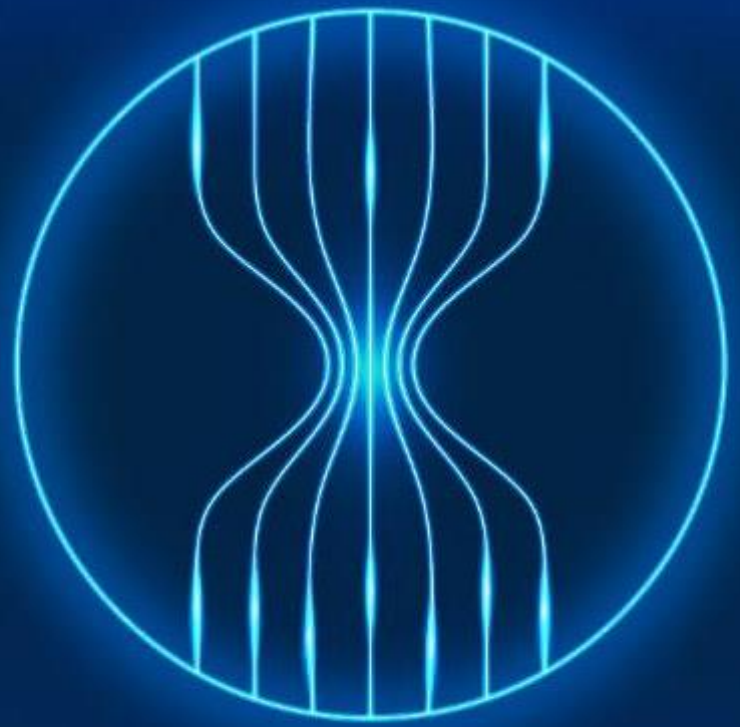

HFM

High Field Magnets

Update of ISAAC mechanical design

J. García Matos, C. Martins, F. Toral (CIEMAT)
J.C. Pérez (CERN)

Outline

- ISAAC goals & constraints (reminder)
- 2D Design baselines and configurations (reminder)
- 2D Design Update
- 3D Design
  - Magnetic – Maxwell
  - Mechanical – Ansys
- Conclusions

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ISAAC goals & constraints (reminder)

- **ISAAC**: **I**nvestigating **S**uperconducting **A**ssembly to **A**ddress **C**ommon coil mechanics
- Main goal: learn for the 14 T model with **existing coils**, mostly on **mechanics**
  - Existing RMC coils made at CERN with MQXF strand are selected
  - Mechanics & assembly as simple as possible
  - Provide ≈14 T in the aperture (100% load)
  - Decrease vertical Lorentz force F_y to achieve low vertical preload: free horizontal movement when coils are energized, without friction
- Assembly with **bladder and keys**, slight **preload** just to keep contact between parts
- **Aluminium shell** also contributes to hold the forces
- Goal: To have a horizontal **coil displacement** due to the EMF **below 0.5 mm** to:
  - Reduce the impact on field quality (0.5 mm -> 1% less field in the aperture)
  - Reduce the possibility of sudden coil movements (to avoid quenches)

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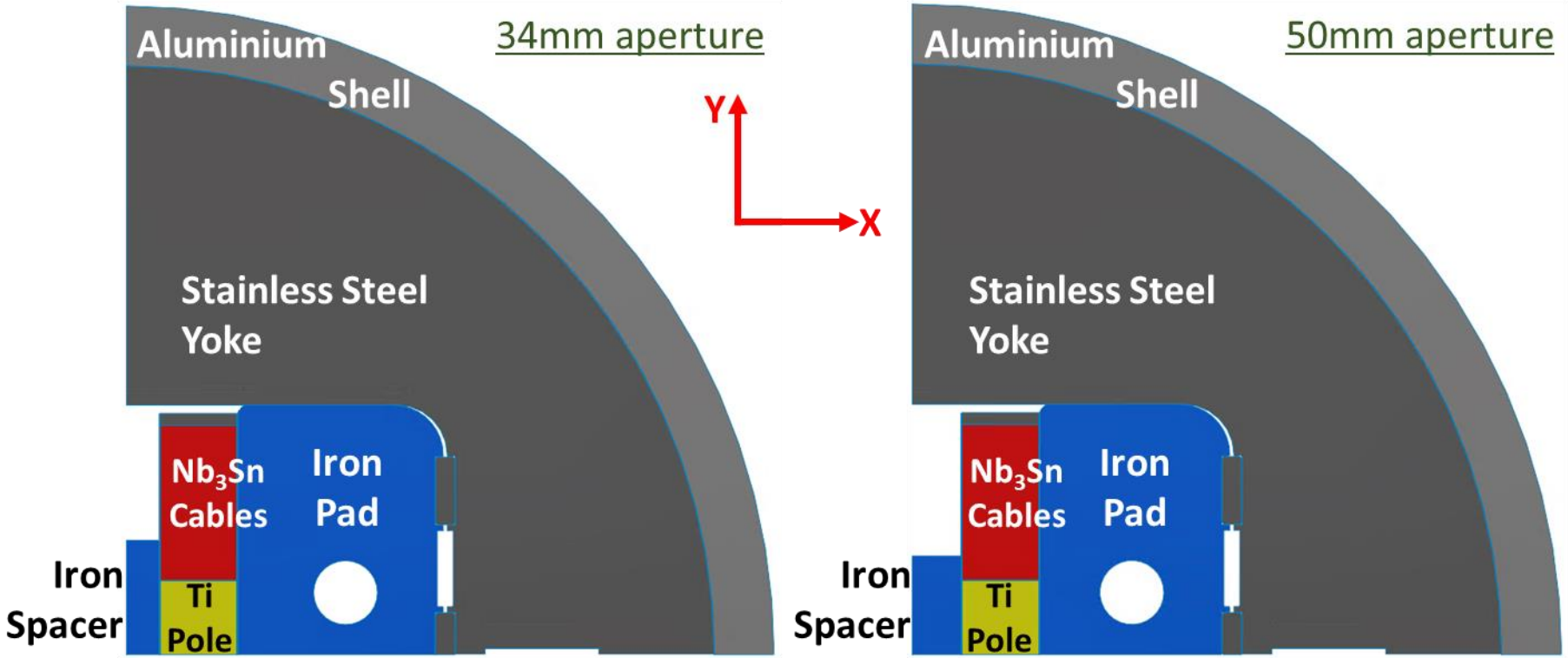
2D Design baselines and configurations (reminder)

- One Ø30 mm Rod per quadrant
- Pad width: 30 mm @ both sides of the rod with 50 mm aperture
- Fixed Yoke and Shell for different apertures (34 mm & 50 mm): Only Pad and Spacer change
- **Shell** dimensions: **Ø Outer**: **650 mm**. **Thickness**: **30 mm** (Ø Inner: 590 mm)
- **Iron** components **EMF** taken into consideration (Spacer & Pad)



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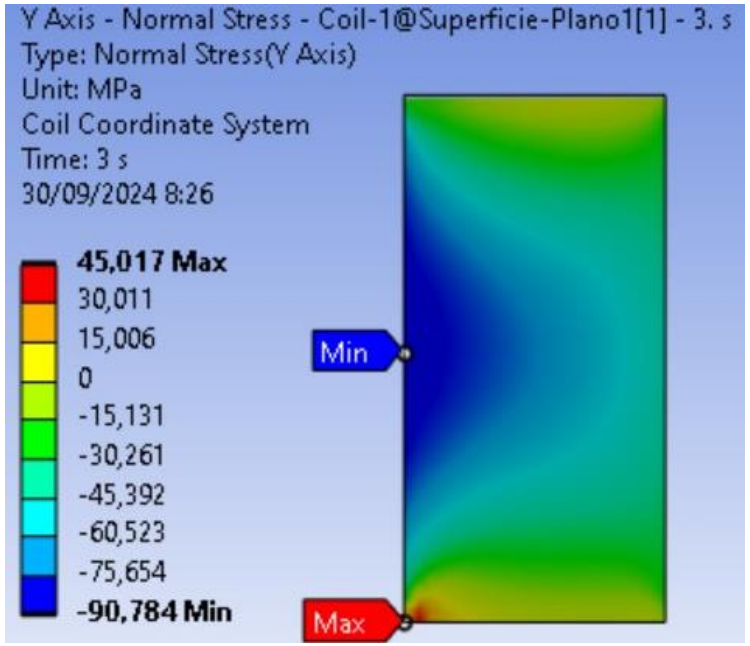
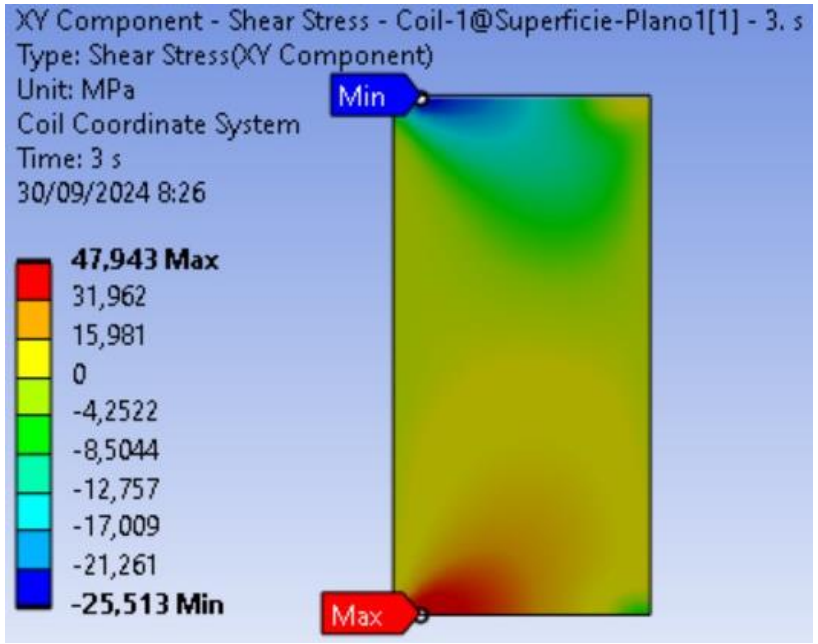
2D Design without preload (34mm aperture)

All components in contact without preload at room temperature

Main concern: **Cable detaching from pole due to Vertical (Y) and Shear Stress**

	Coil Stress				
	X stress	**Y stress**	**Shear Stress**	**VM stress**	
Max	**30,019 MPa**	14,081 MPa	13,982 MPa	36,77 MPa	Cooling
Min	-13,98 MPa	-24,897 MPa	-16,394 MPa	0,6322 MPa	
Max	**95,096 MPa**	**45,017 MPa**	**47,943 MPa**	113,88 MPa	EMF
Min	-101,3 MPa	-90,784 MPa	-25,513 MPa	4,0586 MPa	

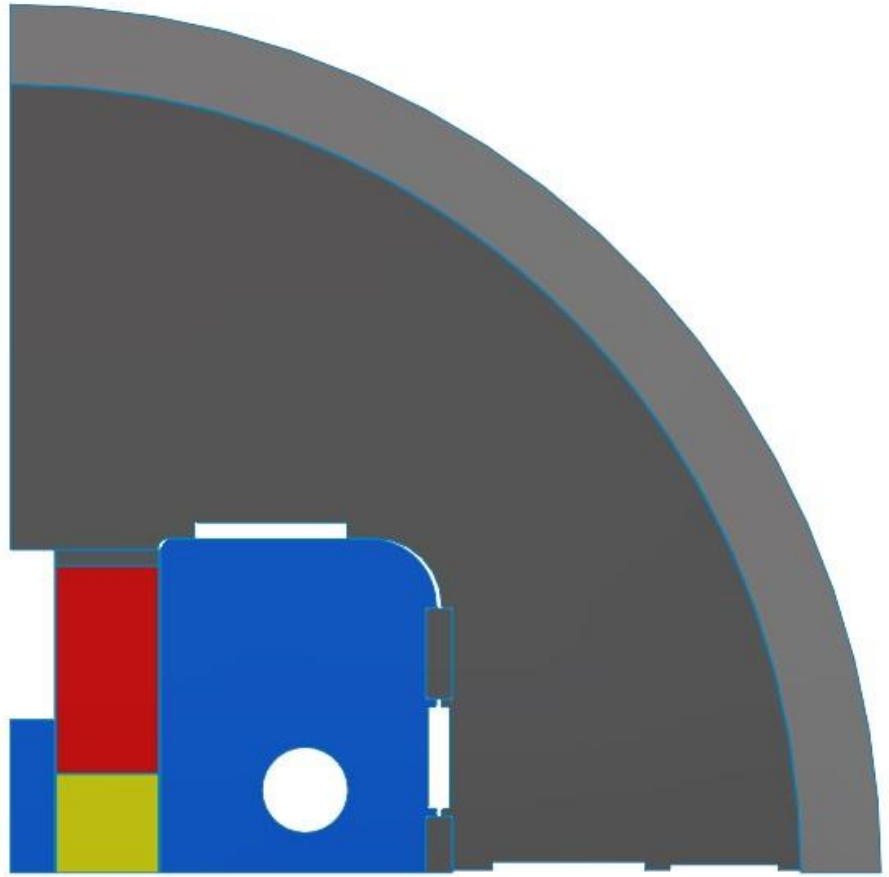




2D Design with (vertical) preload (34mm aperture)

- Slot between Yoke parts for a vertical bladder to allow the assembly at room temperature (RT)
- Yoke slots for additional bladder and/or keys:
  - Between Pad and Yoke: it can allow a bladder or a key
  - Between Yoke parts: the one on the right for a key
- Gap between Pad and Yoke @RT: 0.15mm
- Initial assembly interference @RT: 0.2mm (96.2MPa preload)

	Coil Stress				
	X stress	**Y stress**	**Shear Stress**	**VM stress**	
Max	**29,669 MPa**	-36,583 MPa	16,327 MPa	81,486 MPa	Cooling
Min	-18,83 MPa	-82,215 MPa	-17,284 MPa	43,582 MPa	
Max	**56,24 MPa**	-1,8267 MPa	43,345 MPa	132,72 MPa	EMF
Min	-98,18 MPa	-136,34 MPa	-34,208 MPa	30,046 MPa	

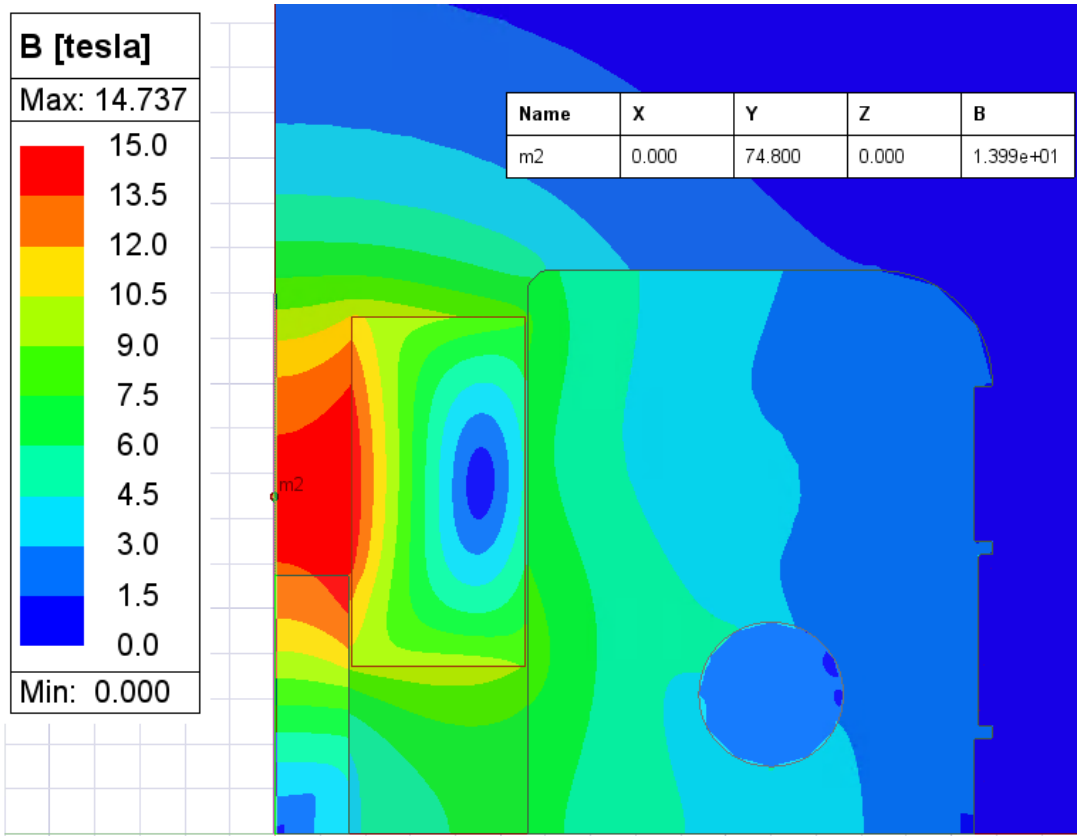


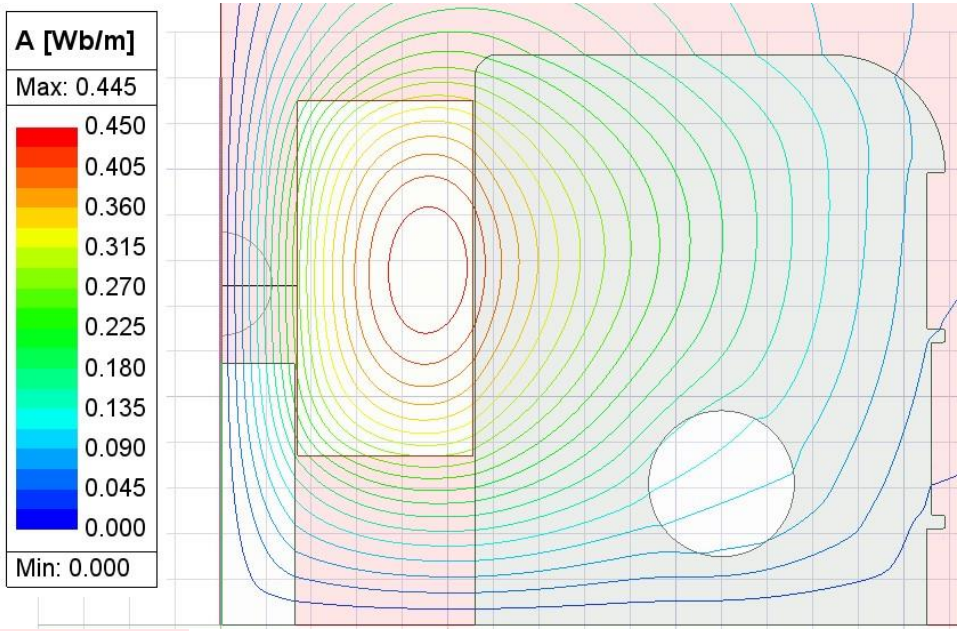
- **Only compression vertical stress** (no tension)
- **Maximum shear stress reduced** (below 45MPa)
- **Horizontal** tension **stress reduced** from 98MPa to 56MPa
- The **VM equivalent stress** is 133MPa (**below** the limit of **150MPa**)

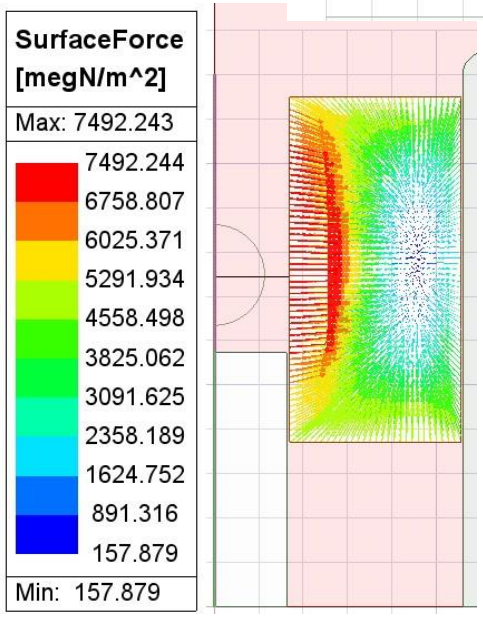
Detailed information about Maxwell and Ansys results in two next slides

Maxwell 2D - 34mm aperture

- Intrabeam: 149.6 mm
- Nominal Current: 19340 A
- Peak Field: 14.74 T
- **Aperture Field: 13.99 T**
- Middle Yoke height (Q1): 57.3 mm (0.5mm to aperture)



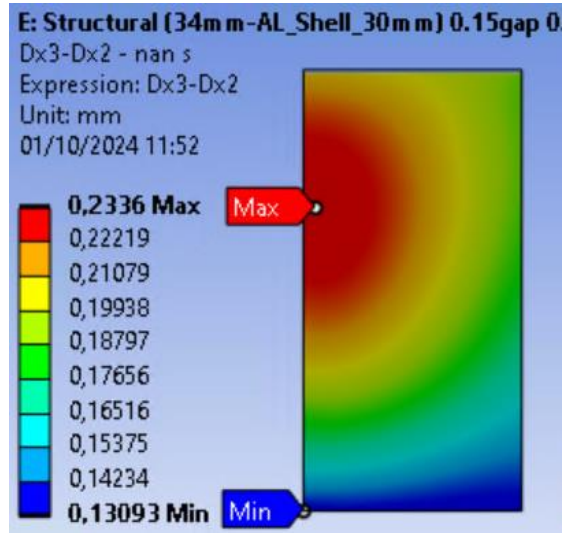




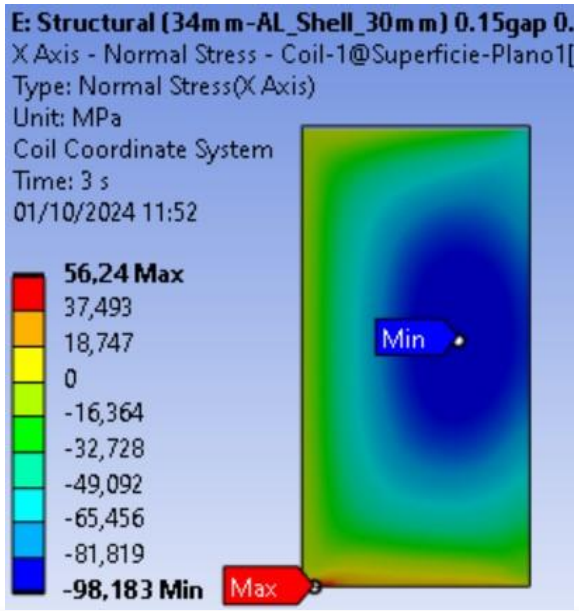
Fx (Coil)	6,397	MN/m
Fy (Coil)	0,441	MN/m
Total F (Coil)	6,412	MN/m
Fx (Spacer)	-0,916	MN/m
Fy (Spacer)	0,304	MN/m
Total F (Spacer)	0,965	MN/m
Fx (Pad)	-1,051	MN/m
Fy (Pad)	-0,253	MN/m
Total F (Pad)	1,081	MN/m

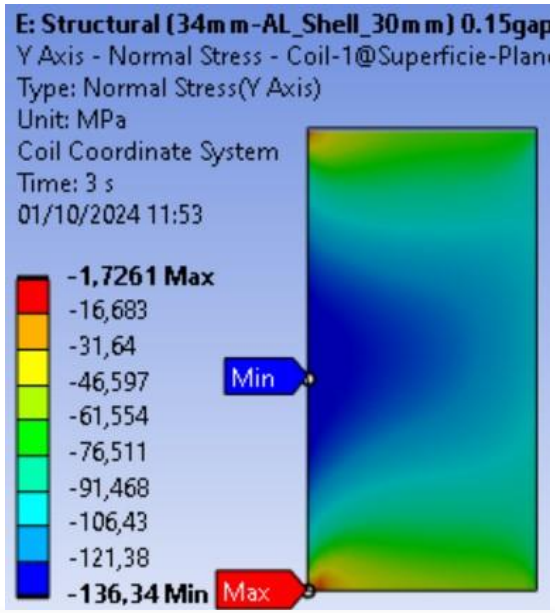
Coil Stress (with vertical preload)

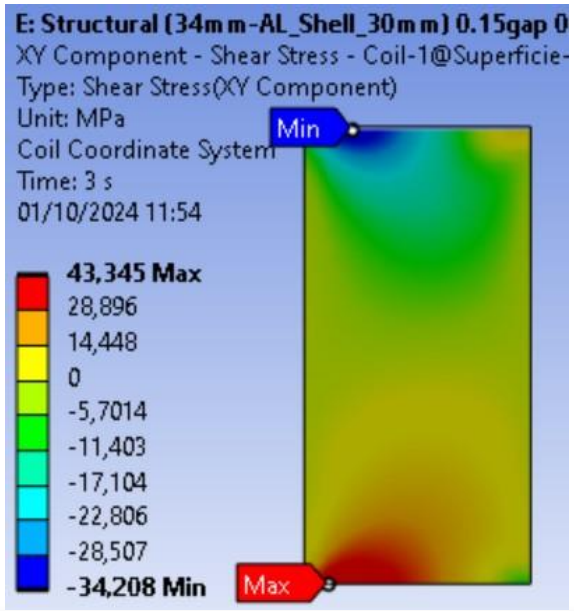
- Max. Horizontal Coil Displacement (X) due to EMF: **0.23** mm
- Max Stress @ Coil (Cooling + EMF):
  - Max X Stress @ Coil: 56.2 MPa (-98.2 MPa)
  - Max Y Stress @ Coil: -1.7 MPa (-136.3 MPa)
  - Max **Shear** Stress @ Coil: **43.3** MPa (located @ Pole – Coil transition)
  - Max **VM** Stress @ Coil: **132.7** MPa

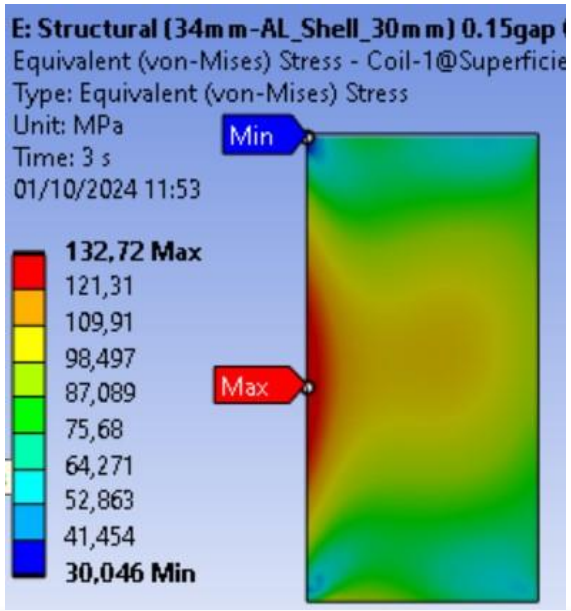


Coil Displacement due to EMF









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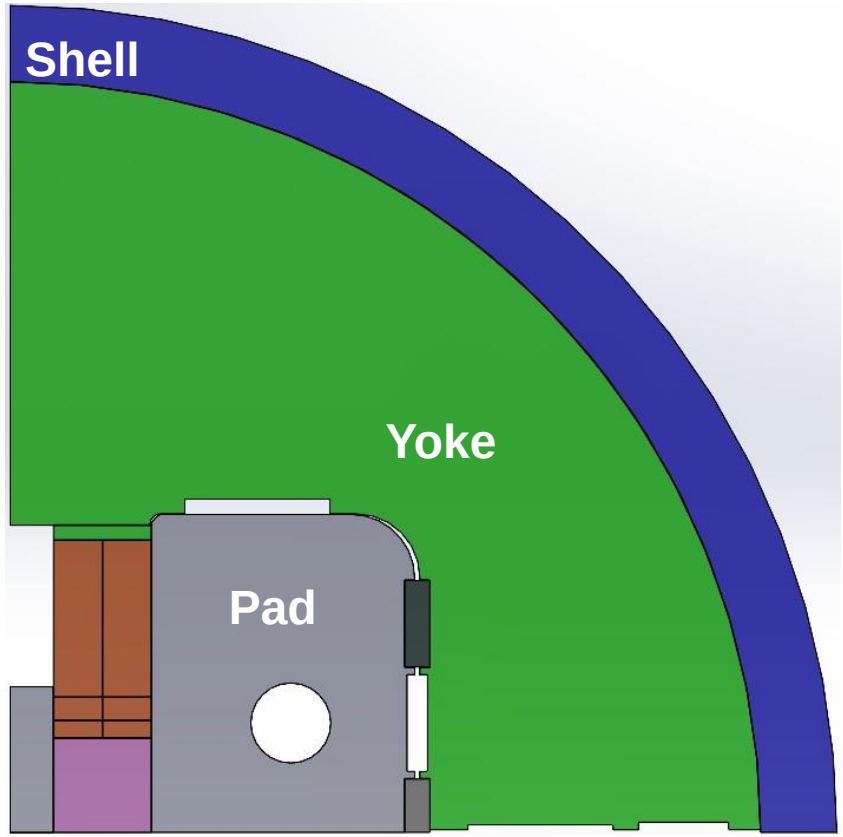
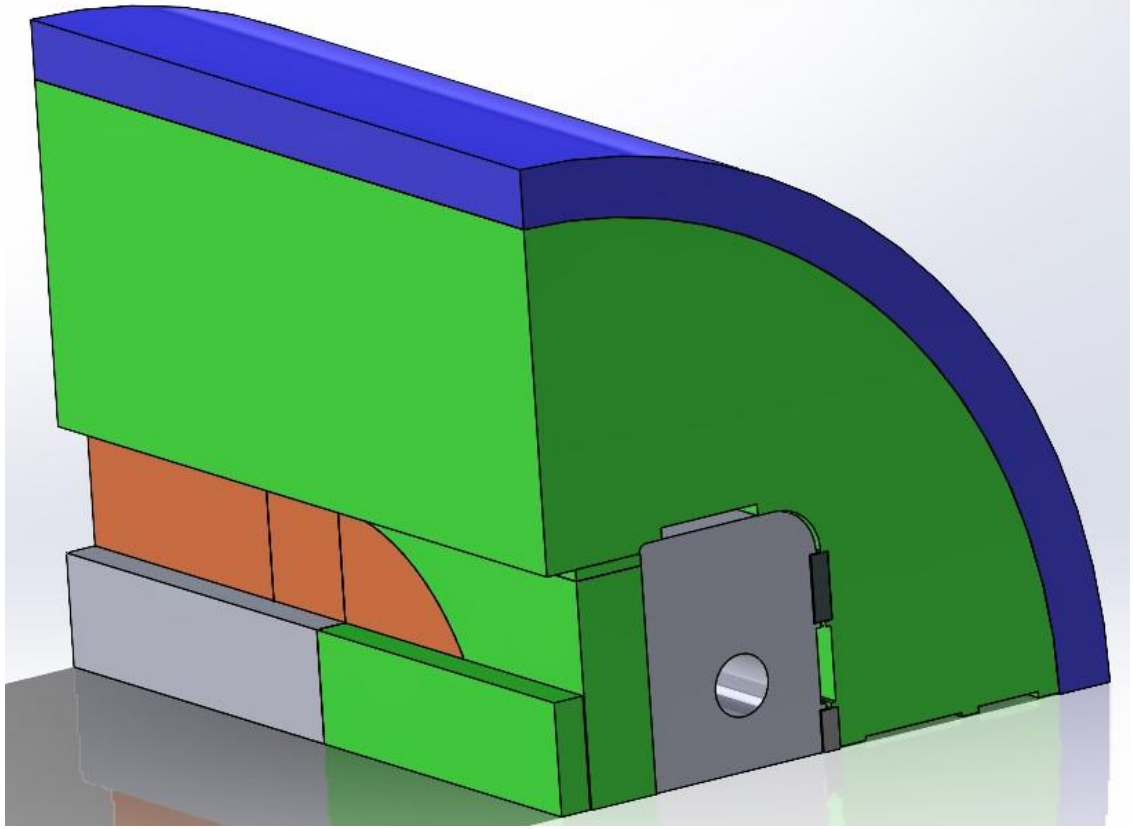
3D Design – 34mm aperture

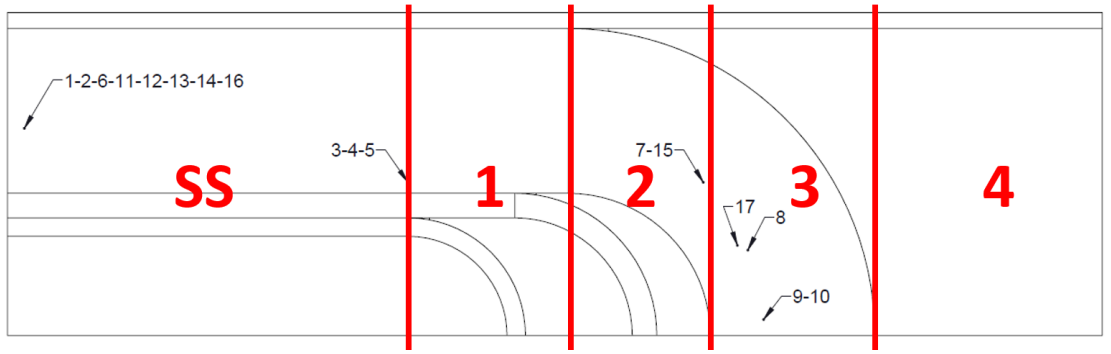
- Geometry and thermal/magnetic conditions as in 2D design
- **Pad entirely made of Iron**
- **Spacer made of Iron in 3rd cable block straight section** (SS+S1), ***ASC2024-1LPo1G-08***



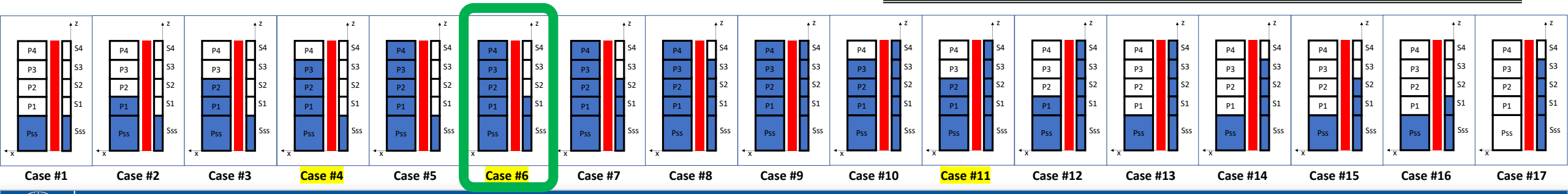


Iron length

- The spacer and the pad can be made in iron.
- If the spacer is made in iron, it should not be longer than the pad. When the peak field is at the straight section, the margin on load line increases.
- The stored magnetic energy decreases with more iron volumen.
- A pad made completely in iron provides better support to the large outwards horizontal electromagnetic forces.
- The best balanced design option is Case #6.



Case	Nominal current (kA)	Aperture Field in SS (T)	Peak Field (T)	Peak Field Loc.	Field Ratio	Transfer Function (T/kA)	Load line (%)	Stored Energy Q1 (kJ)	Fx Structure (kN)
#1	19.340	13.912	14.660	SS	1.054	0.719	99.6	76.06	1508.88
#2	19.040	13.763	14.502	SS	1.054	0.723	98.4	74.38	1461.93
#3	18.804	13.626	14.382	SS/1	1.055	0.725	97.5	73.13	1423.10
#4	18.663	13.547	14.315	SS/1	1.057	0.726	97.0	72.61	1407.84
#5	18.754	13.599	14.370	SS/1	1.057	0.725	97.4	73.52	1443.50
#6	18.665	13.525	14.249	SS	1.054	0.725	96.7	72.81	1408.69
#7	18.604	13.480	15.225	2	1.129	0.725	101.5	72.32	1382.28
#8	18.557	13.460	14.392	3	1.069	0.725	97.2	71.96	1351.00
#9	18.508	13.462	14.499	3	1.077	0.727	97.7	71.82	1345.53
#10	18.509	13.390	14.266	3	1.065	0.723	96.5	71.13	1321.44
#11	18.635	13.464	14.186	SS	1.054	0.723	96.3	71.65	1334.09
#12	18.859	13.596	14.326	SS	1.054	0.721	97.3	72.87	1368.68
#13	19.147	13.738	14.477	SS	1.054	0.717	98.4	74.52	1410.68
#14	19.152	13.751	14.490	SS	1.054	0.718	98.5	74.57	1411.07
#15	19.190	13.780	14.847	2	1.077	0.718	100.4	74.87	1444.02
#16	19.253	13.830	14.574	SS	1.054	0.718	99.1	75.35	1472.37
#17	19.904	13.415	14.366	3	1.071	0.674	98.9	79.30	1518.37



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3D Magnetic Design

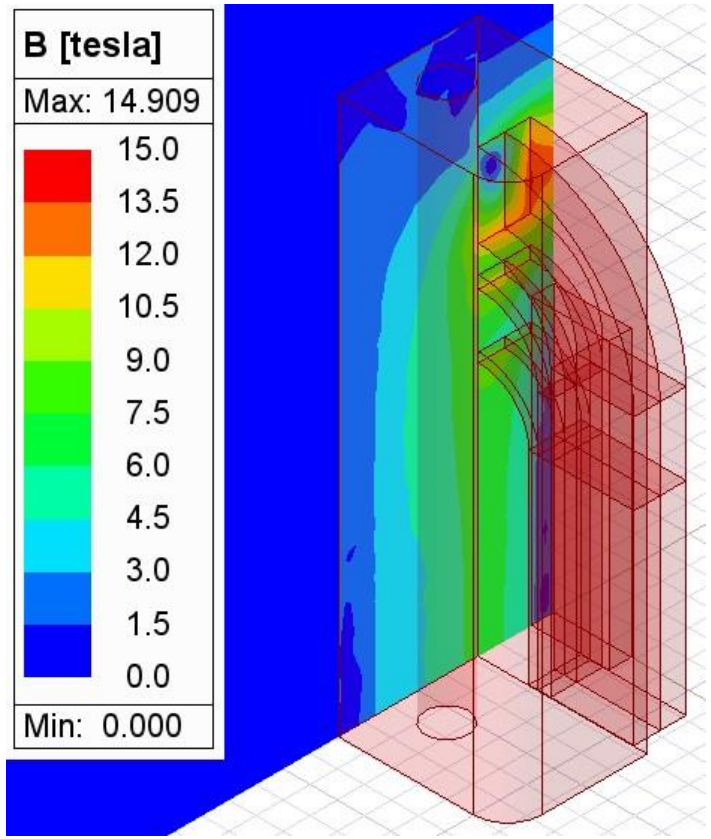
- Nominal current: 19340 A
- Aperture Field: **14.069 T**

Fx (Coil)	2,020	MN
Fy (Coil)	0,418	MN
Fz (Coil)	0,296	MN
Total F (Coil)	2,084	MN

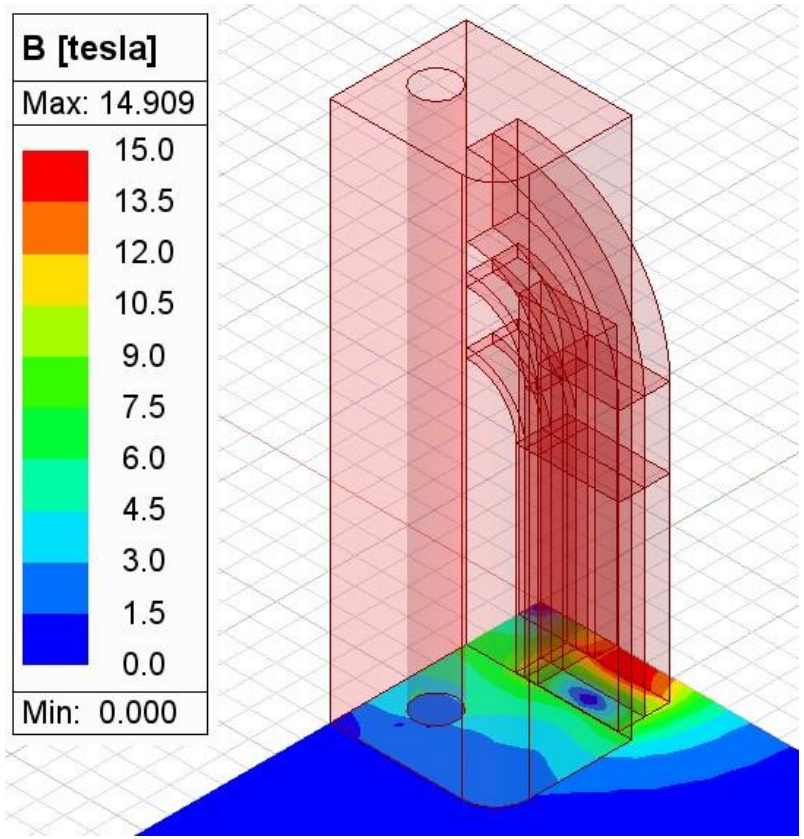
Fx (Pad)	-36,989	kN
Fy (Pad)	-13,259	kN
Fz (Pad)	-64,915	kN
Total F (Pad)	39,826	kN

Fx (Spacer)	-28,631	kN
Fy (Spacer)	58,295	kN
Fz (Spacer)	-24,151	kN
Total F (Spacer)	29,318	kN

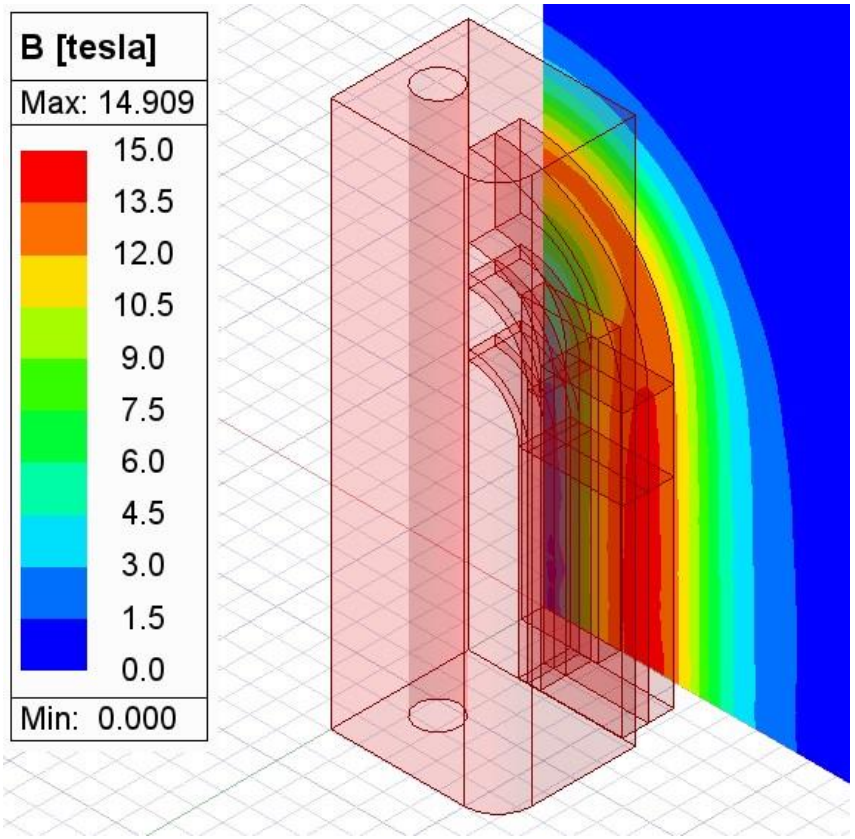
XZ



XY



YZ



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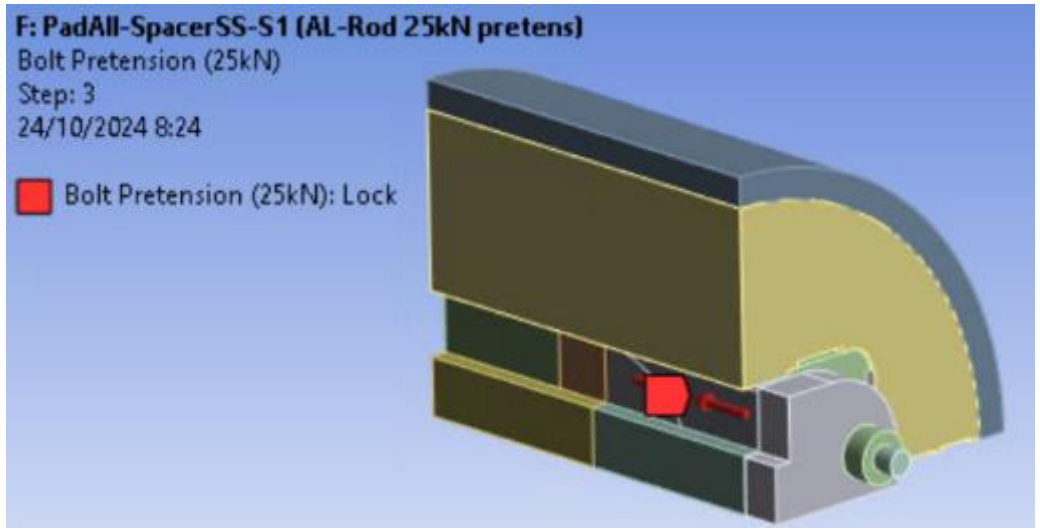
3D Mechanical Design

- **Vertical preload** over Coil: **0.2 mm** interference with Yoke @RT
- Aluminium Rods
- **25kN pretension over Rod**



	COIL DISPLACEMENT DUE TO EMF		
	X	**Y**	**Z**
Max	**0,267 mm**	0,034 mm	**0,211 mm**
Min	0,141 mm	**-0,052 mm**	0,000 mm

EMF(z): 29.64 kN

End Shoe Area: 114.84 x 38.5 mm^2

Total EMF(z) pressure: 67 MPa

Rod Area: 754.77 mm^2

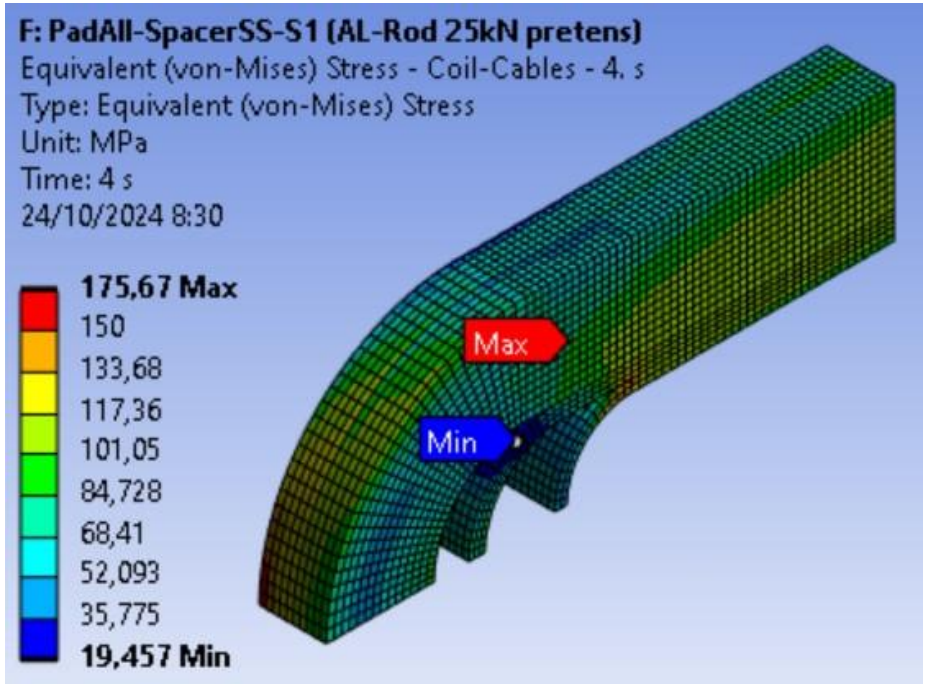
25 kN pretension over Rod applied at RT (half EMF(z) approx)

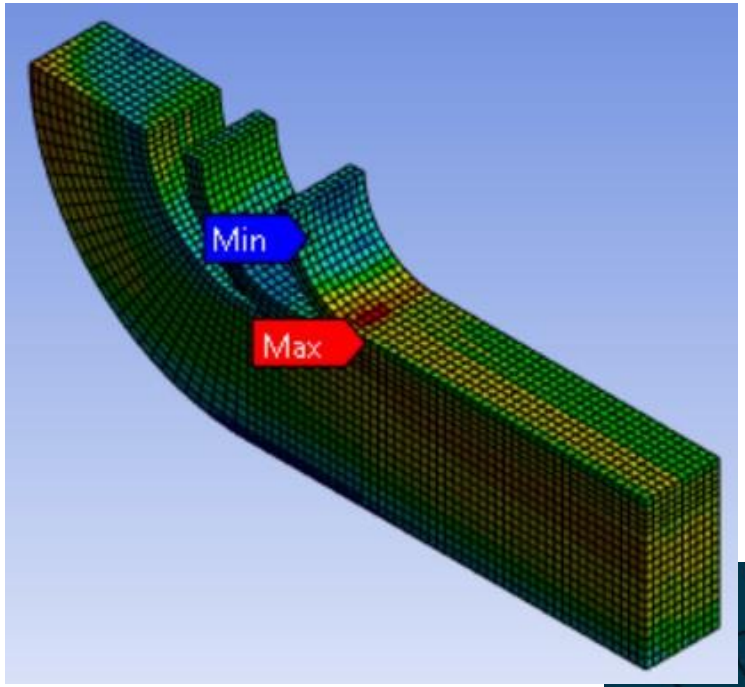
	COIL				
	X stress	**Y stress**	**Z stress**	**VM stress**	
Max	2,45 MPa	-2,72 MPa	5,92 MPa	**21,31 MPa**	RT Assembly
Min	-13,51 MPa	-25,15 MPa	-6,23 MPa	4,61 MPa	
Max	2,72 MPa	-5,02 MPa	-0,47 MPa	**20,06 MPa**	Rod Pretens.
Min	-14,69 MPa	-26,45 MPa	-10,57 MPa	3,32 MPa	
Max	**50,09 MPa**	-2,73 MPa	**54,23 MPa**	**133,22 MPa**	Cooling
Min	-8,57 MPa	-131,37 MPa	-75,56 MPa	**22,09 MPa**	
Max	**68,57 MPa**	**64,52 MPa**	**141,06 MPa**	**175,67 MPa**	EMF
Min	-104,32 MPa	**-167,29 MPa**	-73,47 MPa	19,46 MPa	

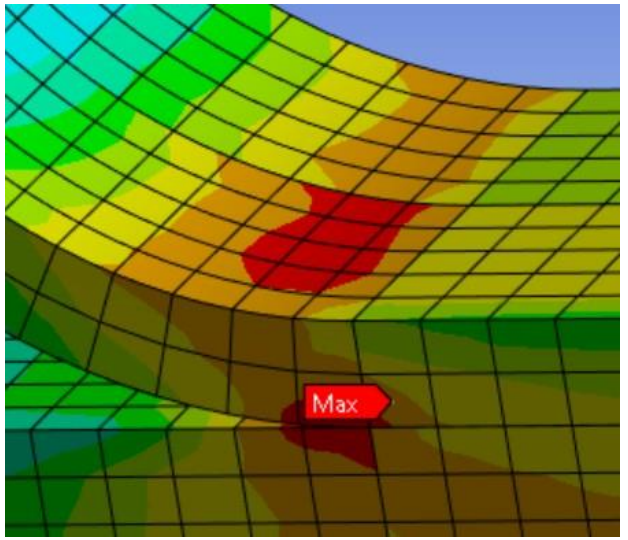
Limits @ RT: -120 MPa <-> 20 MPa

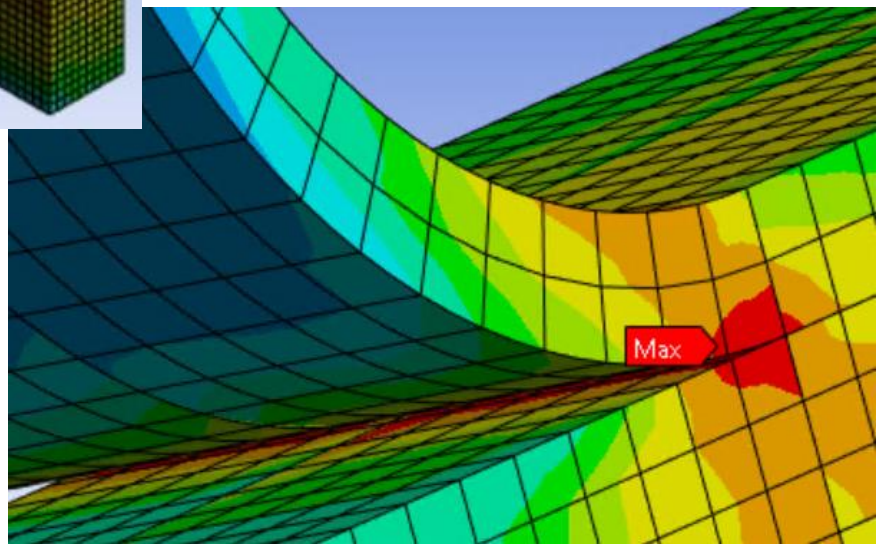
Limits @ Cold: -150 MPa <-> 20 MPa

3D. Coil VM equivalent Stress



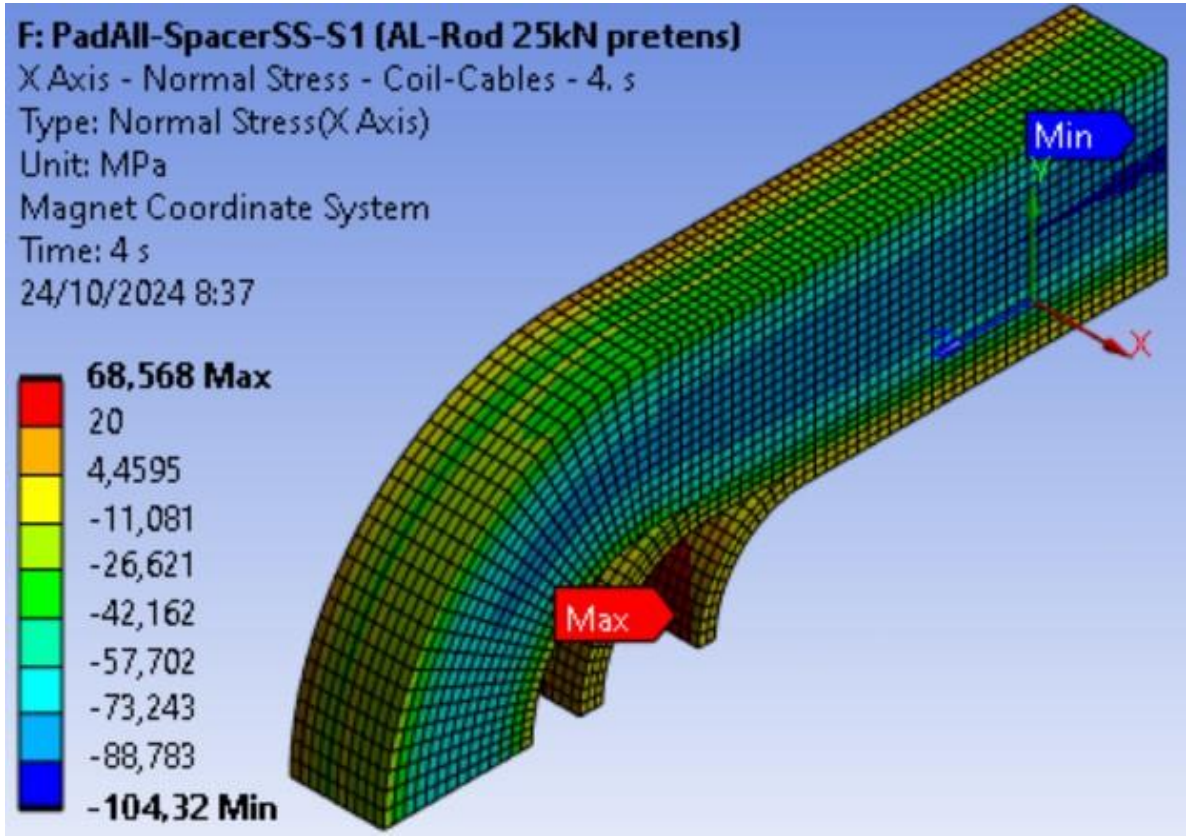


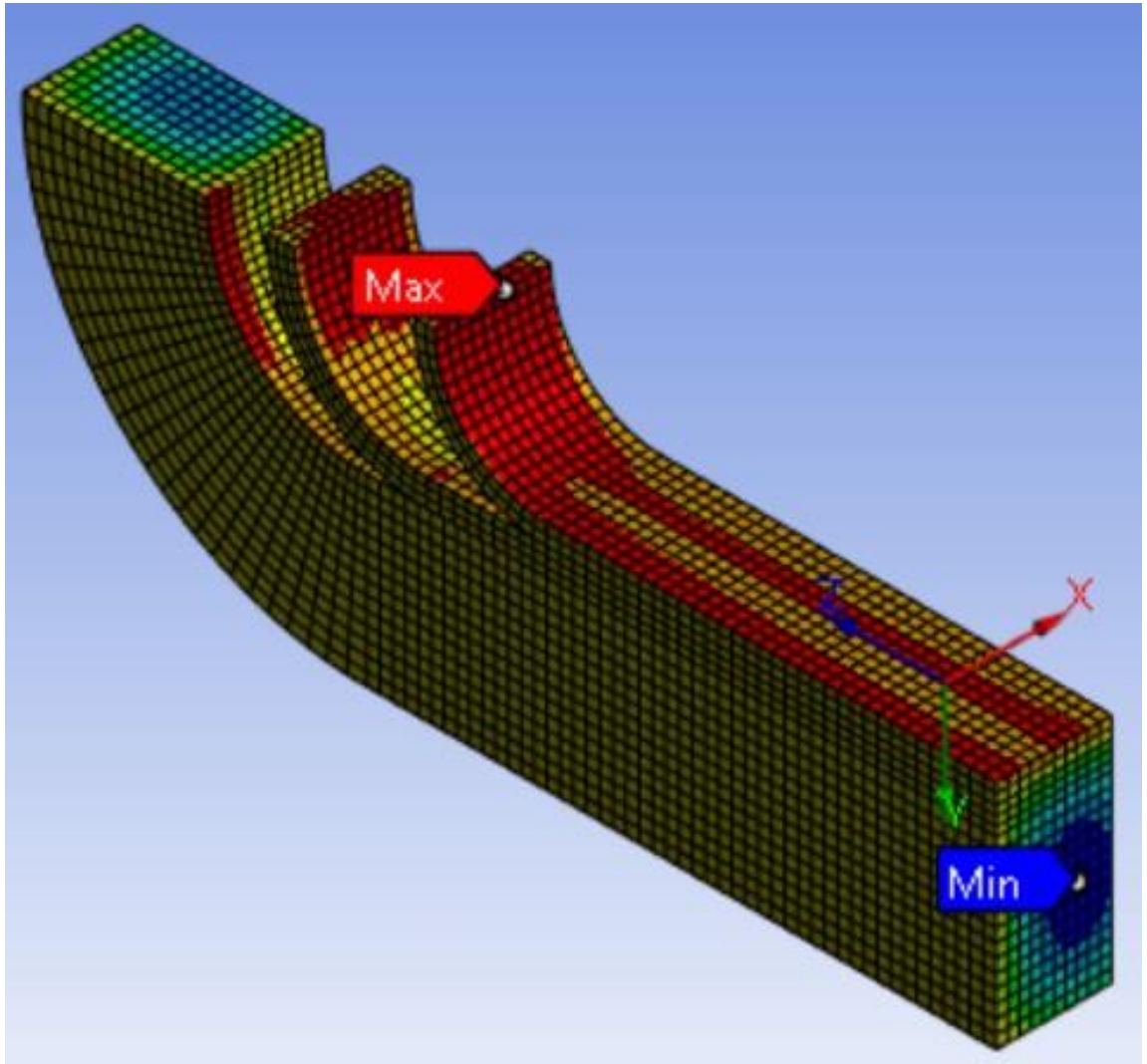




Limits @ Cold: -150 MPa <-> 20 MPa

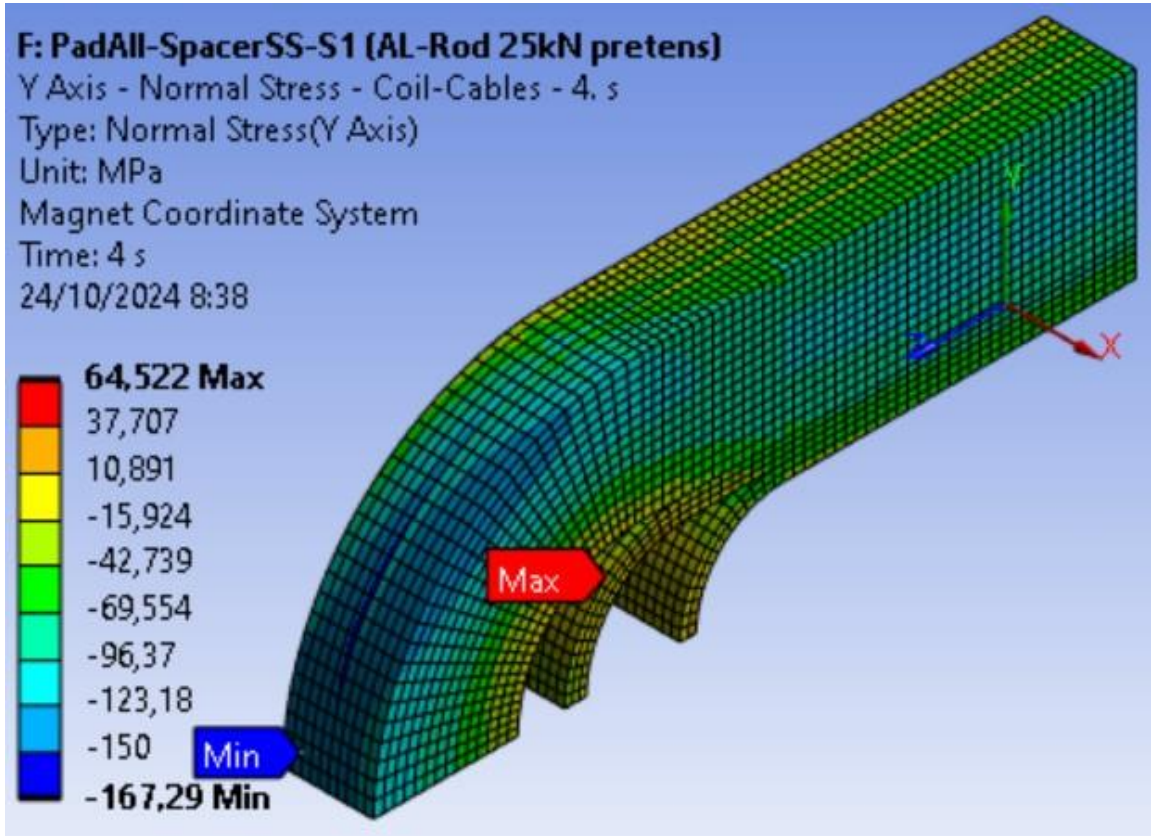
3D. Coil X Stress

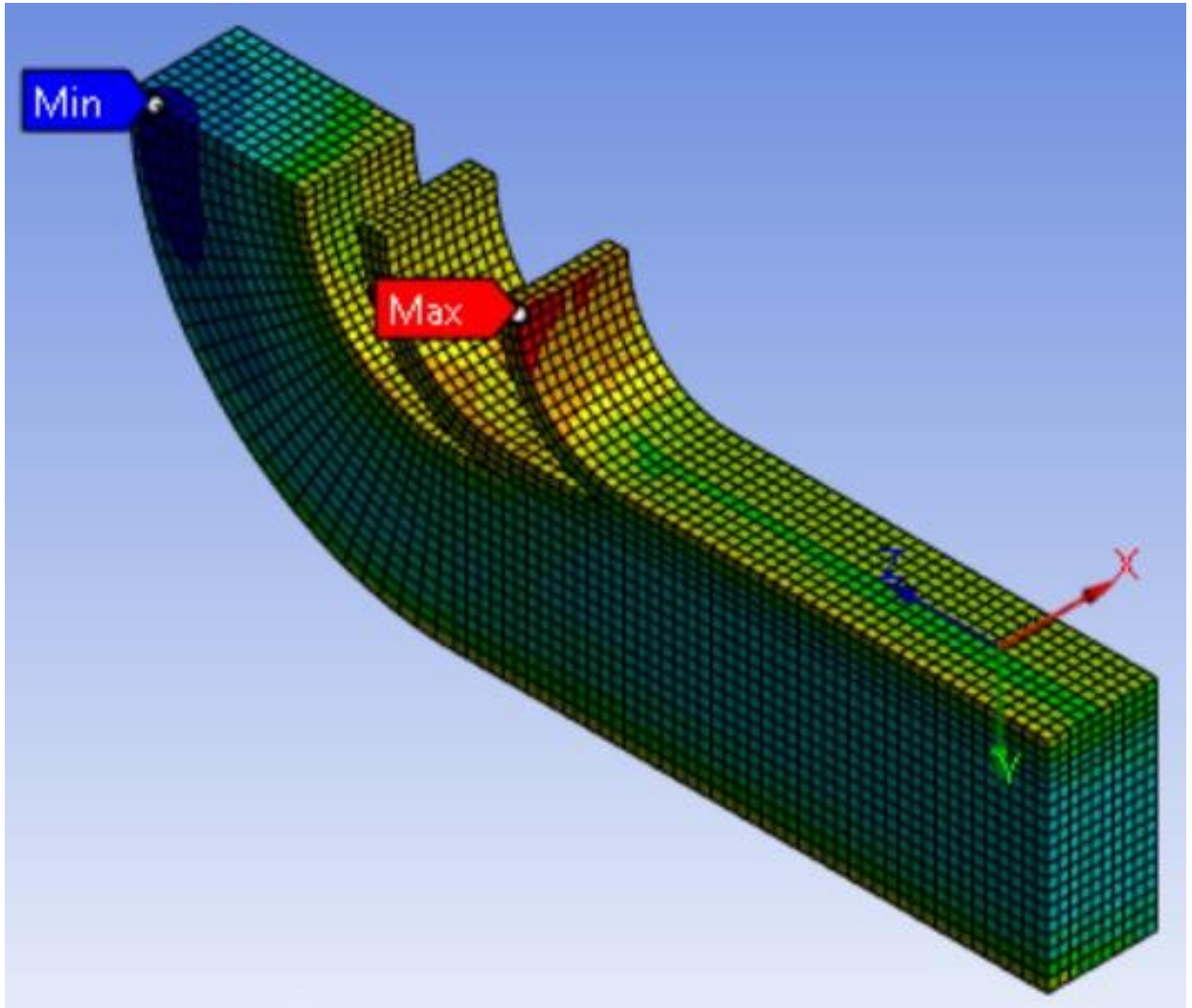




Limits @ Cold: -150 MPa <-> 20 MPa

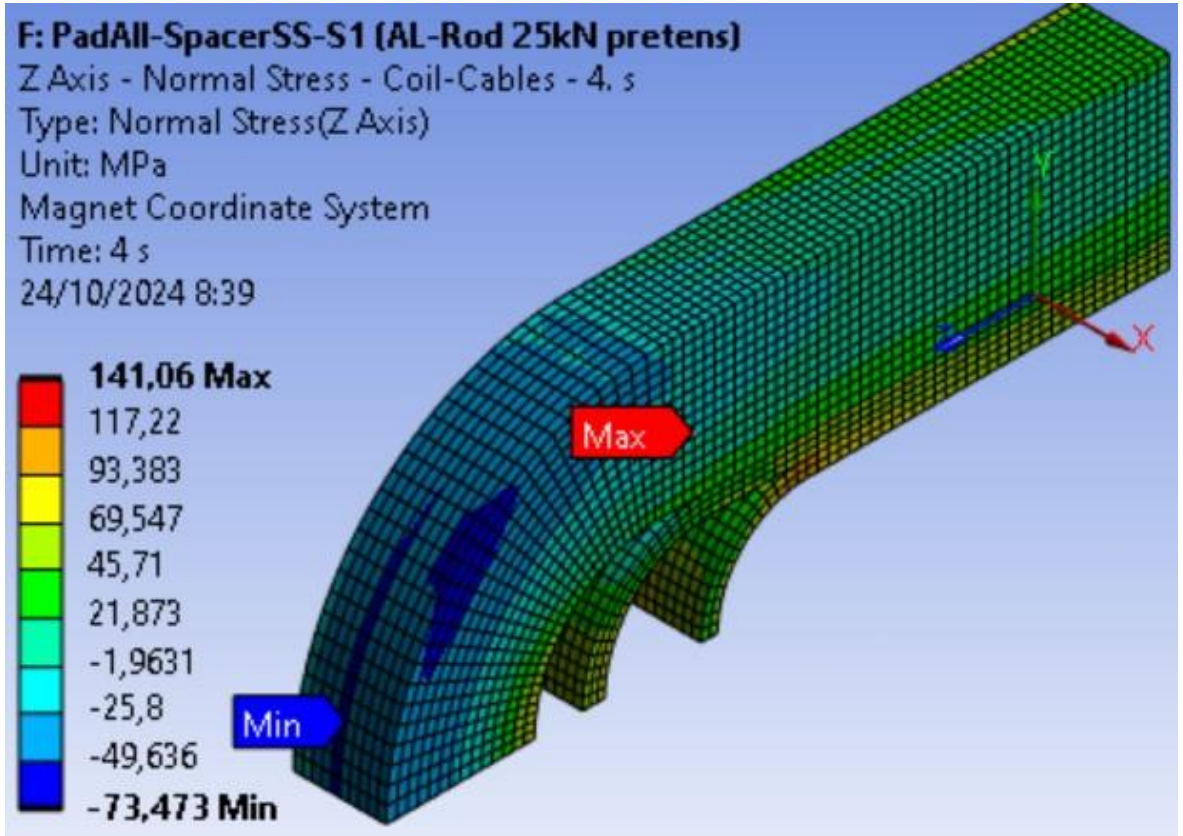
3D. Coil Y Stress

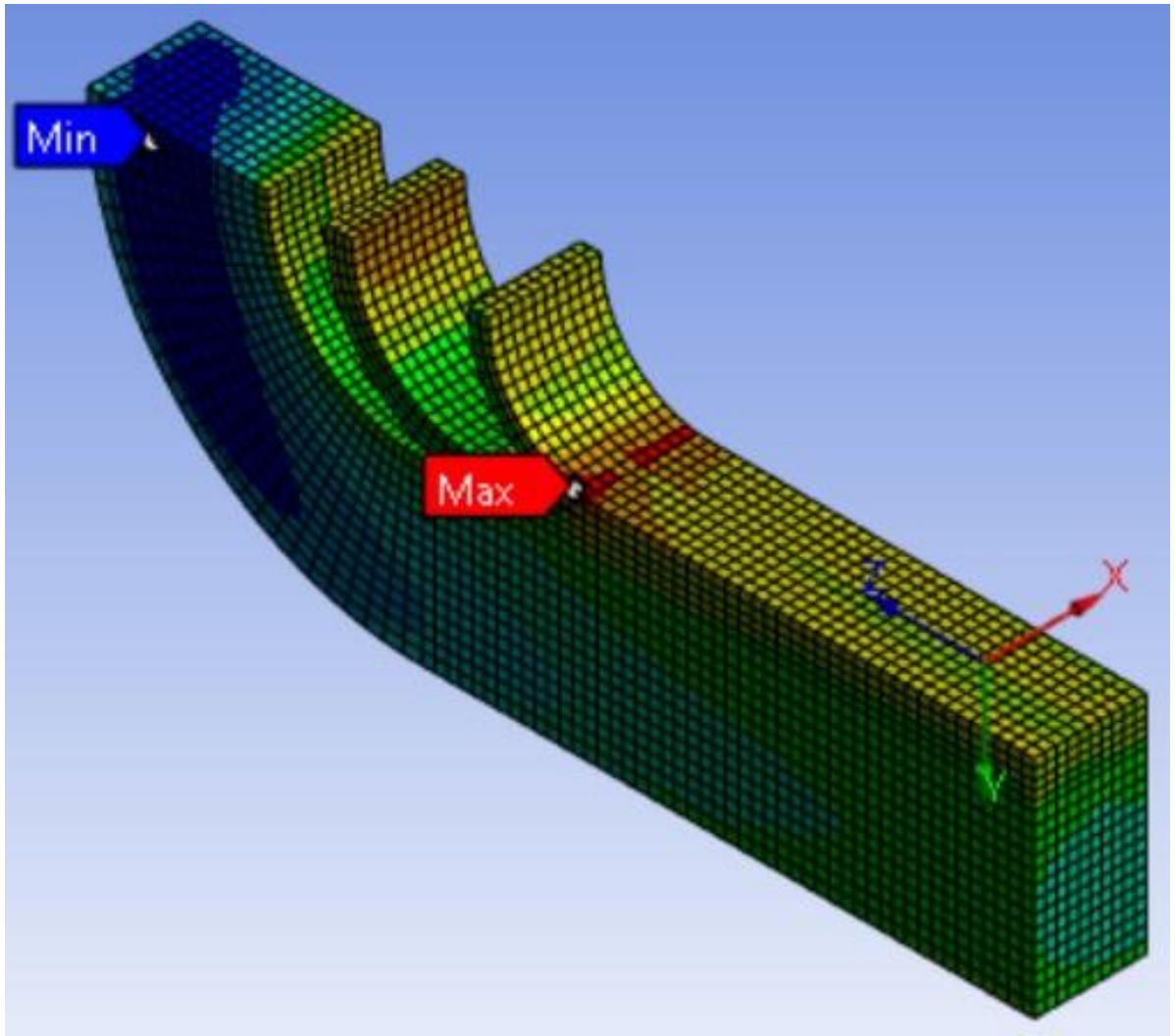




Limits @ Cold: -150 MPa <-> 20 MPa

3D. Coil Z Stress

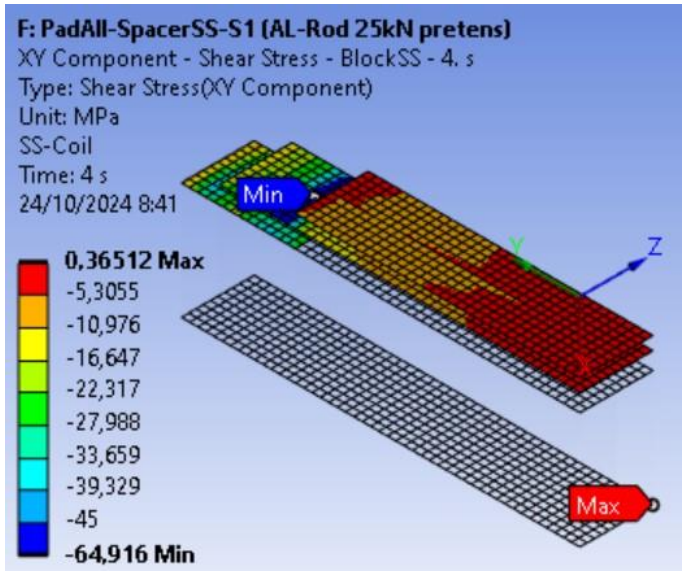


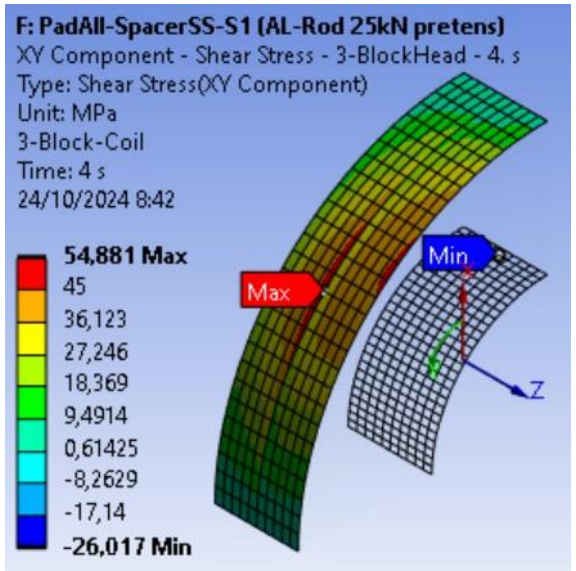


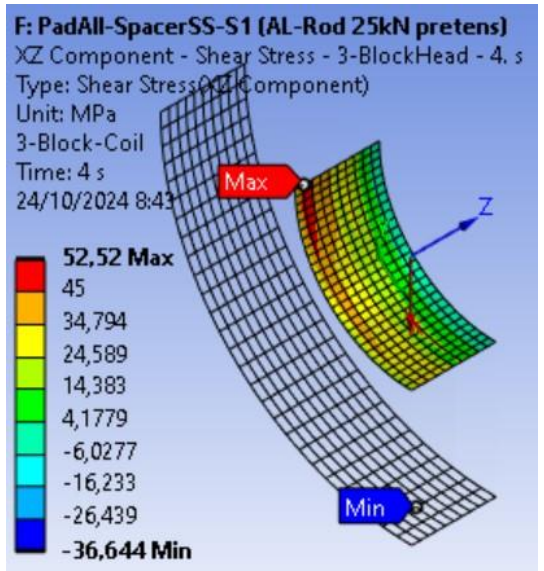
Limits @ Cold: -150 MPa <-> 20 MPa

3D. Coil Shear Stress

	Shear stress (cooling + EMF)								
	COIL (Planar surfaces)		COIL (1st Block surfaces)		COIL (2nd Block surfaces)		COIL (3rd Block surfaces)		
	XY Sh. stress	XZ Sh. stress	XY Sh. stress	XZ Sh. stress	XY Sh. stress	XZ Sh. stress	XY Sh. stress	XZ Sh. stress	
Max	2,02 MPa	1,80 MPa	3,57 MPa	0,28 MPa	3,76 MPa	0,18 MPa	6,75 MPa	1,86 MPa	RT Assembly
Min	-0,86 MPa	-1,08 MPa	-0,31 MPa	-0,30 MPa	-0,22 MPa	-0,38 MPa	-0,17 MPa	-1,34 MPa	
Max	2,13 MPa	1,95 MPa	2,00 MPa	0,26 MPa	2,31 MPa	0,17 MPa	4,70 MPa	2,00 MPa	Rod Pretens.
Min	-0,68 MPa	-1,03 MPa	-0,51 MPa	-0,20 MPa	-0,11 MPa	-0,40 MPa	-0,17 MPa	-1,22 MPa	
Max	0,36 MPa	28,02 MPa	22,47 MPa	31,42 MPa	10,88 MPa	7,26 MPa	32,20 MPa	7,10 MPa	Cooling
Min	-43,19 MPa	-28,08 MPa	-15,49 MPa	-31,83 MPa	-13,15 MPa	-10,66 MPa	-14,49 MPa	-8,65 MPa	
Max	0,37 MPa	44,20 MPa	44,25 MPa	42,03 MPa	29,60 MPa	25,31 MPa	**54,88 MPa**	**52,52 MPa**	EMF
Min	**-64,92 MPa**	-32,35 MPa	-18,90 MPa	-22,82 MPa	-16,86 MPa	-29,34 MPa	-26,02 MPa	-36,64 MPa	







Limits @ Cold: -45 MPa <-> 45 MPa

Outline

- ISAAC goals & constraints (reminder)
- 2D Design baselines and configurations (reminder)
- 2D Design Update
- 3D Design
  - Magnetic – Maxwell
  - Mechanical – Ansys
- Conclusions

Conclusions

- New cross-section design: **Coil vertical preload** (0.2mm interference with yoke) to reduce vertical and shear stress (avoid cable detaching from pole).
- Axial support with **aluminium rods preloaded at 25kN**.
- 2D and 3D magnetic and mechanical analysis done, coherent results. Cable stress over limits in some located areas (bonding with coil components)
- Detailed manufacturing design ongoing.