Mechanical analysis of the 2024 PF coil designs (SPC variant)

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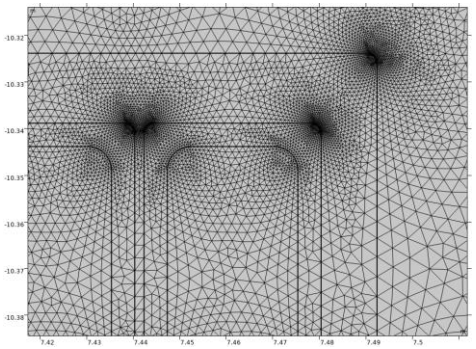
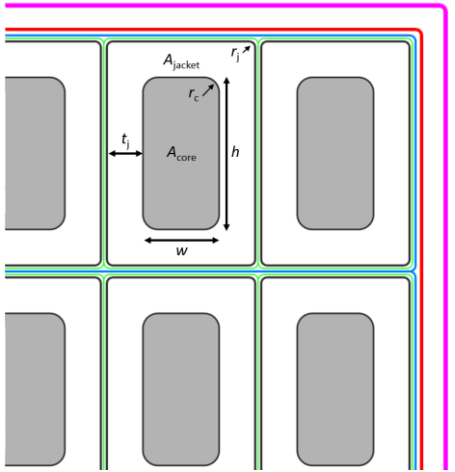
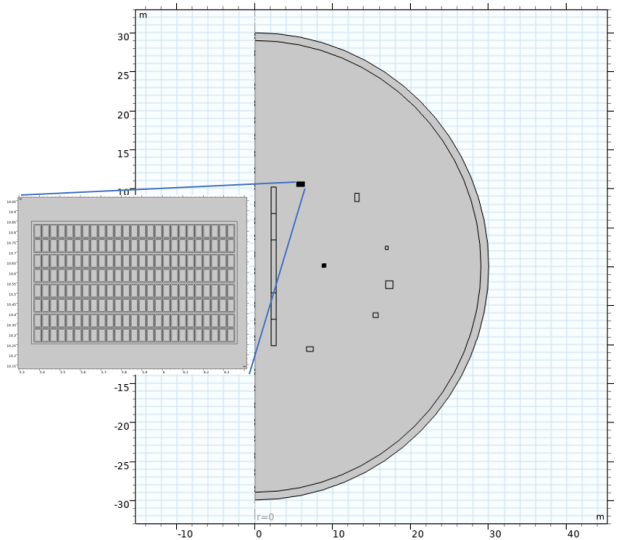
Model geometry

- 2D axisymmetric model.
- The PF coils are modelled with the cable space, jacket and insulation present.
- Two static study steps are used: one for the magnetic field analysis, and a second step for the mechanical analysis.
- Coils can slide in *r*-direction, but are fixed in *z*.







Electromagnetic model

- Each CS and PF coil is modelled as a block with a prescribed current density, which is the amp-turns divided by the area.
- The position of the CS coils are taken from Ambrosino [3], and the position of the PF coils is taken from the pre-conceptual design [1].
- A current density is applied to the cable space, with the current density equal to the amp turns divided by the cable space area.
- The magnetic field generated by the plasma is modelled as a line current.

	Premag	SOF	SOB	EOF
I_{plasma} [MA]	0	18.77	18.79	18.79
I_{CS3U} [MAt]	31.05	13.04	24.08	-8.63
I_{CS2U} [MAt]	35.08	3.01	0.58	-29.15
I_{CS1} [MAt]	70.16	-1.77	-7.31	-69.90
I_{CS2L} [MAt]	35.08	-8.32	-8.26	-35.08
I_{CS3L} [MAt]	33.76	26.82	24.25	-21.16
I_{PF1} [MAt]	9.62	11.65	6.58	-1.95
I_{PF2} [MAt]	2.30	-8.32	-8.32	-8.92
I_{PF3} [MAt]	-1.59	0.15	2.86	1.55
I_{PF4} [MAt]	3.09	-5.89	-12.90	-11.38
I_{PF5} [MAt]	-1.37	-6.55	-2.00	-4.11
I_{PF6} [MAt]	9.62	8.66	7.24	2.91

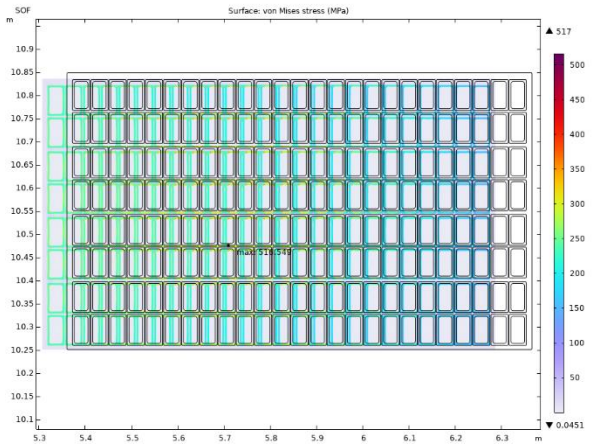
Mechanical Model

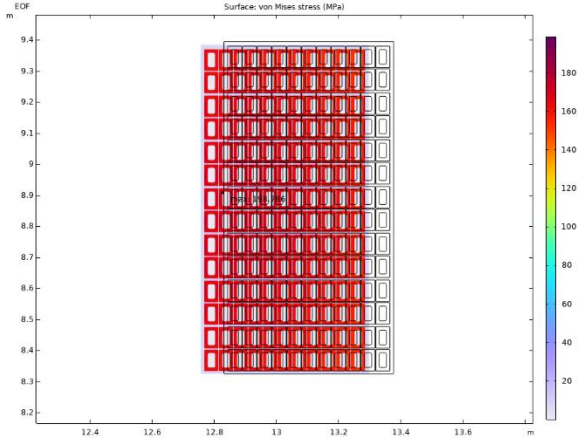
- The Young's modulus of the cable space is kept artificially low to simulate that it cannot take up any mechanical load.
- The materials are assumed to be linearly elastic.
- The mechanical model incorporates the cool-down from 293 K to 4.2 K, as well as the mechanical load generated by the Lorentz forces on the coil windings.
- These include the contributions of the CS, PF and plasma when present.

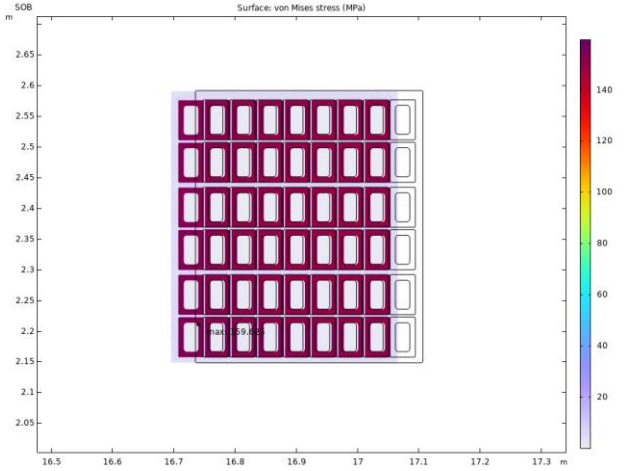
	E [GPa]	ν	α [1/K]
AISI 316LN	208	0.282	10.2e-6
Conductor	0.100	0.34	9.24e-6
Polyimide	3.1	0.34	1.52e-5

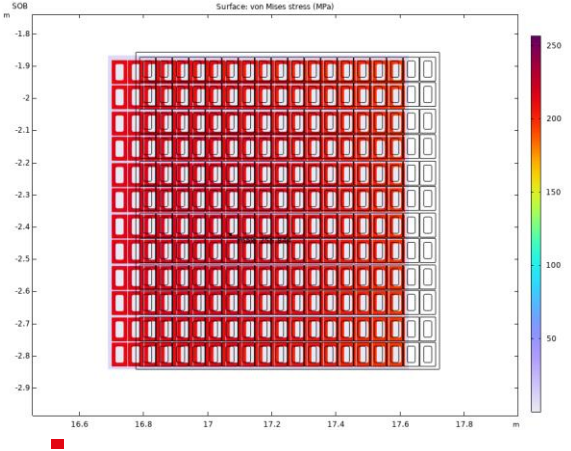
Results: displacement (1/2)

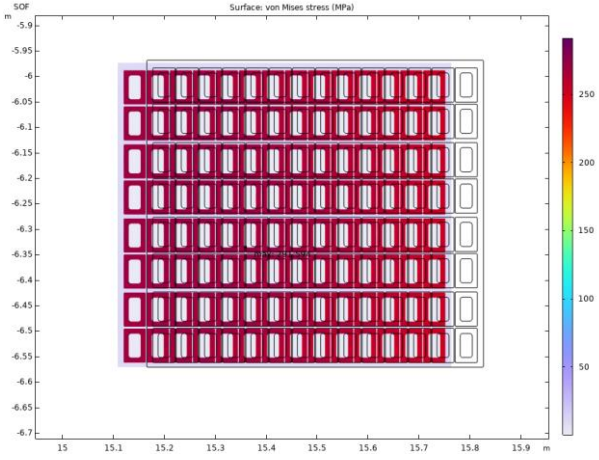
Speaker

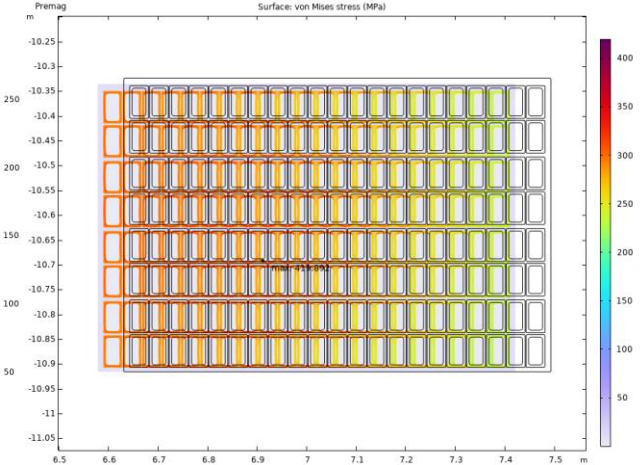










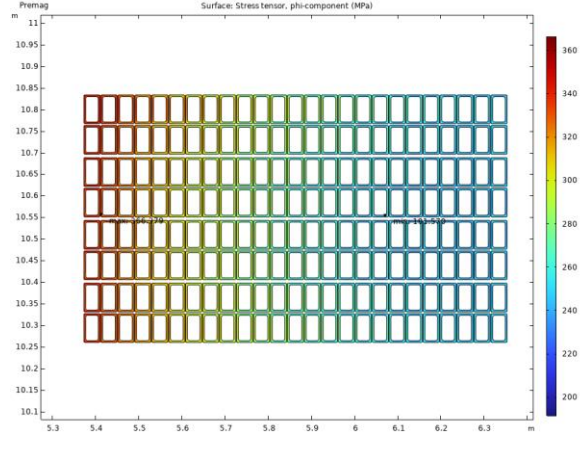


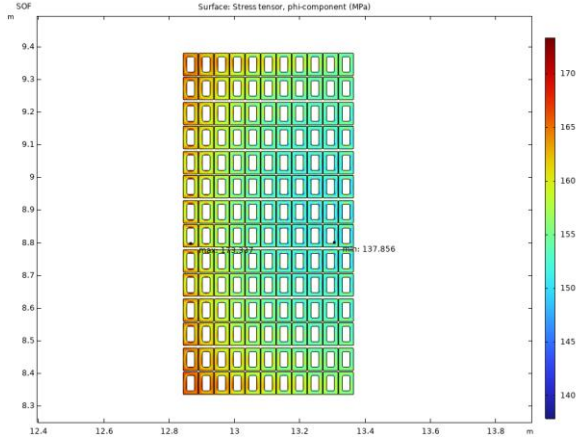
Results: displacement (2/2)

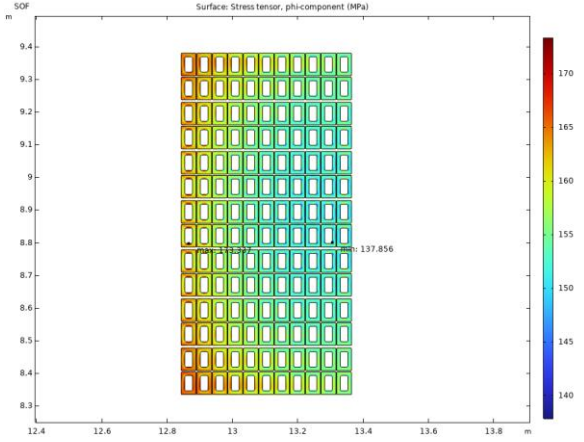
- To calculate the displacement of the inner radius, a line average is used in the inner coil boundary.
- All displacements are inwards

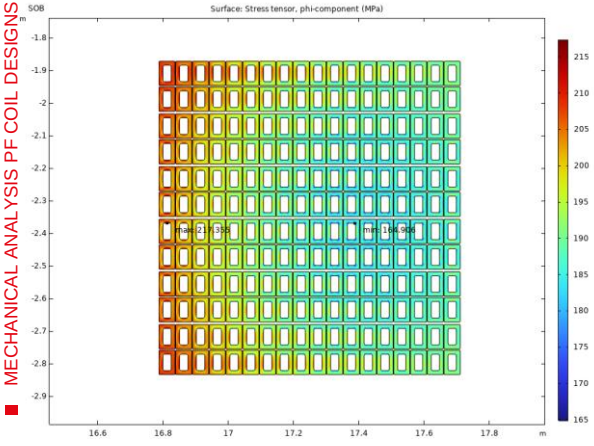
	Premag	SOF	SOB	EOF
PF1 u_{in} [mm]	-6.74	-9.75	-15.5	-14.4
PF2 u_{in} [mm]	-37.8	-27.4	-28.0	-27.8
PF3 u_{in} [mm]	-47.6	-50.1	-61.7	-55.8
PF4 u_{in} [mm]	-49.2	-44.8	-32.4	-37.0
PF5 u_{in} [mm]	-44.6	-25.1	-38.3	-31.7
PF6 u_{in} [mm]	-10.1	-16.4	-17.5	-20.0

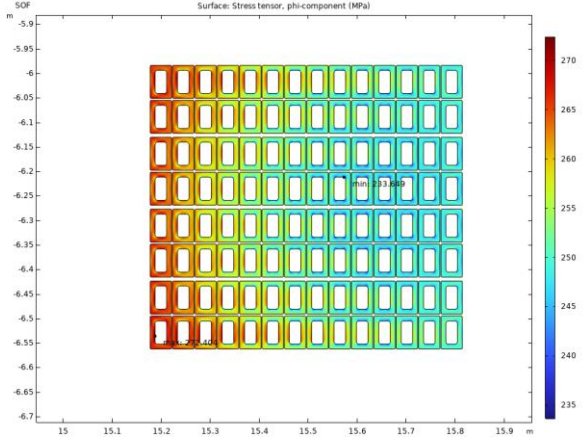
Results: hoop stress (1/2)

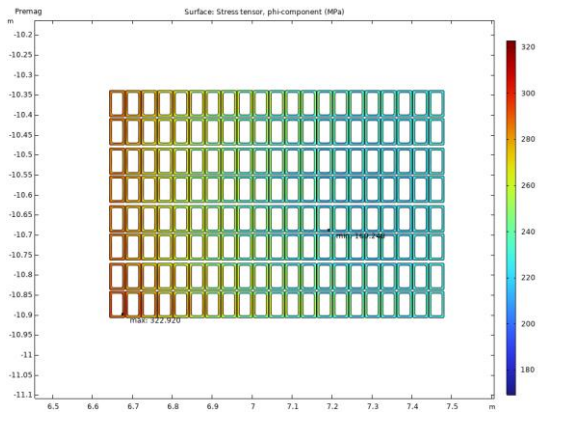












MECHANICAL ANALYSIS PF COIL DESIGNS

Results: hoop stress (2/2)

- For PF1, the model shows that the jacket thickness is not sufficient to keep the hoop stresses under the required 350 MPa and must therefore be made thicker.
- For the other coils, the jacket thickness is sufficient. For PF2, PF3, PF4, the jacket thickness can even be decreased.

	Premag	SOF	SOB	EOF
PF1 $\sigma_{\theta,max}$ [MPa]	367	257	24.0	64.1
PF2 $\sigma_{\theta,max}$ [MPa]	1.80	173	164	169
PF3 $\sigma_{\theta,max}$ [MPa]	23.7	-6.61	-146	-75.5
PF4 $\sigma_{\theta,max}$ [MPa]	5.37	58.8	217	159
PF5 $\sigma_{\theta,max}$ [MPa]	4.41	272	90.8	182
PF6 $\sigma_{\theta,max}$ [MPa]	323	114	75	-7.97

Results: vertical force

- The total vertical force is calculated by integrating the surface integral over the full coil domain:
  - $f_z = \iint_\Omega -J_\phi B_r \, \mathrm{d}A \,,$
- Then revolving it about the symmetry axis to turn it into a volume integral.

	Premag	SOF	SOB	EOF
PF1 F_z [MN]	-202	-76.0	-58.4	-21.2
PF2 F_z [MN]	-13.6	30.4	43.3	-20.3
PF3 F_z [MN]	13.4	2.37	104	52.5
PF4 F_z [MN]	3.75	-145	-227	-217
PF5 F_z [MN]	-17.9	112	80.7	165
PF6 F_z [MN]	168	47.1	34.2	-38.6

Conclusion

- a 2D axisymmetric COMSOL model was made
  - that coupled electromagnetic forces with solid mechanics.
- For PF1 and PF6,
  - the model indicates that the current jacket thickness does not keep hoop stresses below the required 350 MPa and must therefore be increased. For the remaining coils, the thickness is adequate, and for
- PF2, PF3, and PF4 jacket can even be reduced.
- Future work:
  - The jacket thickness of the PF coils can be optimized using this model.
  - Capturing the 3D aspects in the mechanical load distribution due to the discrete supports of the PF coils
  - Crack growth model studying the actual fatigue lifetime.

Thanks for your attention!

References

- [1] R. Ambrosino and E. Acampora, "2024 DEMO Single Null baseline with aspect ratio 2.8: reference electromagnetic plasma scenario " EUROfusion, 2024.
- [2] M. Kumar, " MAG-2.1-T025-D003 - Design of the PF coil based on the 2018 DEMO reference" EUROfusion, 2020. [Online]. Available: https://idm.euro-fusion.org/default.aspx?uid=2MVZQV
- [3] K. Sedlak, "MAG-S.01.01-T001-D004 - Revise Design Philosophy Manual," EUROfusion, 2023. [Online]. Available: https://idm.euro-fusion.org/default.aspx?uid=2P8ZVJ