16 T dipole in common coil configuration: mechanical design

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2-D mechanical conceptual options

- A number of conceptual mechanical options have been explored, these will be shown during the next slides:
  - Without ancillary coils (Magnetic design option 1):
    - Key & Bladder
    - Internal Rods
    - Internal Case
  - With ancillary coils (Magnetic design option 2):
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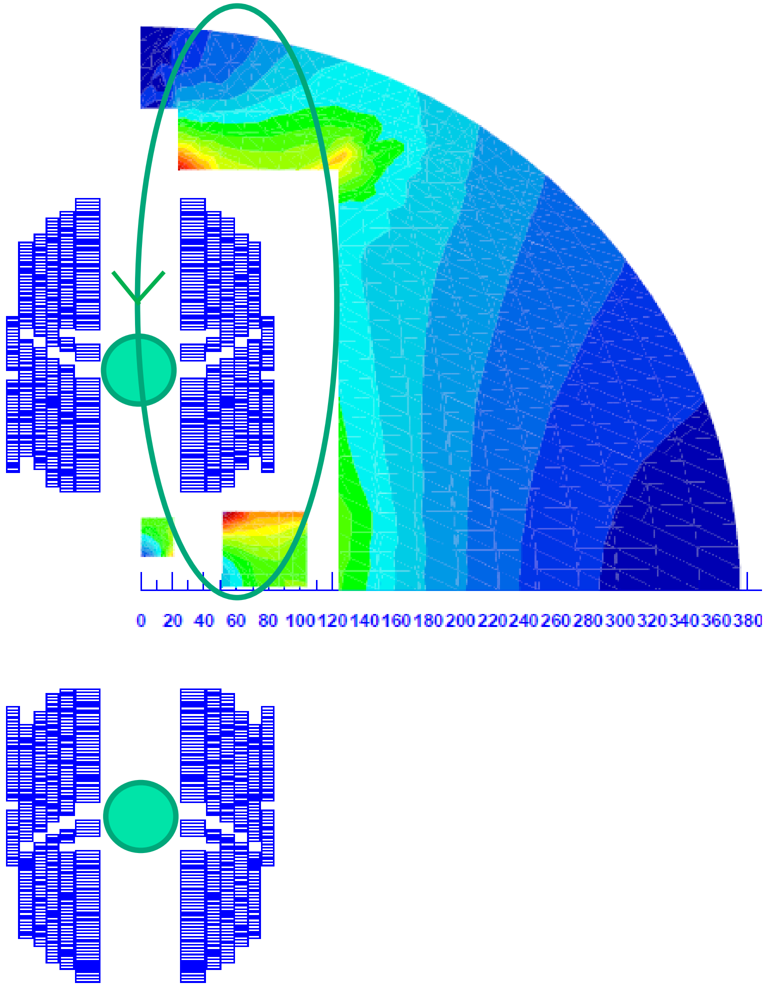
2-D magnetic design



- The common coil layout is based on two flat coils.
- A unique support structure for two apertures, placed at the same vertical plane.
- Main advantage: pure flat coils.
- Disadvantages: large stored energy and electromagnetic forces, complicated assembly.

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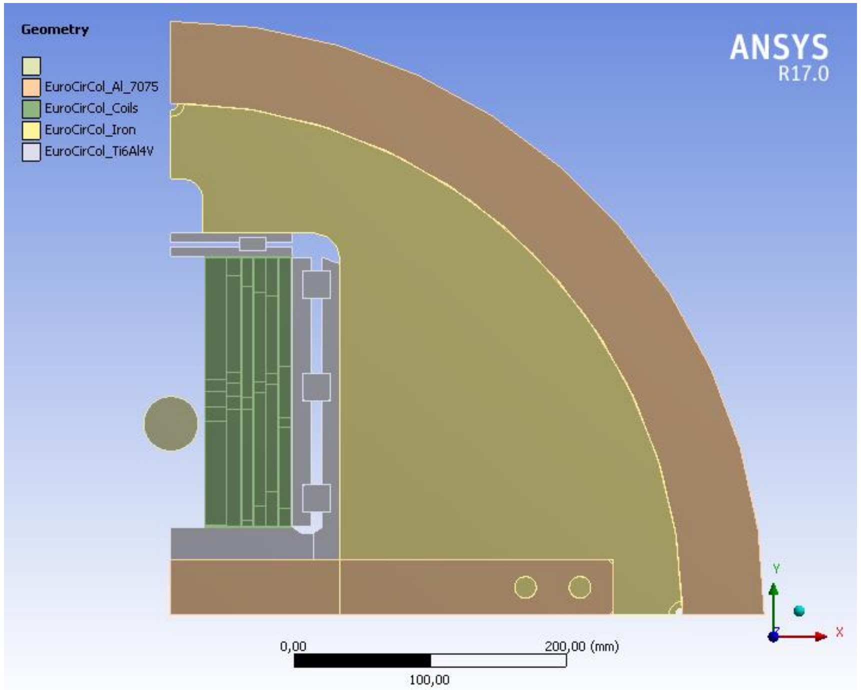
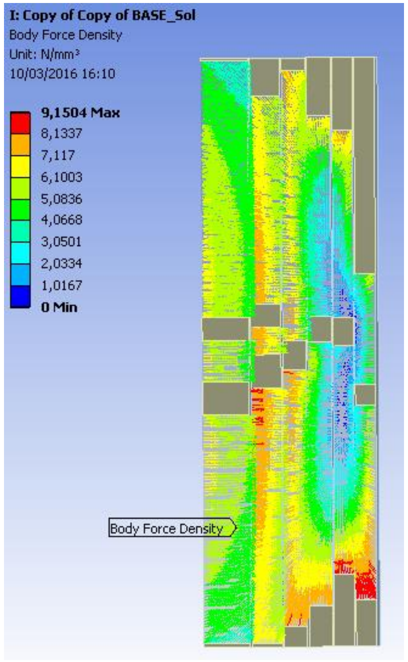
Support structure layout

- Support structure is based on bladder&key concept. There are keys for horizontal and vertical preload.
- An outer shell of aluminum provides the pre-stress to the coils.
- Cable blocks are modeled with smeared-out properties.
- Lorentz forces are transferred on each cable position.
- No friction between the parts.
- Iron symmetry in horizontal axis is assumed



Mechanical model showing beam pipe



Lorentz forces map

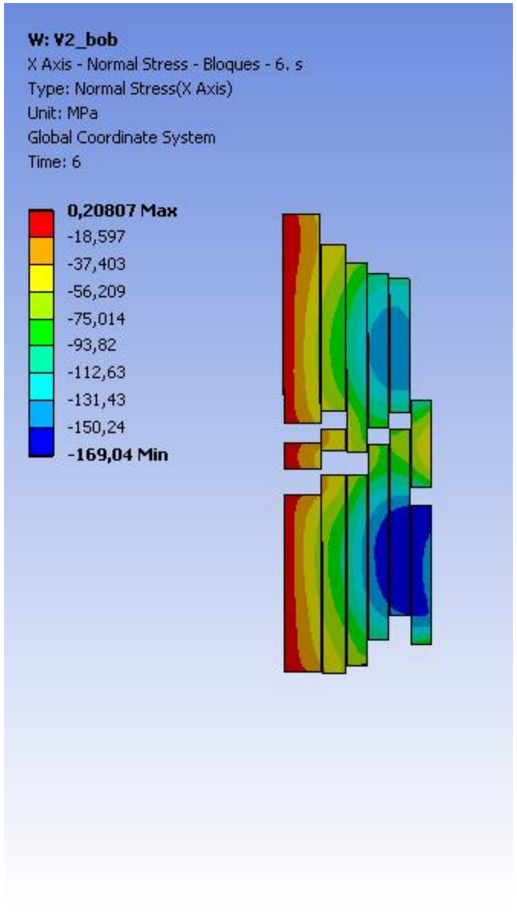
Mechanical properties

- We are using the mechanical properties agreed by the EuroCircol WP5.

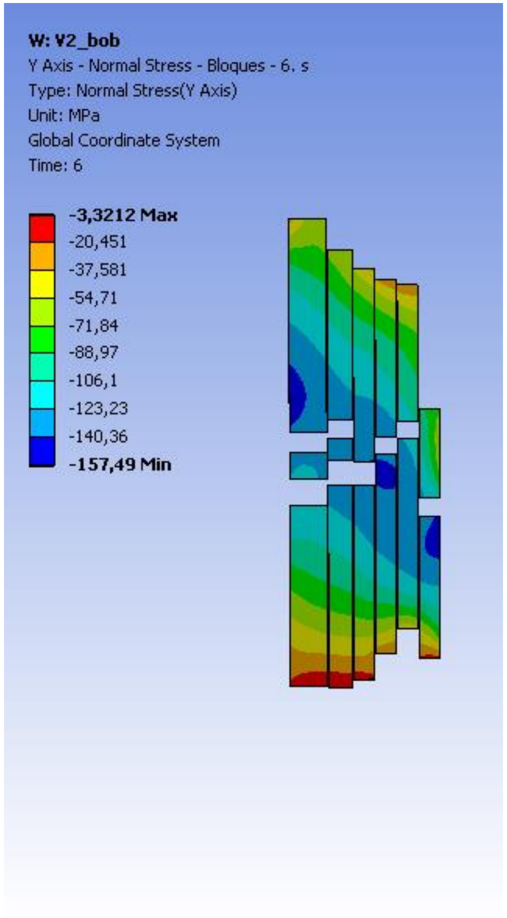
	Stress limit (MPa) 293/4 K		E (GPa)		P	α (293 to 4.2 K)
Coil	150	200	Ex=52 Ey=44 Gxy=21	Ex=52 Ey=44 Gxy=21	0,3	X=3,1e-3 Y=3,4e-3
316LN	350	1050	193	210	0,28	2,8e-3
7075	480	690	70	79	0,3	4,2e-3
Iron	180	720	213	224	0,28	2,0e-3
Titanium	800	1650	130	130	0,3	1,7e-3

Coil stress

- Good news: stress on cables well below 200 MPa at 16 T.
- It is a bit above 200 MPa at 18 T.
- These values will slightly increase because the optimal magnetic design (higher current density) is not considered in these mechanical calculations.



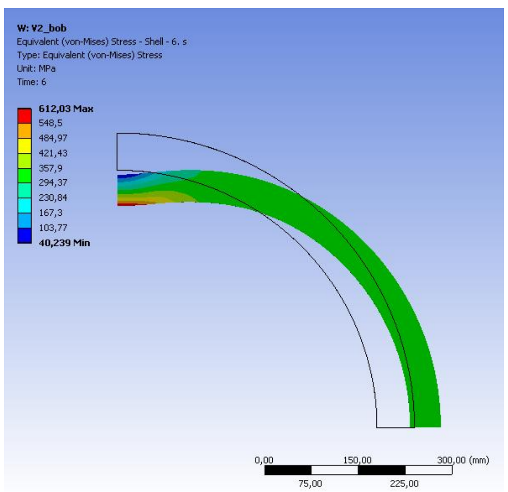
Horizontal normal stress



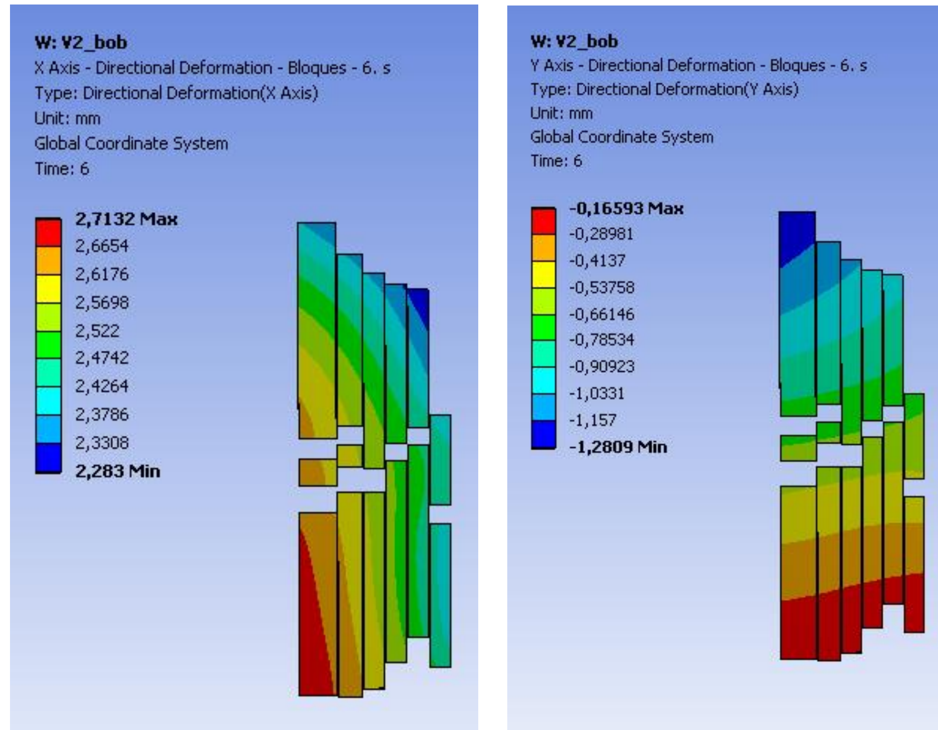
Vertical normal stress

Challenge: large coil displacements

- Total displacement <u>of more than 2 mm in horizontal axis.</u>
- It includes a small tilt of coils.
- Not enough lateral stiffness from iron and shell to withstand magnetic forces.
- Shell is 60 mm thick. Thicker shells provide too high stress on the coils.



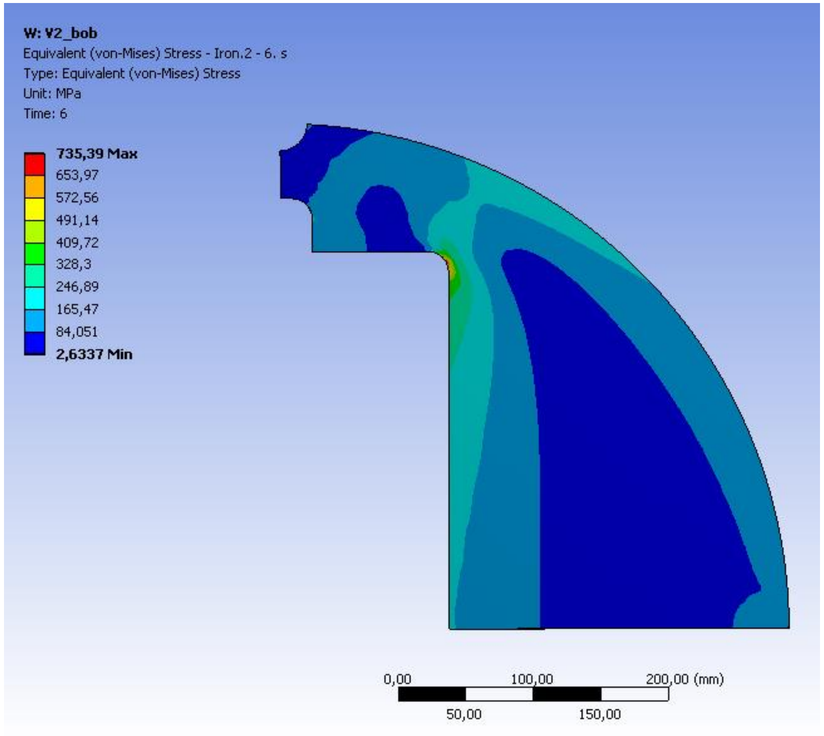
Shell stress (enlarged deformation)



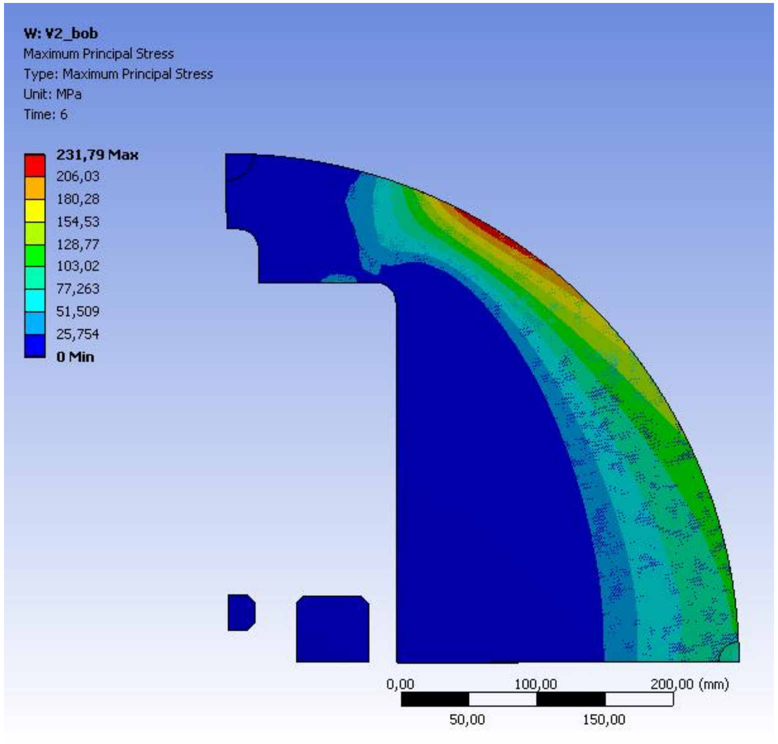
Coil blocks overall displacement in mm: horizontal (left) and vertical (right)

Challenge: large stresses in iron

Iron (Von Misses): 16T @ 4,2K
Von Mises criterion peak= 736 MPa ⇨ It is too high at the fillet.
Max. Prin. Stress = 232 MPa



Von-Mises criterion map



Maximum principal stress map

2-D mechanical conceptual options

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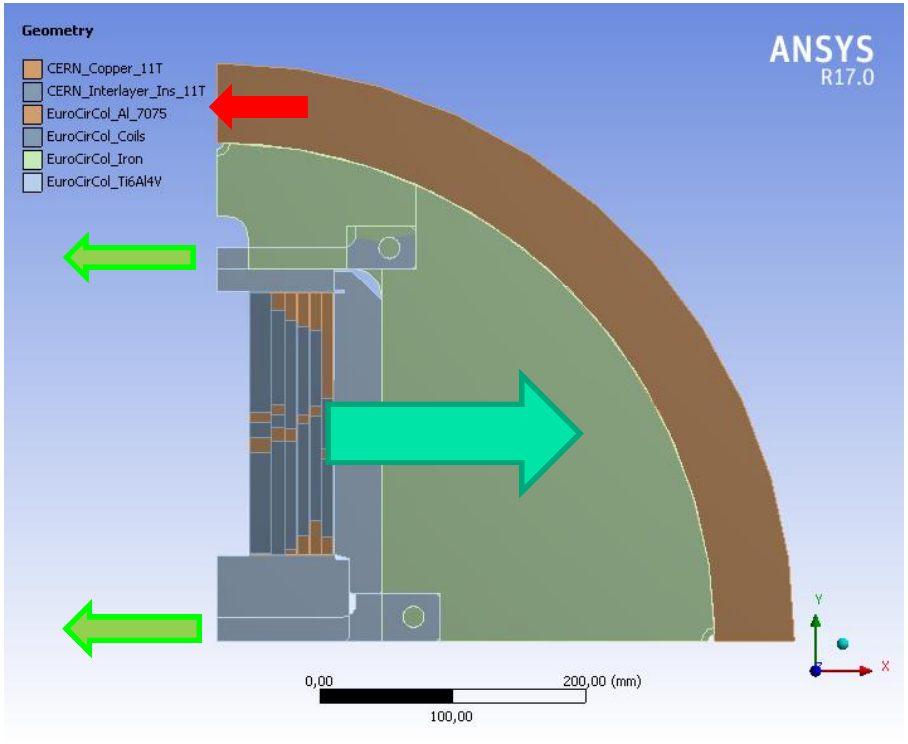
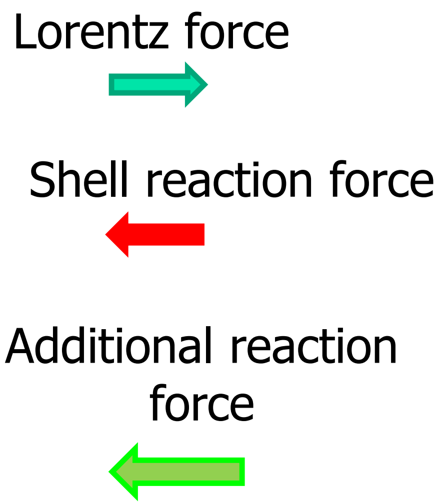
    - Internal Case

Option: Ti Rods

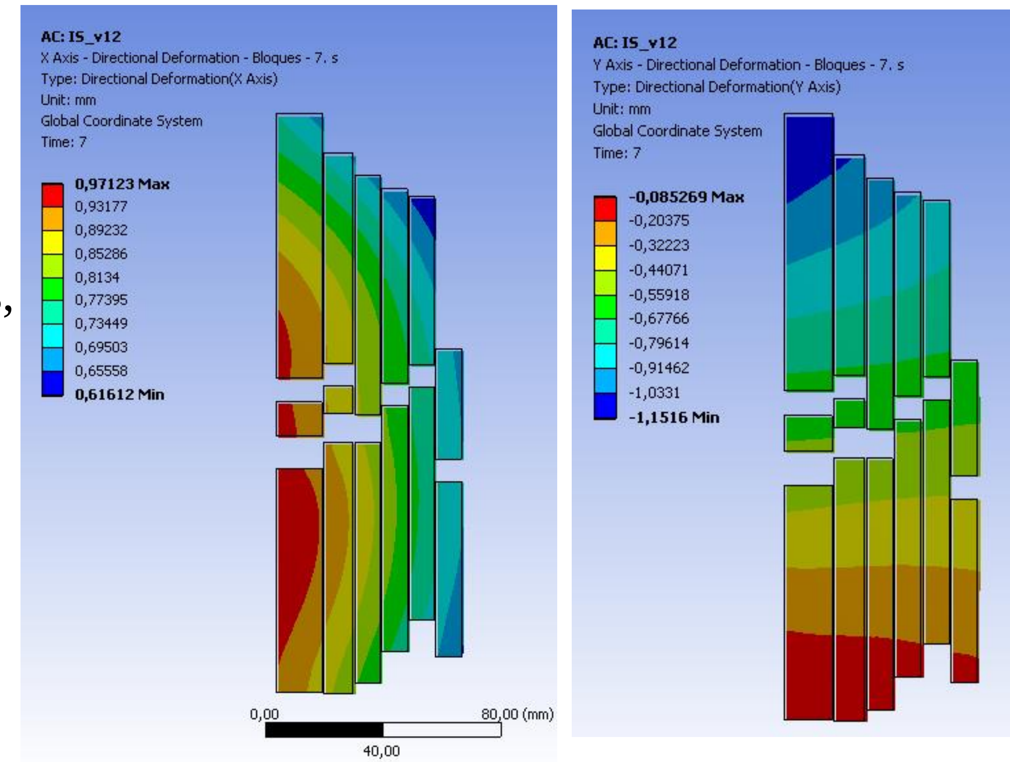
- The outer shell is not enough to hold the Lorentz forces (19 MN/m per aperture).
- Different iron shapes have been studied: vertical split, horizontal split, collared iron. No good results because of high tensile stresses in the iron. For comparison, iron is symmetric in horizontal axis as the other options
- Thermal contraction of the coil is very different in vertical and horizontal directions because of the coil size.



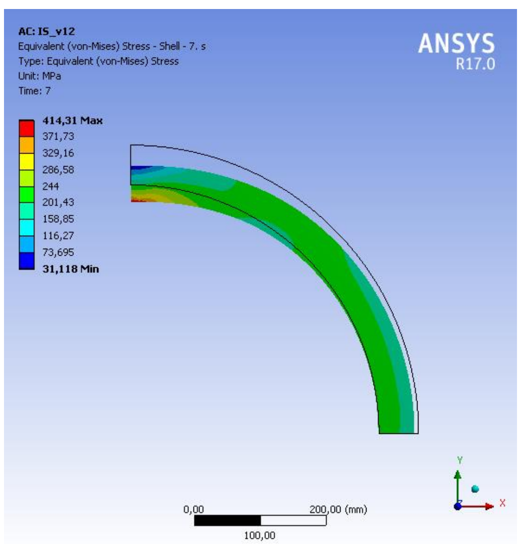


Coil displacements with Ti Rods

- Additional internal support improve horizontal stiffness, keeping displacements below 1 mm. Rotation of coils also decreases.
- Shell deformation is lower for the same thickness (60 mm).
- Coils have been modeled as cable blocks, copper spacers and insulation layers.



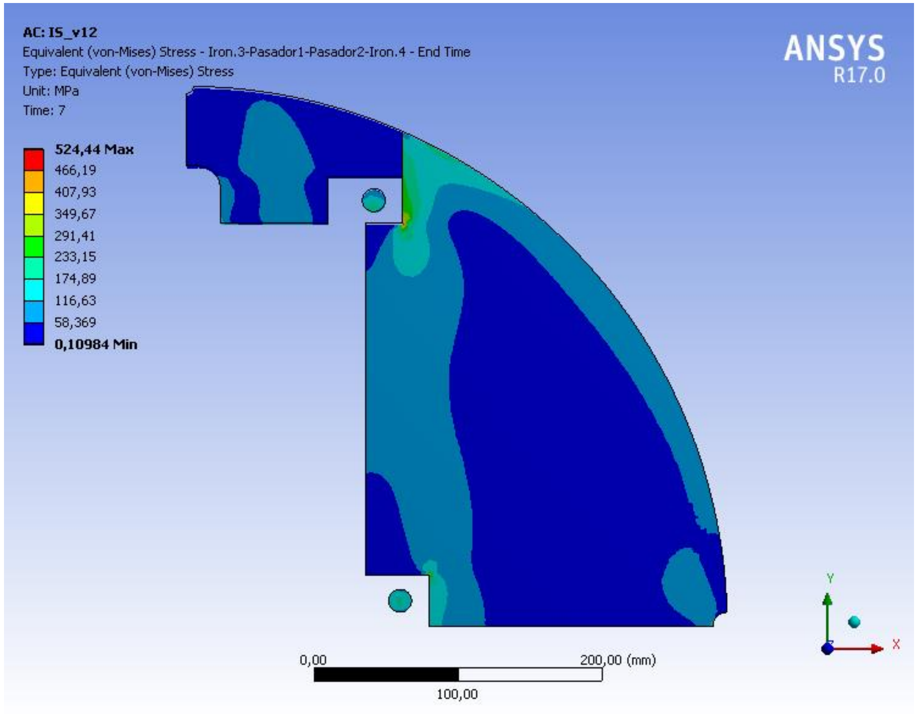
Coil blocks overall displacement in mm: horizontal (left) and vertical (right)



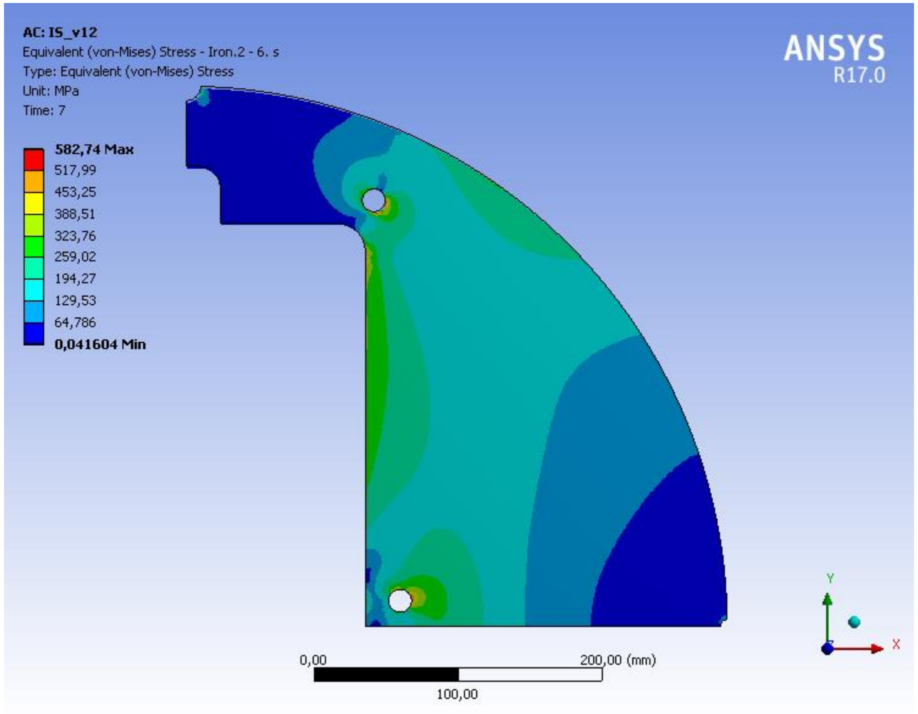
Shell stress (enlarged deformation)

Stress in iron with Ti Rods

Iron (Von Misses): 16T @ 4,2K
Maximum Von Mises criterion= 582 MPa
Peak Principal Stress = 400 MPa because of local stress concentration at pins.
Ongoing study with larger pins.



Von-Mises criterion map



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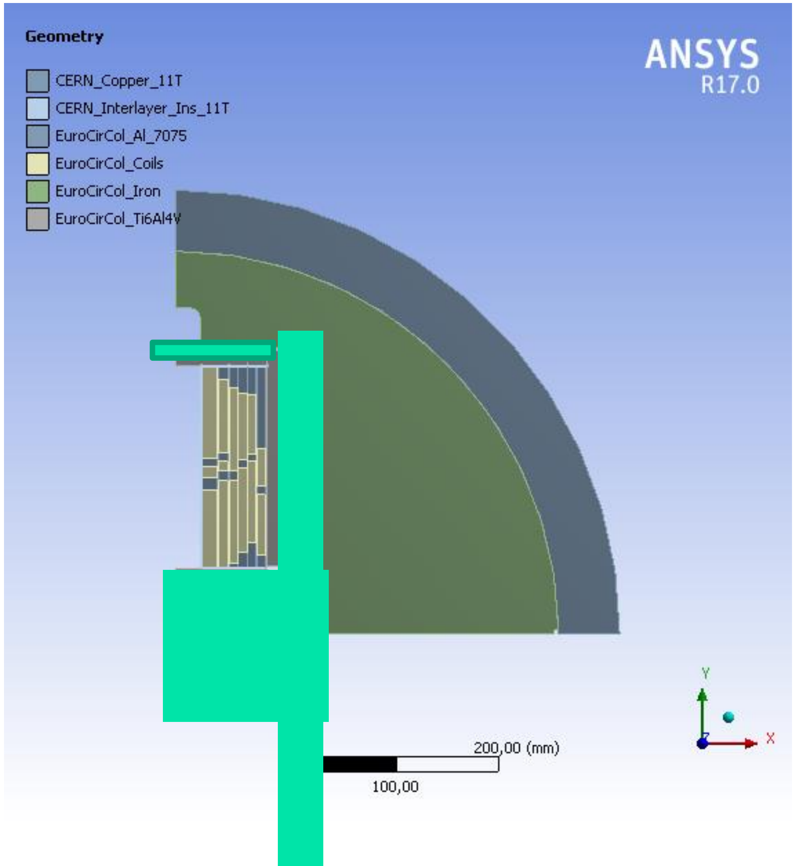
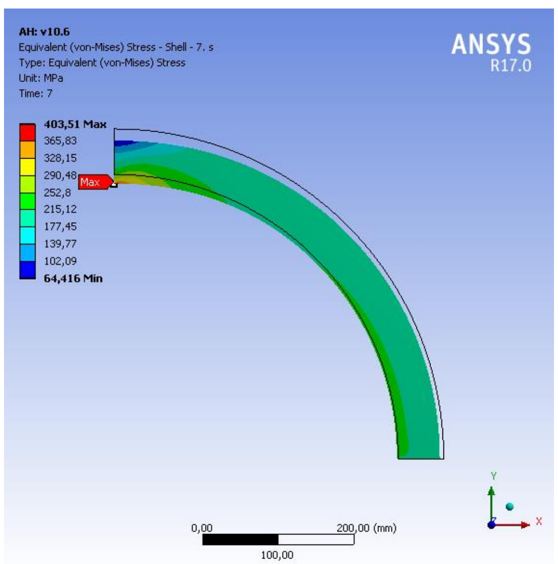
Option: Internal Ti Case

- Ti Rods results in very high stress concentration to iron because space limitation
- *H-shape* Ti case can provide lateral stiffness while covers can transfer thermal contraction from shell.
- These covers can be made with steps or split for each coil

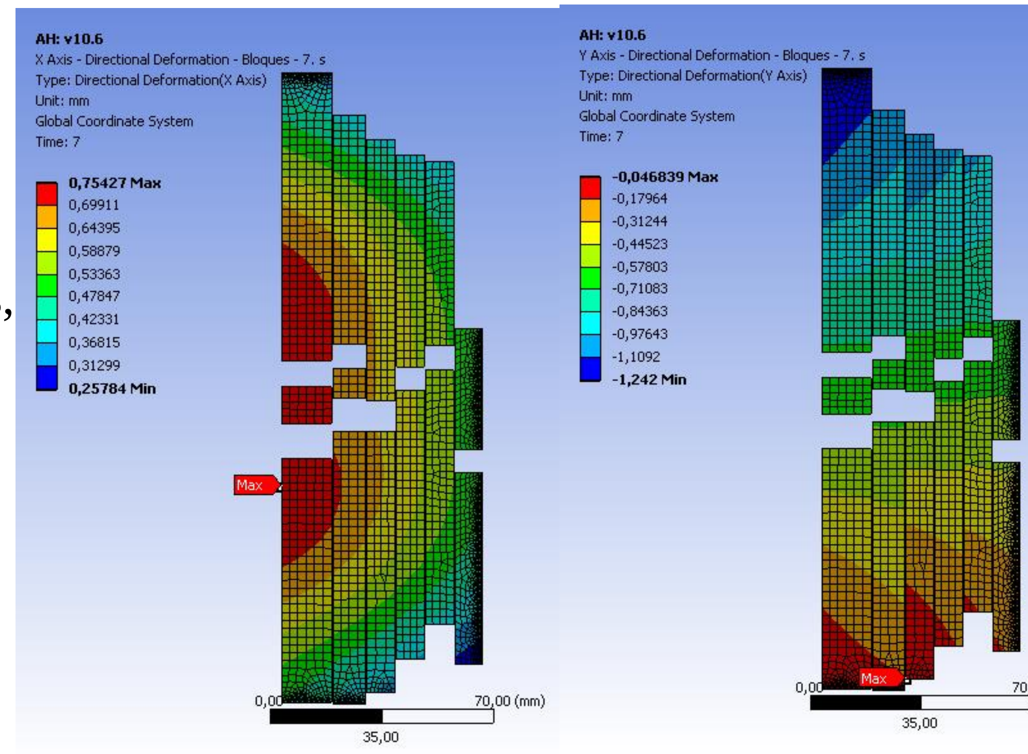


Coil displacements with Ti Case

- Additional internal support improve horizontal stiffness, keeping displacements below 1 mm. Rotation of coils also decreases.
- Shell deformation is even lower for the same thickness (60 mm).
- Coils have been modeled as cable blocks, copper spacers and insulation layers.



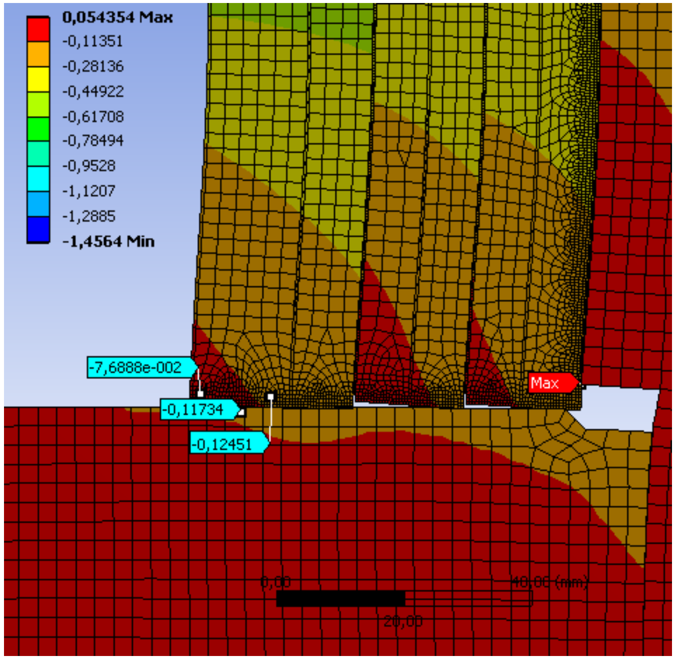
Shell stress (enlarged deformation)



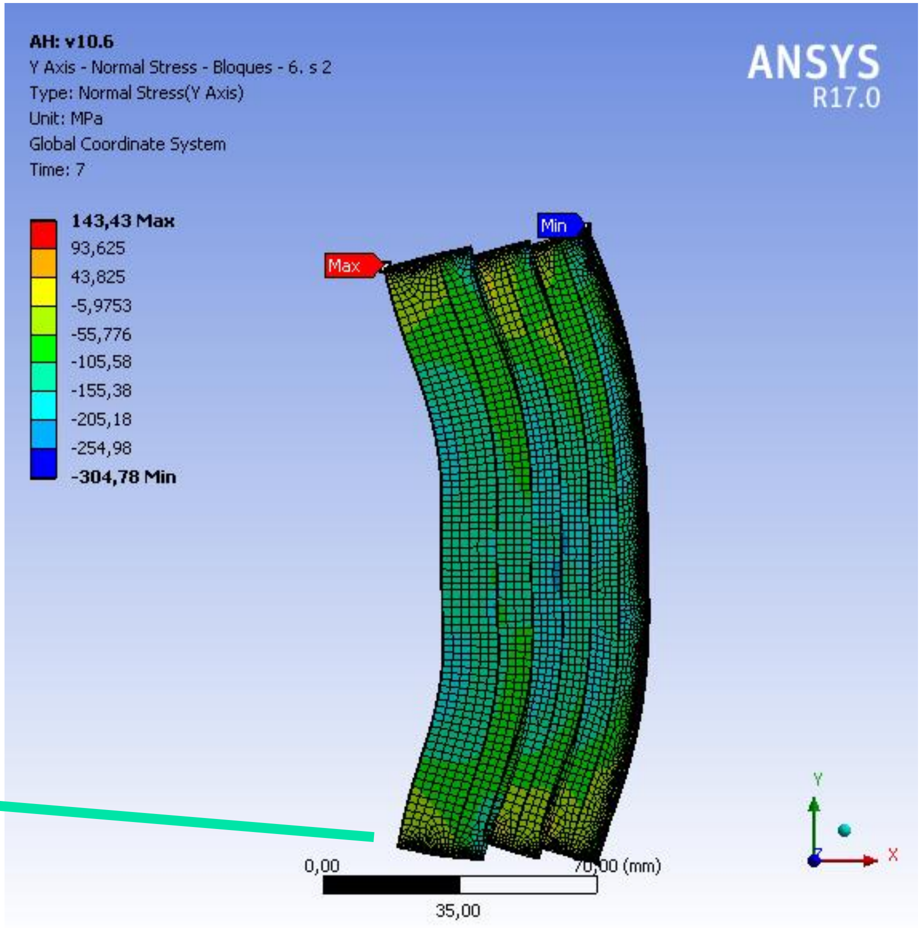
Coil blocks overall displacement in mm: horizontal (left) and vertical (right)

Coil stresses with Ti Case

- Three coils are modelled independently
- They are hold by the case without friction just by thermal preload and EM forces.
- Cu Fillers suffer higher stresses from the contact pressure in some corners
- Coils lose contact on left corners because magnetic forces



Vertical displ. on case-coils contact (enlarged deformation)



Coil blocks vertical stresses and shape (enlarged deformation)

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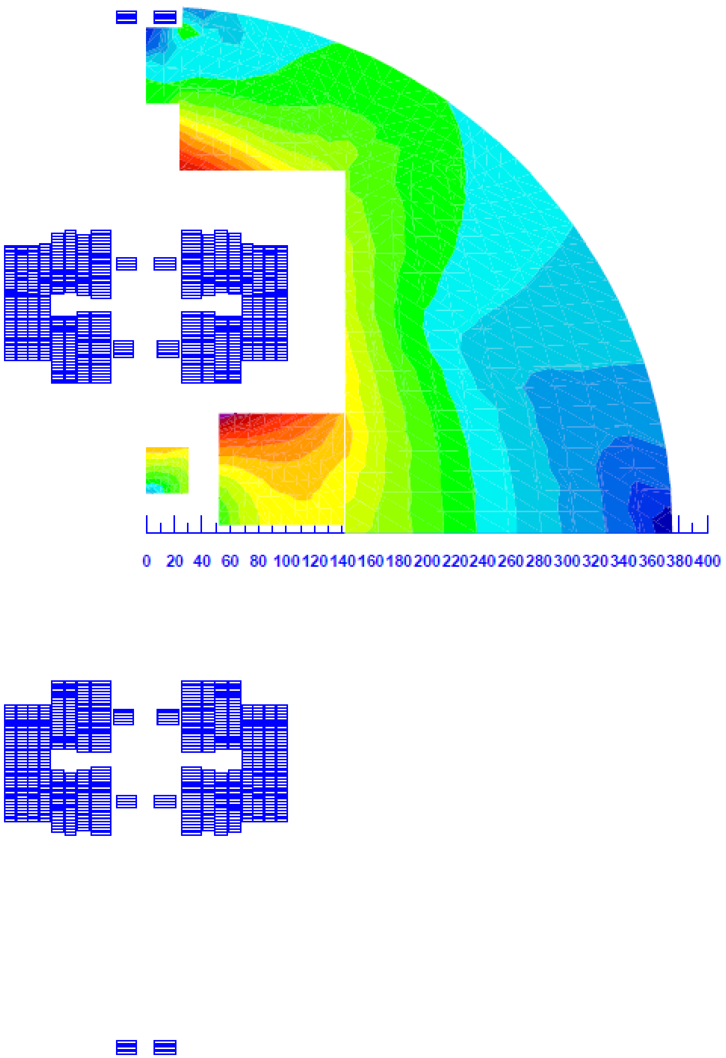
2-D design with ancillary coils

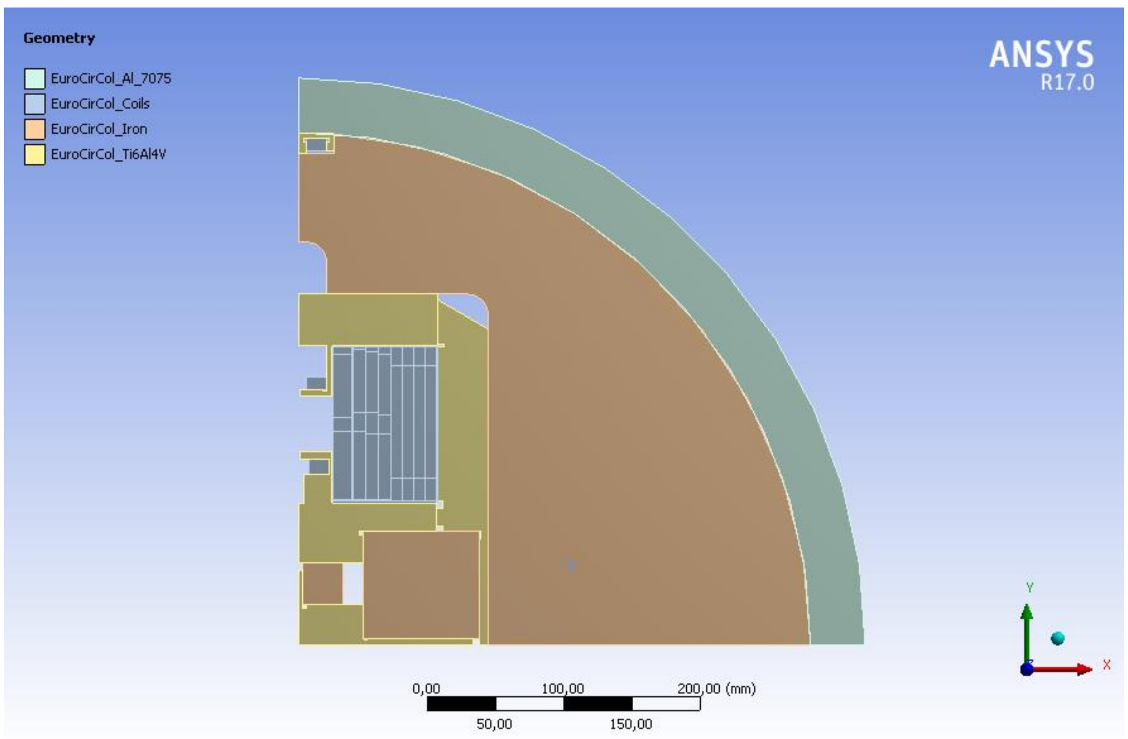


- The mechanical advantages of this layout would be:
  - Enhanced superconductor efficiency. Optimal aspect ratio of block is around 1.5 (width/height)
  - Large bending radius: react and wind coils.
  - Outer iron radius could be reduced.

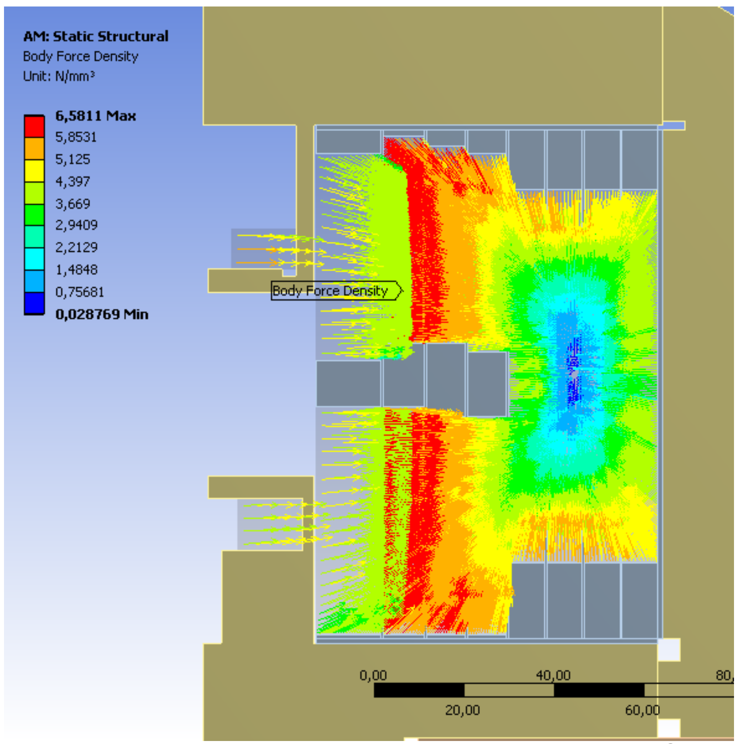
  - Lateral forces: 19.11 MN/m to 14.71 MN/m
  - Vertical forces: 1.5 MN/m to 0.79 MN/m

Support structure layout (Ongoing)

- Internal case option is shown
- An outer shell of aluminum provides the pre-stress to the coils.
- Cable blocks are modeled with smeared-out properties.
- Lorentz forces are transferred on each cable position.
- No friction between the parts.
- Iron symmetry in horizontal axis is assumed



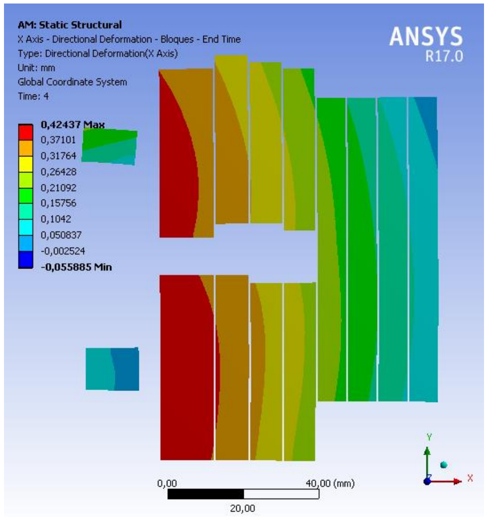
Internal Case layout

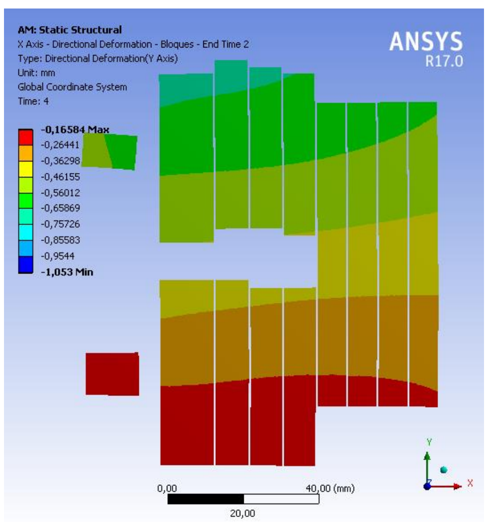


Lorentz forces map

Coil displacements and stresses

- Lower aspect ratio results in easier transfer of preload.
- Less forces results in less deformation and stresses



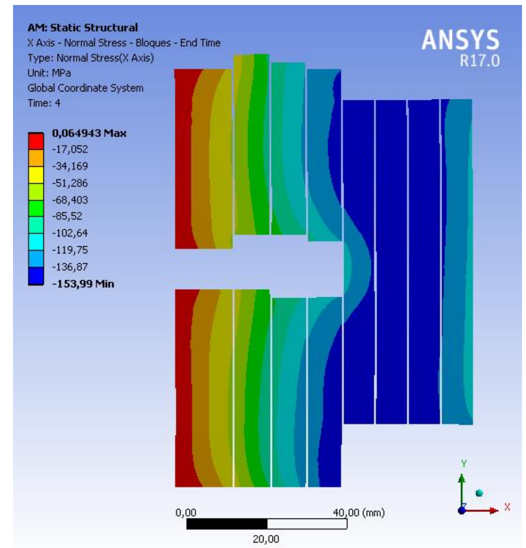


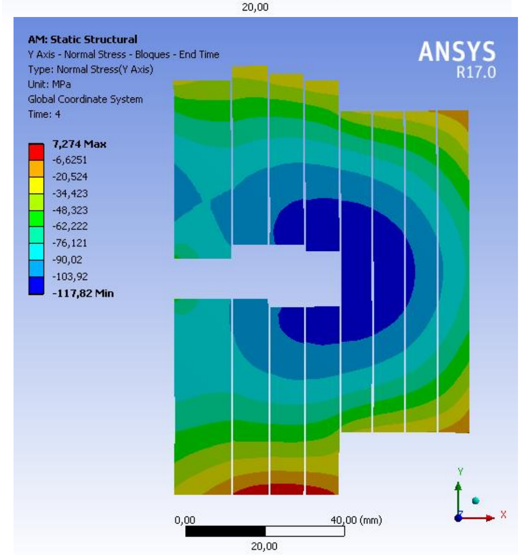
LEFT: Displacements (mm)

Horizontal: -0.05 to 0.42
Vertical: -1.05 to -0.16

RIGHT: Stresses (MPa)

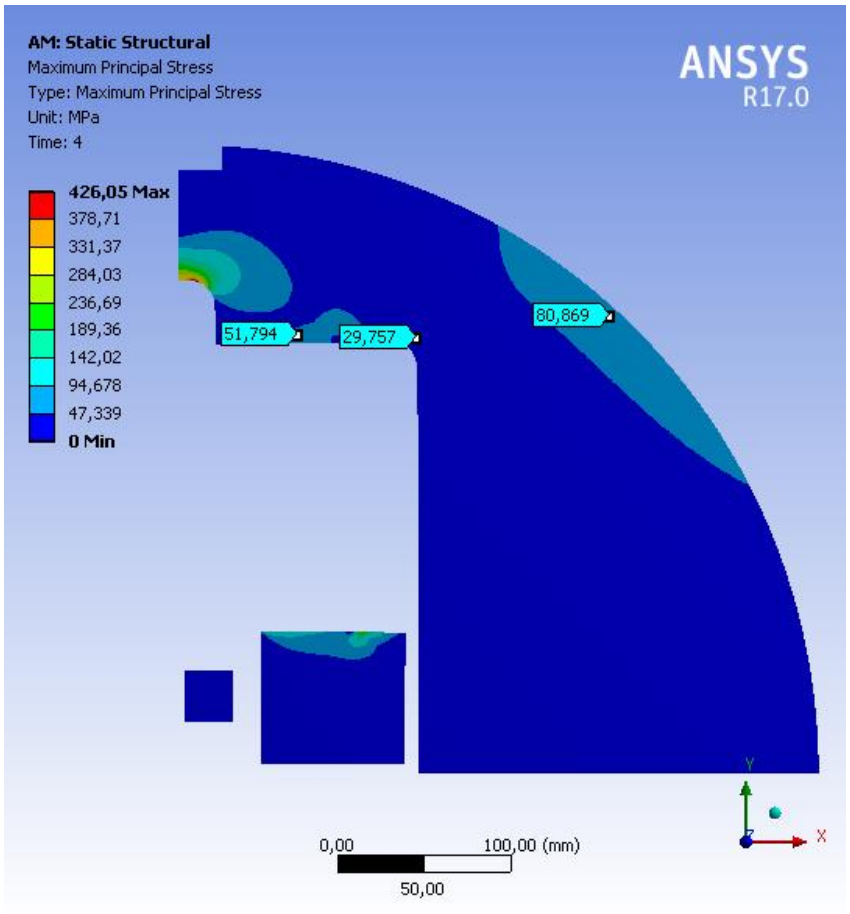
Horizontal: -154 to 0.06
Vertical: -118 to 7.27

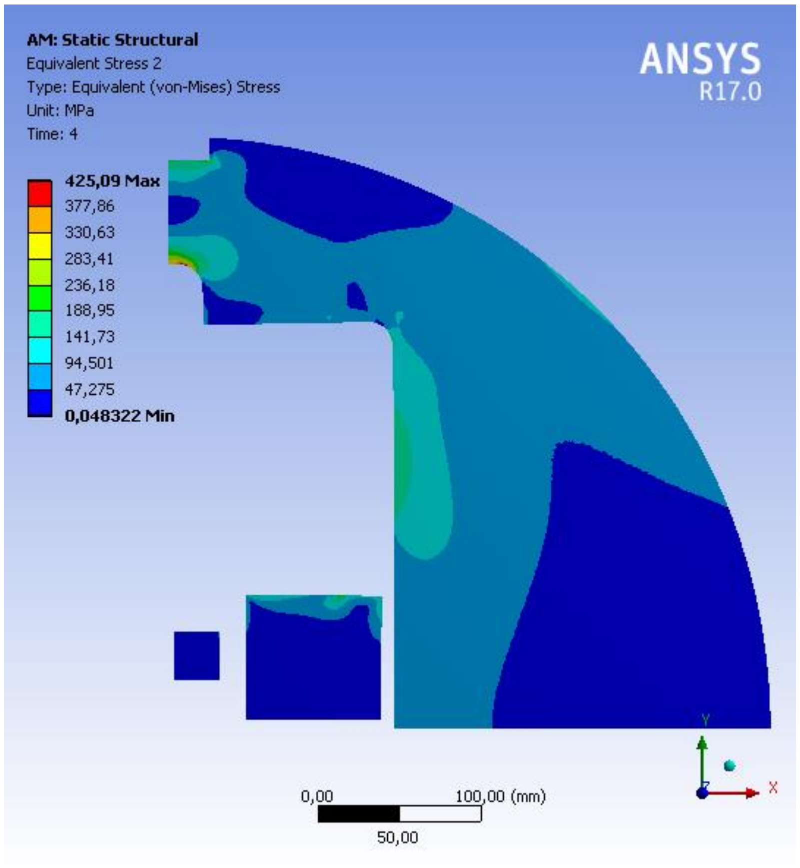




Iron

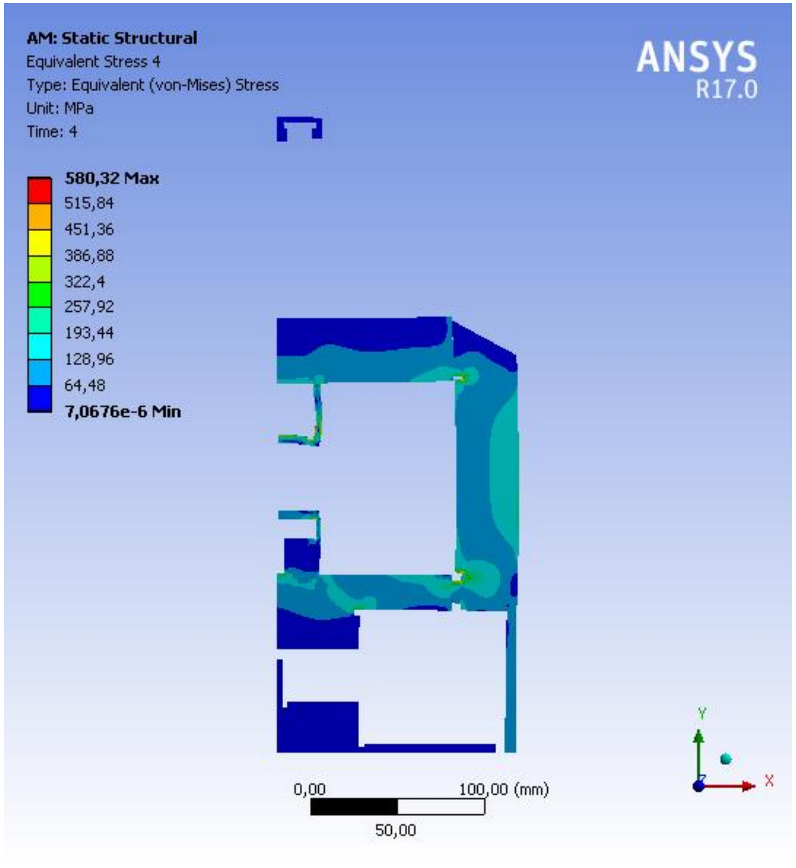
- First concept attempt results in stress concentration in iron to be checked
- Maximum principal stress (left), equivalent stress (right)

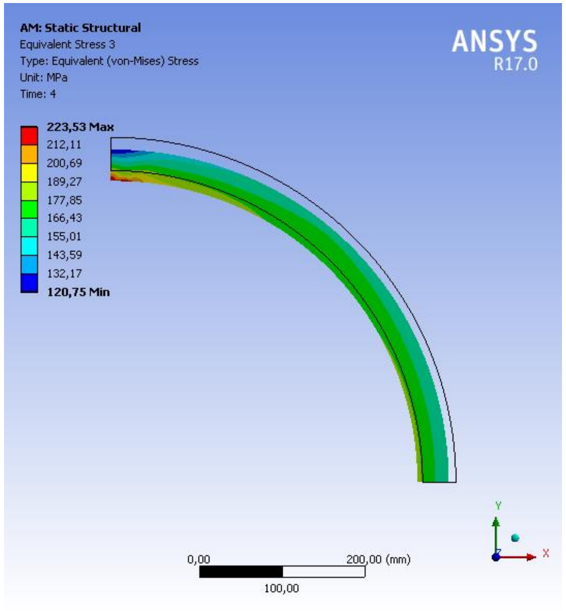




Supporting Case and Shell

- Same H-shape case concept has been done as first attempt
- Max. equiv. stress on the casing 580 Mpa at 1.05 nominal current
- Outer shell deformation (right): Almost cylindrical, low stresses





Conclusions

- 2-D mechanical calculations without ancillary coils:
  - Too large coil displacements when using only an aluminum shell to hold the Lorentz forces.
  - Supporting tension rods results on too high peak stresses in iron ($\sigma 1$)
  - Internal Ti H-shaped case seems to be a promising option, but assembly feasibility should be studied

- 2-D mechanical calculations with ancillary coils (preliminary):
  - The change in the aspect ratio and magnetic efficiency goes in the good direction both for coil displacement and stresses
  - Additional supports to withstand the ancillary collars should be made, but they seem to be feasible. They could lead to a challenging assembly procedure.
  - Additional studies about this conceptual option should be developed