Magnet design, final parameters

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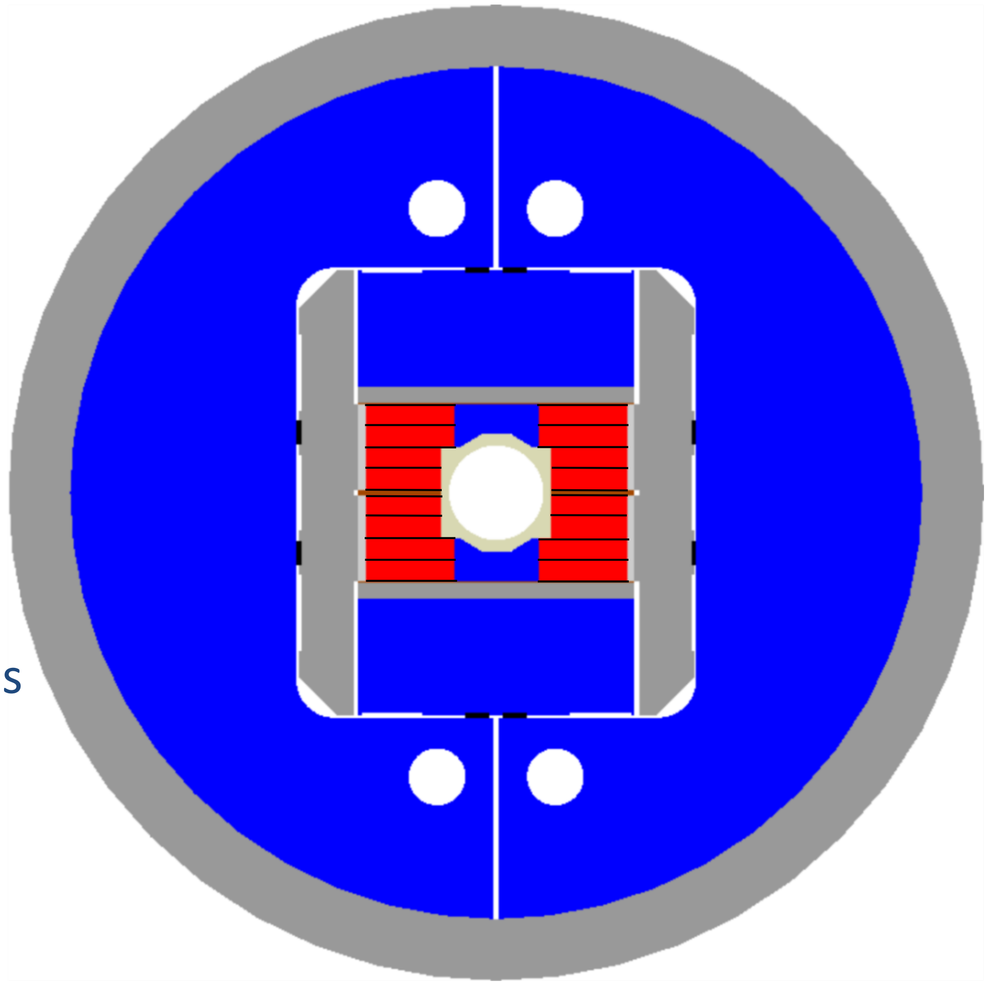
Outline

- Introduction: magnet overview
- Conductor and cable parameters
- Coil design and magnet parameters
- Pre-load and stresses
- End forces and axial support
- Conclusions

Introduction
Overview of magnet design

- OD: 1.030 m
- Al shell, 65 mm thick
- Iron yoke
  - Holes for axial rods
- Horizontal s.s pad
  - 3 bladders, 75 mm wide
  - 2 load keys
- Vertical iron and s.s. pad
  - 2 bladders, 60 mm wide
  - 2 load keys
- Auxiliary bladders between yokes
- Four double-layer coils
- Iron and Ti alloy central posts
- 100 mm aperture
- Target bore field: 13 T

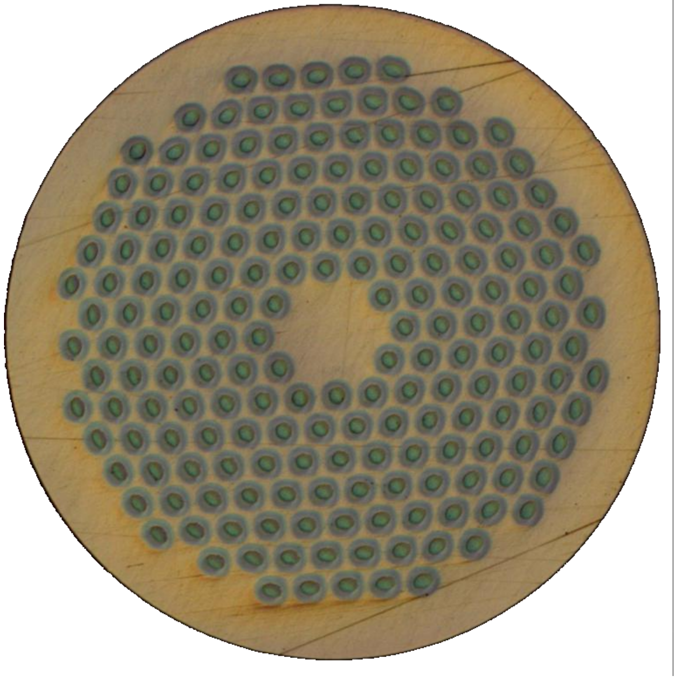


Conductor and cable parameters

- Strand diameter: 1 mm
- Cu/Sc: 1.25 → 56% Cu
- Strand #: 40
- Bare width after cabling: **20.900** mm
- Bare thickness after cabling: **1.860** mm

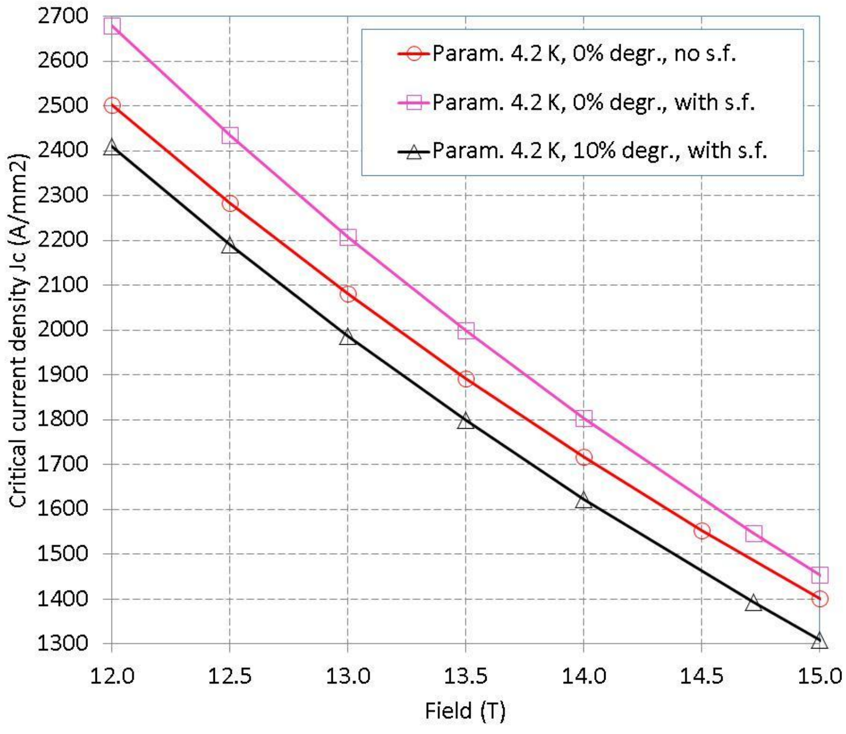
- Insulation: 0.200 mm

- Assumed growth during HT
  - 4% in thickness and 2% in width
- Bare width after HT: **21.400** mm
- Bare thickness after HT: **1.934** mm



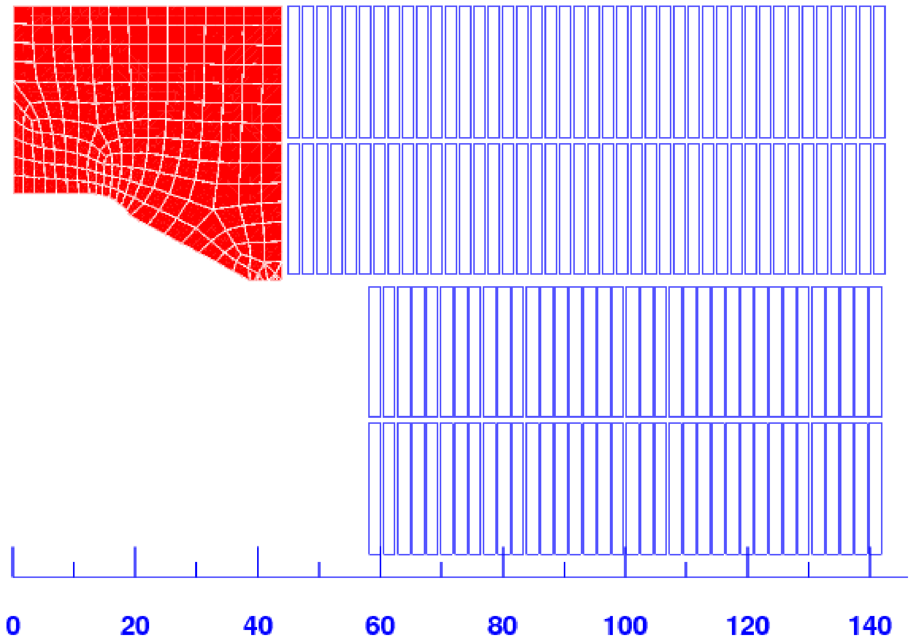
Conductor and cable parameters

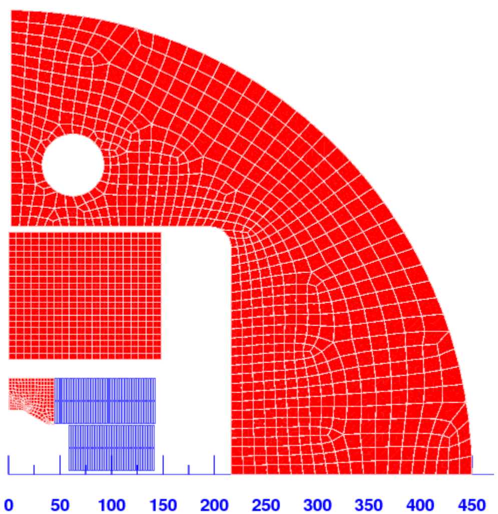
- J_c of virgin strand (4.2 K) from short-sample measurements
  - 2500 A/mm^2 at 12 T
  - 1400 A/mm^2 at 15 T
- Self field corr. of 0.41 T/kA (by B. Bordini)
- 10% cabling degradation
- Resulting J_c for computations
  - 2400 A/mm^2 at 12 T
  - 1300 A/mm^2 at 15 T



2D magnetic analysis
Coil cross-section

- Two double-layers with 36 and 42 turn
- Iron pole in layer 3-4
- 3.5 mm mid-plane shim
- 1.5 mm inter-coil gap
- 0.5 mm inter-layer shim

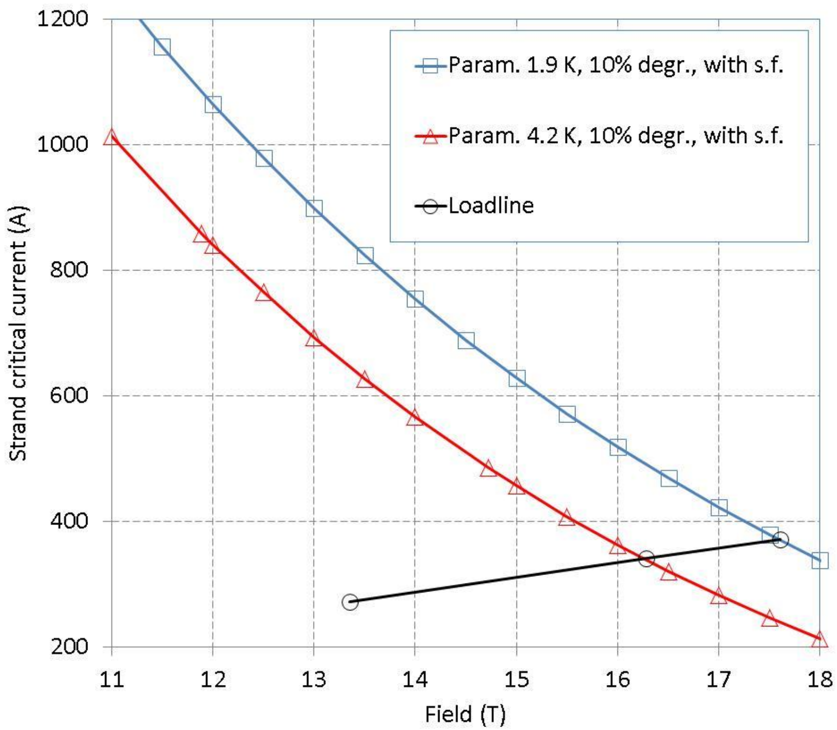




- Coil aperture 116 mm, bore 100 mm
- Iron yoke with OD of 0.9 m
- Iron filler
- S.S. horizontal pads

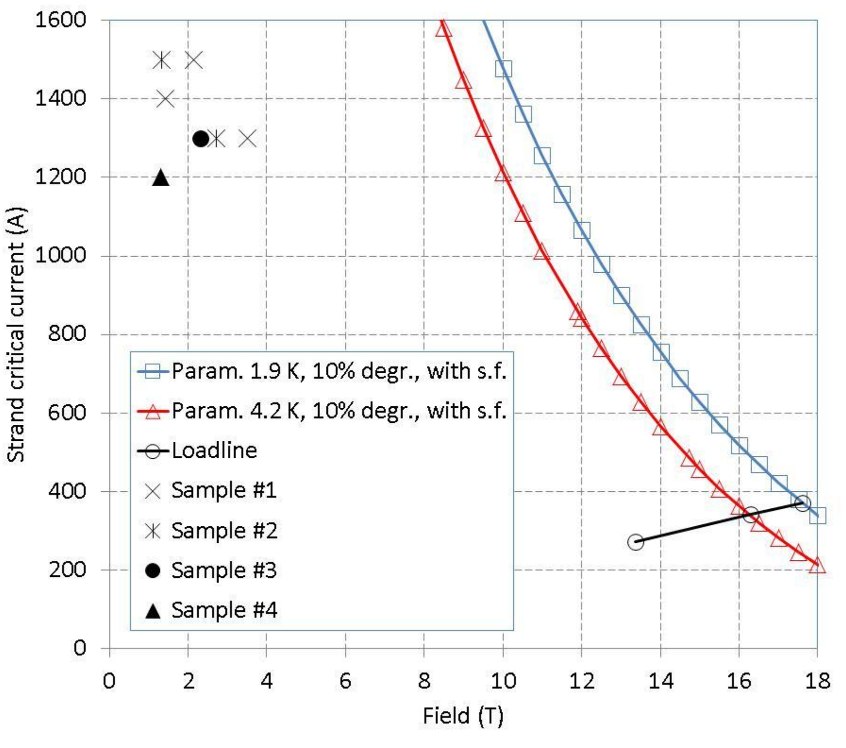
2D magnetic analysis
Magnet parameters

- Short sample conditions
  - 4.2 K, I_{ss}: 13.6 kA
    - B_{bore}: 15.8 T
    - B_{peak}: 16.4 T
  - 1.9 K, I_{ss}: 14.9 kA
    - B_{bore}: 17.0 T
    - B_{peak}: 17.6 T
  - Strain during loading/excitation not included
- Operational conditions
  - 13 T bore field
  - I_{op}: 10.9 kA
  - B_{peak_op}: 13.4 T
  - 80% of I_{ss} at 4.2 K
  - 73% of I_{ss} at 1.9 K



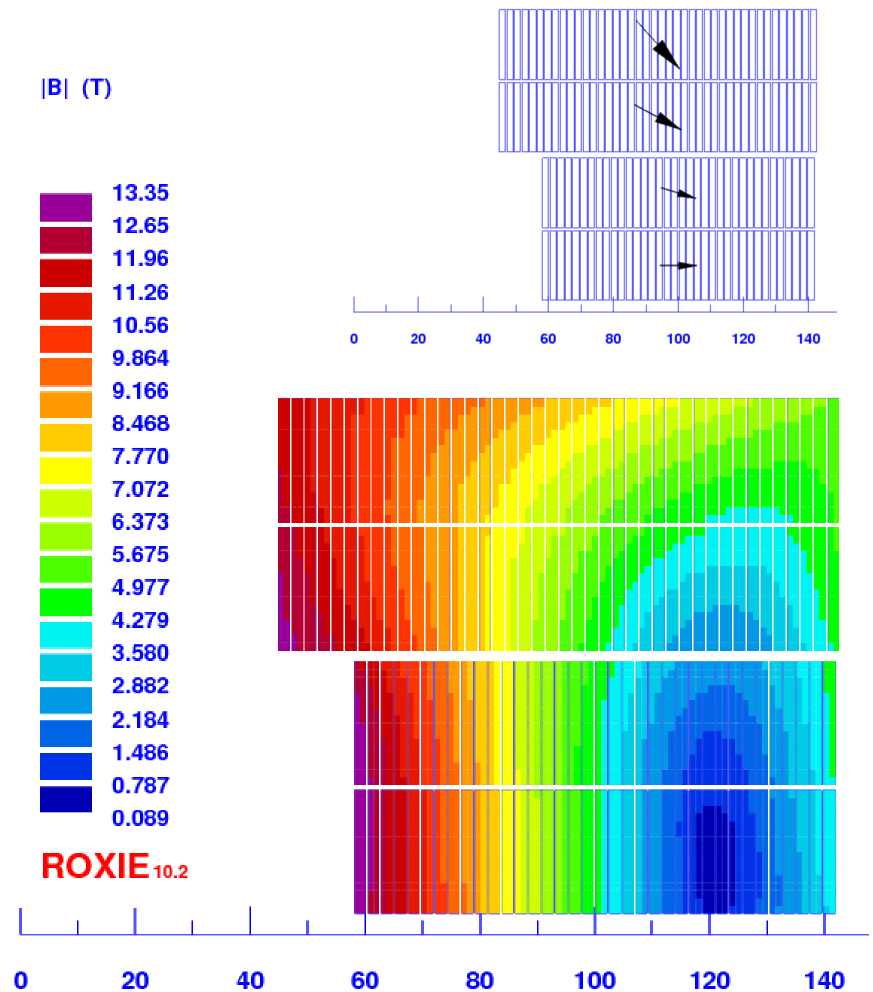
2D magnetic analysis
Magnet parameters

- Stability current I_s a factor of 3 higher then maximum strand current at short sample cond.



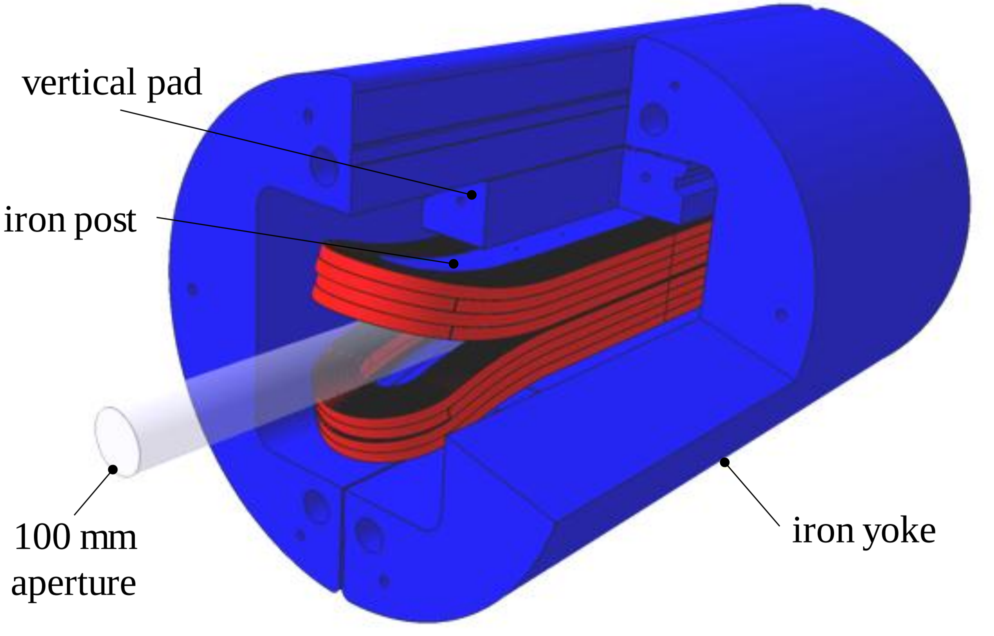
2D magnetic analysis
Magnet parameters

- Peak field in layer 1
  - Layer 2 with field 1% lower
- Margin in L3 and L4
  - From 3 to 9 %
- Field quality at 2/3 of aperture
  - <1% homogeneity
    - ~70 units of b_3, ~30 of b_5
- E.m. forces directed outwardly
  - Lorentz stress
    - Ranging from 80 MPa in L12 to 100 MPa in L34
    - 150 MPa with 15 T bore field



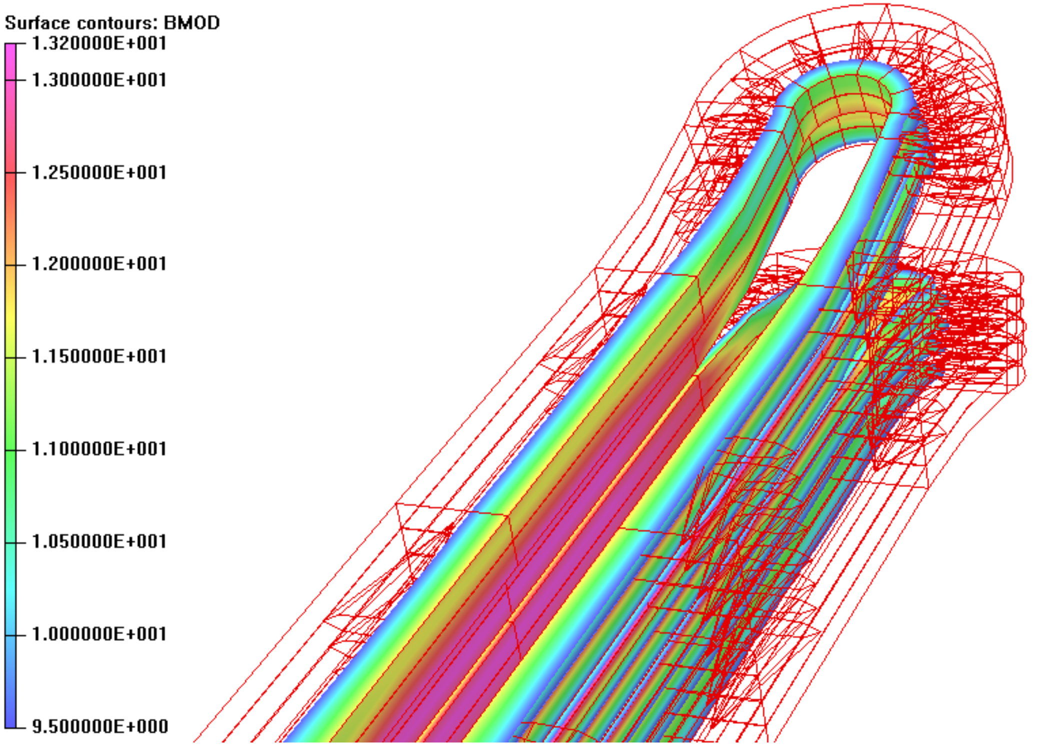
3D magnetic analysis
Coil design

- 730 mm of total straight section
- Hard-way bend with minimum radius of 700 mm
- Inclined straight section (17 degr.) of about 30 mm
- Overall coil length of 1.5 m
- Iron parts
  - Winding post in L34
  - Vertical pad over straight section
  - Full length yoke



3D magnetic analysis
Magnet parameters

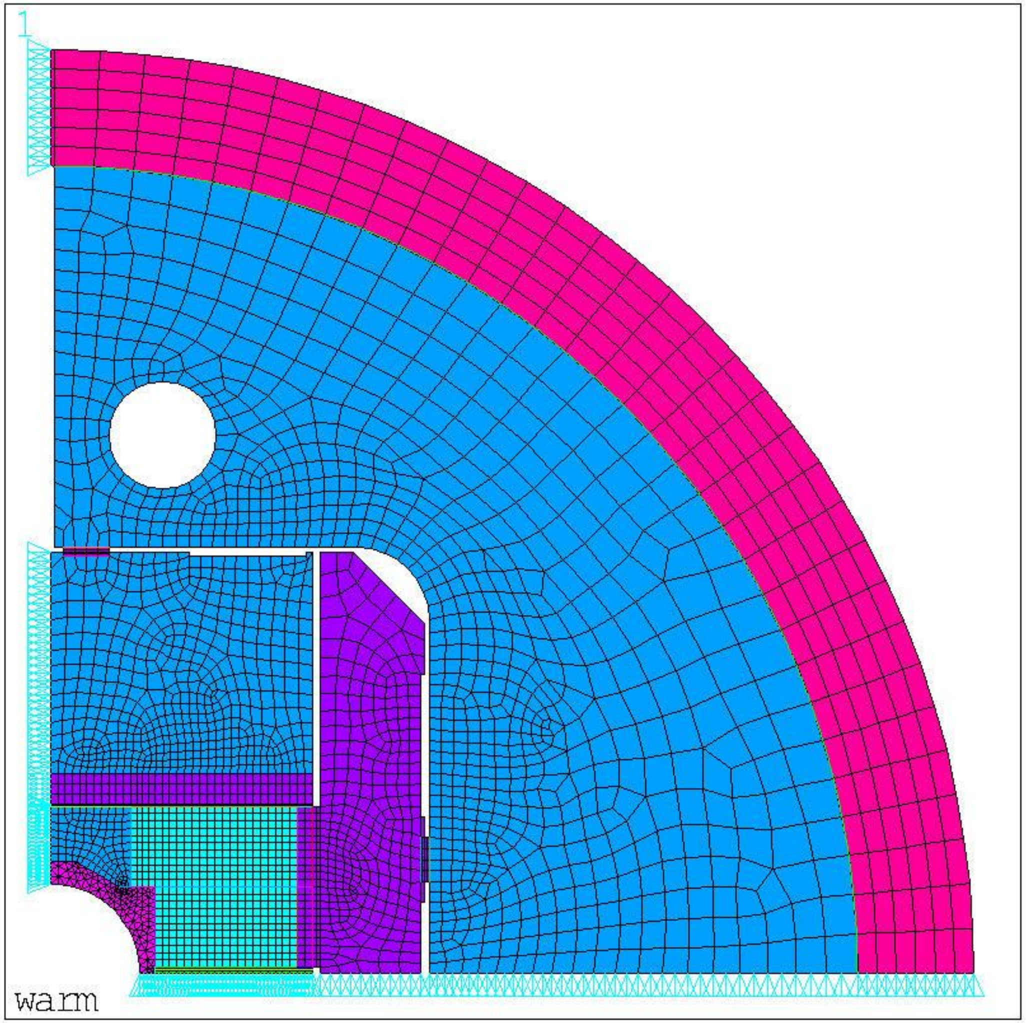
- 10% (about 1.5 T) of margin in the ends
- 1% uniformity of B_y over 540 mm along z
- Stored energy
  - FRESCA2 (13 T): **3.8 MJ**
    - HD2 (13 T): 0.6 MJ
    - LQ (240 T/m): 1.4 MJ
    - HQ (170 T/m): 0.8 MJ
- Stored energy density (J/cm^3 of coil)
  - FRESCA2 (13 T): **80 J/cm^3**
    - HD2 (13 T): 78 J/cm^3
    - LQ (240 T/m): 101 J/cm^3
    - HQ (170 T/m): 97 J/cm^3



2D mechanical analysis
Load sequence and assumptions

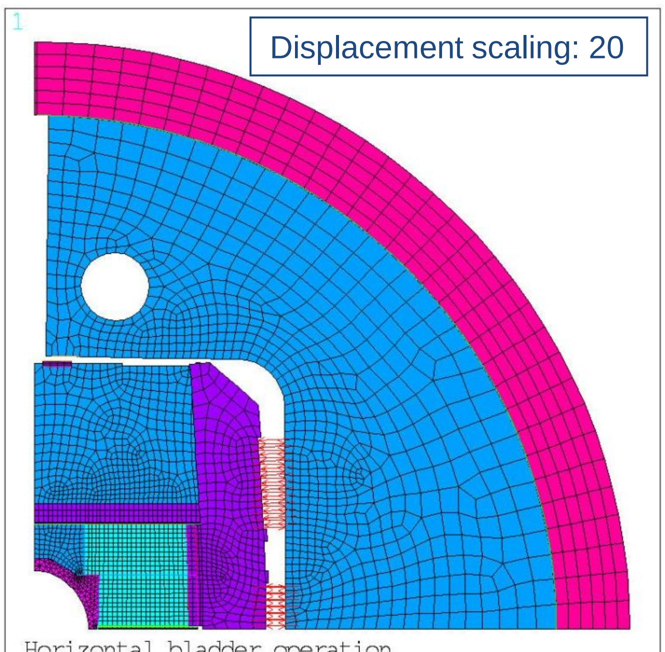
1. Bladders inflated to open clearance between pads and yoke
2. Load key shimmed
3. Bladder deflated to lock the keys
4. Cool-down
5. E.m. forces

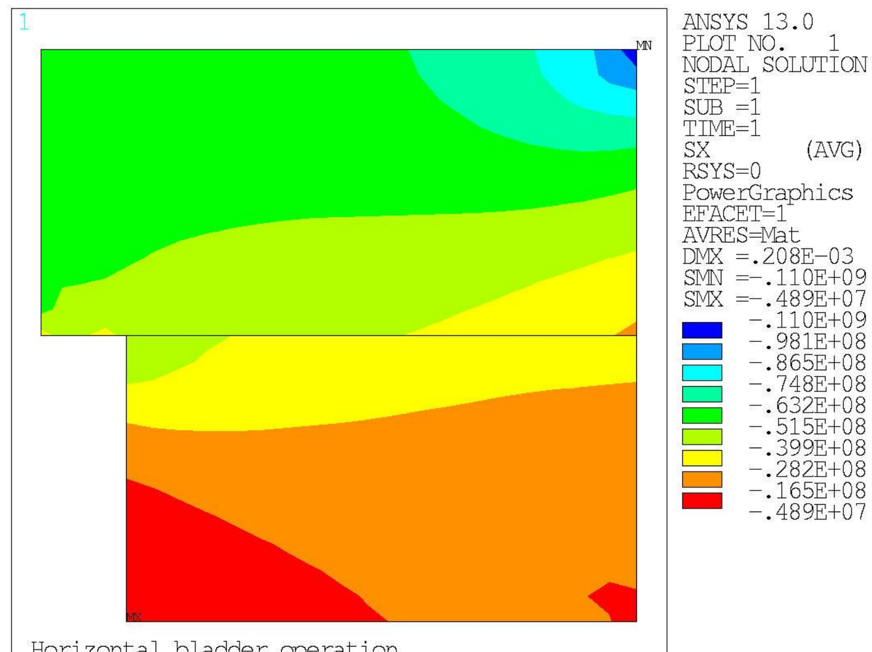
- Coil pre-load to prevent separation/tension between pole turn and post with e.m. forces
- 0.2 friction between component
- Coil parts bonded



2D mechanical analysis
Bladder operation

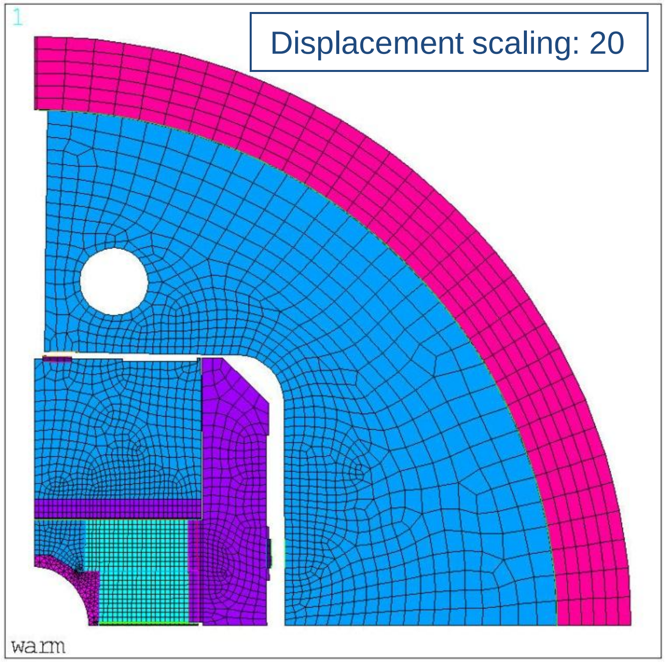
- Clearance of 0.7 mm created by horizontal bladders pressurized to about 30-40 MPa
- Coil peak stress ~100 MPa
  - Mainly due to bending of horizontal pad

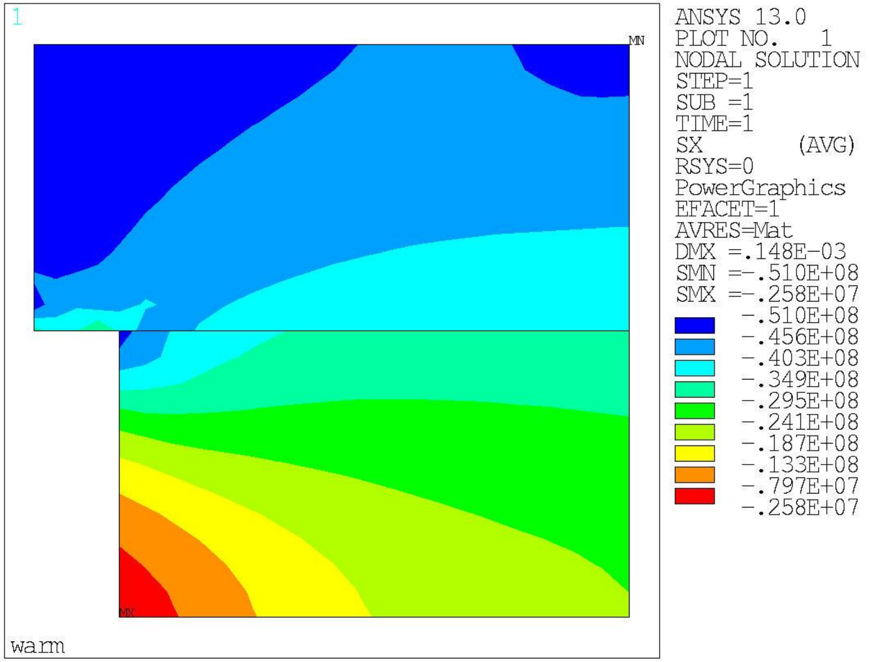




2D mechanical analysis
Key insertion

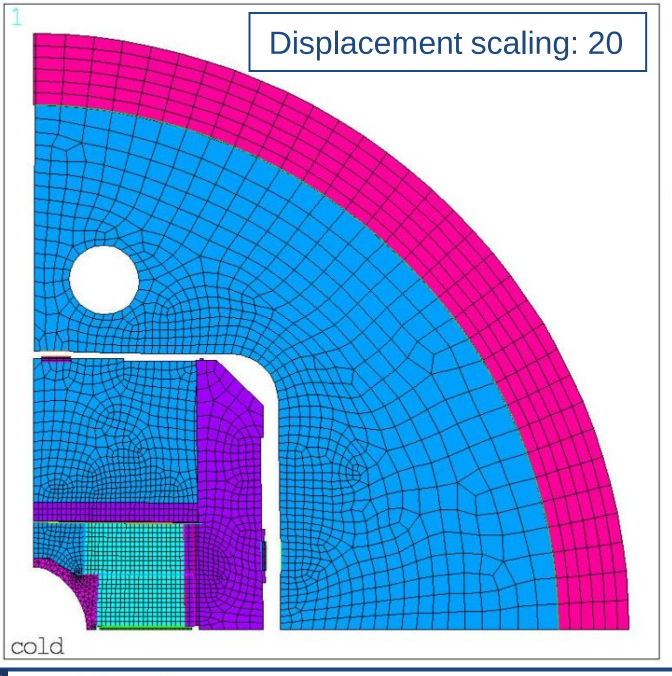
- Insertion of a shim in hor. load keys of about 0.6 mm
- Coil peak stress reduced to ~ 50 MPa
  - No pad bending → more uniform pre-load from

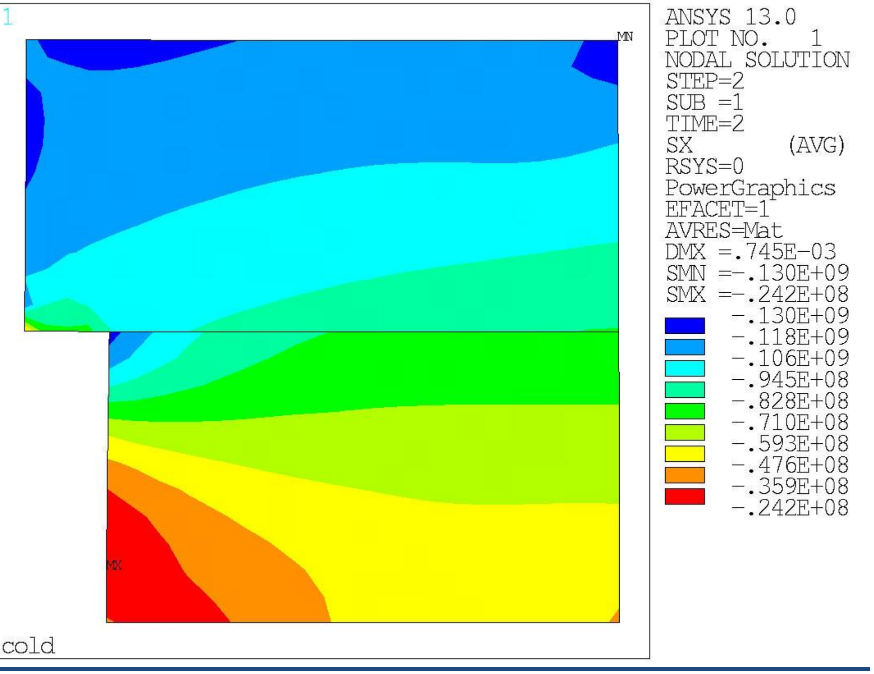




2D mechanical analysis
Cool-down

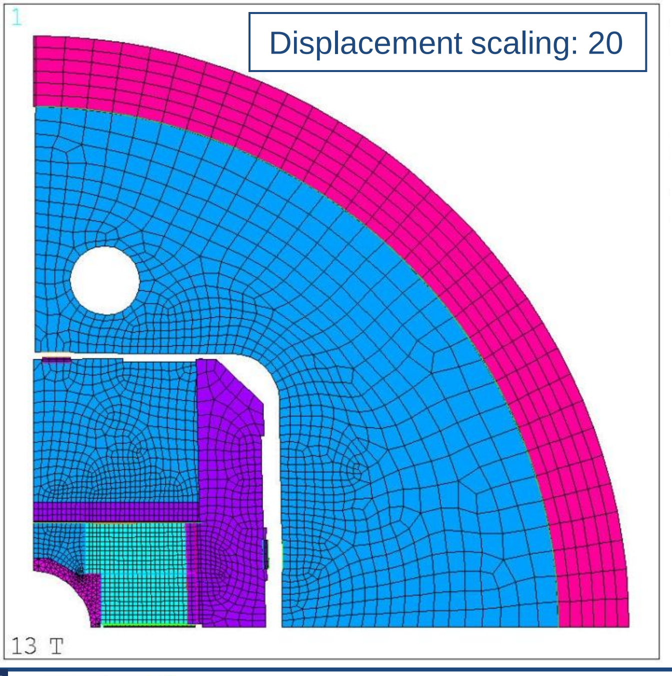
- Increase of average shell stress from 50 to 150 MPa
- Coil peak stress ~ 130 MPa
  - Deformation of L12 post

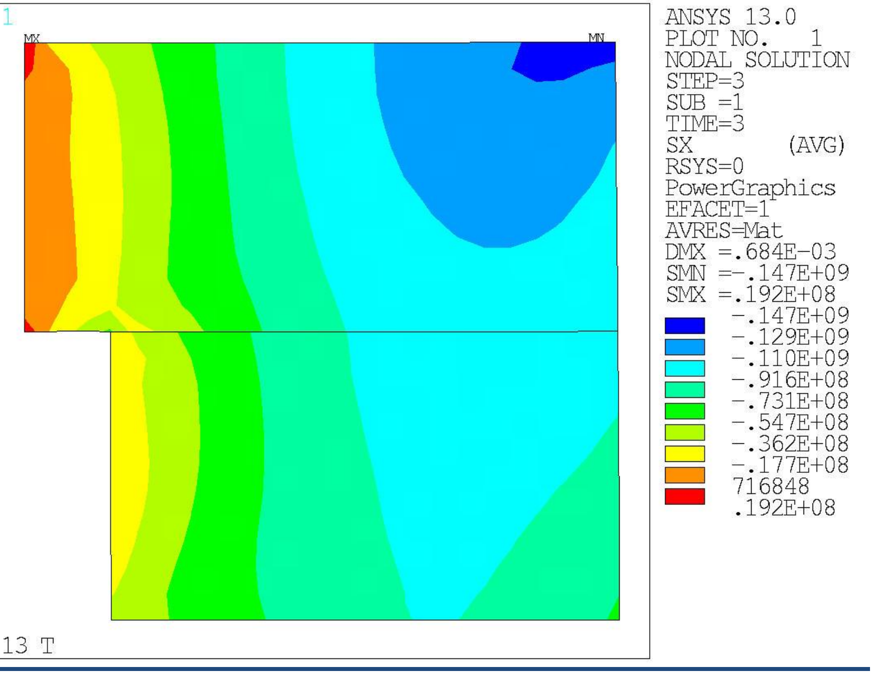




2D mechanical analysis
Excitation

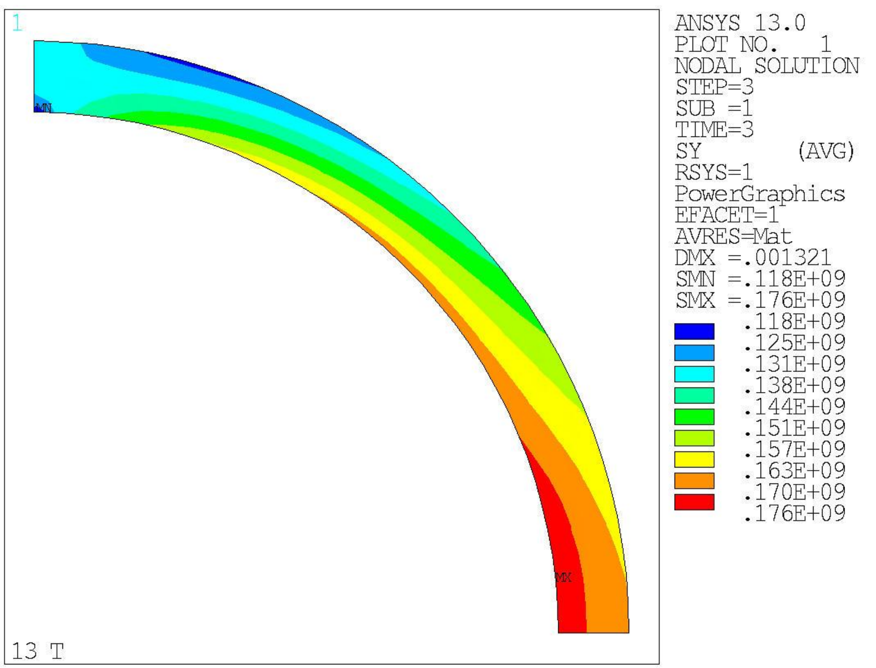
- Coil pole turns still in contact with posts
- Coil peak stress <150 MPa
  - Maximum stress moved to low field region

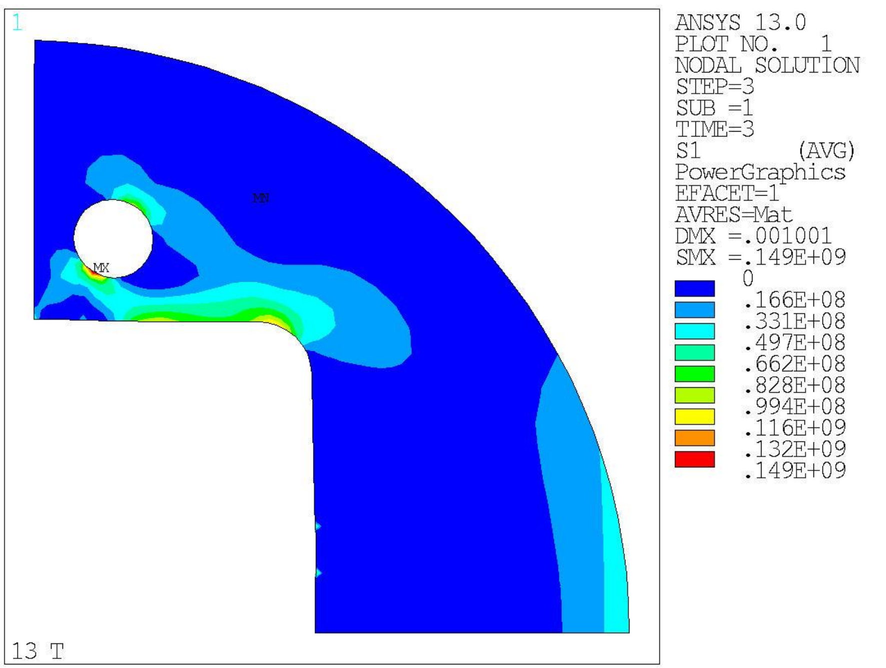




2D mechanical analysis
Stress in the support structure

- Peak shell stress: from 70 to 180 MPa
- Maximum tensional stress in the iron: 150 MPa
- All other components within yield stress limits

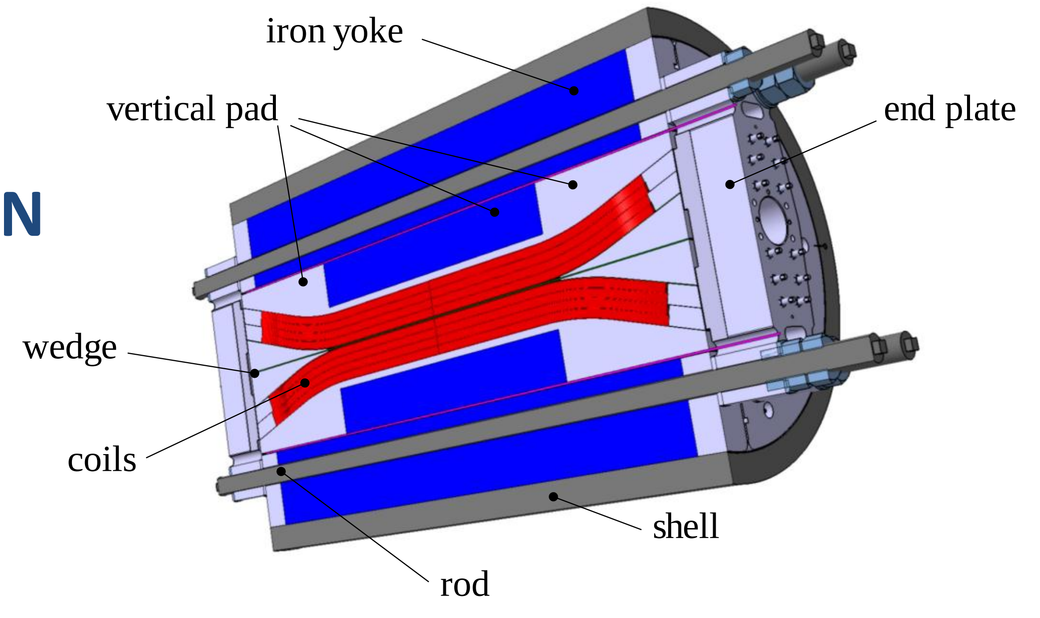




3D mechanical analysis
Support structure design

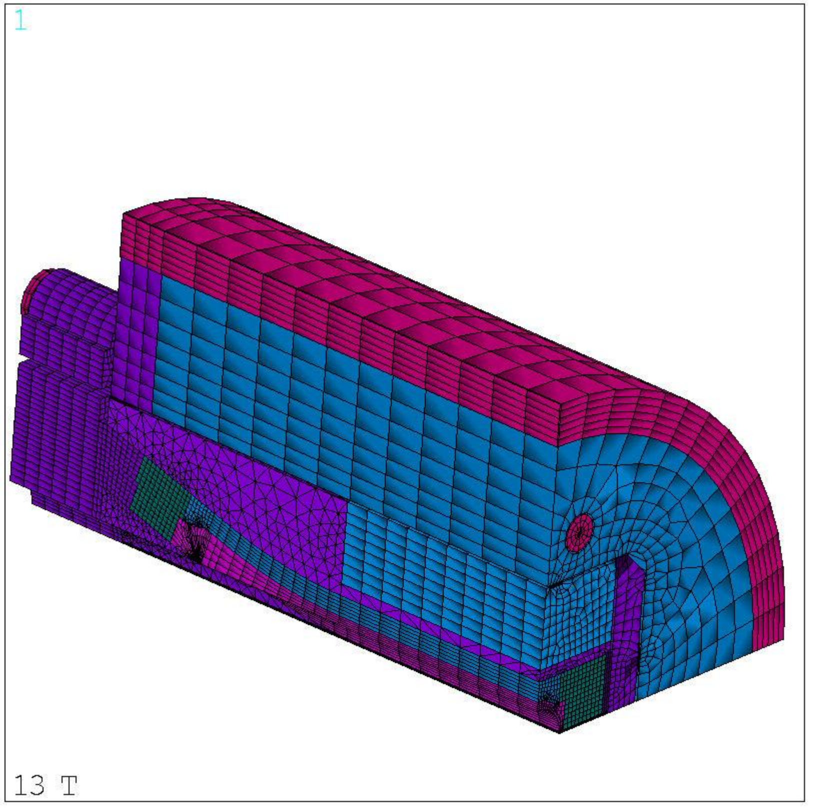
- Axial support composed by
  - Aluminum rods with a diameter of 60 mm
  - Nitronic 50 end plate 150 mm thick
    - Bullets to deliver pre-load to end-shoes and wedge

- Axial force
  - FRESCA2 (13 T): **2.8 MN**
    - HD2 (13 T): 0.7 MN
    - LQ (240 T/m): 0.5 MN
    - HQ (170 T/m): 0.8 MN



3D mechanical analysis
Load sequence and assumptions

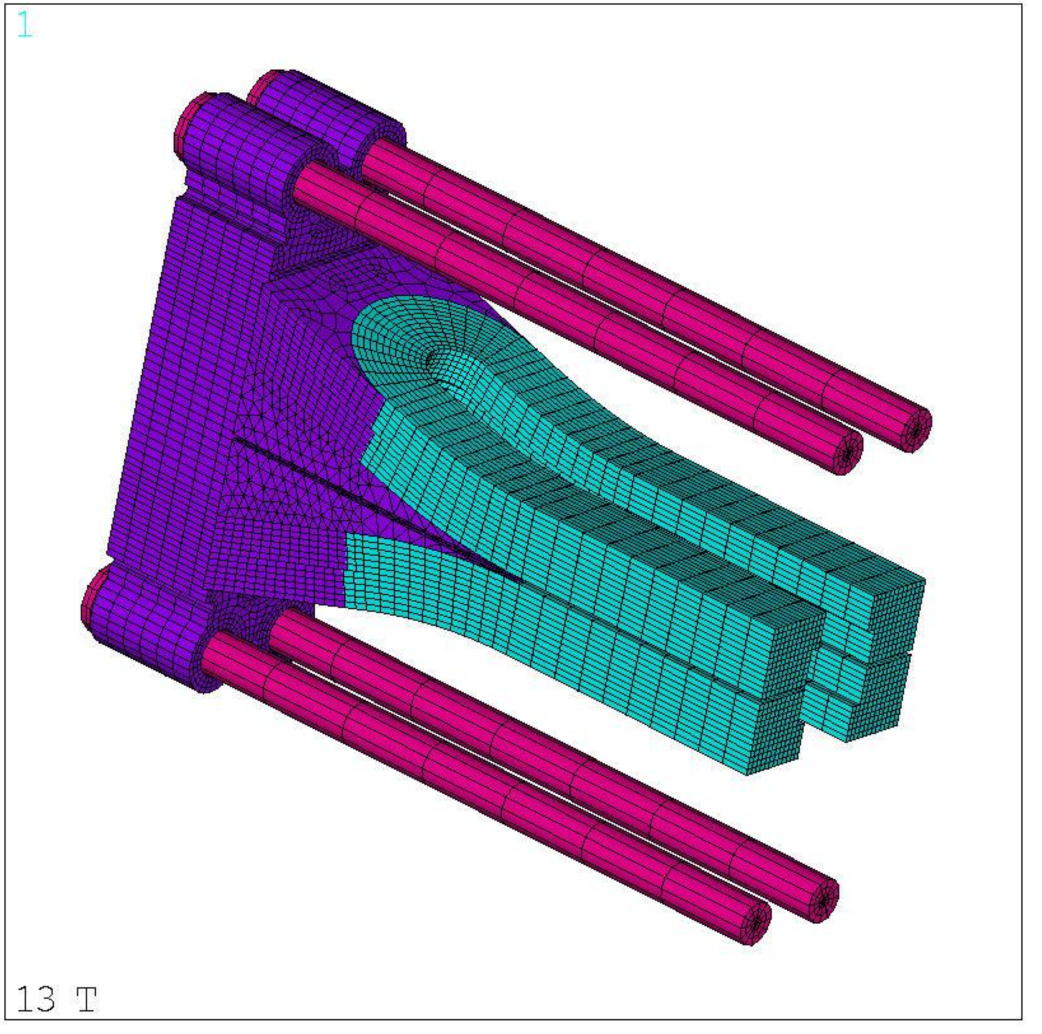
1. Piston system to pre-tension axial rods
2. Rod nuts torqued
3. Piston system released
4. Cool-down
5. E.m. forces



- Coil axial pre-load to prevent separation/tension between pole turn and post with e.m. forces
- 0.2 friction between component
- Coil parts bonded

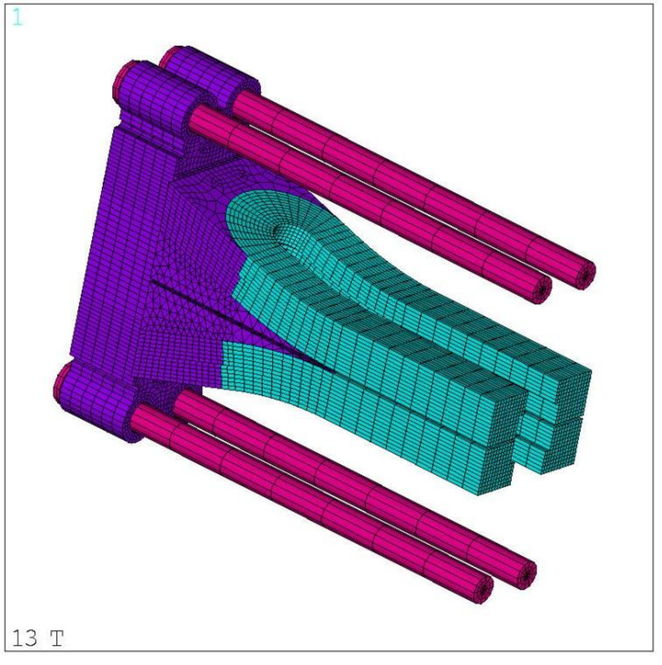
3D mechanical analysis
Axial pre-load

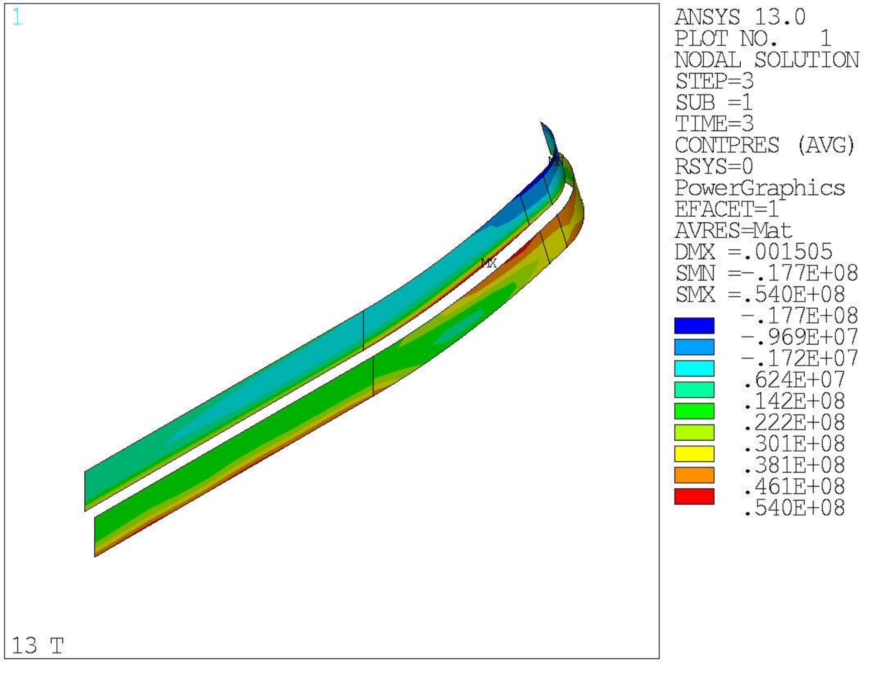
- E.m. axial force
  - 2.8 MN
- Room temperature pre-load
  - Rod stress: 150 MPa
  - 1.7 MN
  - Provided by 150-200 t piston
- 4.2 K pre-load
  - Rod stress: 260 MPa
  - 2.8 MN
  - Provided to end-shoes and wedge (glued)



3D mechanical analysis
Contact pressure coil-pole

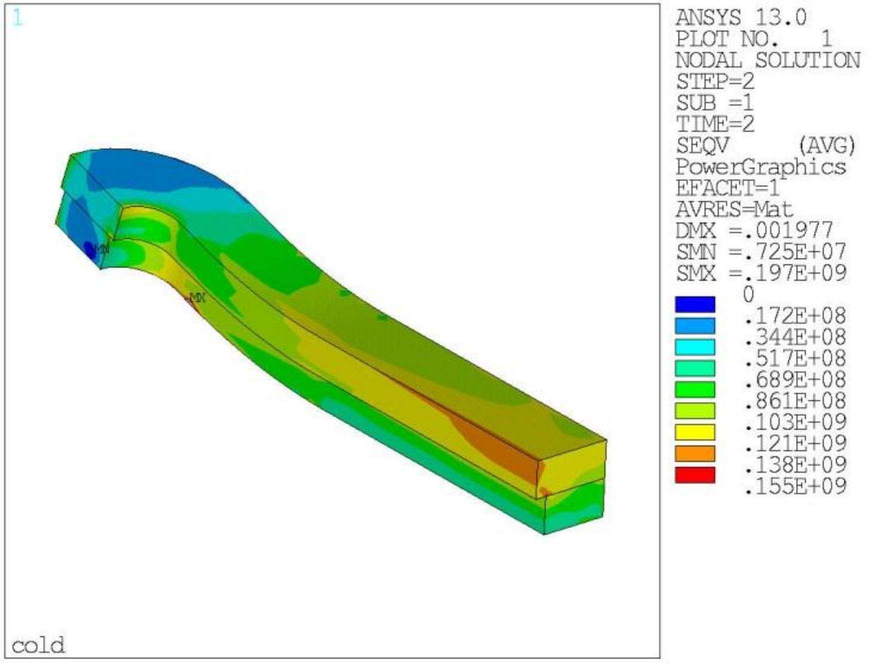
- Contact pressure (or tension <20 MPa) between pole turn and pole pieces
  - From straight section to hard-way and easy-way bent

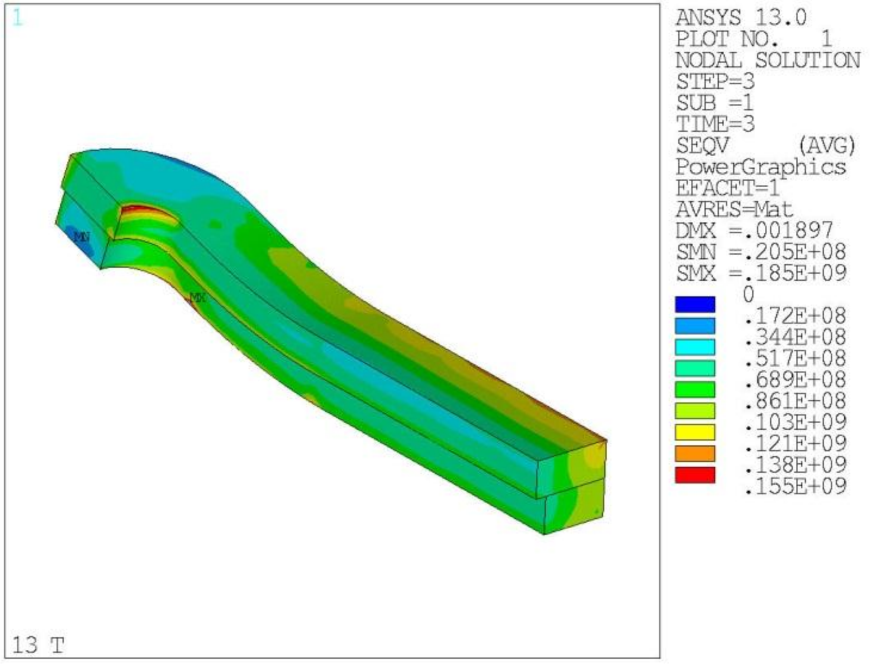




3D mechanical analysis
Stress in the coil

- Von Mises stress in the coil <150 MPa after cool-down and with e.m. forces





Conclusions

- 2D and 3D magnetic and mechanical analysis performed
  - Updated computations with cable growth during reaction and recent extracted strand measurements
- Operational conditions: 13 T bore field
  - 80% of I_{ss} at 4.2 K
  - 73% of I_{ss} at 1.9 K
  - Large magnetic stability margin
- Coil peak stress below 150 MPa during all magnet operations
- Support structure capable of providing full pre-load (up to 15 T) in straight section, ramp, and end region

Appendix

3D mechanical analysis
Stress in axial support components

- Stress in axial rod (aluminum) and end-plate (Nitronic 50) within yield stress limits