FRESCA2 magnet design latest version

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EuCARD ESAC review for the FRESCA2 dipole
CEA, Saclay
27-29 February, 2013

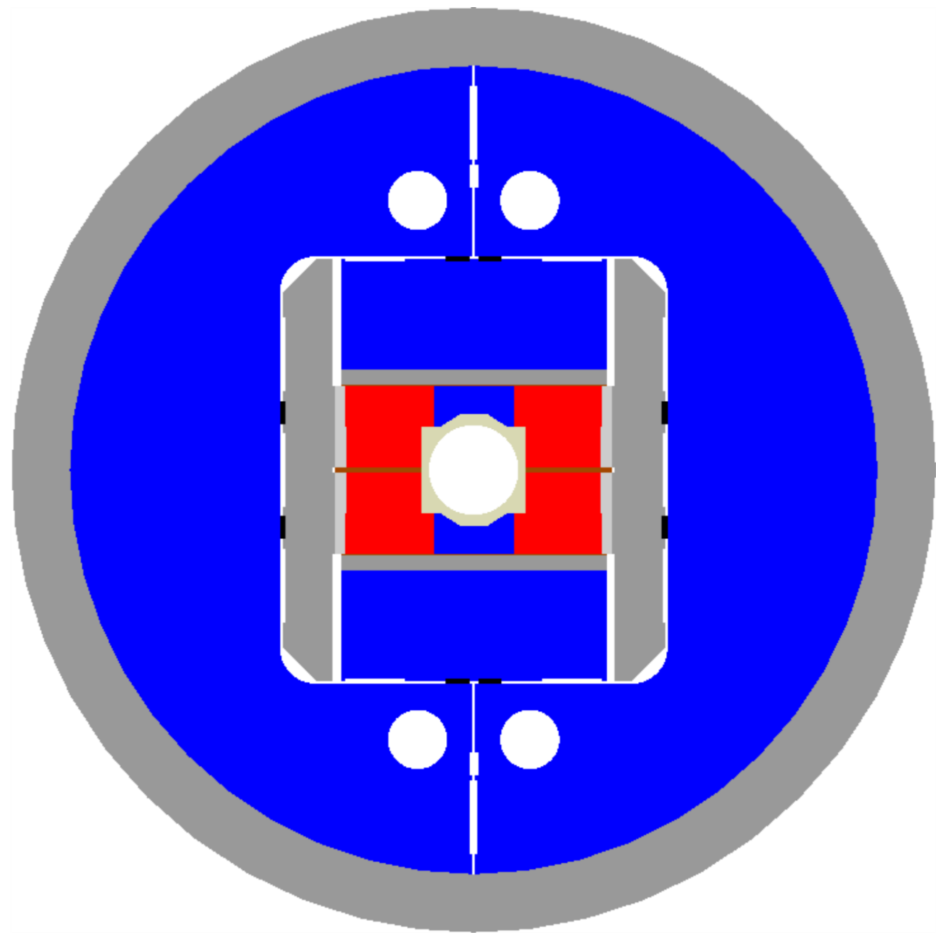
Outline

- Introduction: magnet overview
- Conductor and cable parameters
- Coil design and magnet parameters
- Support structure and stresses
- 3D FE analysis
  - Horizontal and axial pre-load conditions
- Conclusions

Introduction
Overview of magnet design

- Target: 13 T in 100 mm clear bore

- OD: 1.030 m; length: 2.255 m
- Al shell, 65 mm thick, 1.6 m long
- Bladder and key pre-load
- Iron yoke
  - Holes for axial rods (60 mm ∅)
- Horizontal stainless steel pad
  - 3 bladders per side, 75 mm wide
  - 2 load keys
- Vertical iron pad
  - 2 bladders per side, 60 mm wide
  - 2 load keys
- Four double-layer coils
- Iron and Ti alloy central posts



Timeline

- Version tracker

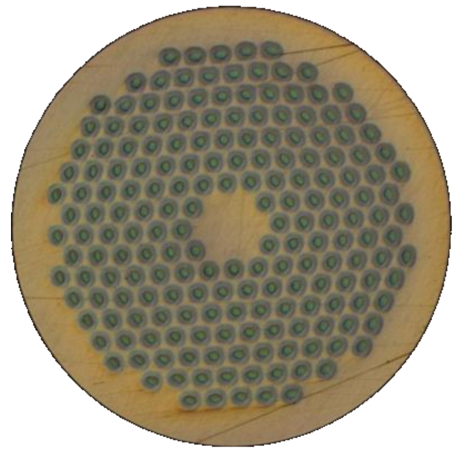
Date	#	Status
2012 June	**4.4**	**Structure has been realized and assembled successfully** **Winding tests will be done on this version**
2011 October	3.4	Last corrections before realization of the structure
2011 July	2.3	Call-for-tenders of Coil pack mockup + Structure
2011 March	2.2	"Optimized" coil/structure geometry
2011 February	1.1	"Baseline" version

Conductor and cable parameters

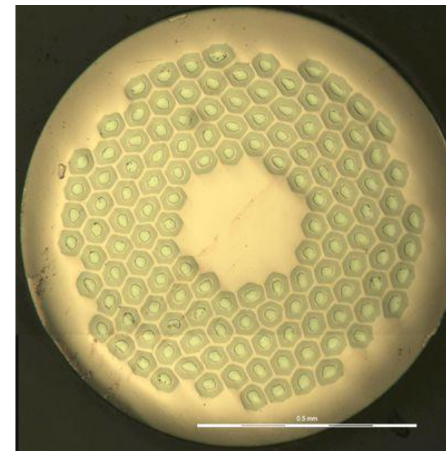
- PIT (192) and RRP (132/169)
- Strand diameter: 1 mm
- Cu/Sc: 1.3 → 56% Cu
- Strand #: 40
- Bare width after cabling: **20.90** mm
- Bare thickness after cabling: **1.82** mm
- Braided insulation: 0.2 mm

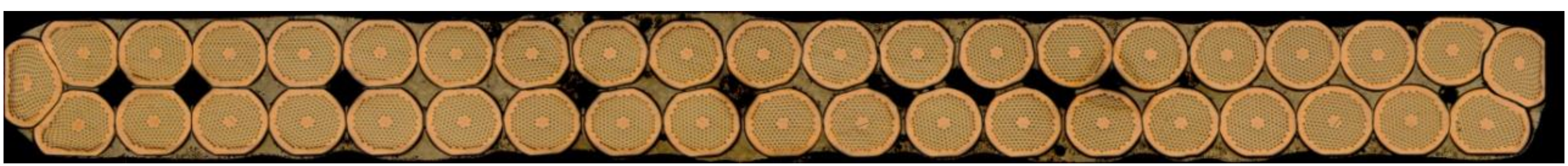
- Assumed growth during HT
  - 4% in thickness and 2% in width
    - Based on LARP and SMC experience
- Bare width after HT: **21.32** mm
- Bare thickness after HT: **1.89** mm

PIT strand



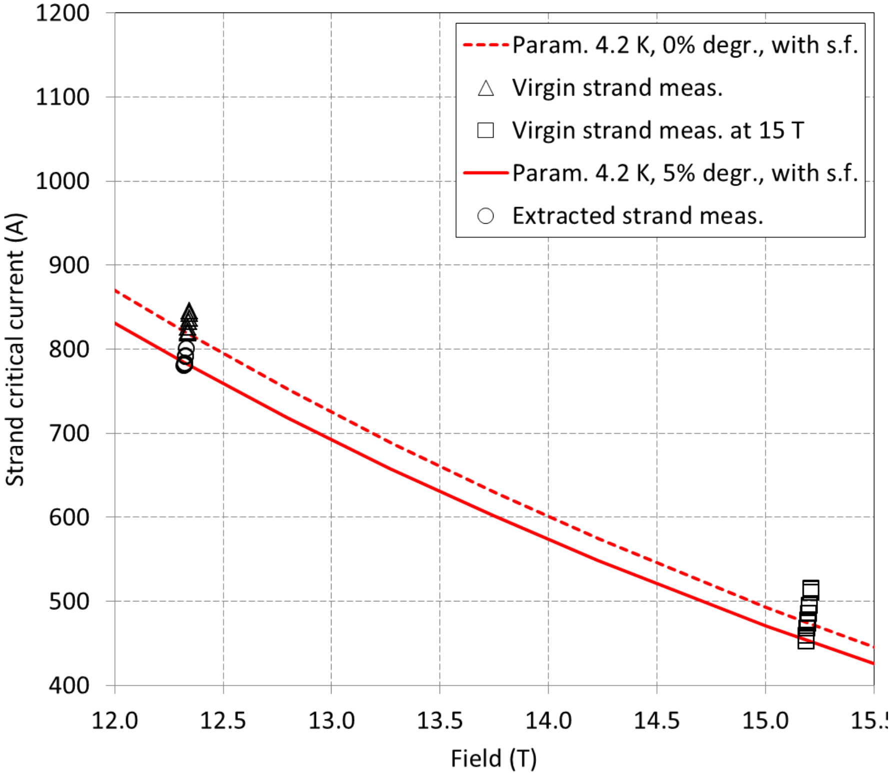
RRP strand



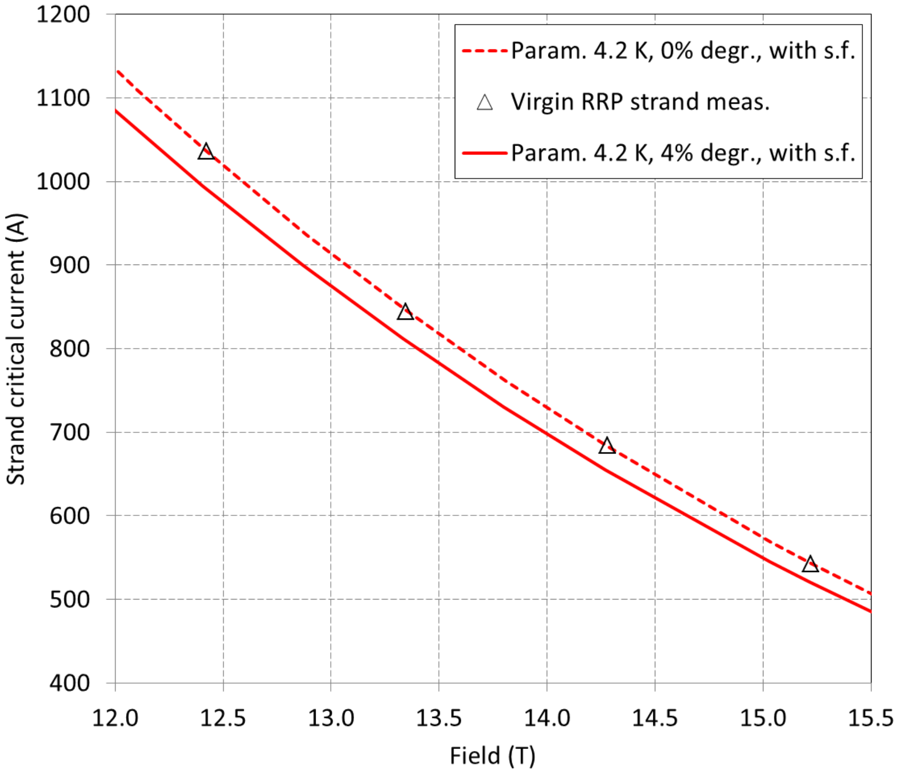


Conductor properties: I_c (with self-field correction)

- PIT
  - 5% cabling degradation

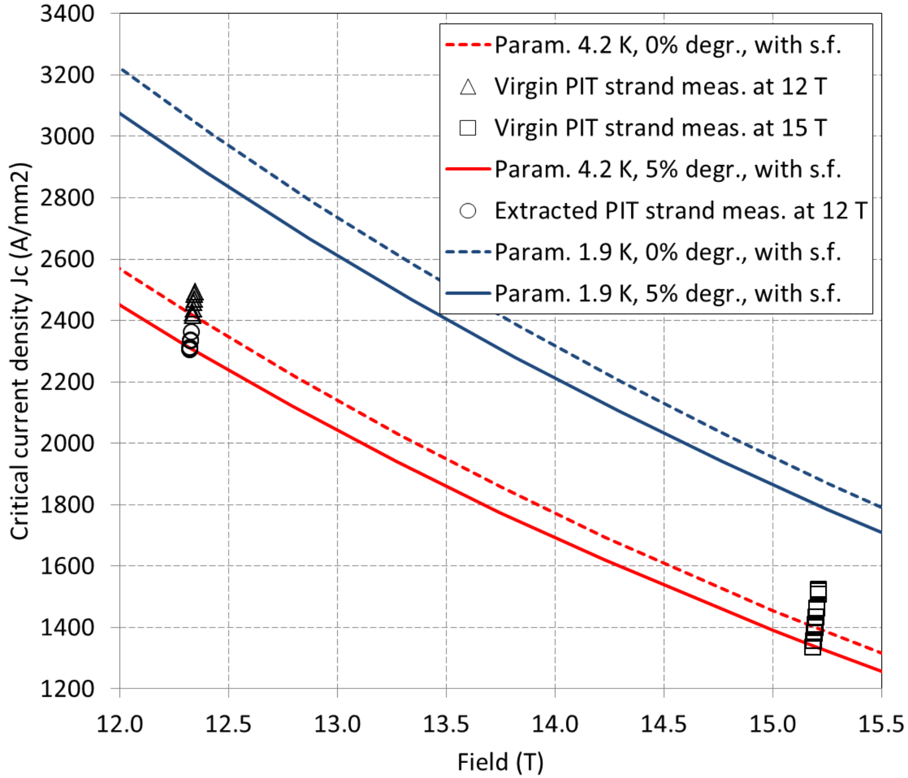


- RRP
  - 4% cabling degradation

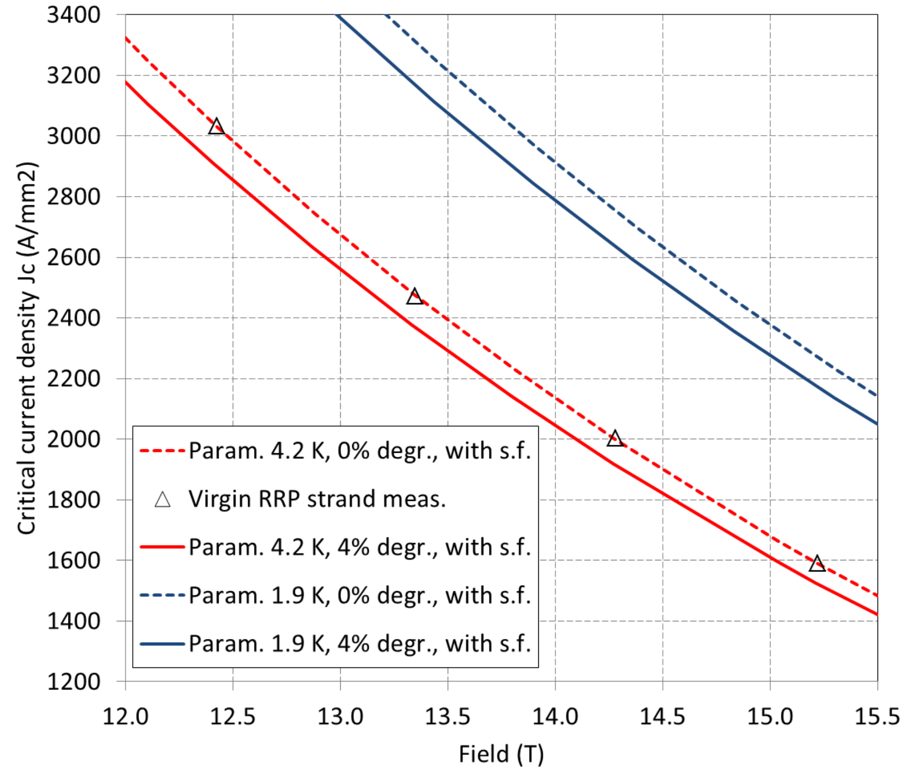


Conductor properties: J_c (with self-field correction)

- PIT
- J_c (A/mm^2): 2450 at 12 T, 1400 at 15 T

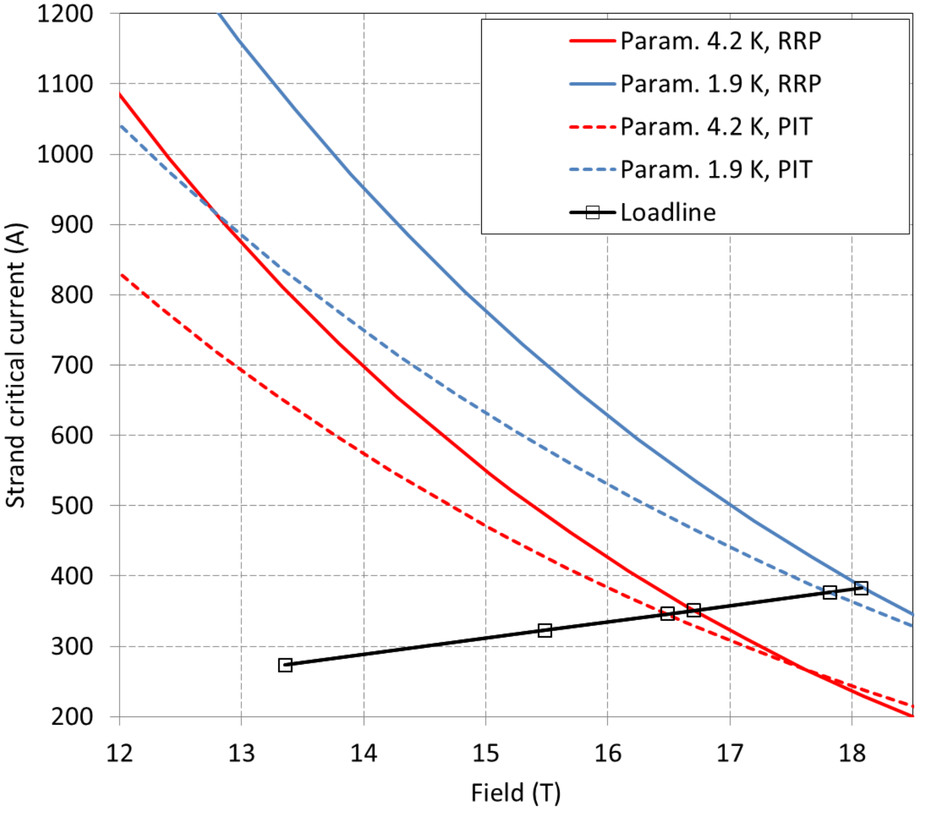


- RRP
- J_c (A/mm^2): 3150 at 12 T, 1600 at 15 T



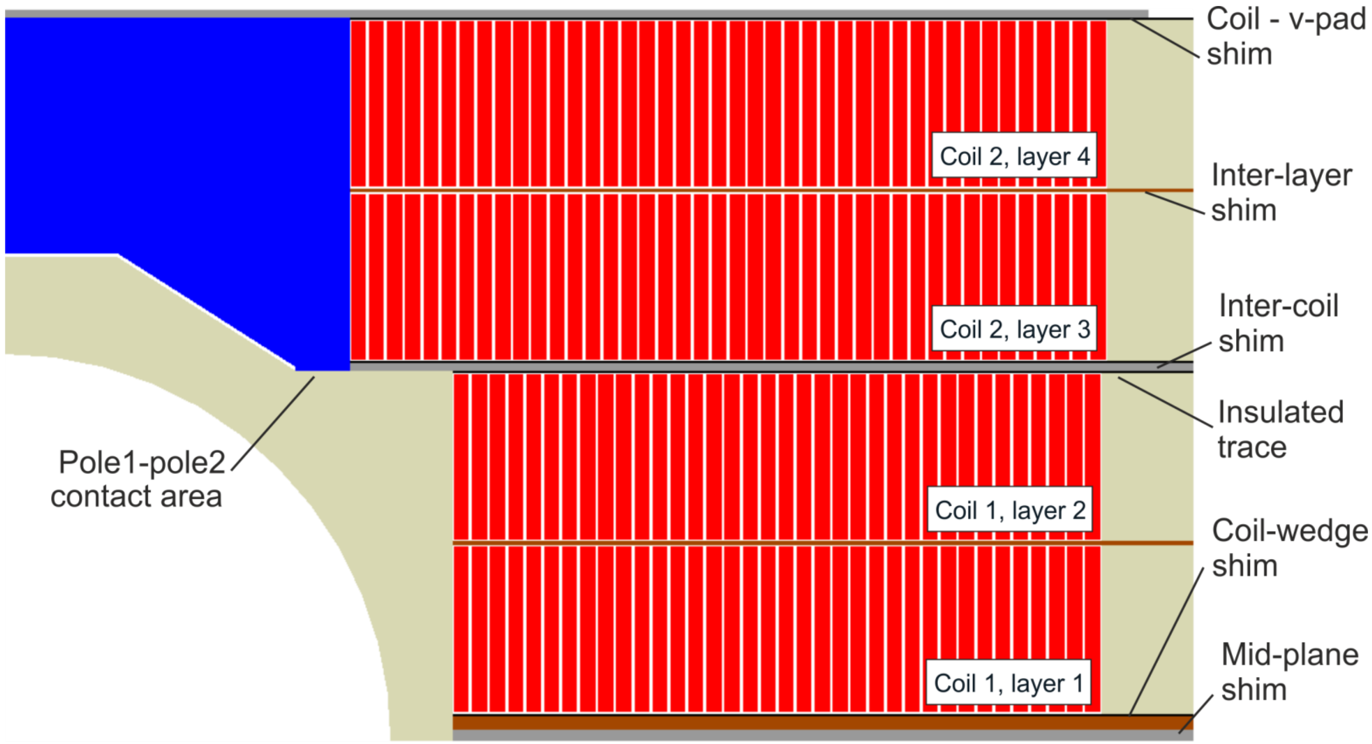
Magnet parameters

- Operational condition (13 T)
  - I_{op}: 10.9 kA
  - B_{peak_op}: 13.4 T
  - ~79% of I_{ss} at 4.2 K
    - B_{bore_ss}: 16.0 T
  - ~72% of I_{ss} at 1.9 K
    - B_{bore_ss}: 17.2 T;
- 15 T bore field ("ultimate")
  - 86% of 1.9 K I_{ss}
- 1% difference (load-line) between PIT and RRP



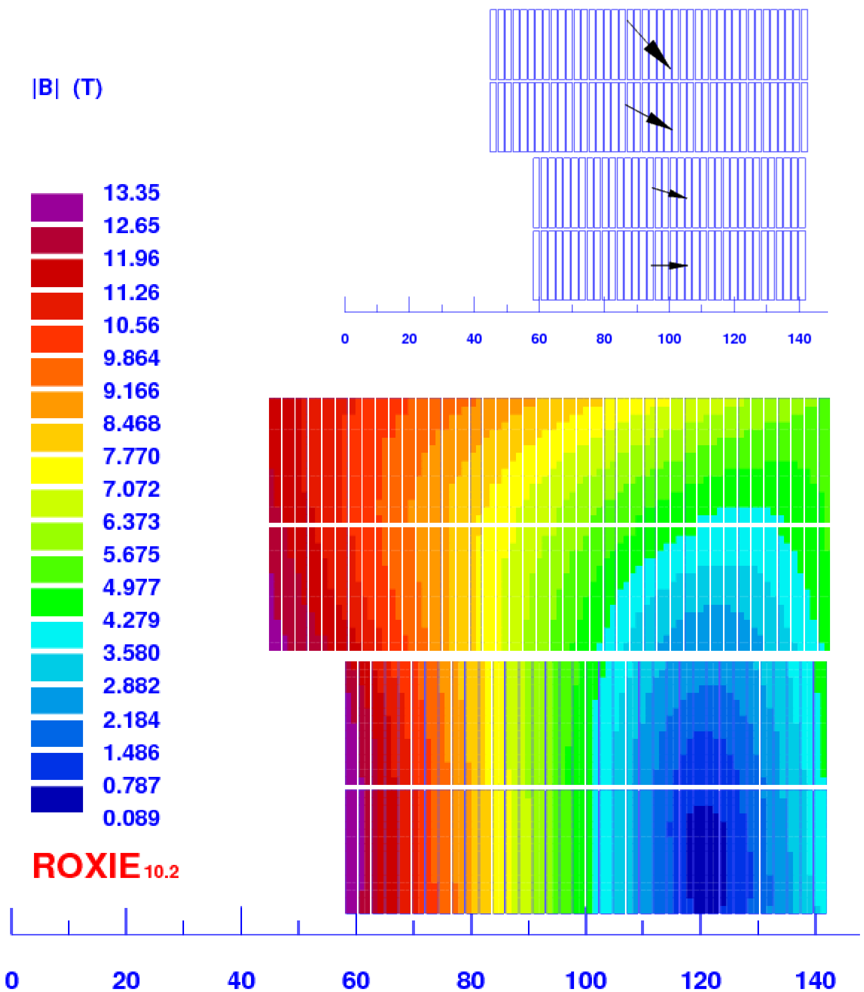
Coil cross-section

- Two double-layers with 36 and 42 turns
- Bore aperture 100 mm
- Iron and Ti poles
- Inter-coil gap and mid-plane “tailored” shim



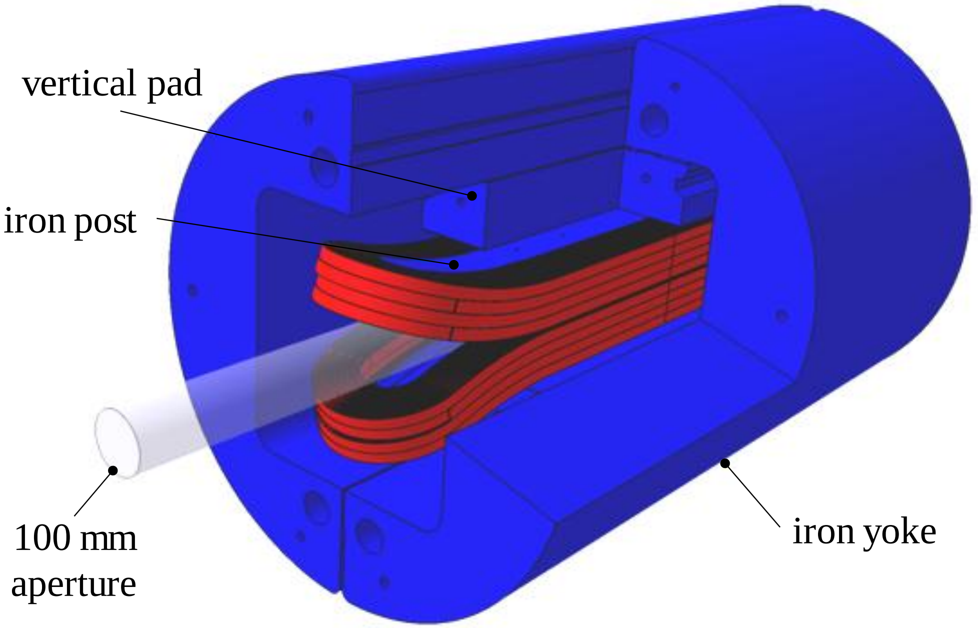
2D magnetic analysis

- Peak field in layer 1
  - Layer 2,3,4 with field 1%,3%,9% lower
- Field quality (2/3 of R_{bore})
  - <1% homogeneity
    - ~70 units of b_3, ~30 of b_5
- E.m. forces
  - Lorentz stress
    - 75 MPa in L12
    - 95 MPa in L34
      - 130 MPa with 15 T bore field



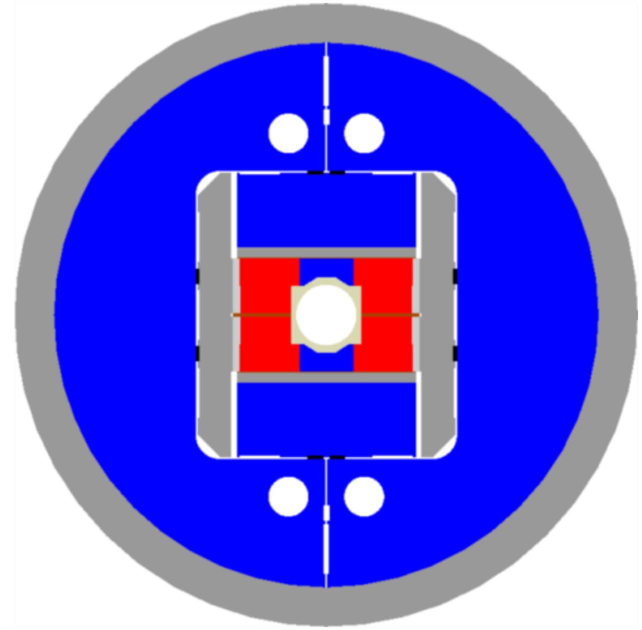
3D magnetic analysis
Coil design

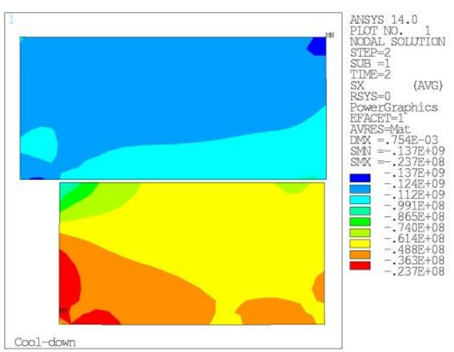
- 730 mm of total straight section
- Hard-way bend with minimum radius of 700 mm
- Inclined straight section (17 degr.) of about 30 mm
- Coil length of 1.5 m
- 10% field margin in the ends
- 1% uniformity of over 540 mm along z
- Stored energy (13 T): **3.8 MJ**
  - Stored energy density comparable to other Nb_3Sn magnets

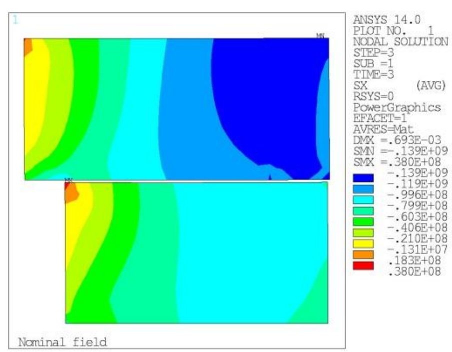


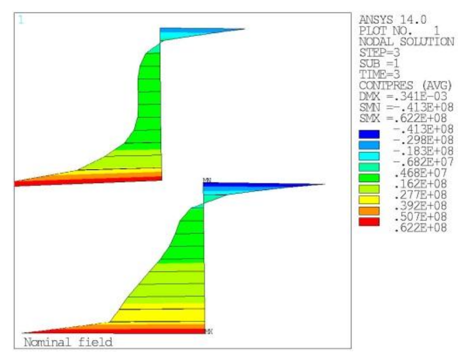
Support structure

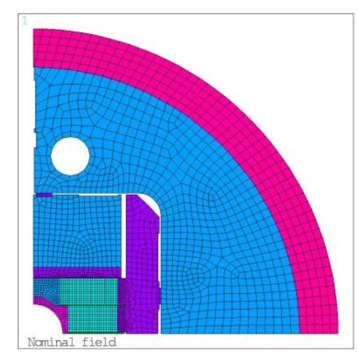
- Horizontal bladders pressurized to 30 MPa
  - Insertion of a shim in horizontal load keys of 0.6 mm
- Shell σ from 65 (293 K) to 185 (4.2 K) MPa
- Structure capable to withstand ultimate field (15 T)
- 2D model (13 T)
  - no coil-pole separation and σ_{coil}~140 MPa









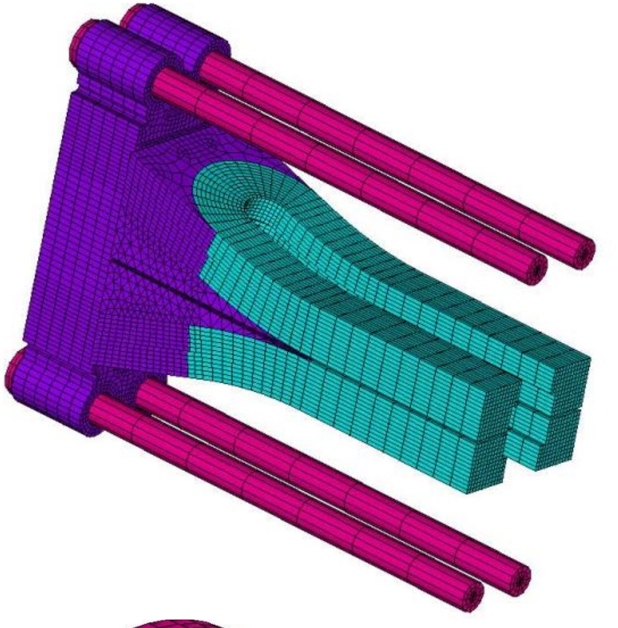


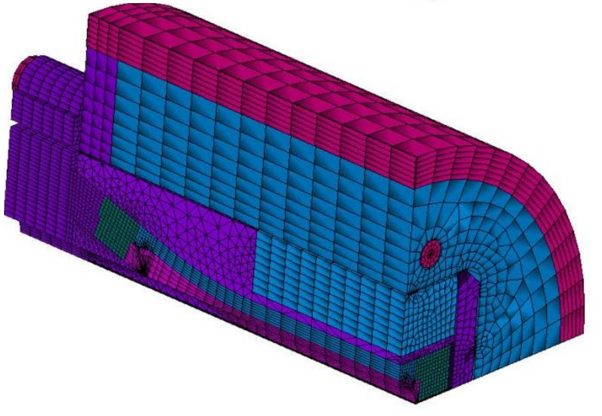
End forces and support

- Axial force: 2.8 MN
- Axial piston used to pre-load the rods
  - 60 mm diameter

- Room temperature pre-load
  - Rod stress: 150 MPa
  - 1.7 MN (170 t) provided by 200 t piston
- 4.2 K pre-load
  - Rod stress: 260 MPa
  - 2.8 MN (280 t) to end-shoes and wedge (glued)

- Alternative option
  - Axial force from rod to yoke (bullets on coil/wedge)
    - Infinitely rigid condition



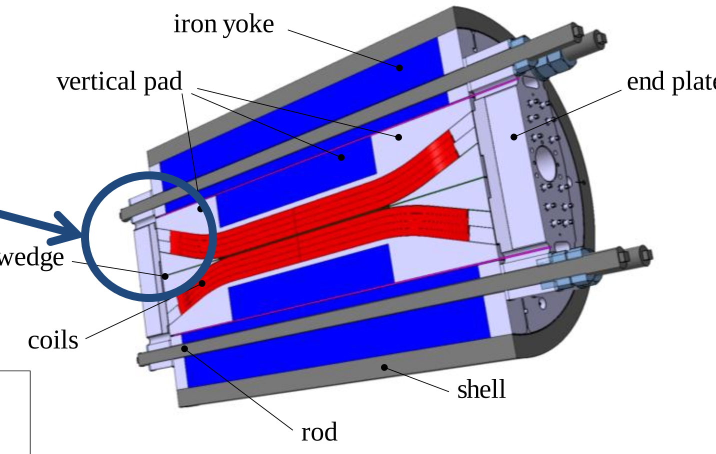


Conclusions

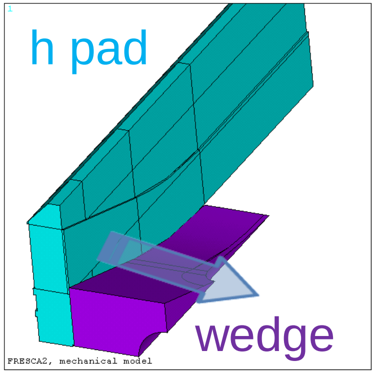
- FRESCA2 development from design to fabrication/assembly phase
  - Goal: 13 T in 100 mm bore
- According to measured strand properties, the magnet operates with more than 20% of current margin
- Coil peak stress below 150 MPa during all magnet operations
- Support structure capable of providing full pre-load (up to 15 T) in straight section, ramp, and end region

Study in progress: an overview

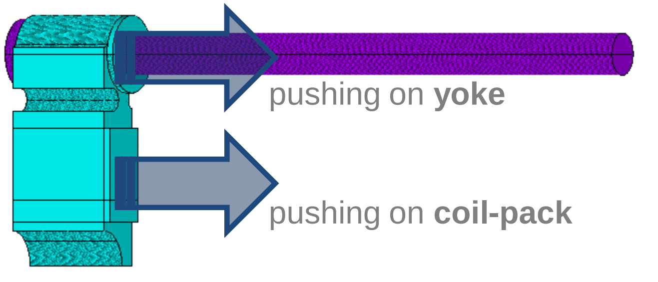
Wedge:
- Impregnated with coil 1-2?
- Or not impregnated?



Lateral support:
- Contact in **h-pad / wedge**?
- Or no contact?

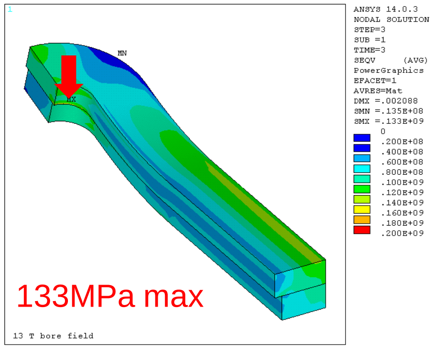


Axial loading:
- Pushing on the **coil-pack** only
- Pushing on the **coil-pack** and **yoke**

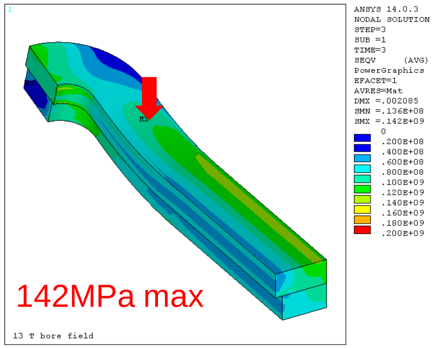


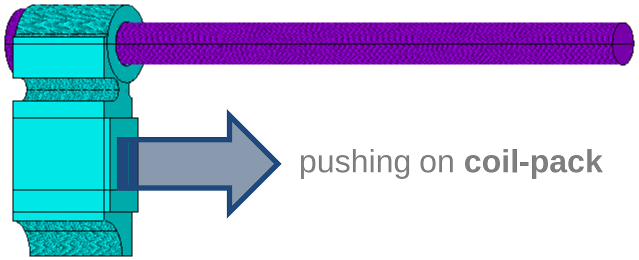
Cases of study: impregnation of the wedge

Case 1: Wedge **non** impregnated
contact on the wedge

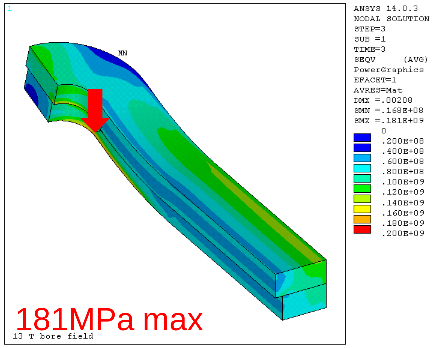


Case 2: Wedge **non** impregnated
no contact on the wedge

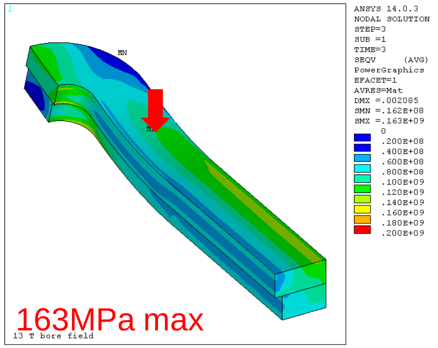




Case 3: Wedge **impregnated**
contact on the wedge

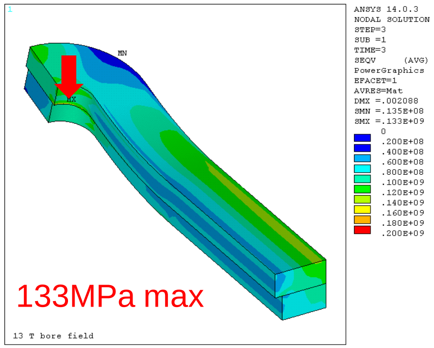


Case 4: Wedge **impregnated**
no contact on the wedge

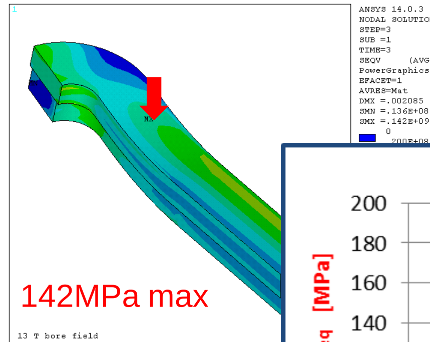


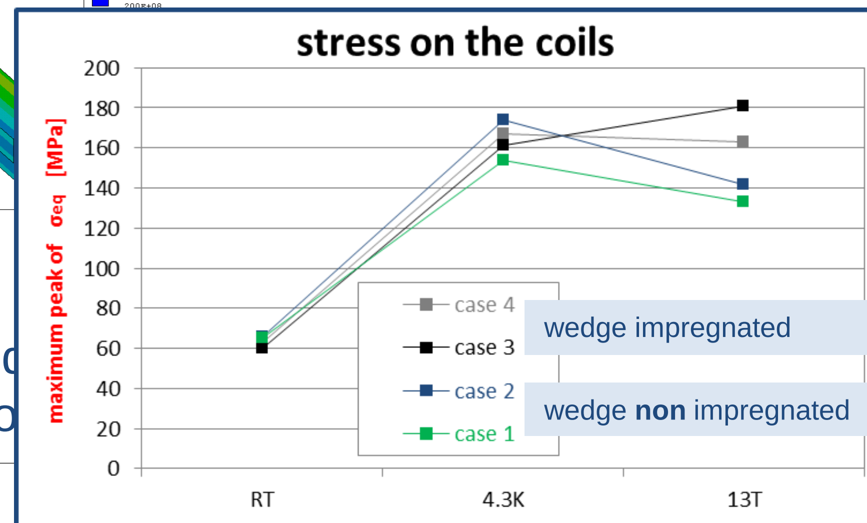
Cases of study: impregnation of the wedge

Case 1: Wedge **non** impregnated contact on the wedge

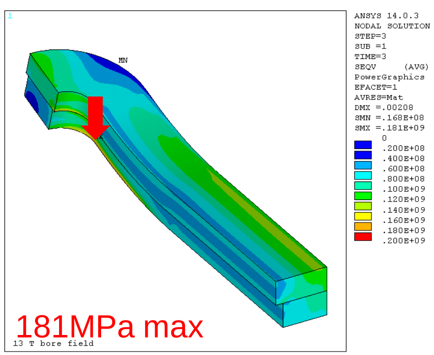


Case 2: Wedge **non** impregnated **no** contact on the wedge



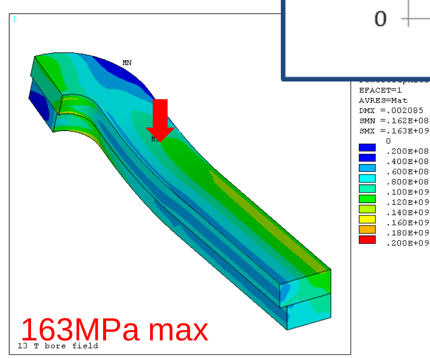


Case 3: Wedge **impregnated** contact on the wedge

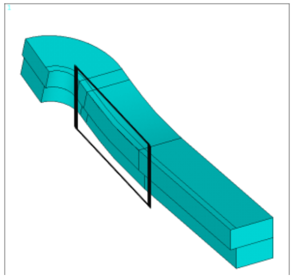


Case 4: Wed

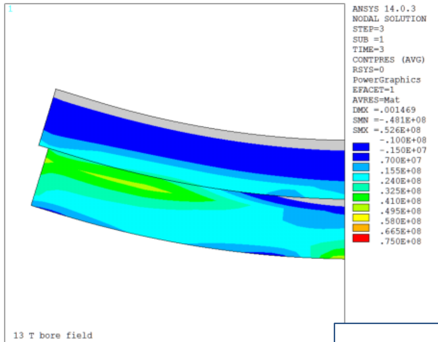
no contact o



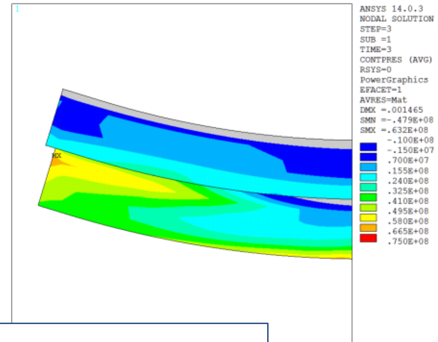
Cases of study: lateral support



Case 1: Wedge **non** impregnated
contact on the wedge

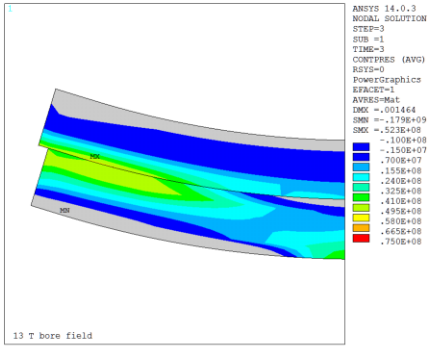


Case 2: Wedge **non** impregnated
no contact on the wedge

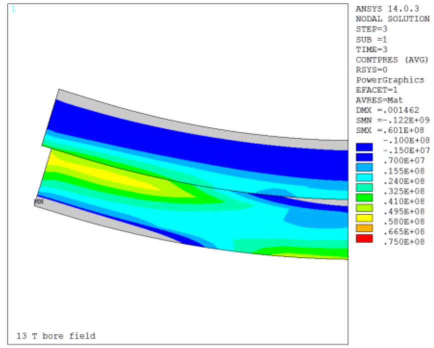


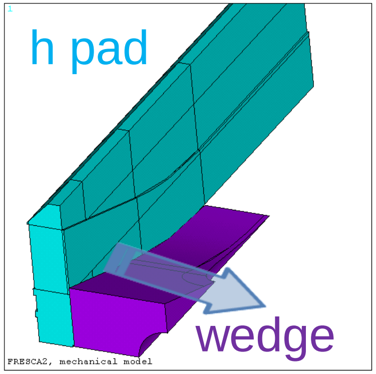
colored area: compression
gray area: **<10MPa** in tension

Case 3: Wedge **impregnated**
contact on the wedge

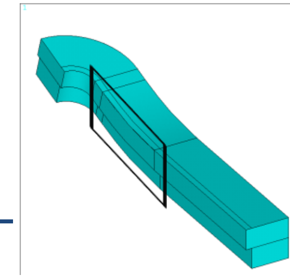


Case 4: Wedge **impregnated**
no contact on the wedge



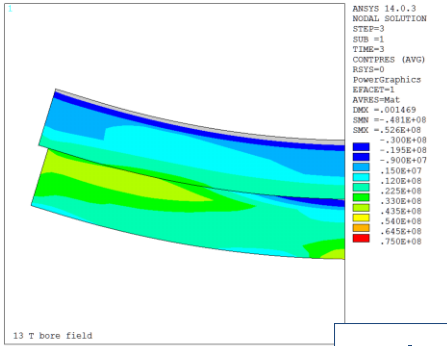


Cases of study: lateral support

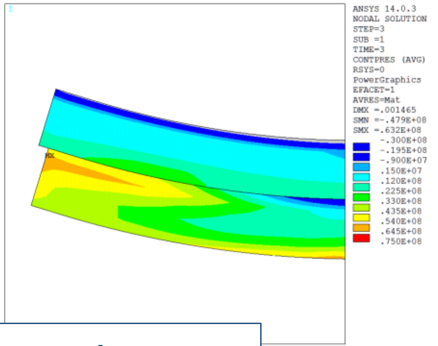


in-side hard-way-bend @13T

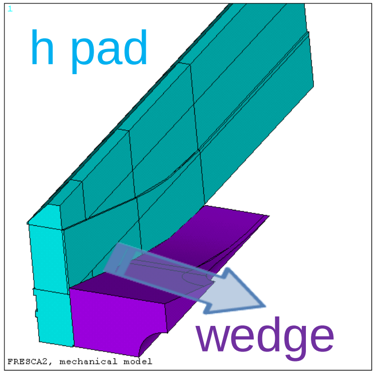
Case 1: Wedge **non** impregnated
contact on the wedge



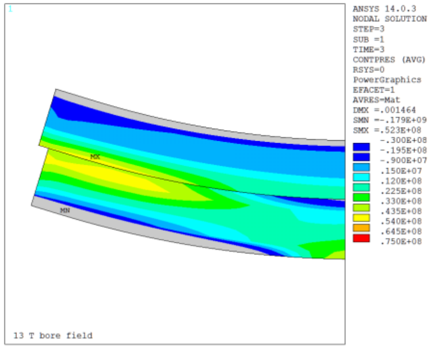
Case 2: Wedge **non** impregnated
no contact on the wedge



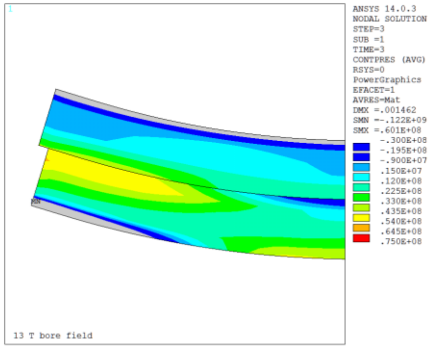
colored area: compression
gray area: **<30MPa** in tension

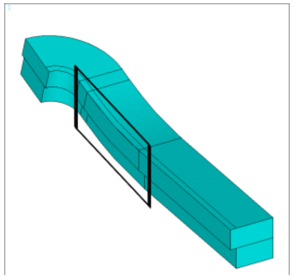


Case 3: Wedge **impregnated**
contact on the wedge



Case 4: Wedge **impregnated**
no contact on the wedge

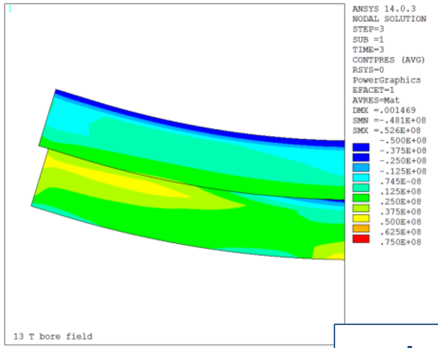




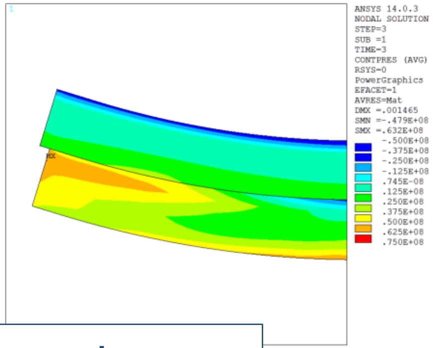
Cases of study: lateral support

in-side
hard-way-bend
@13T

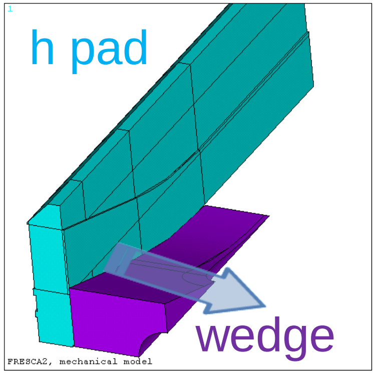
Case 1: Wedge **non** impregnated
contact on the wedge



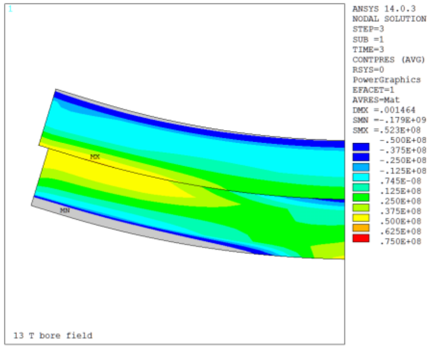
Case 2: Wedge **non** impregnated
no contact on the wedge



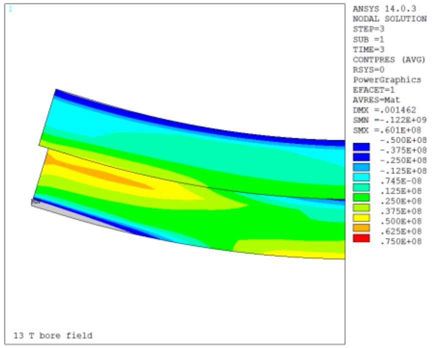
colored area: compression
gray area: **<50MPa** in tension



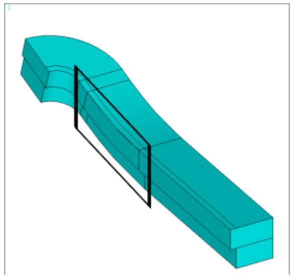
Case 3: Wedge **impregnated**
contact on the wedge



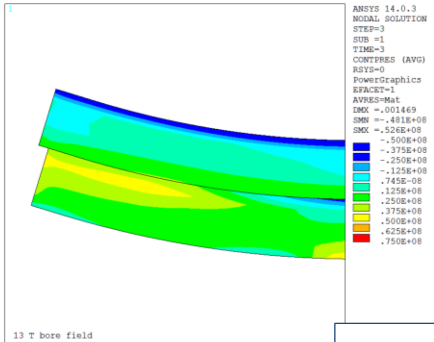
Case 4: Wedge **impregnated**
no contact on the wedge



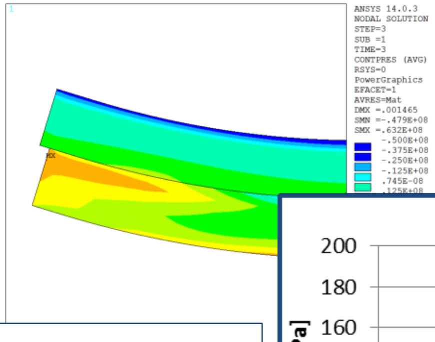
Cases of study: lateral support



Case 1: Wedge **non** impregnated contact on the wedge

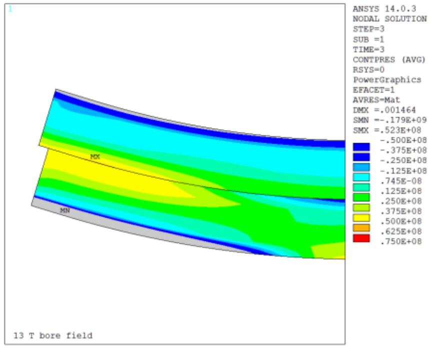


Case 2: Wedge **non** impregnated **no** contact on the wedge

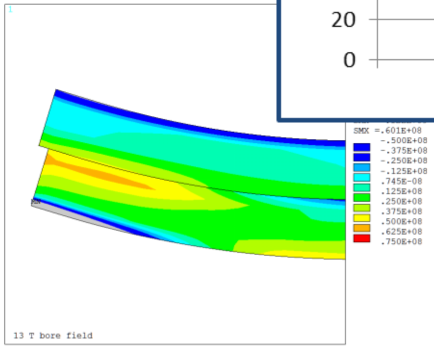


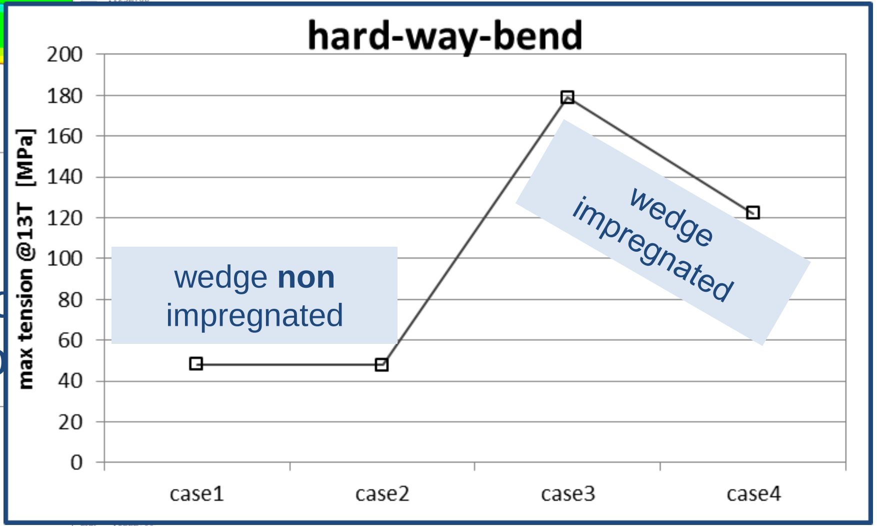
colored area: compression
gray area: **<50MPa** in tension

Case 3: Wedge **impregnated** contact on the wedge



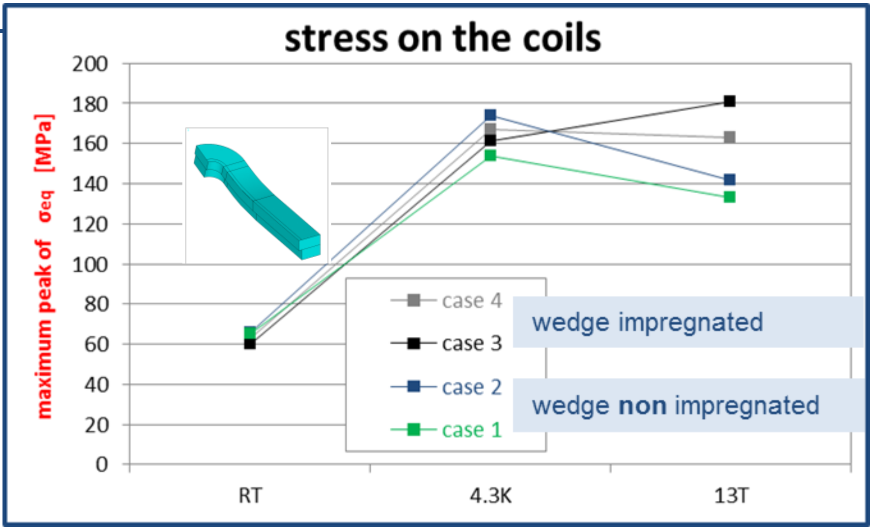
Case 4: Wed
no contact o

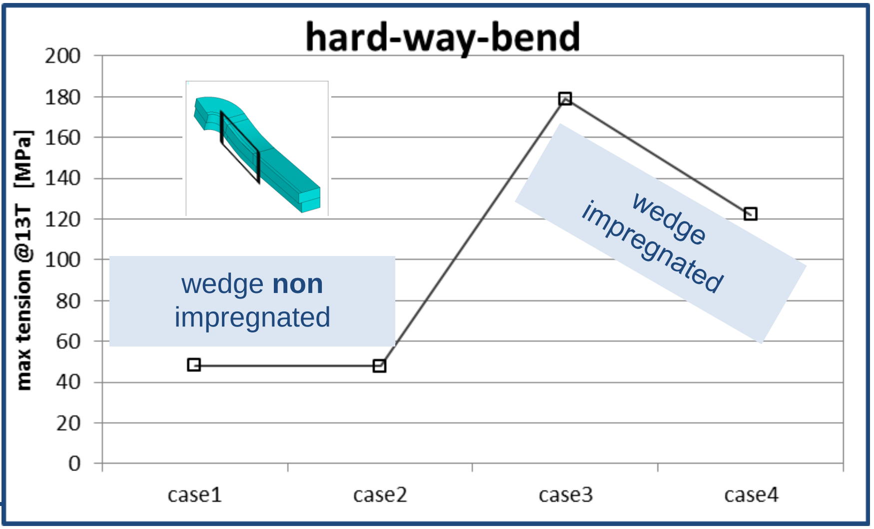




Cases of study on wedge: preliminary conclusions

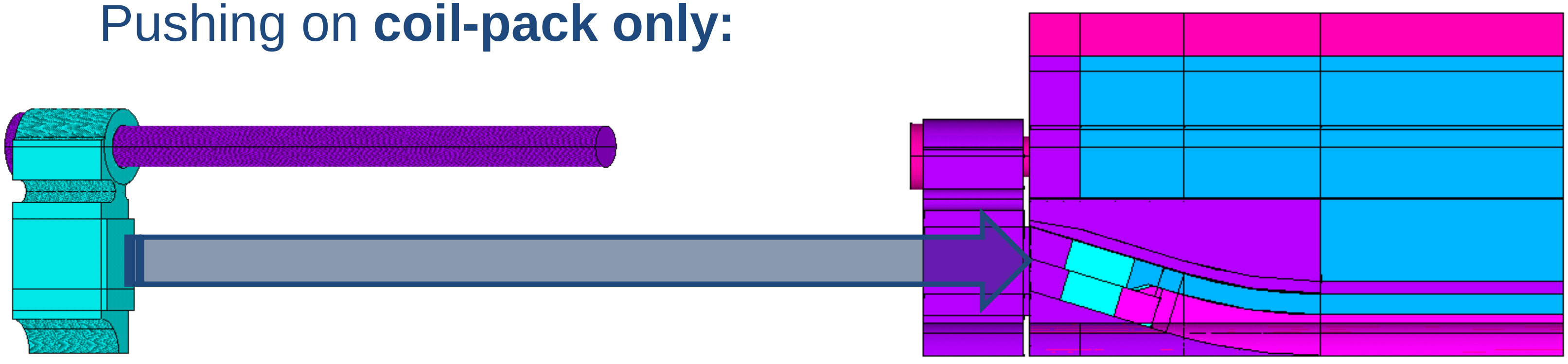
- Lower max stress peak in the coil with the **wedge not impregnated**
- Lower contact tension in the *hard-way-bend* side of the coil with the **wedge not impregnated**
- With the wedge not impregnated
  - Contact tension is slightly lower when there is no contact on the wedge (no lateral support)
  - Coil peak stress slightly lower with lateral contact with the wedge



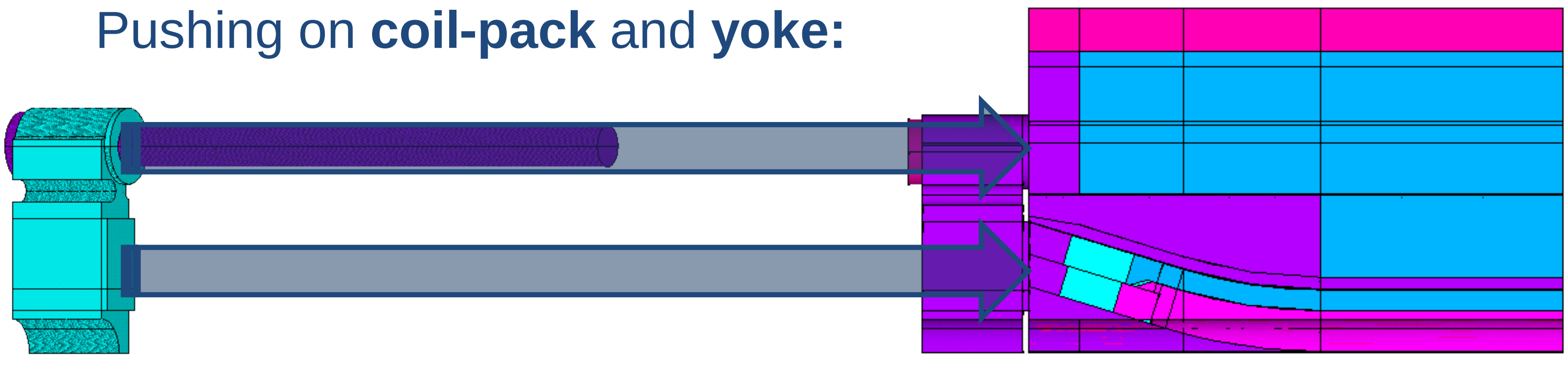


Cases of study: axial loading

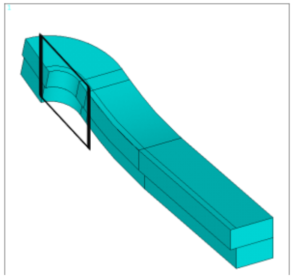
Pushing on **coil-pack only:**



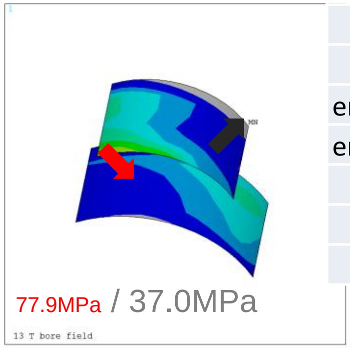
Pushing on **coil-pack** and **yoke:**



Cases of study: axial loading

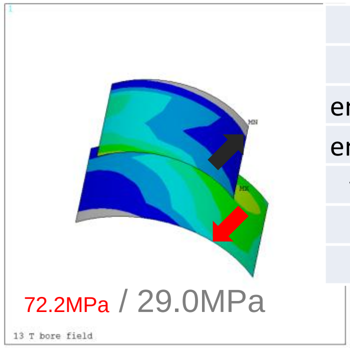


Case 1: Wedge **non** impregnated contact on the wedge



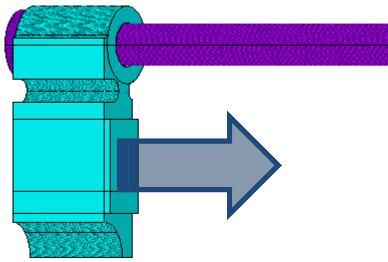
	forces [kN]	
	293K	**4.3K**
endshoe1	-106	-176
endshoe2	-326	-529
wedge	-5	-41
total	*-437*	*-746*
rod	437	740

Case 2: Wedge **non** impregnated **no** contact on the wedge



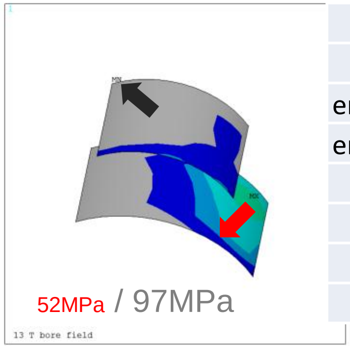
	forces [kN]	
	293K	**4.3K**
endshoe1	-109	-196
endshoe2	-320	-516
wedge	-7	-27
total	*-436*	*-739*
rod	437	740

pre-tension @RT= 156MPa



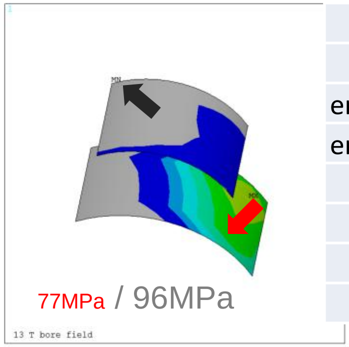
pushing on **coil-pack**

No contact end-plate - coil



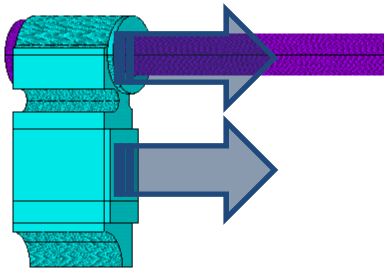
	forces [kN]	
	293K	**4.3K**
endshoe1	-31	0
endshoe2	-52	0
wedge	-16	0
yoke	-328	-882
total	*-427*	*-882*
rod	427	880

No contact end-plate - coil



	forces [kN]	
	293K	**4.3K**
endshoe1	-40	0
endshoe2	-52	0
wedge	-10	0
yoke	-323	-878
total	*-425*	*-878*
rod	426	878

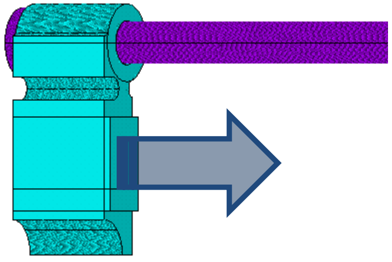
pre-tension @RT= 151MPa



pushing on **coil-pack** and **yoke**

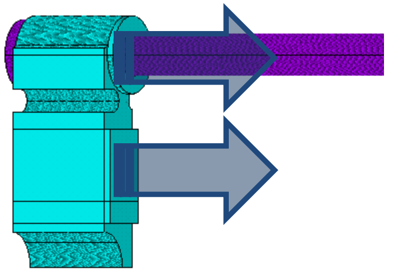
Cases of study on axial load: preliminary conclusions

pre-tension @RT= 156MPa



pushing on **coil-pack**

pre-tension @RT= 151MPa



pushing on **coil-pack** and **yoke**

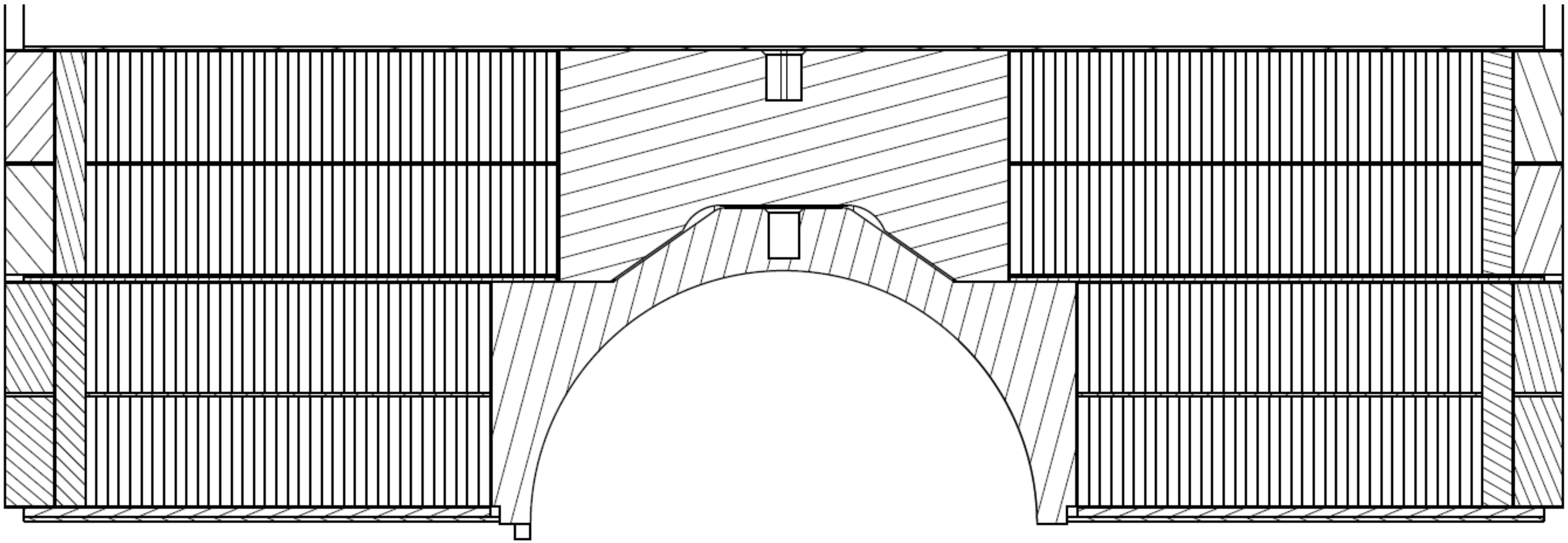
- At 293 K most of the force on endshoe2
  - Still contact with endshoe1 and wedge
- At 4.2 K, similar force distribution
- At 13 T, lower contact tension coil-pole

- At 293 K most of the force on the yoke
  - Still contact with coil and wedge
- At 4.2 K, loss of contact endplate-coil
- At 13 T, higher contact tension coil-pole

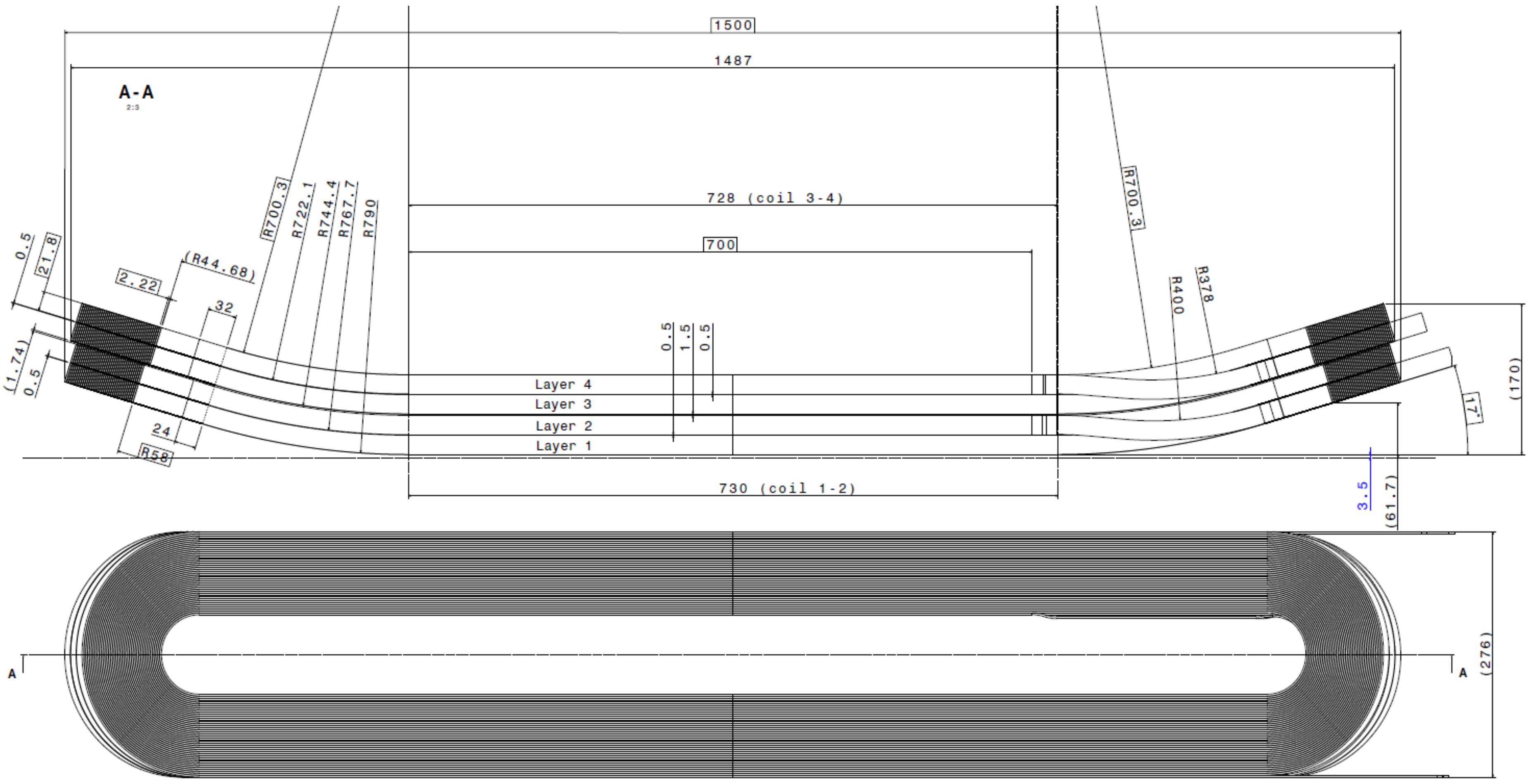
- Next step
  - Try to simulate situation with contact with end-plate and yoke+coil after cool-down

Appendix

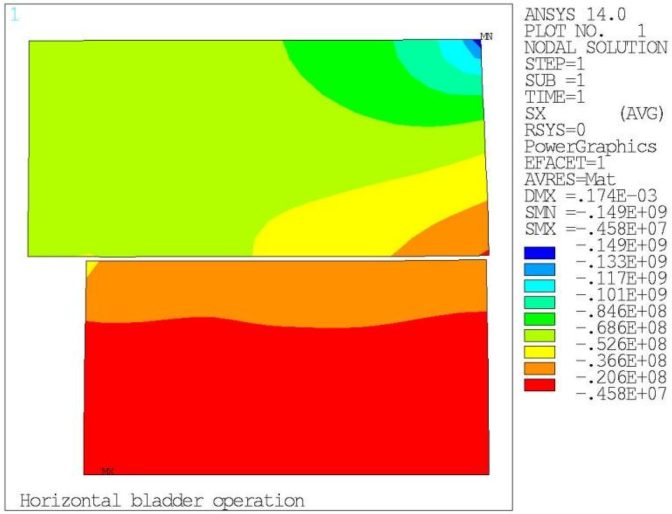
Coil cross-section

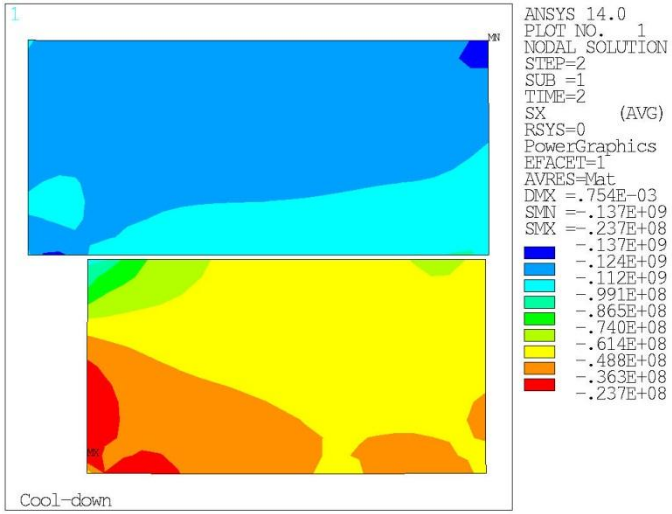


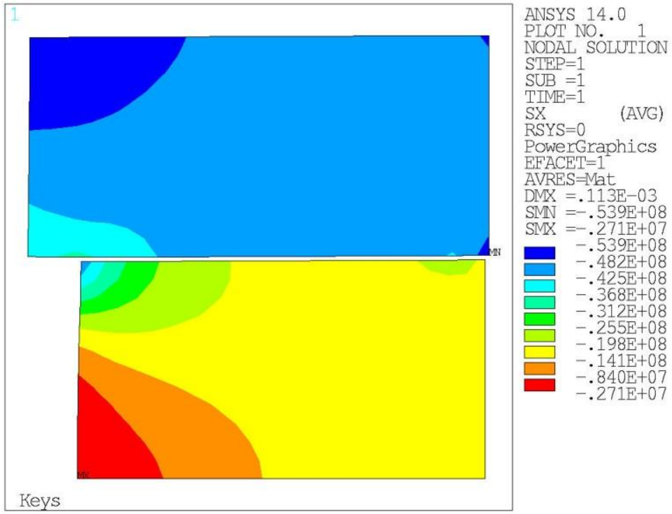
Coil 3D design

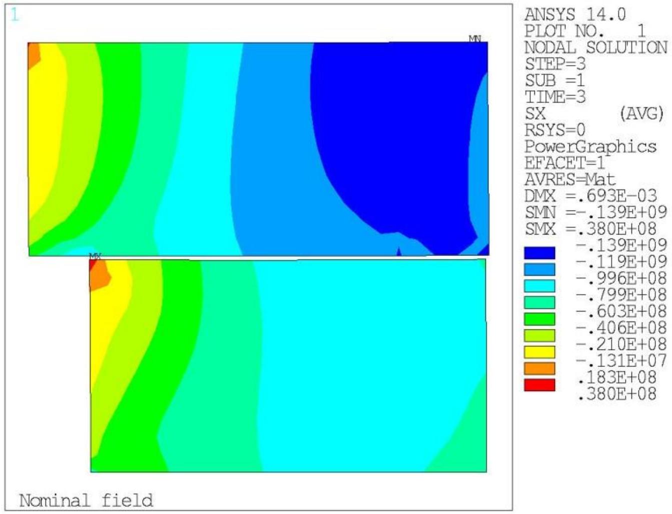


Coil stresses (MPa)

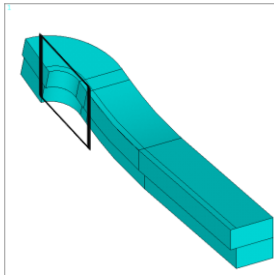






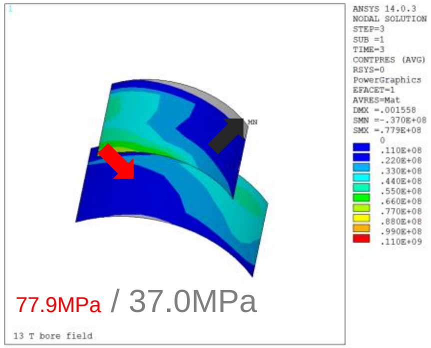


Cases of study: pushing on the coil-pack only

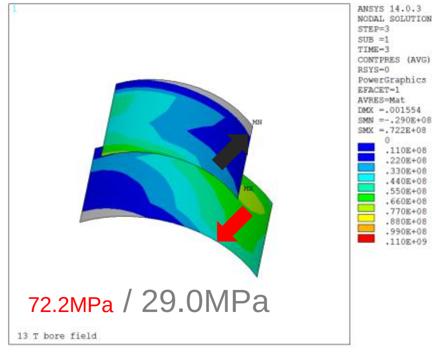


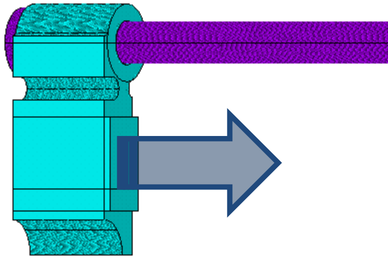
in-side easy-way-bend @13T

Case 1: Wedge **non** impregnated contact on the wedge



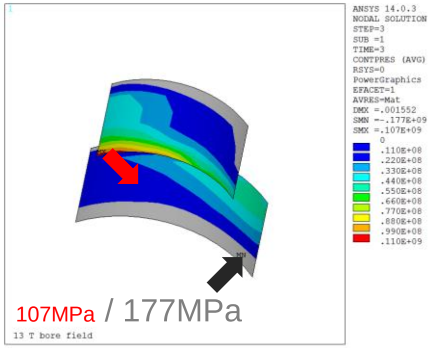
Case 2: Wedge **non** impregnated **no** contact on the wedge



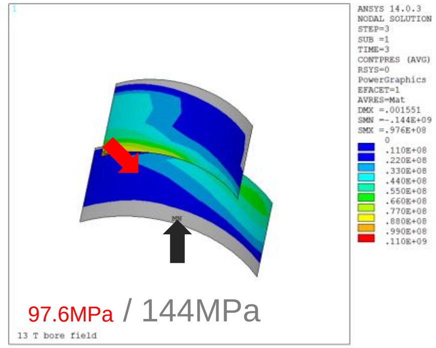


pushing on **coil-pack**

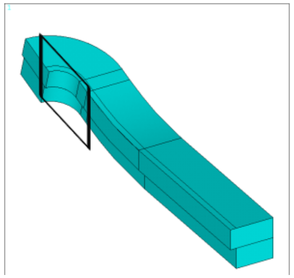
Case 3: Wedge **impregnated** contact on the wedge



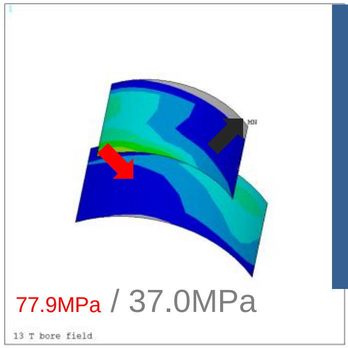
Case 4: Wedge **impregnated** **no** contact on the wedge



Cases of study: axial loading



Case 1: Wedge **non** impregnated contact on the wedge

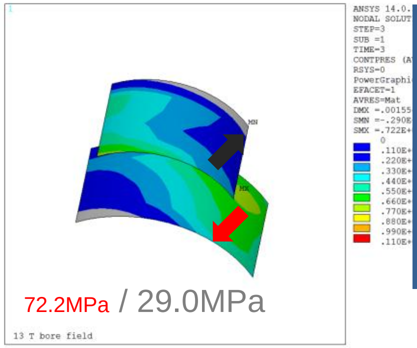


Forces @13T

Endshoe1 -191.8628 kN
Endshoe2 -509.5457 kN
Wedge -43.2852 kN
total = -744.6937 kN

Rod = 744.4216 kN
pre-tension @RT= 156MPa

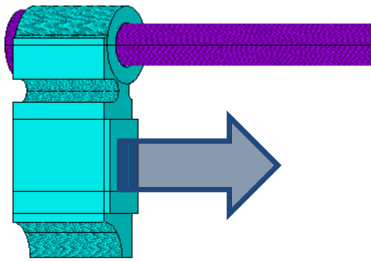
Case 2: Wedge **non** impregnated **no** contact on the wedge



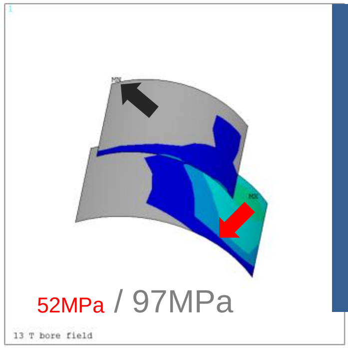
Forces @13T

Endshoe1 -210.6606 kN
Endshoe2 -489.4995 kN
Wedge -44.444 kN
total = -744.6041 kN

Rod = 744.4396 kN
pre-tension @RT= 156MPa



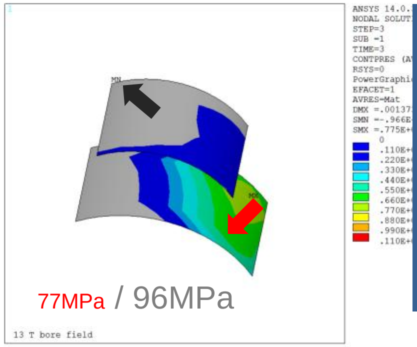
pushing on **coil-pack**



Forces @13T

Endshoe1 0 kN
Endshoe2 0 kN
Wedge -19.5163 kN
Yoke -861.8969kN
total = - 881.4132kN

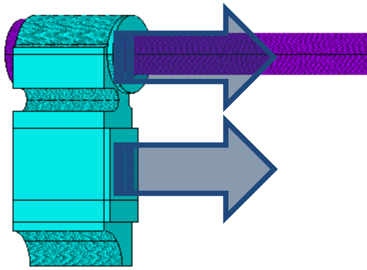
Rod = 881.301 kN
pre-tension @RT= 151MPa



Forces @13T

Endshoe1 -3.75244kN
Endshoe2 0 kN
Wedge -40.1981 kN
Yoke -835.9605 kN
total = -879.91112kN

Rod = 879.7984 **kN**
pre-tension @RT= 151MPa



pushing on **coil-pack** and **yoke**