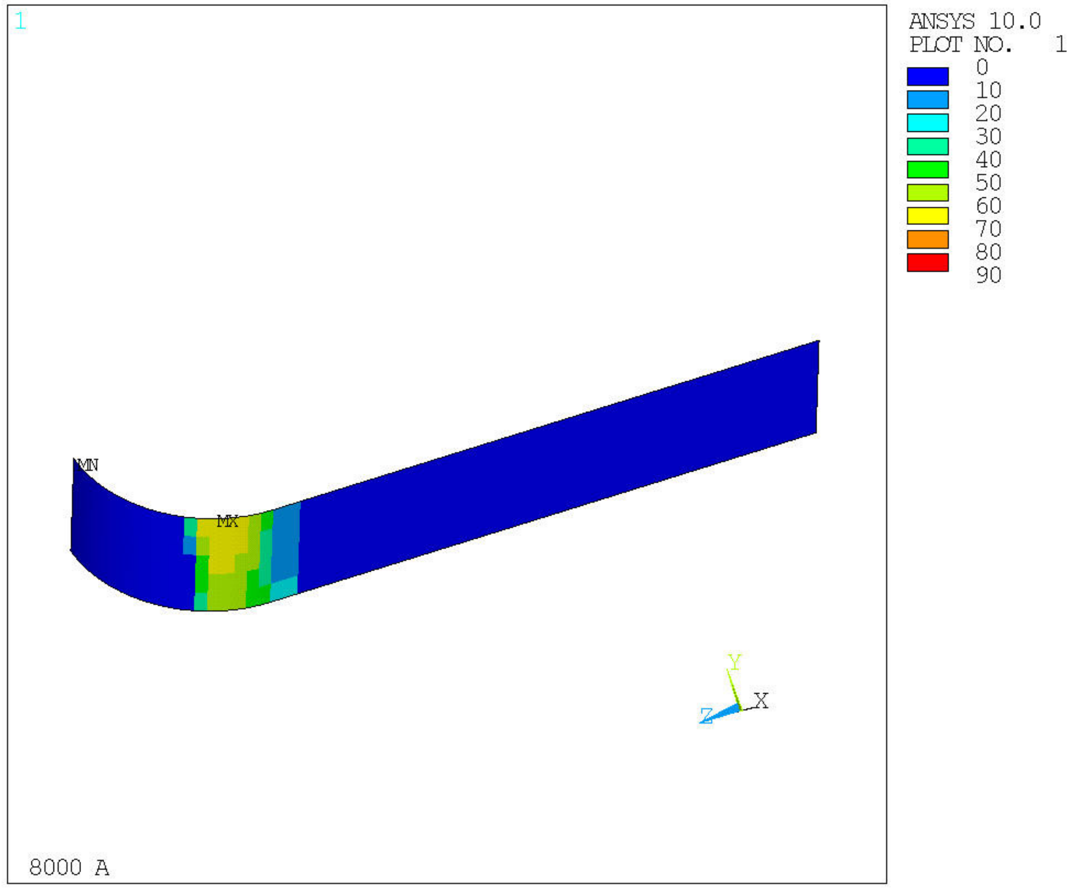
=> Energy is dissipated by sliding friction

Results of the analysis :

Path dependent



E dissipation from 7 to 8kA (J/m2)



Ratcheting: Modeling

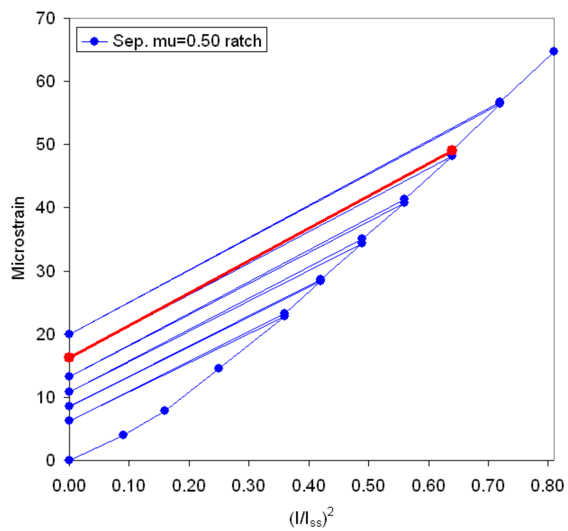
The model simulates a non-conservative system:

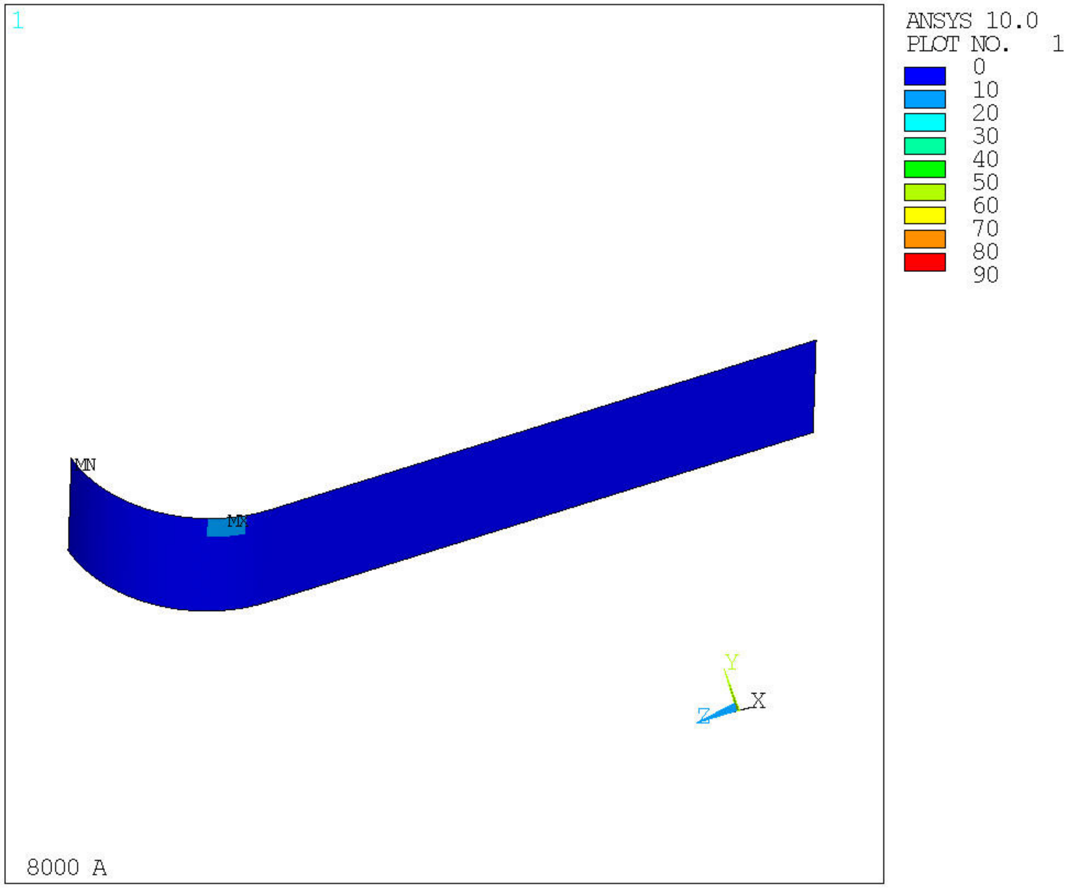
=> Energy is dissipated by sliding friction

E dissipation from 0 to 8kA (J/m2)

Results of the analysis :

Path dependent





Ratcheting: Modeling

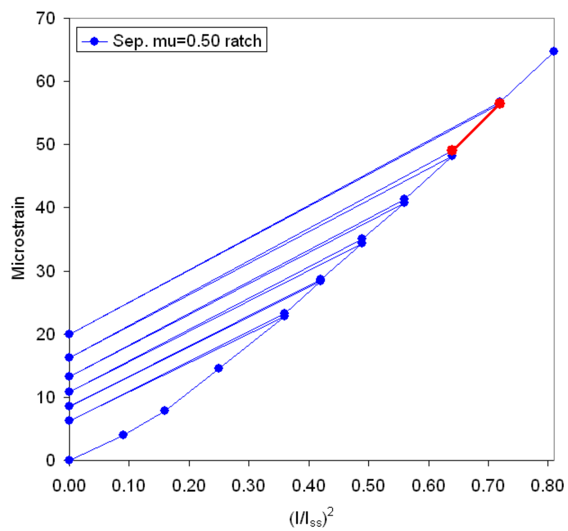
The model simulates a non-conservative system:

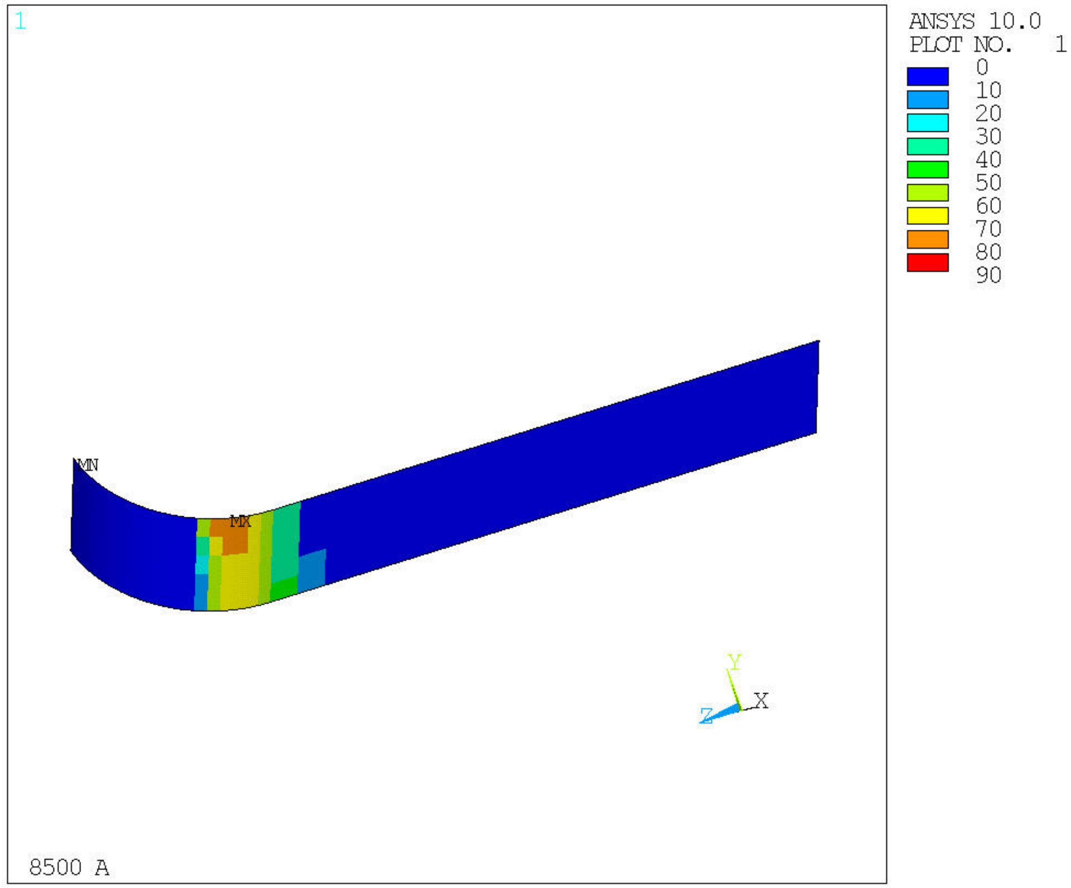
=> Energy is dissipated by sliding friction

E dissipation from 8 to 8.5kA (J/m2)

Results of the analysis :

Path dependent





05/05/2009

3rd Special Worshop on Magnet Simulation for Particle Accelerator

Ratcheting: Modeling

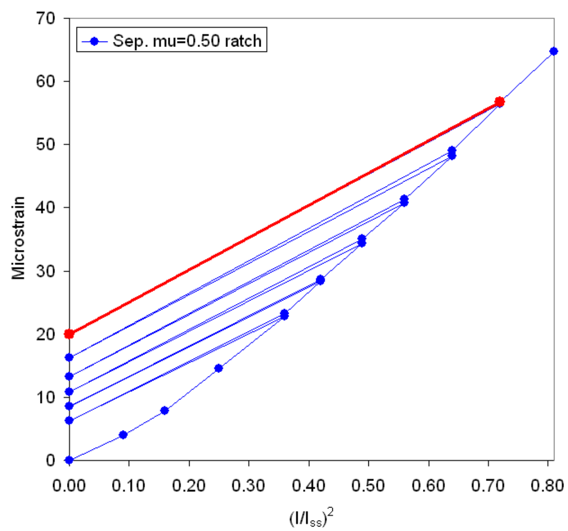
The model simulates a non-conservative system:

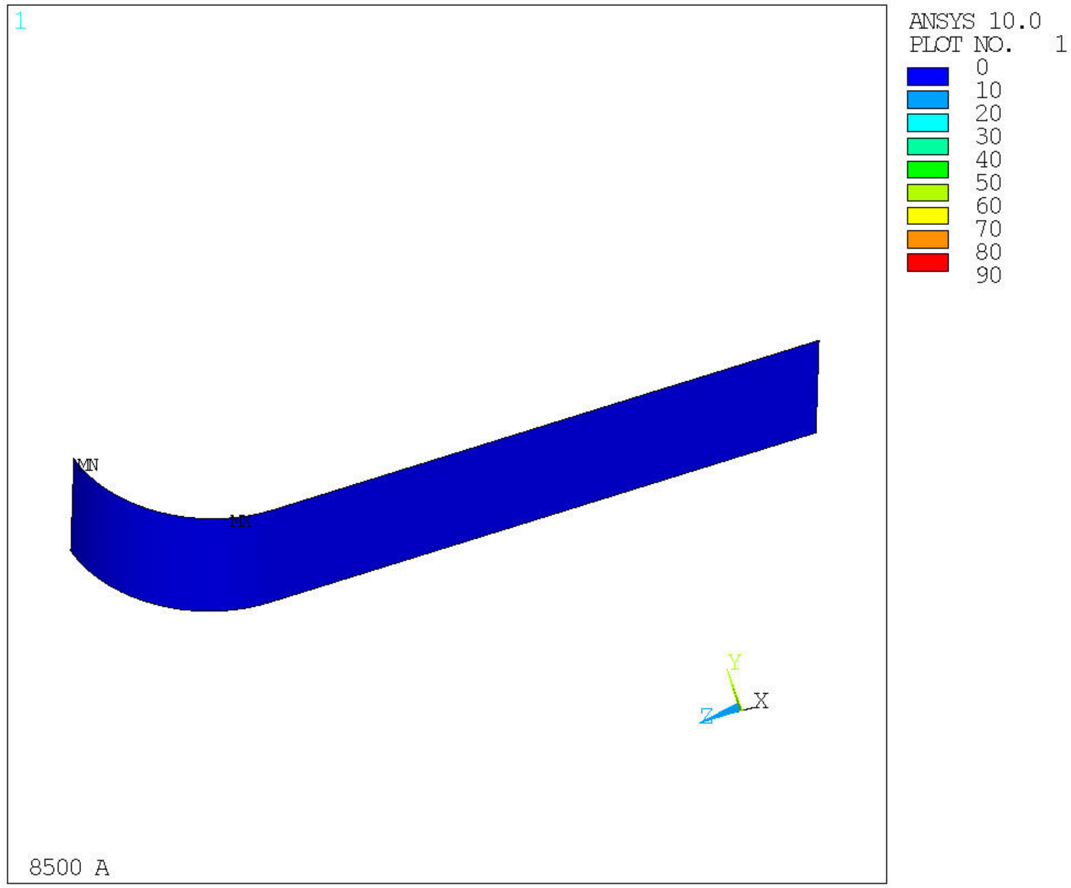
=> Energy is dissipated by sliding friction

E dissipation from 0 to 8.5kA (J/m2)

Results of the analysis :

Path dependent





Ratcheting: Modeling

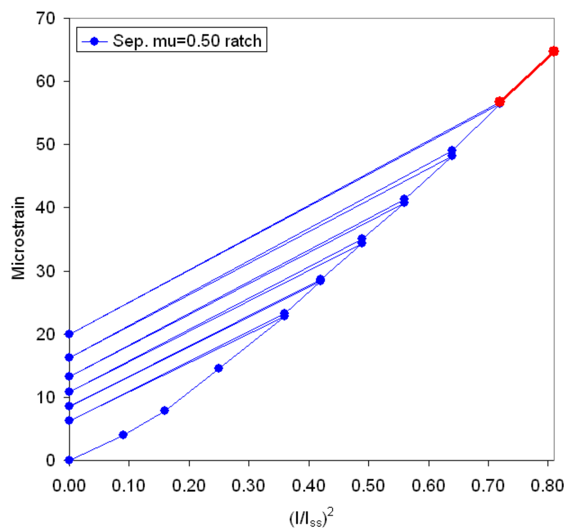
The model simulates a non-conservative system:

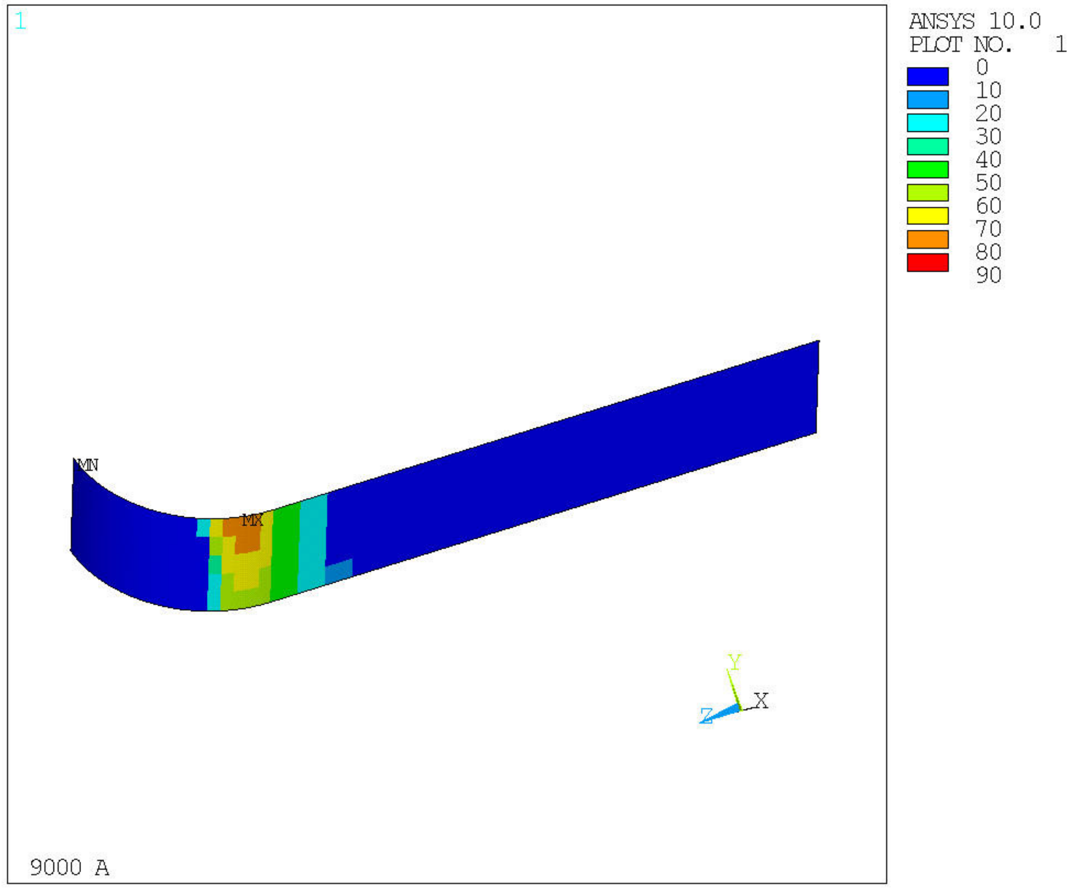
=> Energy is dissipated by sliding friction

E dissipation from 8.5 to 9kA (J/m2)

Results of the analysis :

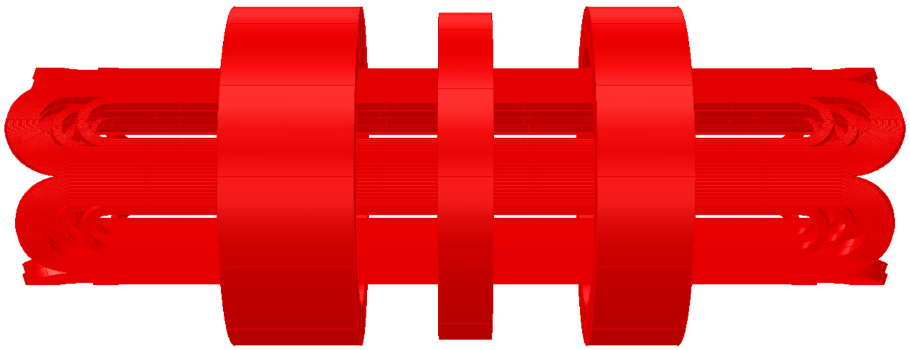
Path dependent

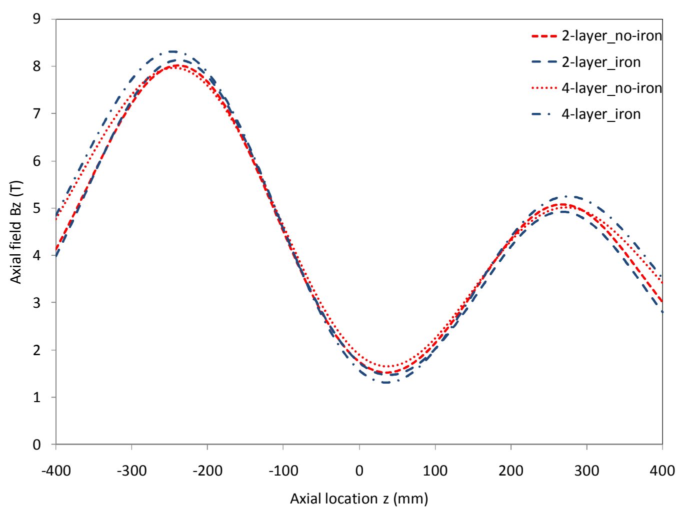




When 2D does not work…

Example of the ECR





Combination of

- 1 sextupole (cos3θ)

- 3 solenoids

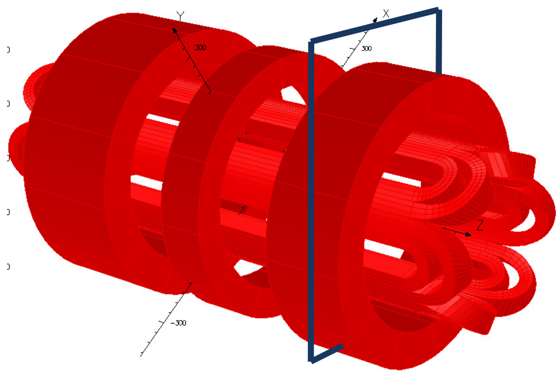
Modeled in VF Opera 3D

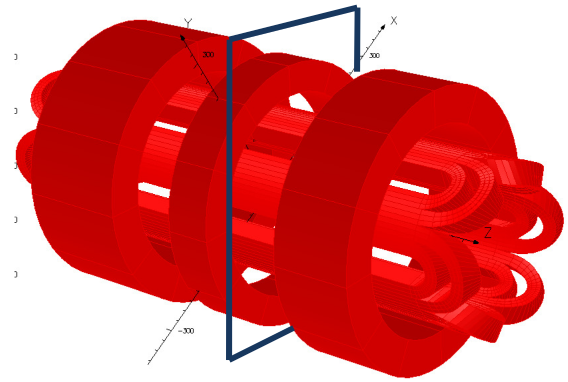
- constant perimeter with the sextupole

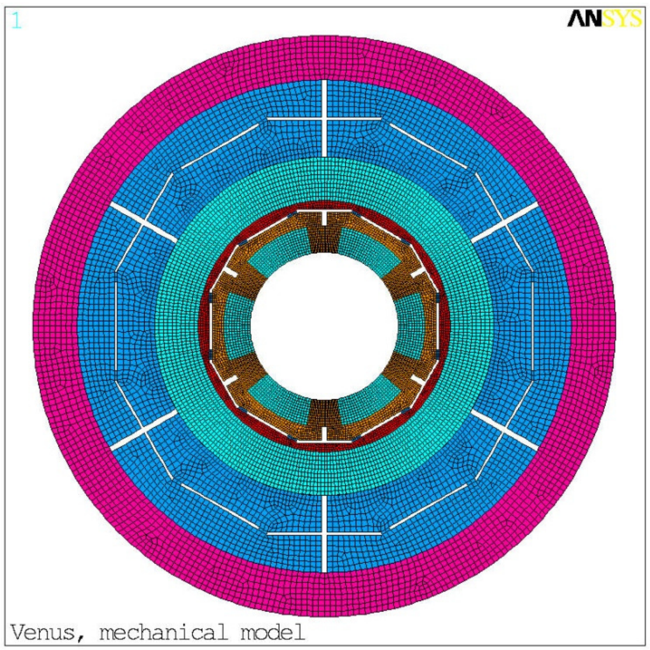
-Sextupole => 30 degrees model

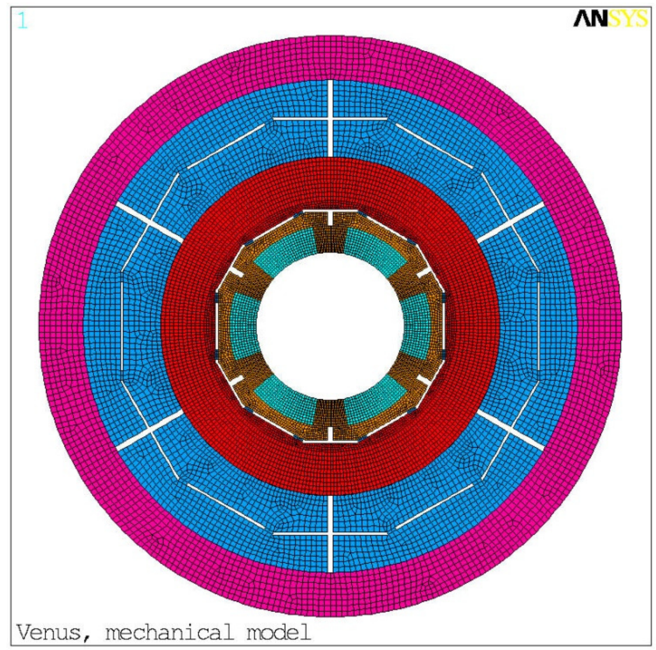
- Sextupole + Solenoid => 60 degrees model because of the z field

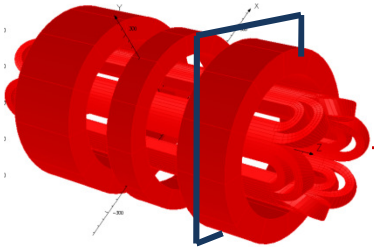
ECR Mechanical Analysis



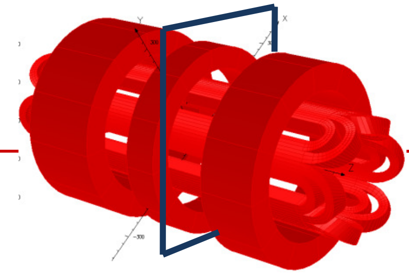








ECR Mechanical Analysis (II)



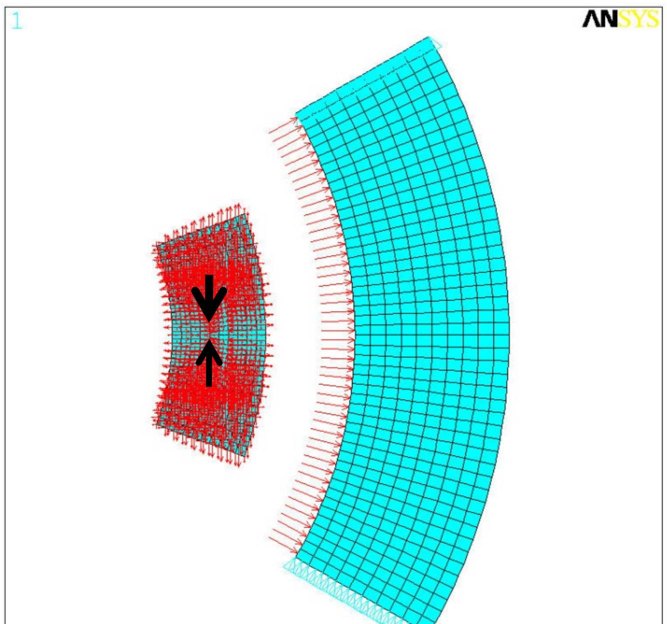
Sextupole force (per block)

=> No force from solenoid (B_z)

Solenoid force

=> No force from sextupole

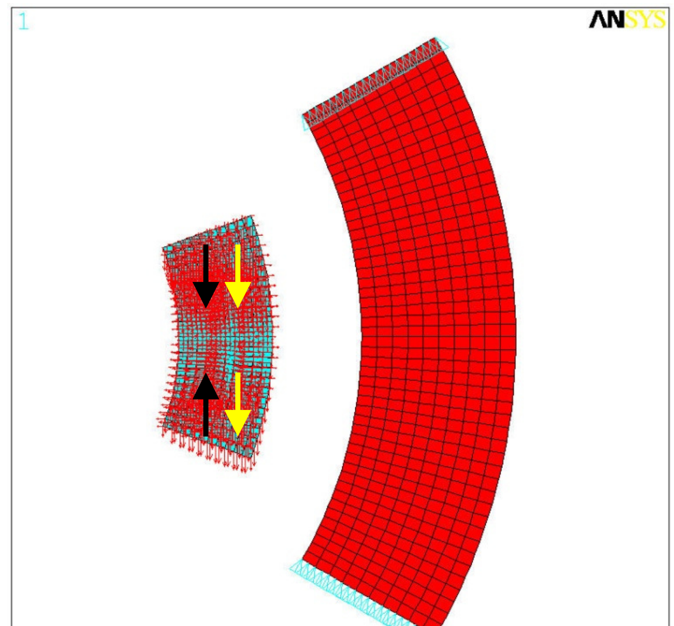
=> Magnetic pressure



Sextupole e.m. forces and solenoid magnetic press

Sextupole force (per block)

=> Effect of the radial field of the solenoid on the sextupole



Sextupole e.m. forces and solenoid e.m. forces