16 T dipole in common coil configuration: mechanical design

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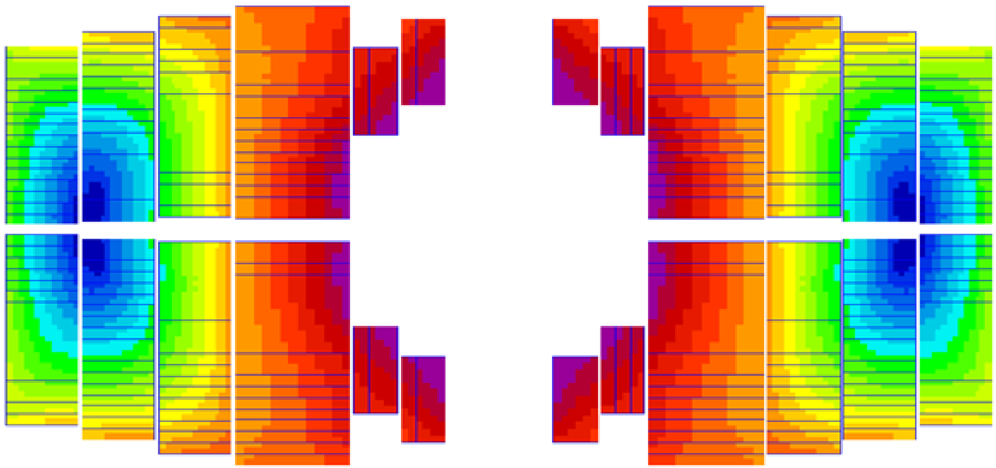
Common Coil scheme: Magnetic field

Ancillary coils

Main Coils

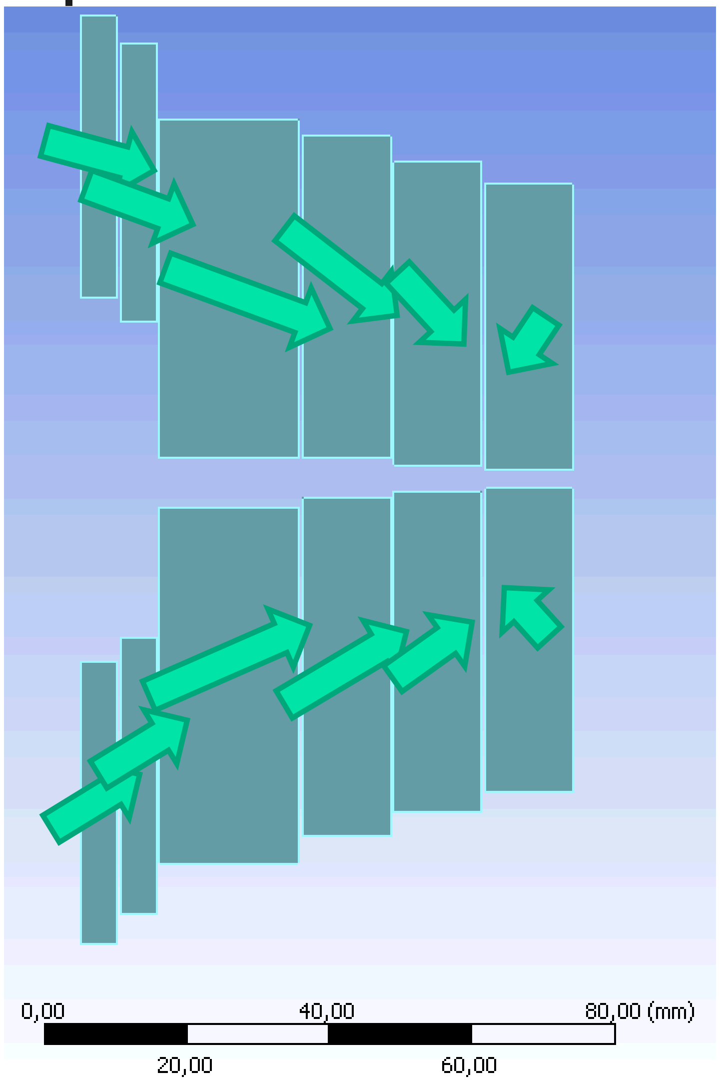
Main Coils

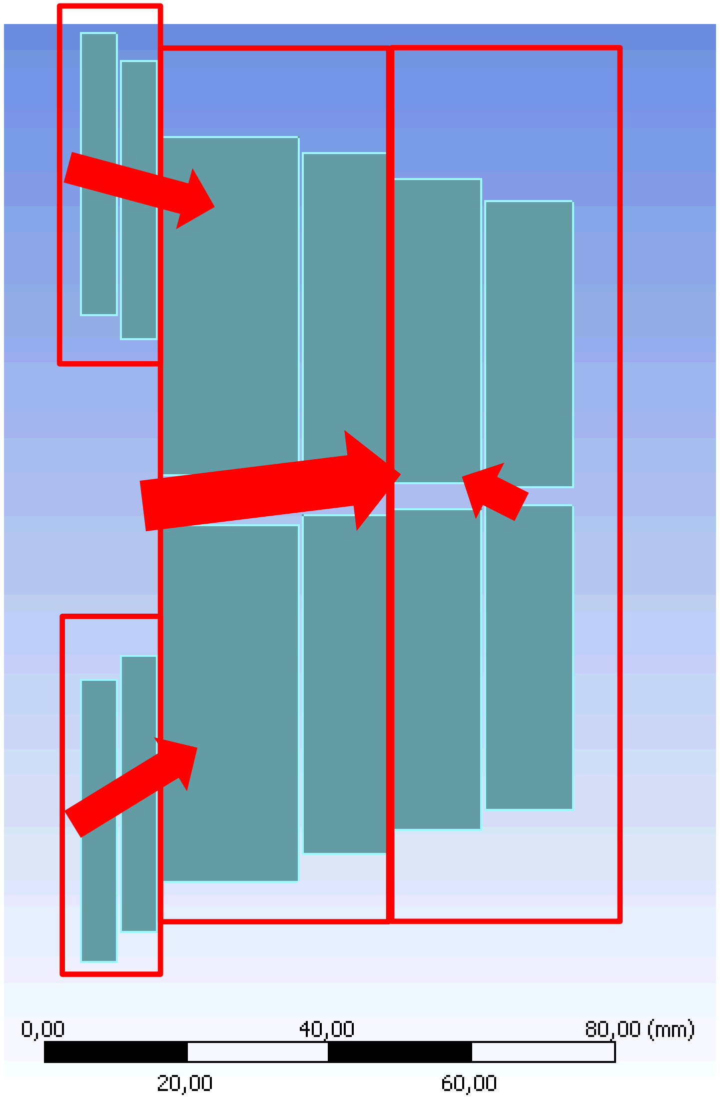


Notice orientation of cables

How forces are acting on these coils?

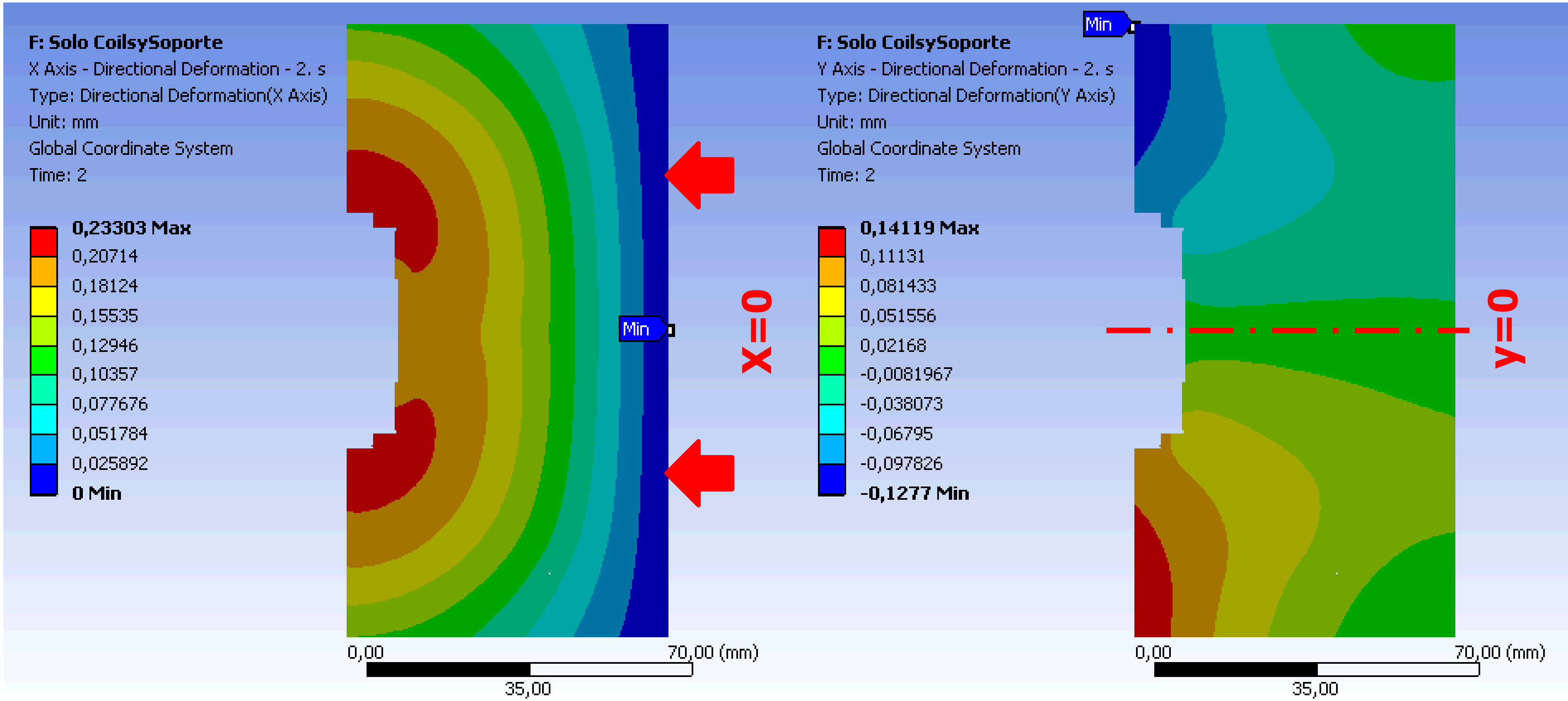
Common Coil scheme: Forces at coils





Common Coil scheme: Coils

JUST COILS: Horizontal movement constrained



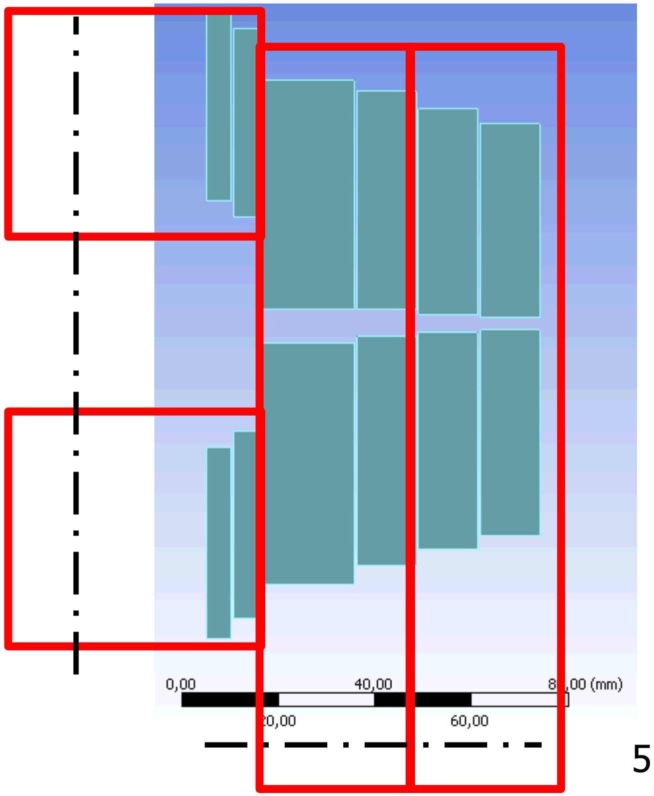
Horizontal force: +14,5 MN/m
Vertical force: +0,6 MN/m

Horizontal displacement: +0,23 mm
Vertical displacement: -0,13 / +0,14 mm

Concept design

- Main specifications to be reached:
  1. 150 MPa, Equivalent VM stress, at warm
  2. 200 MPa, Equivalent VM stress, at cold
  3. Coils under compression at any situation
  4. As low displacement of coils as possible when powered

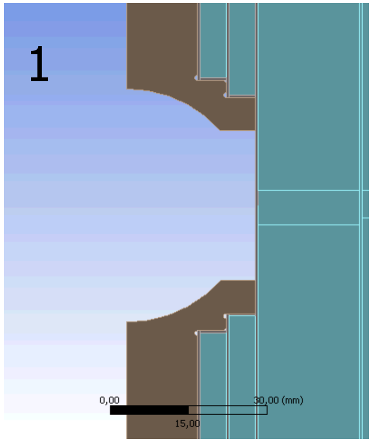
- Typical configurations for supporting structure are possible and they were evaluated, but:
  - Common coil cables are "rotated" compared to block design (except ancillary coils)
  - Main forces act over "narrow side" of the cable
  - Ancillary coil are connected "horizontally", while main coils are connected "vertically"
  - So, 8 coils are needed in this configuration
  - Some of them cannot be impregnated together

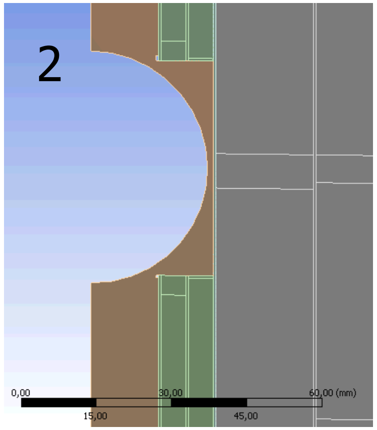


Concept design: Inner support

- Two different approaches are being studied:
  1. Open structure at beam pipe:
     - Optimized magnetic design
     - Not horizontal support available for coil pre-stress at mean plane
  2. Closed structure at beam pipe
     - Coils should be moved around 2 mm from beam pipe to accomodate this closed structure
     - Stiffer support for higher horizontal pre-stress
     - It could reduce horizontal displacements of the coils
     - Less efficiency from magnetic point of view -> More cable needed
     - Higher elastic energy in the coils due to prestress

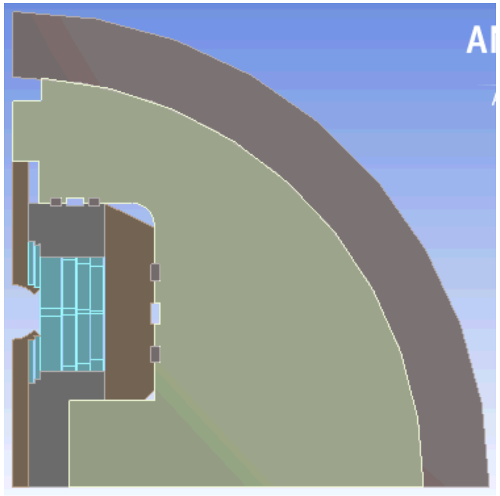
Option 1 has been selected (by now), for magnetic efficiency





Concept design: external support

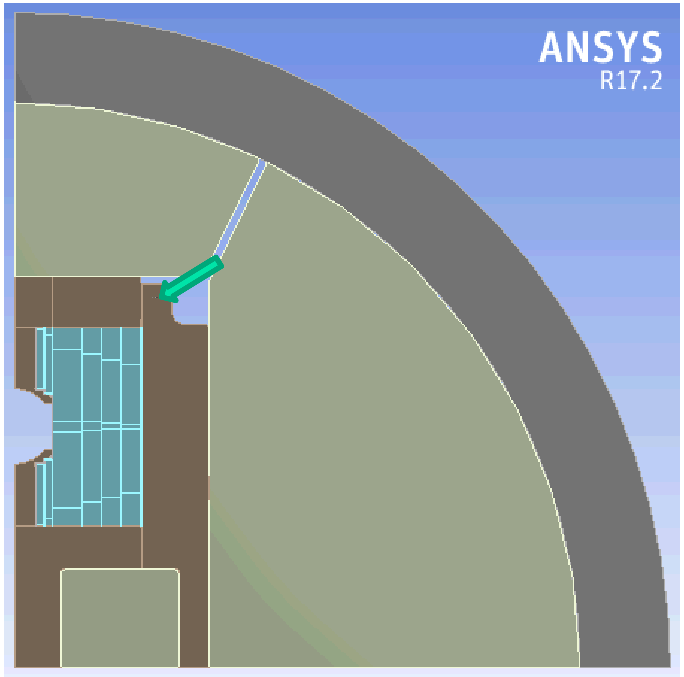
- Typical configurations and options have been evaluated, but
- None of them provide, by preliminar studies, all the requirements:
  - Traction arise at certain areas
  - In corners and some peak stresses due to magnetic forces distribution
  - High displacements and shape changing
  - Independent coils/Impregnated together
  - Lose of contact at certain current levels
  - …



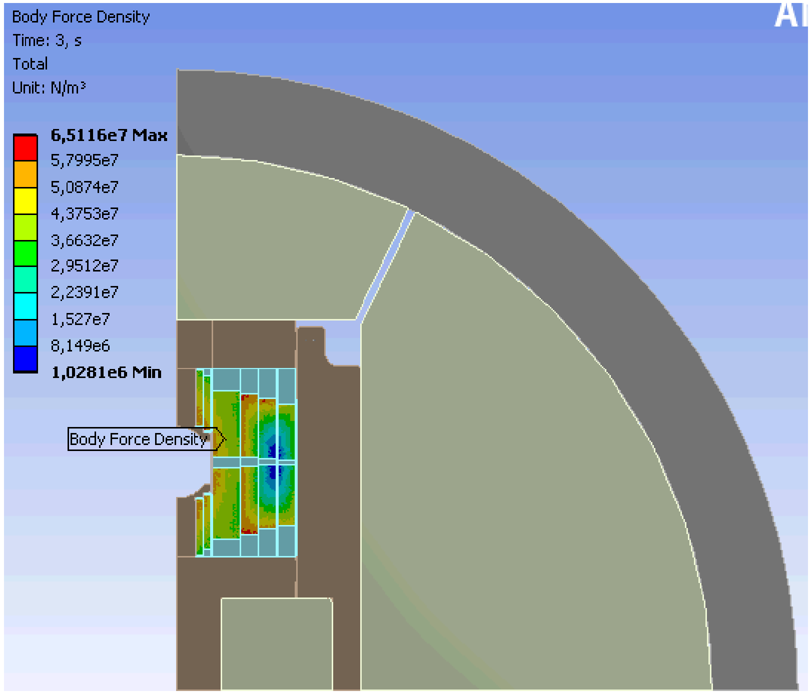
- Best solution detected to deal with horizontal forces and stresses concentrations:
  - Make independent support and coils (not bonded)
  - But some slip and friction could appear at coil surfaces

Support structure layout

- An outer shell of stainless steel holds the magnet against horizontal forces.
- Ancillary coils are impregnated beside an aluminum foil 0,5 mm for improving compression when cold
- Iron is cut in 4 pieces
- More freedom to coils: Main coils are impregnated together with, but NONE of them are bonded to supporting structure



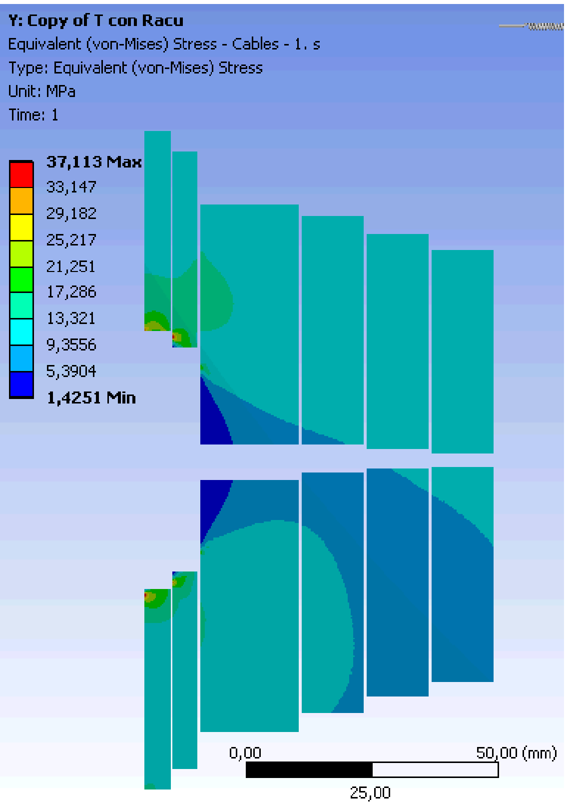
Mechanical model

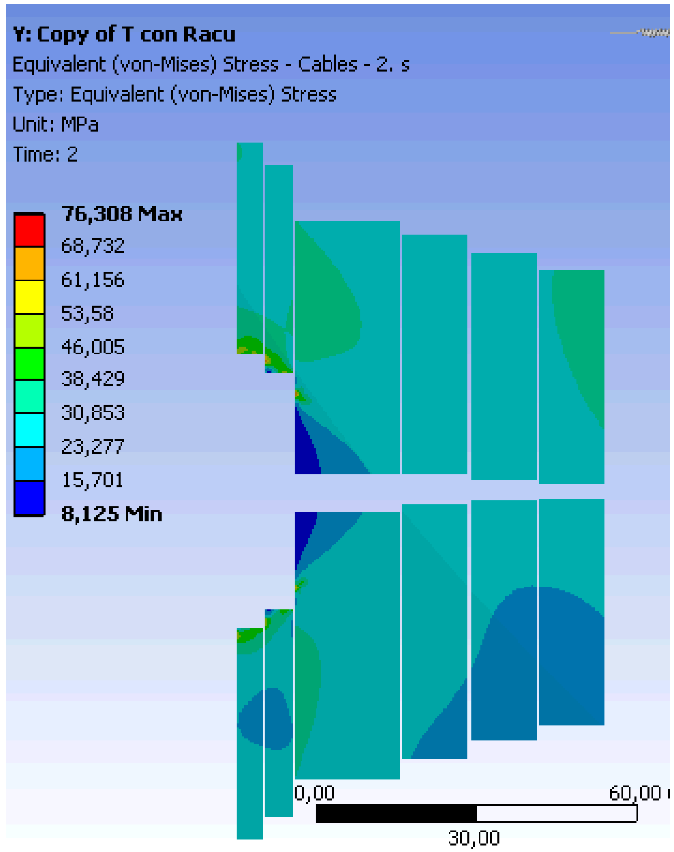


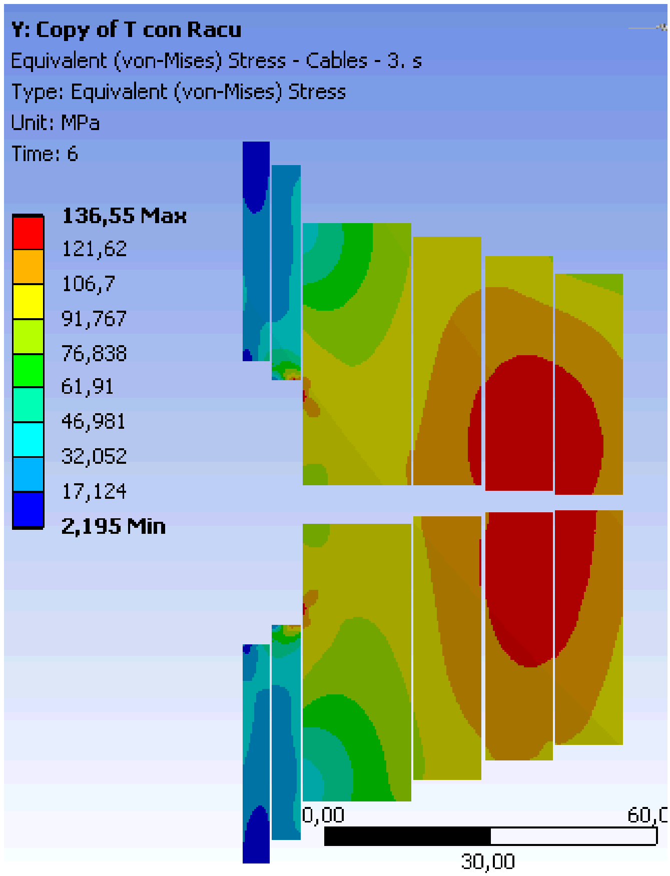
Lorentz Horizontal forces map

Coils stress

- Von Mises stress at each step.
- Some corners arise peak values due to contact effects







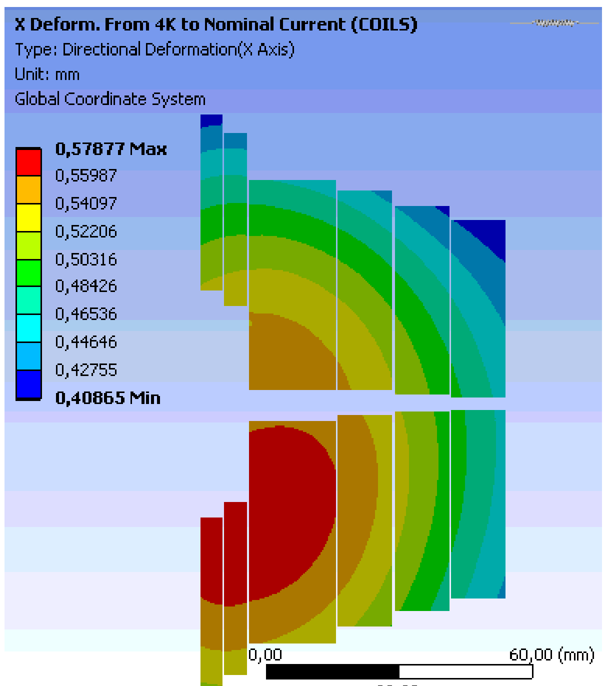
Assembly
Peak 36 Mpa

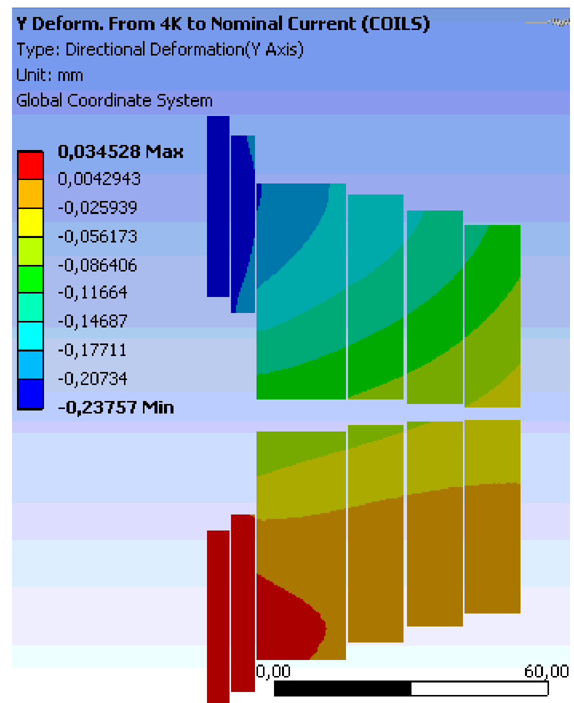
Cool down
Max 76 Mpa

16 T
Max 136 Mpa

Coils displacements from 0T to 16T

- Total displacement **less than 0,6 mm in horizontal axis,**
  -0,07 mm in vertical (mean plane).
- Slight shape deformation (not parallel displacement along the coils)
  - Horizontal max/min (0,58-0,40=0,18 mm), vertical (0,03-(-0,23)=0,26mm)



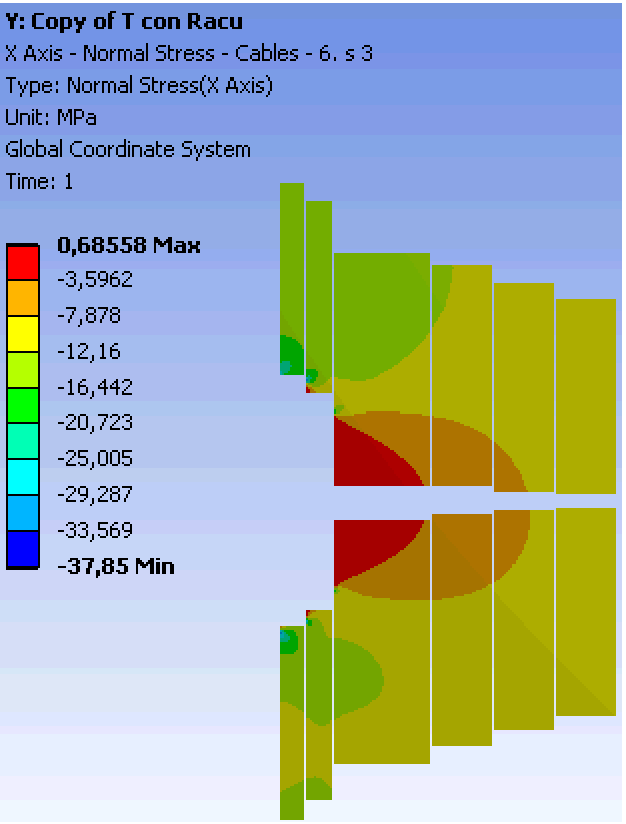


Coils RELATIVE displacement in mm:
horizontal (left) and vertical (right)

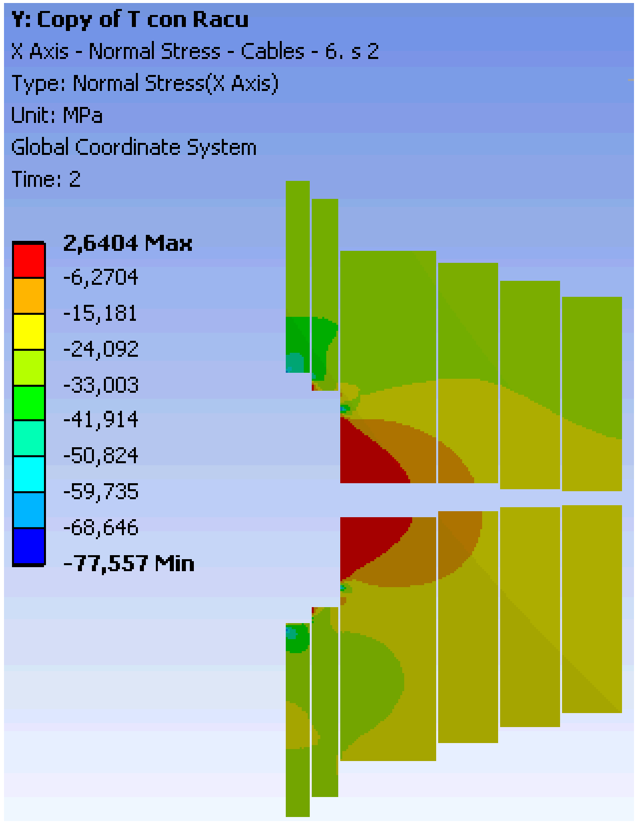
(displacement between cool down to nominal current)

Coils X stress

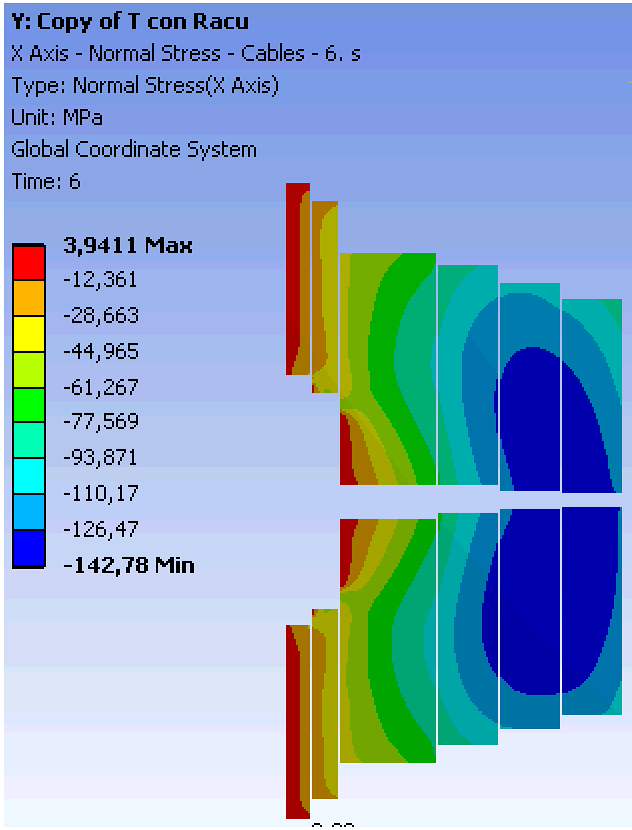
- “azimuthal” stress for Ancillary coils
- “radial” stress for main coils



Assembly
Peaks +0,7/-38 Mpa



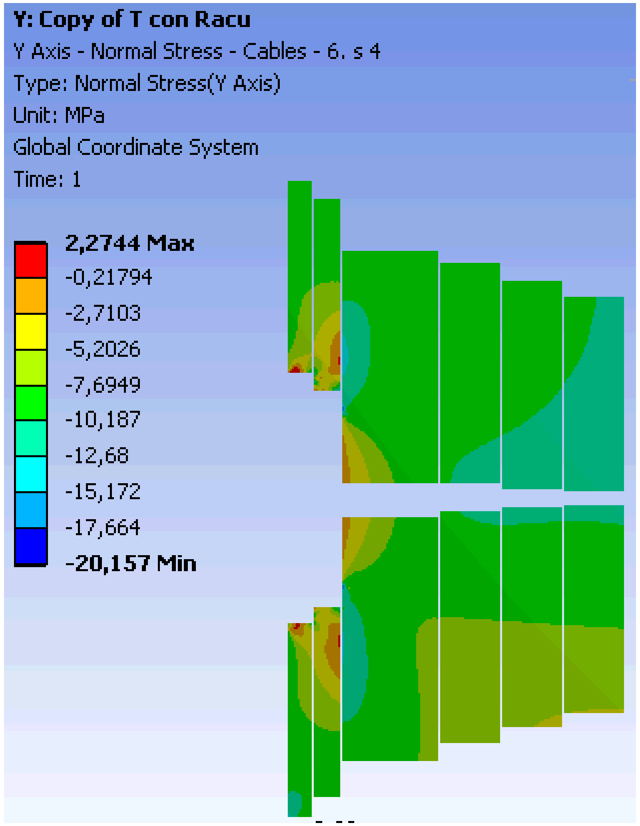
Cool down
Peaks +2,6/-78 MPa

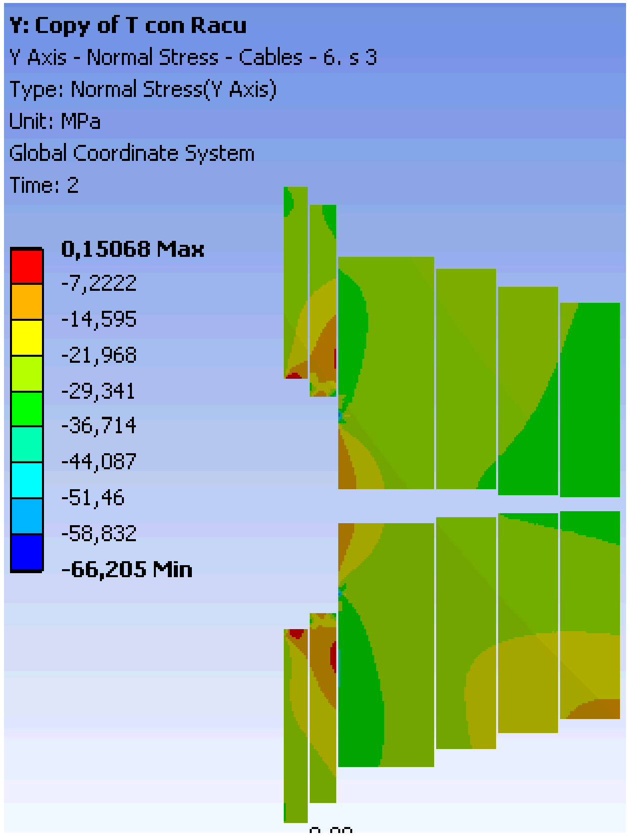


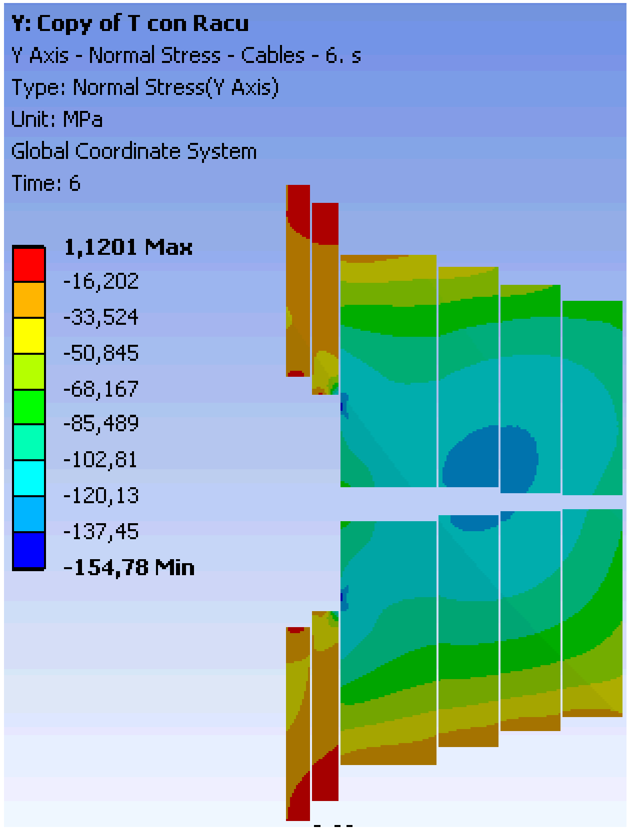
16 T
Peak 4 MPa
"Max" 1/-140 Mpa

Coils Y stress

- "azimuthal" stress for main coils
- "radial" stress for ancillary coils





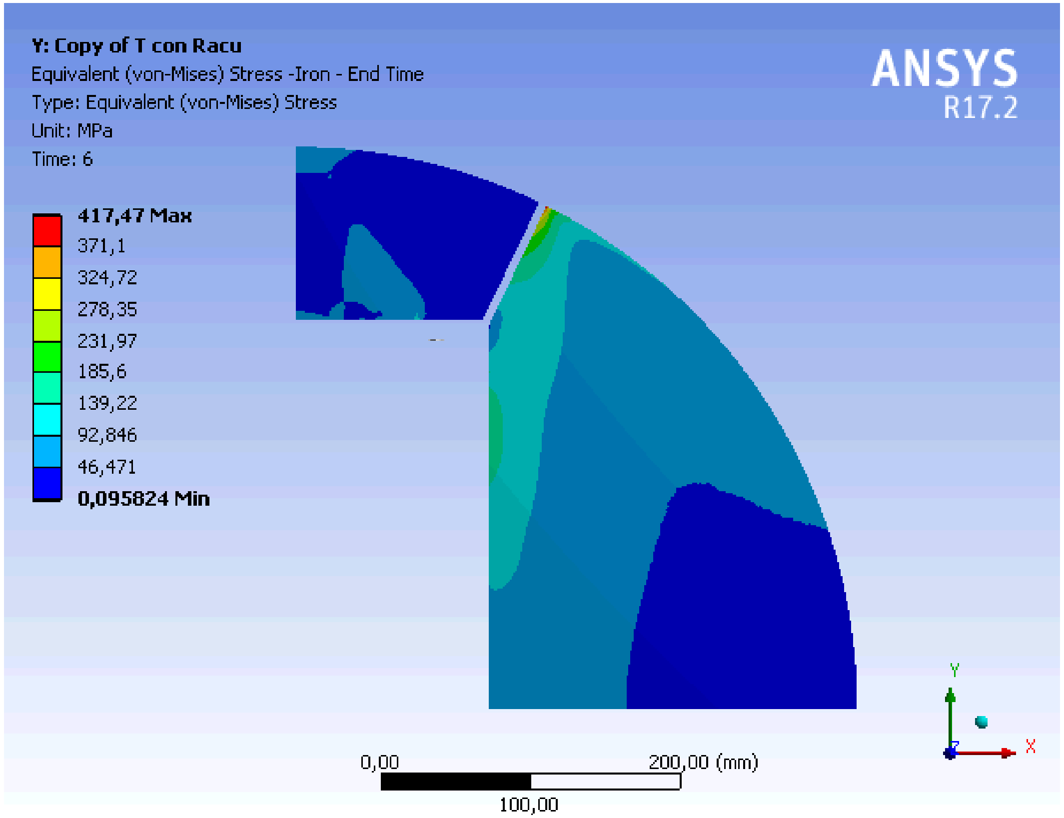


Assembly
Peak +2,3 /-20 MPa

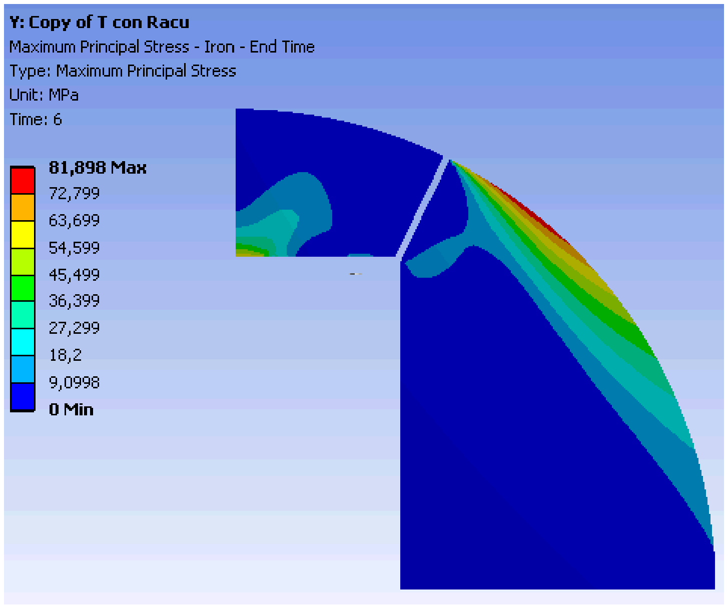
Cool down
Peak +0,15/ -66 Mpa

16 T
Peak +1/-155 MPa

Stress in iron, 16T

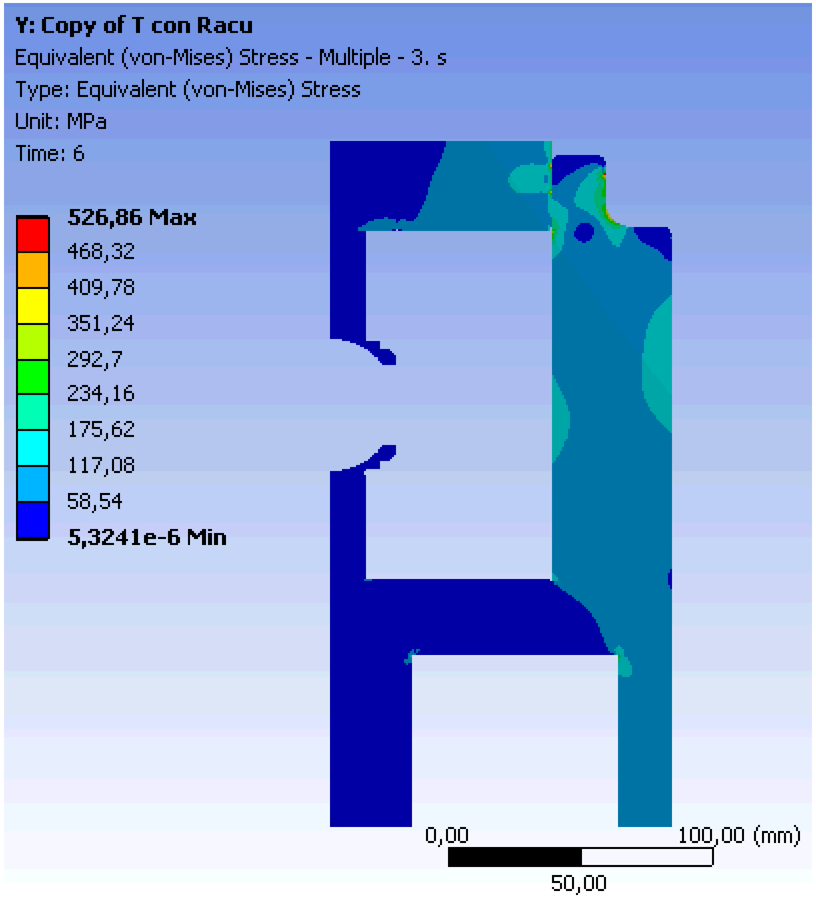


Von-Mises stress Max 418 MPa



Max. P. stress 82 MPa

Stress in supports



Von-Mises stress map: Max 527 MPa

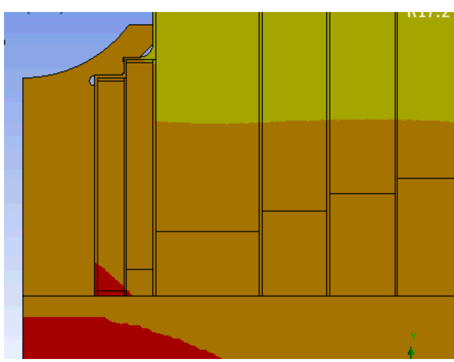
Summary results

	Assembly	Cold	16T
σ_{VM} COIL (MPa)	36	76	136
σ_x COIL (MPa)	+4,5 / -38	+2,6 / -78	+1 / -140
σ_y COIL (MPa)	+2,3 / -20	+0,2 / -66	+1 / -155
Displ. X COILS (mm)			0,58 / 0,40
Displ. Y COILS (mm)			0,03 / -0,23
σ_{VM} Support (MPa)			527
σ_{VM} Iron (MPa)			418
σ_1 Iron (MPa)			82

Open questions

- "Free coils" seems to behave much better in terms of stresses
- Displacement can be limited to certain level by means of shell and support
- Every cable is under compression, even if it lose contact partially (fig 1)
- But, what about the relative displacement between coils and supports?
  - This could be as high as 0,5 mm at certain points
  - At certain points, there is some slip between parts under compression force -> friction heating, but not directly on cable (fig 2)

Fig 1



Color: Vertical Displacement
Left-half coil lose contact

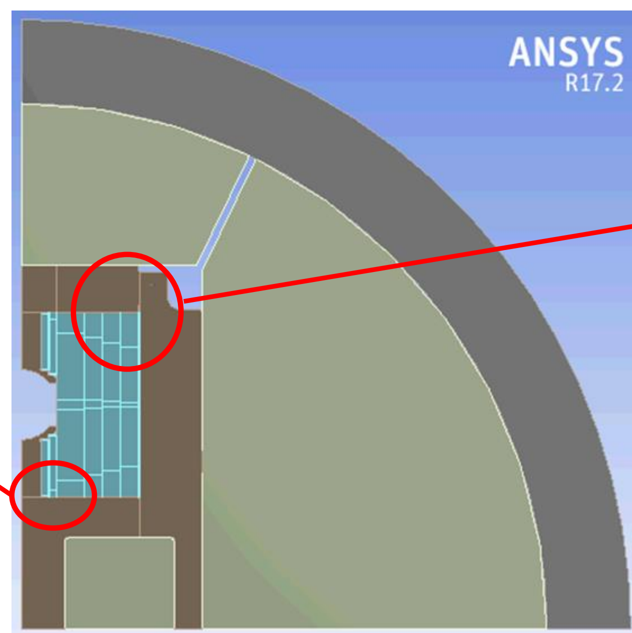
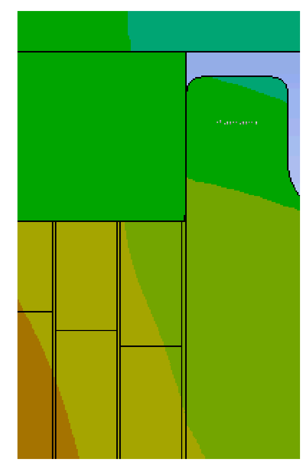


Fig 2



Color: Horizontal Displacement
While vertical compression force

Conclusions

- A closed inner support would help by increasing preload, but the amount of cable will increase.
- *Not-bonded coils* concept seems to be a great option from the point of view of stresses and good enough from displacements
- Additional studies on the effect of friction and possibilities to deal with it should be done

- Several paths of work are still open, comments and suggestions are appreciated

Thank you for your attention