EuroCirCol Cosθ 16 T dipole

2^{nd} EuroCirCol WP5 Review
Monday 9 -Tuesday 10 October 2017

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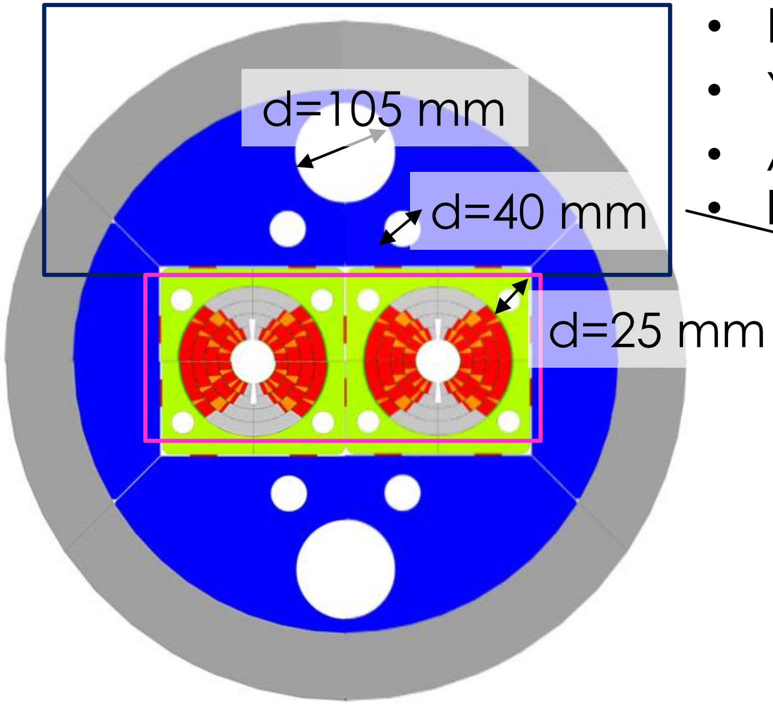
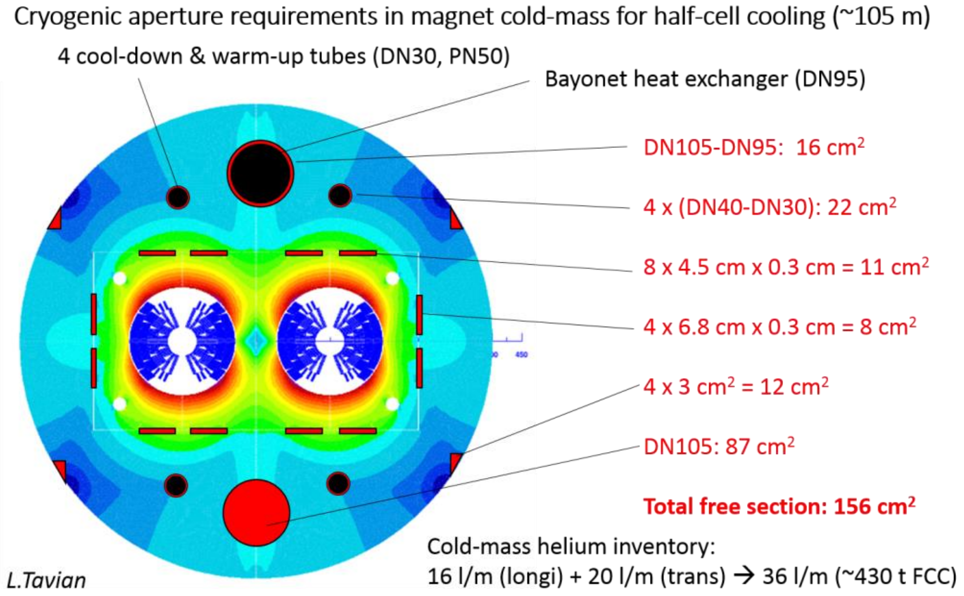
Outlook

- Latest design – double aperture
- Conductor:
  - VM stress
  - Contact pressure to the pole
  - Displacements
- Mechanical structures:
  - VM Stress
  - Displacements
- Conclusions

Cosθ layout

- Cooling channels
- Holes in the steel pad for the iron rods for b3 correction
- Yoke outer diameter: 600 mm
- Al alloy outer ring thickness: 75 mm
- Inter-beam distance: 204 mm





Mechanical Constraints

- Stress in the conductor < 150 MPa @ RT
- < 200 MPa @ 1.9 K
- Stress on mechanical structure < yield strength
- No detachment between coil and pole

MATERIAL	Stress limit [MPa] RT	Stress limit [MPa] 1.9 K	E [GPa] RT	E [GPa] 1.9 K	ν	α RT→1.9K
Coil	150	200			0.3	
Radial dir			30	33		$3.1\ 10^{-3}$
Azimuthal dir			25	27.5		$3.4\ 10^{-3}$
Austenitic steel (316LN)	350	1050	193	210	0.28	$2.8\ 10^{-3}$
Al7075	480	690	70	79	0.3	$4.2\ 10^{-3}$
Ferromagnetic iron	230	720*	213	224	0.28	$2.0\ 10^{-3}$
Ti6Al4V	800	1650	115	126	0.3	$1.7\ 10^{-3}$

Critical Current Measurements of High-J_c Nb_3Sn Rutherford Cables under Transverse Compression

B. Bordini, P. Alknes, A. Ballarino, L. Bottura, L. Oberli

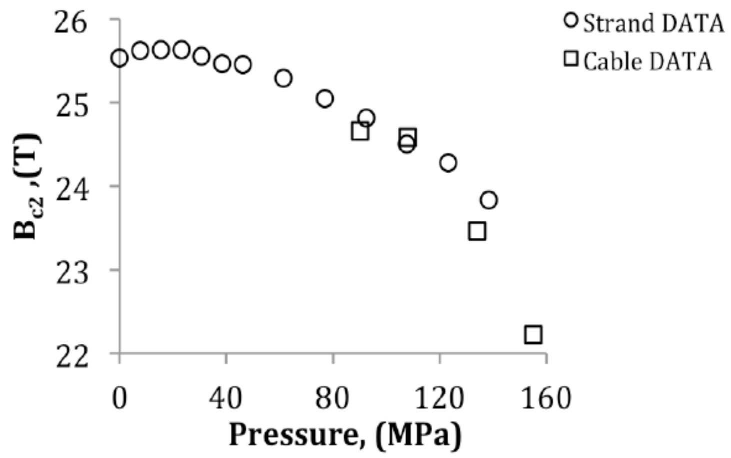
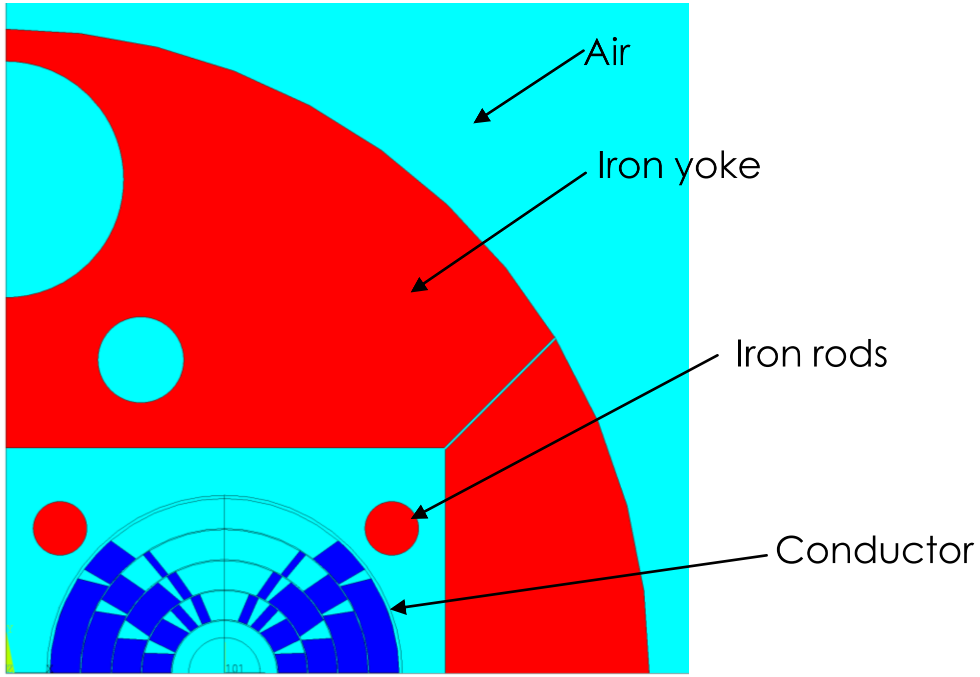


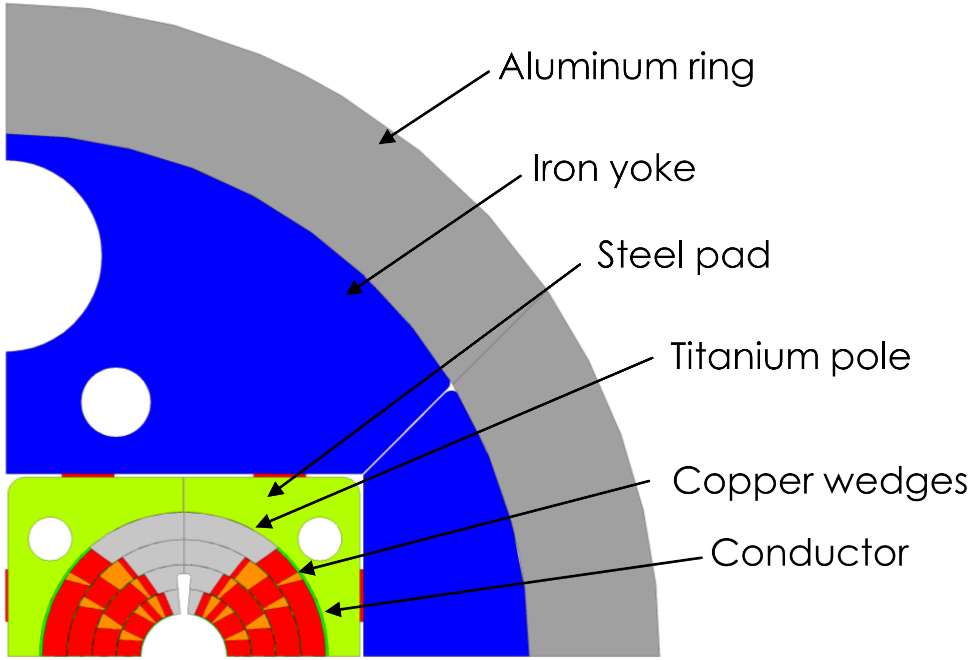
Fig. 6. Upper critical field at 4.2 K estimated from the critical current measurements under transversal pressure.

ANSYS models

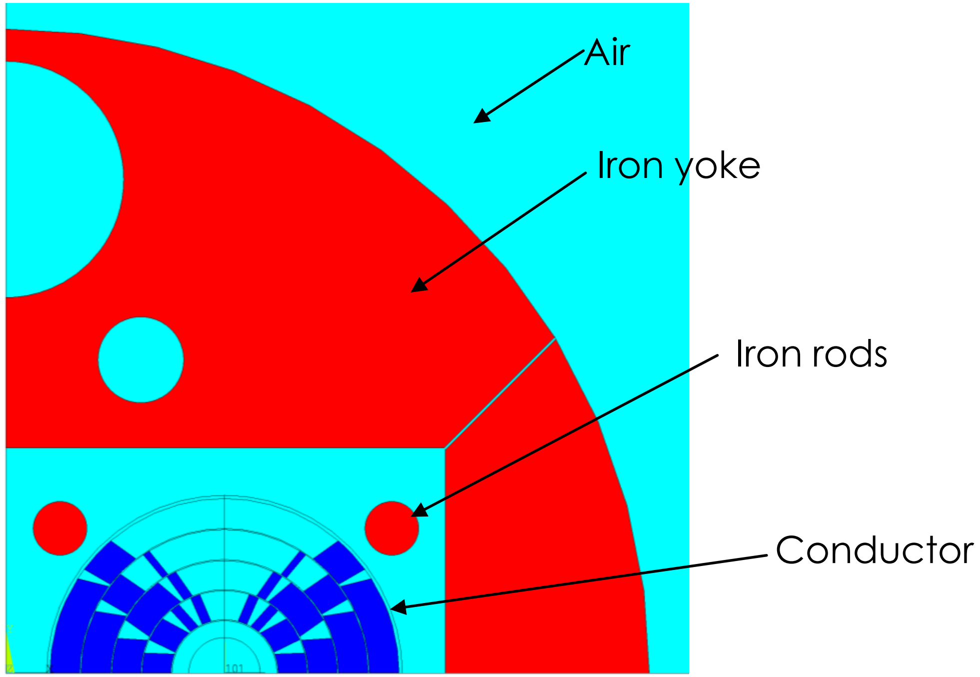
ANSYS magnetic model

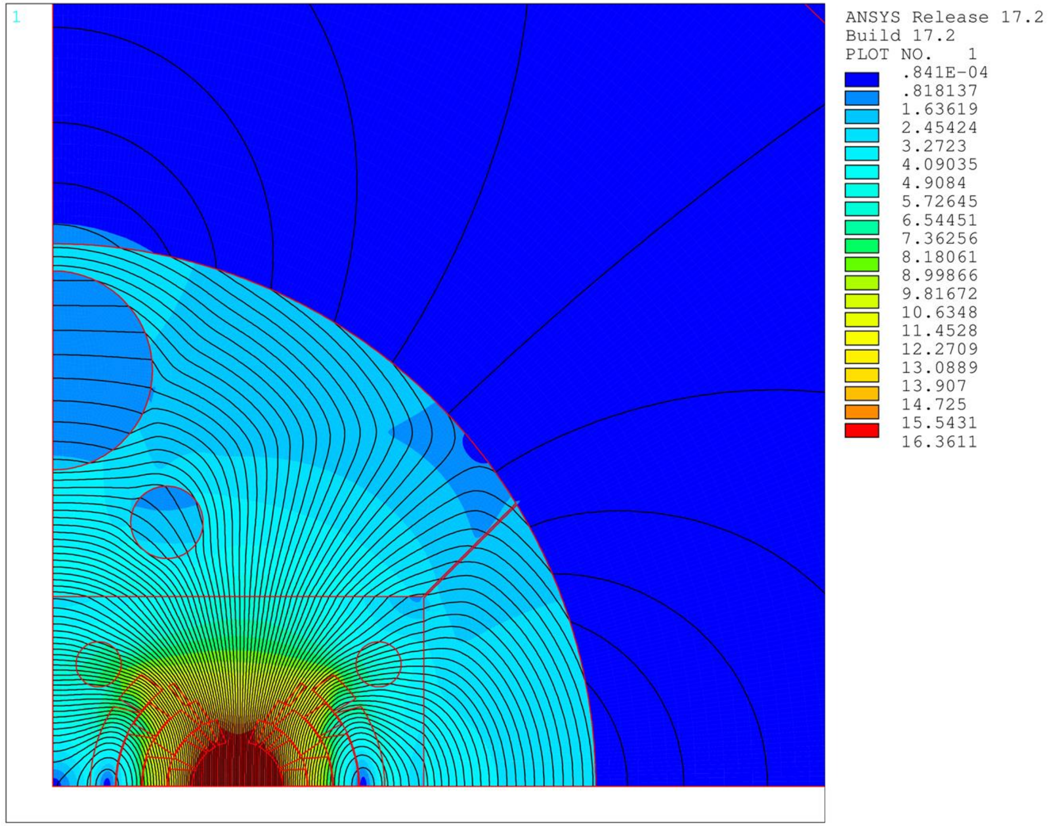


ANSYS mechanical model

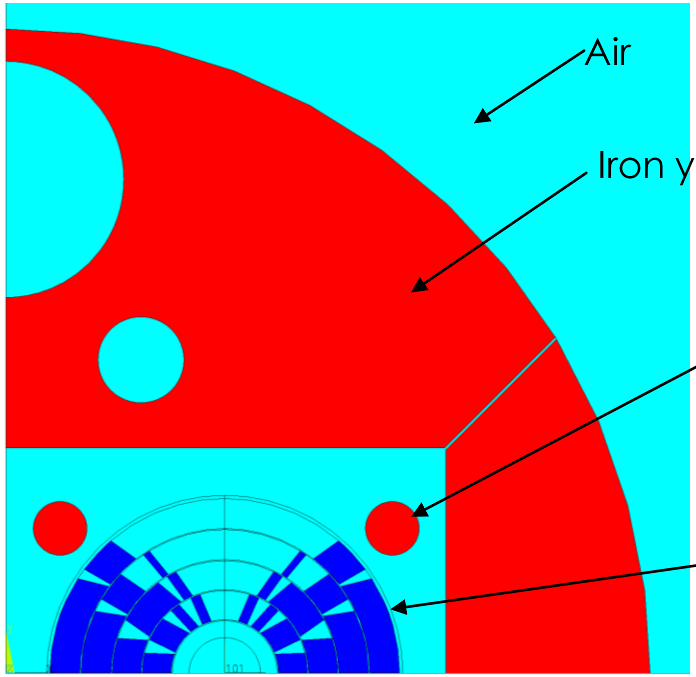


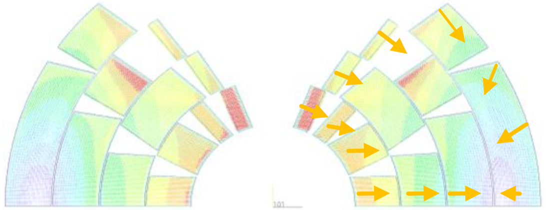
Magnetic analysis





Lorentz Forces

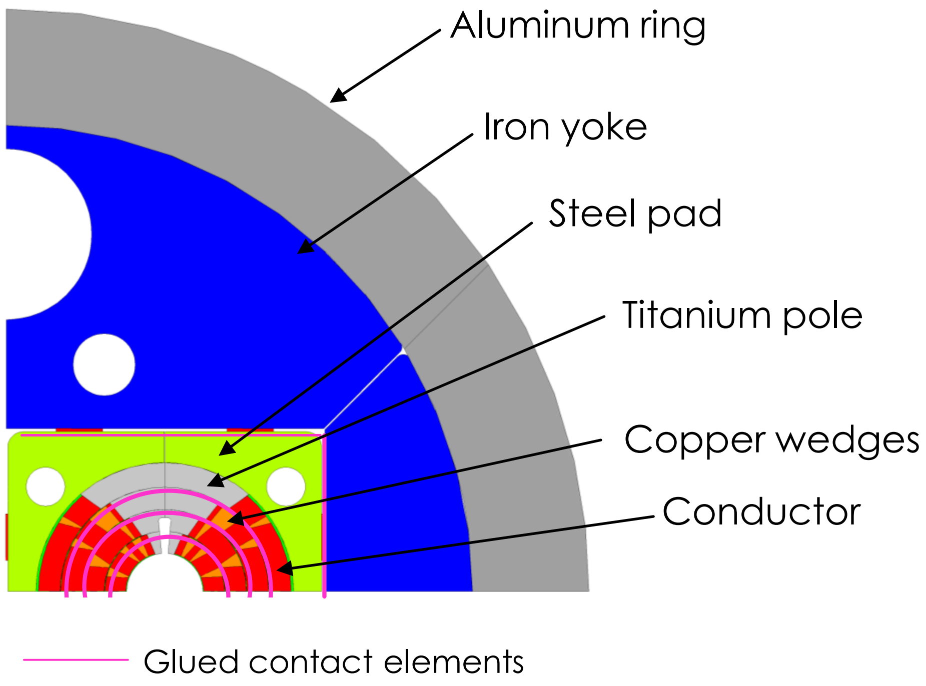




DX	FX sum (MN)	Fy sum (MN)	Fθ sum (MN)	σθ (MPa)
1	2.1	-0.2	-2.1	-153
2	2.3	-0.5	-2.3	-173
3	2.0	-1.0	-2.0	-143
4	0.4	-2.0	-0.4	-28
total dx	6.8	-3.7	-6.8	-120
SX	FX sum (MN)	Fy sum (MN)	Fθ sum (MN)	σθ (MPa)
1	-2.1	-0.2	2.1	156
2	-2.4	-0.6	2.4	178
3	-2.2	-1.1	2.2	157
4	-0.7	-2.2	0.7	50
total	-7.4	-4.1	7.4	131
Total winding	-0.6	-7.8	0.6	—

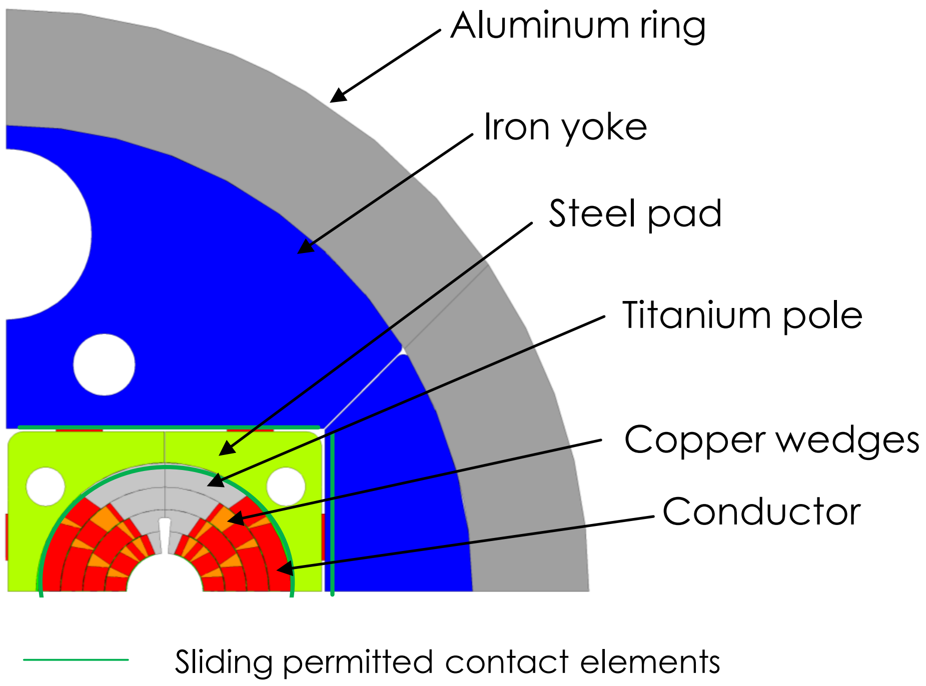
Mechanical analysis

ANSYS model



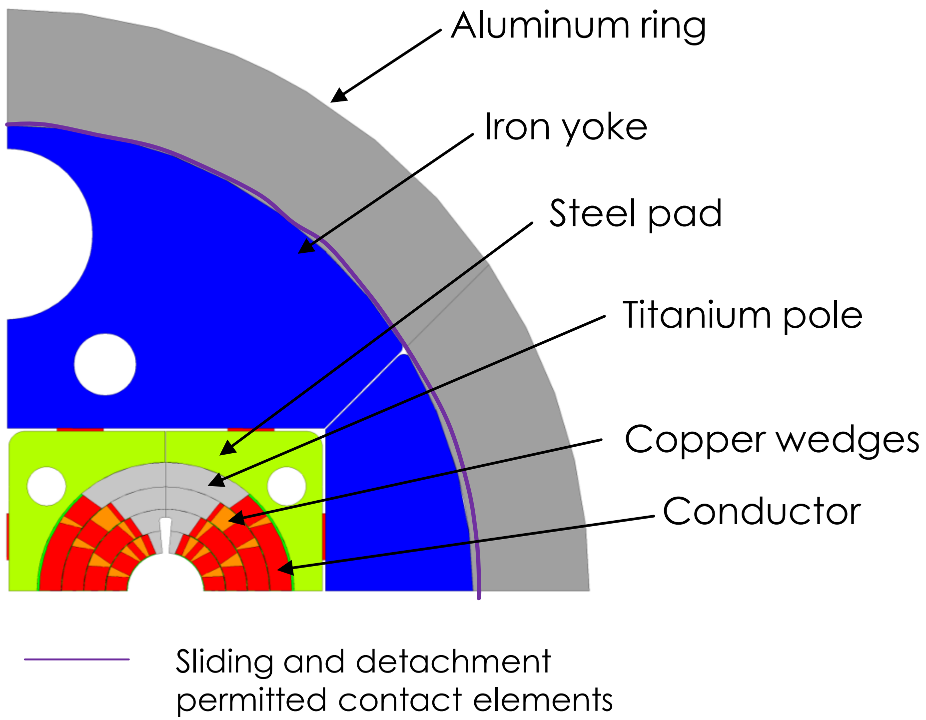
Mechanical analysis

ANSYS model



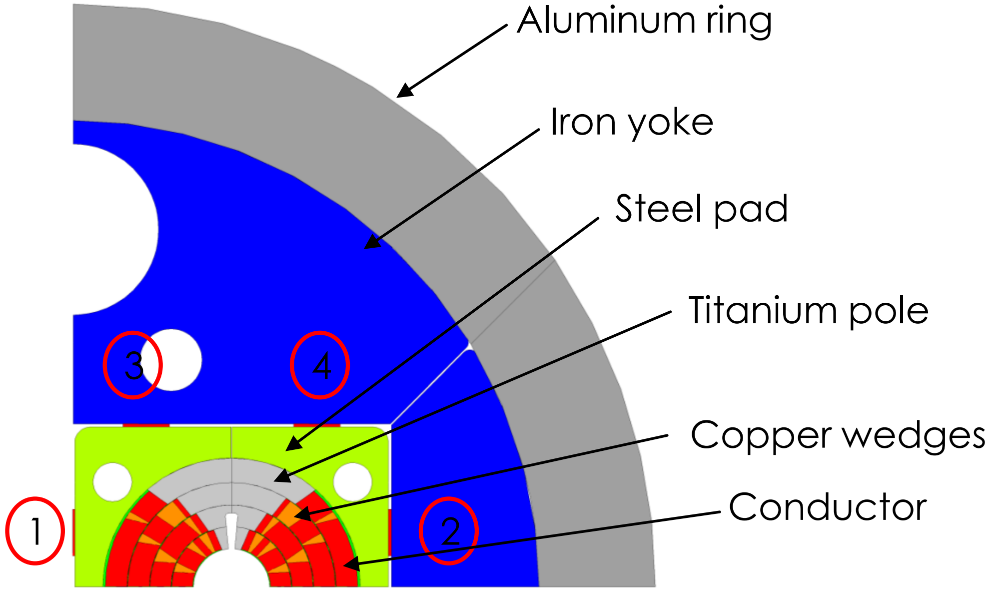
Mechanical analysis

ANSYS model



Mechanical analysis

ANSYS model

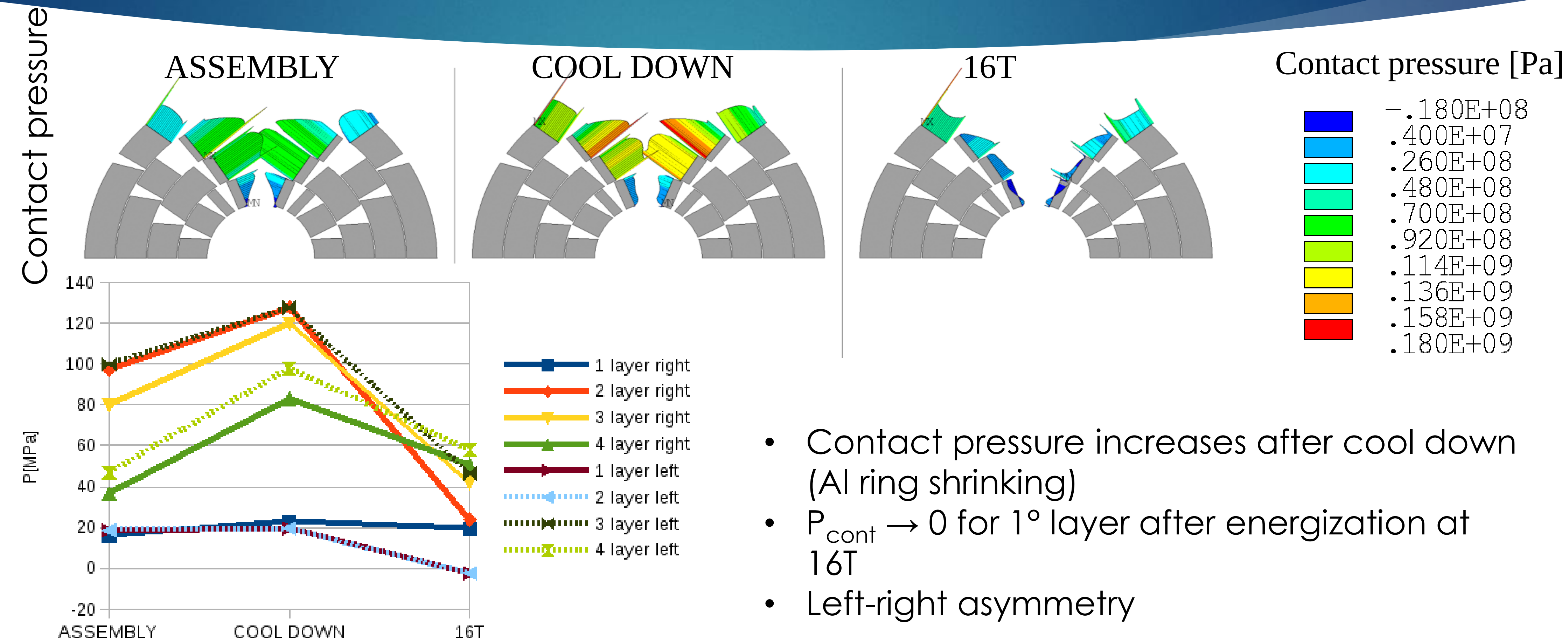


- Step 1: insertion of key 1
- Step 2: insertion of key 2 (60 Mpa applied)
- Step 3 insertion of keys 3 and 4 (30 Mpa applied)

} assembly

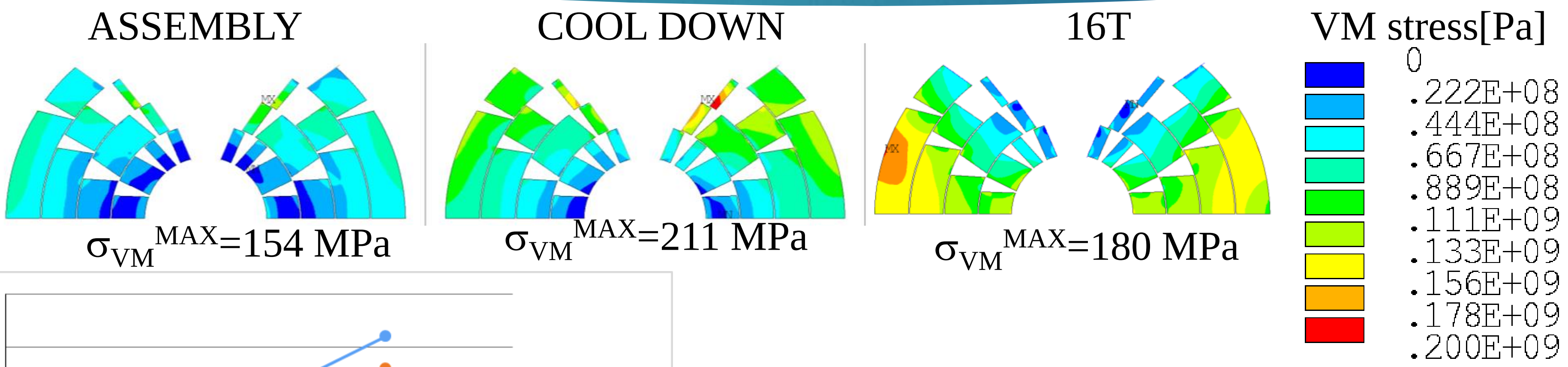
- Step 4: cooling down
- Step 5: energization to 16 T (application of Lorentz forces to the conductor elements)

Contact Pressure



- Contact pressure increases after cool down (Al ring shrinking)
- $P_{cont} \rightarrow 0$ for 1° layer after energization at 16T
- Left-right asymmetry

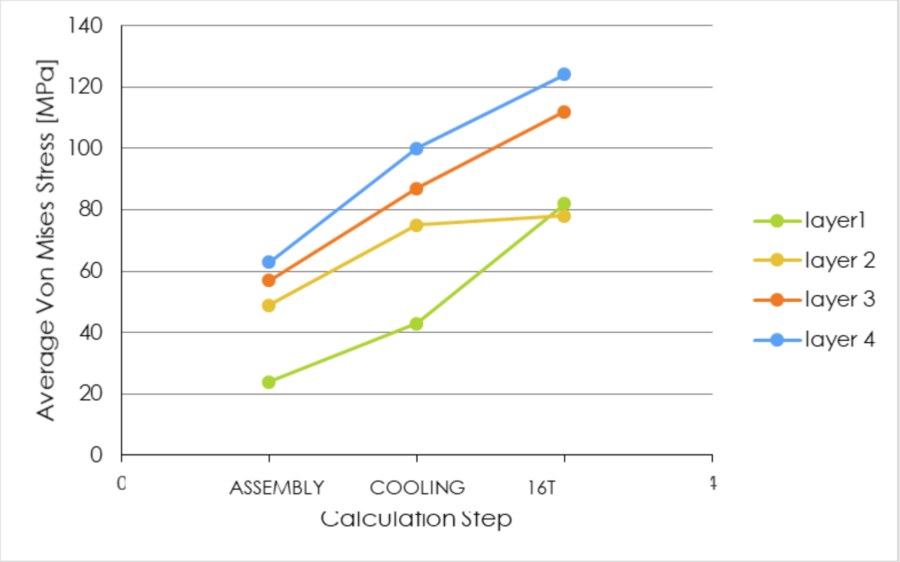
VM stress on conductors



σ_{VM}^{MAX}=154 MPa

σ_{VM}^{MAX}=211 MPa

σ_{VM}^{MAX}=180 MPa

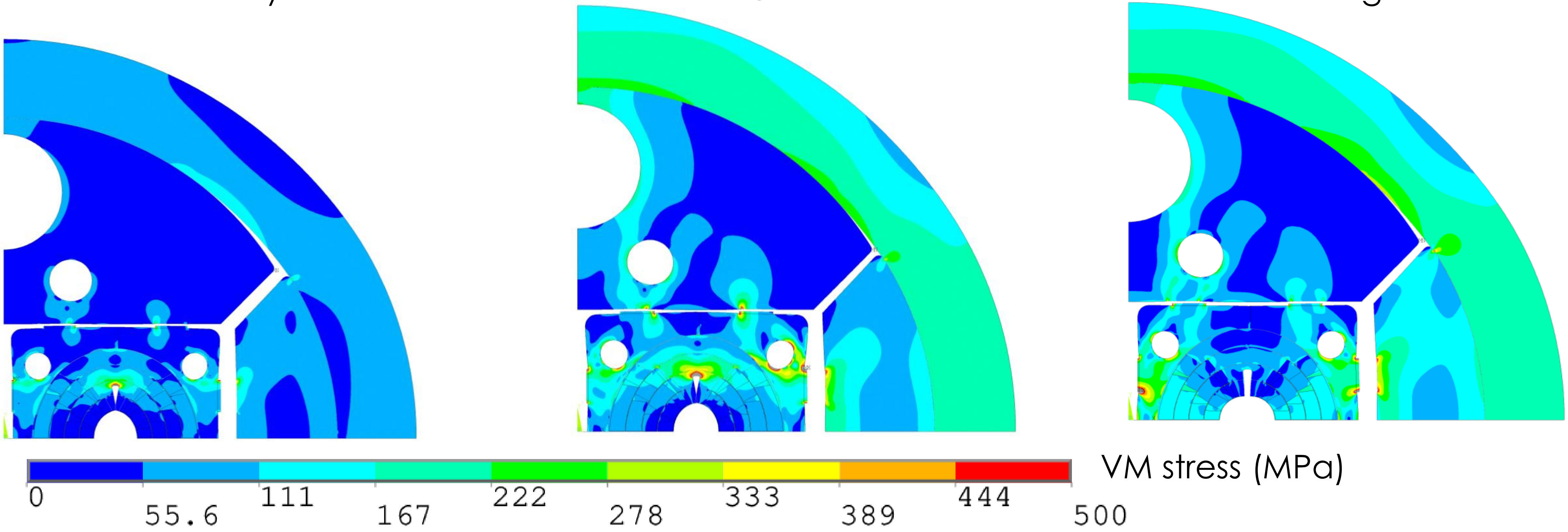


- VM stress far below current degradation limit (150 MPa @ RT -200 MPa @ 1.9K)
- Localized hot spot after cooling down (edge effect, negligible)

Mechanical analysis

Deformation x 20

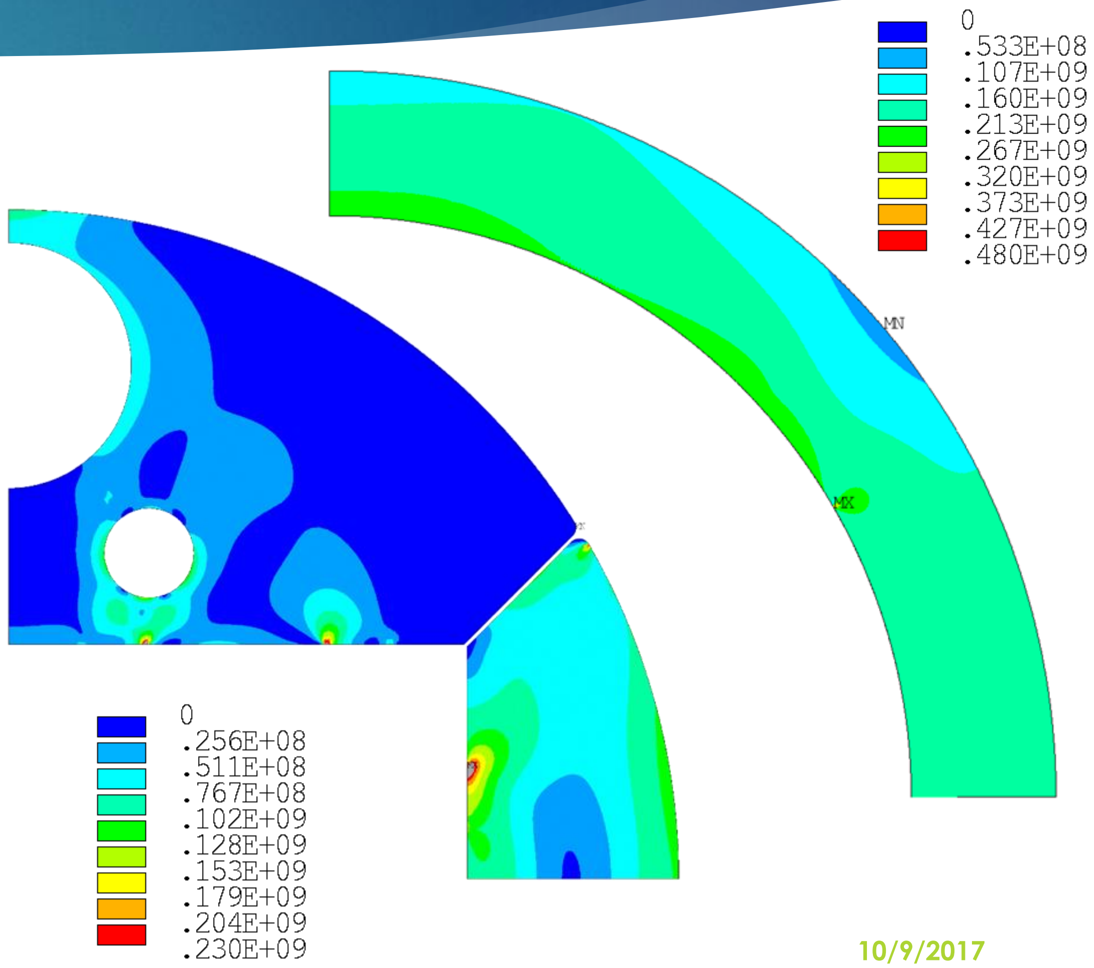
Assembly Cool down Energization

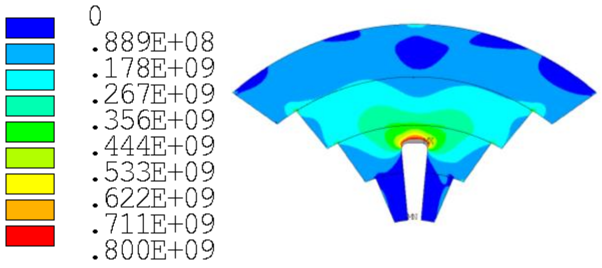


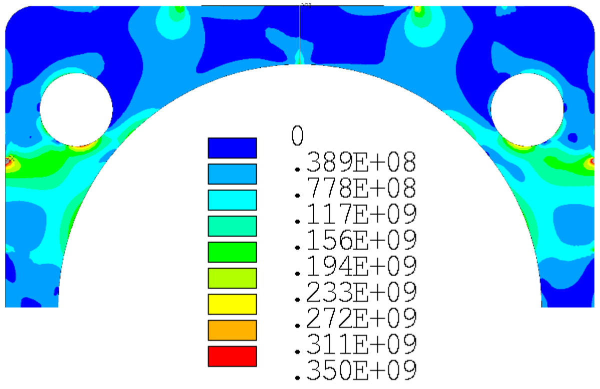
Mechanical analysis

ASSEMBLY

MATERIAL	Stress limit [MPa]	
	RT	1.9 K
Austenitic steel (316LN)	350	1050
Al7075	480	690
Ferromagnetic iron	230	720
Ti6Al4V	800	1650



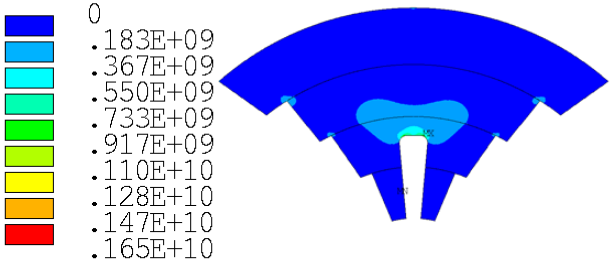


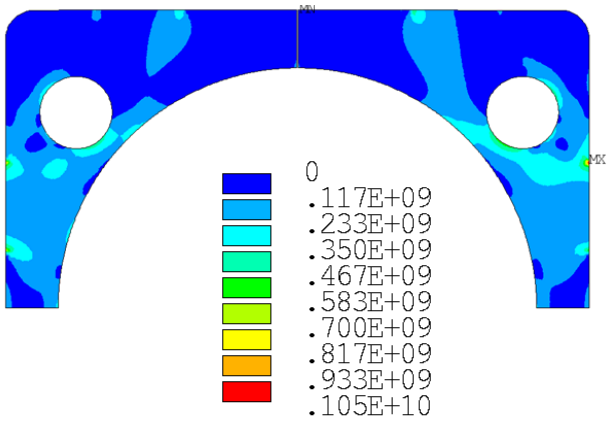


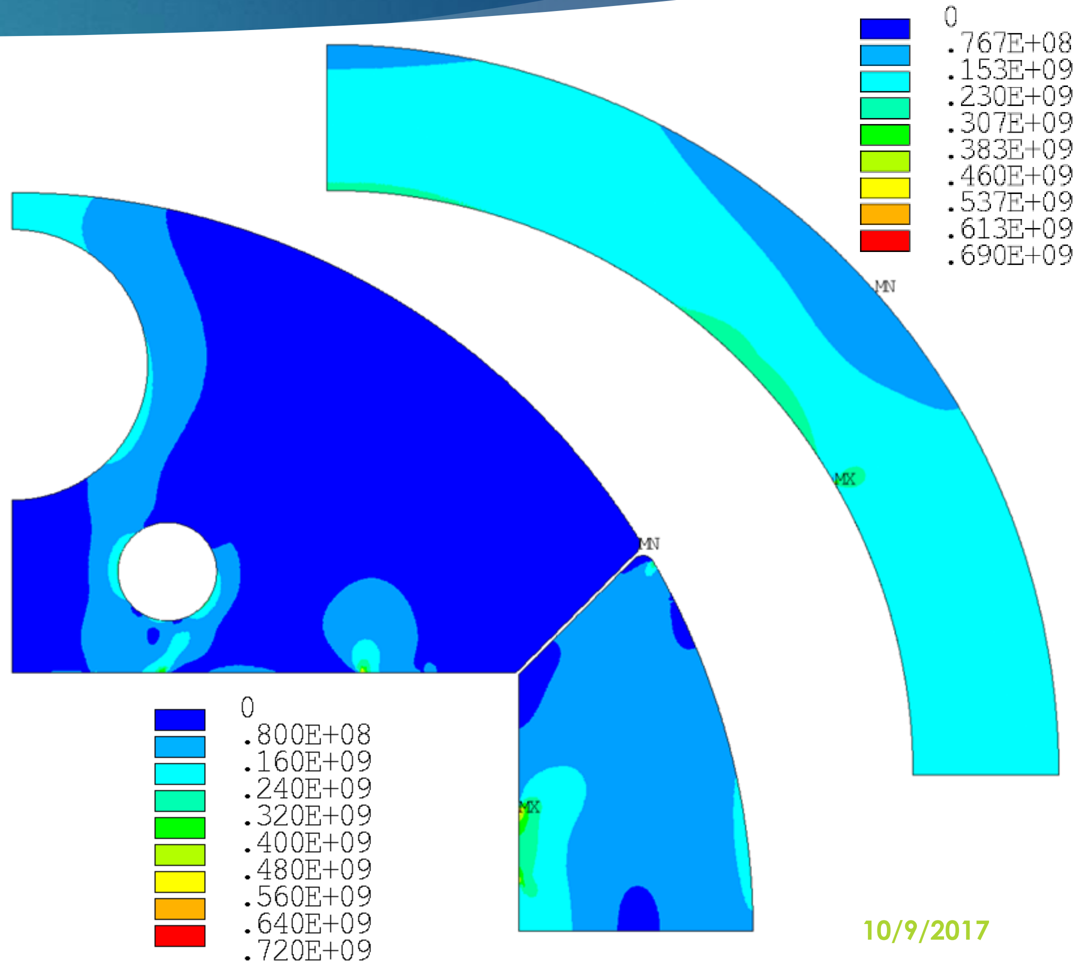
Mechanical analysis

COOL DOWN

MATERIAL	Stress limit [MPa] RT	1.9 K
Austenitic steel (316LN)	350	1050
Al7075	480	690
Ferromagnetic iron	230	720
Ti6Al4V	800	1650



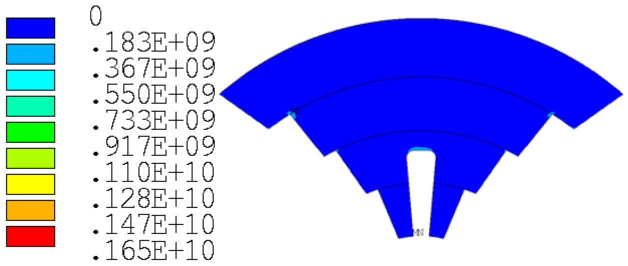


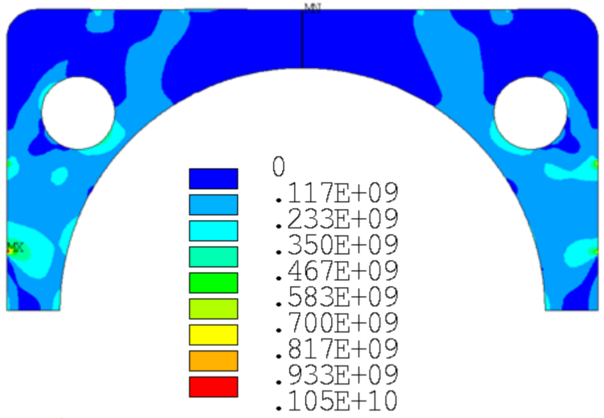


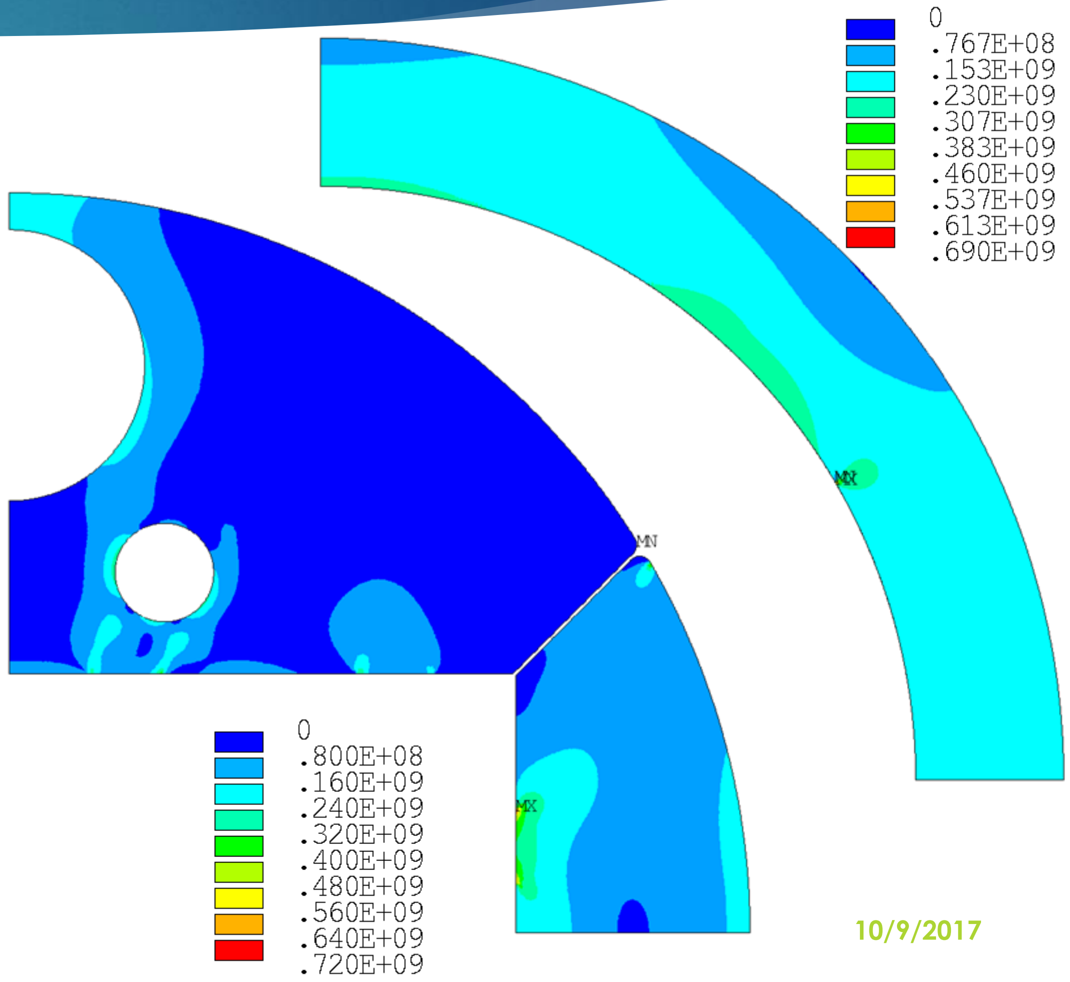
Mechanical analysis

ENERGIZATION

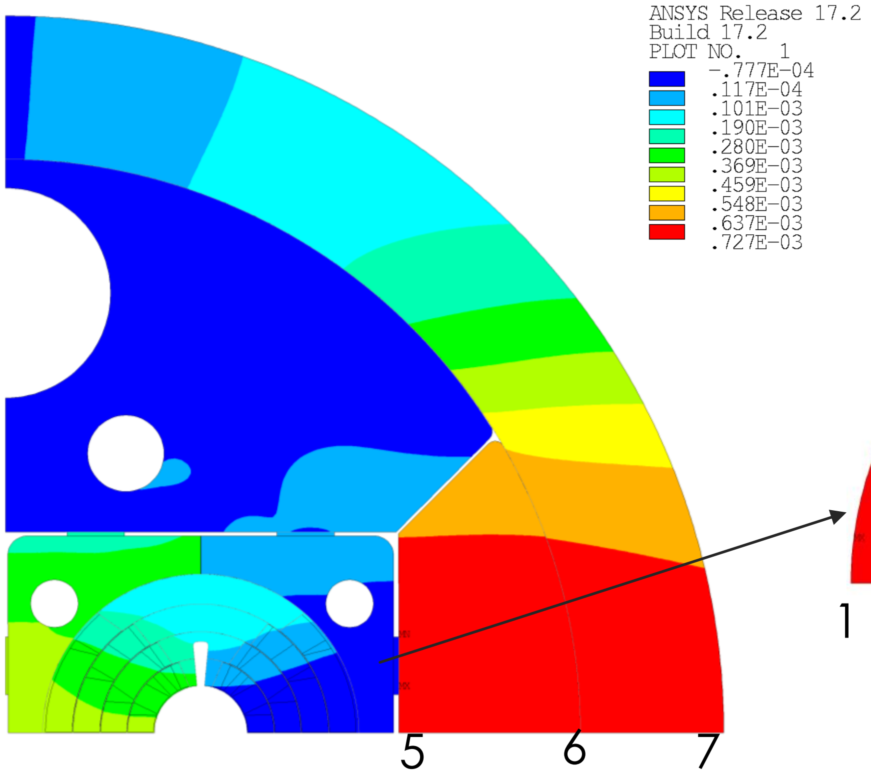
MATERIAL	Stress limit [MPa]	
	RT	1.9 K
Austenitic steel (316LN)	350	1050
Al7075	480	690
Ferromagnetic iron	230	720
Ti6Al4V	800	1650

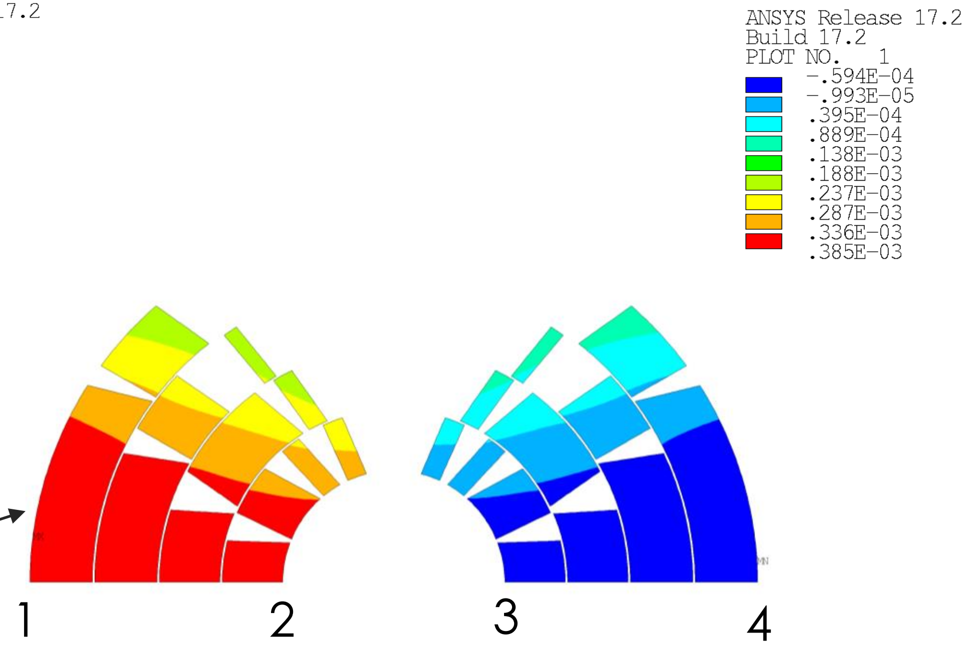






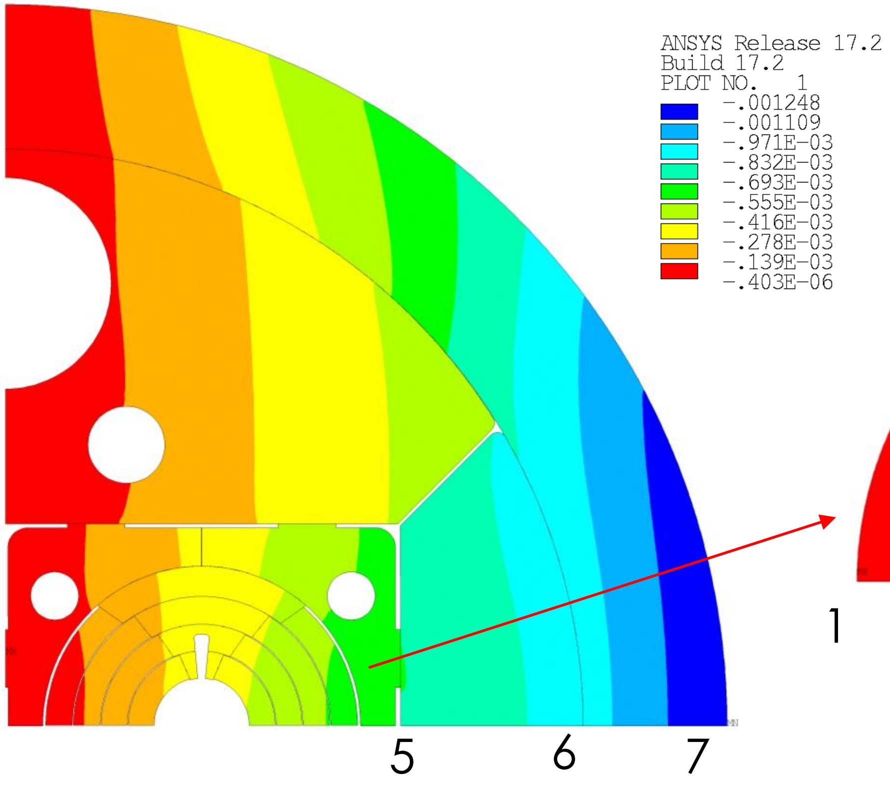
Displacements
Assembly - Undeformed

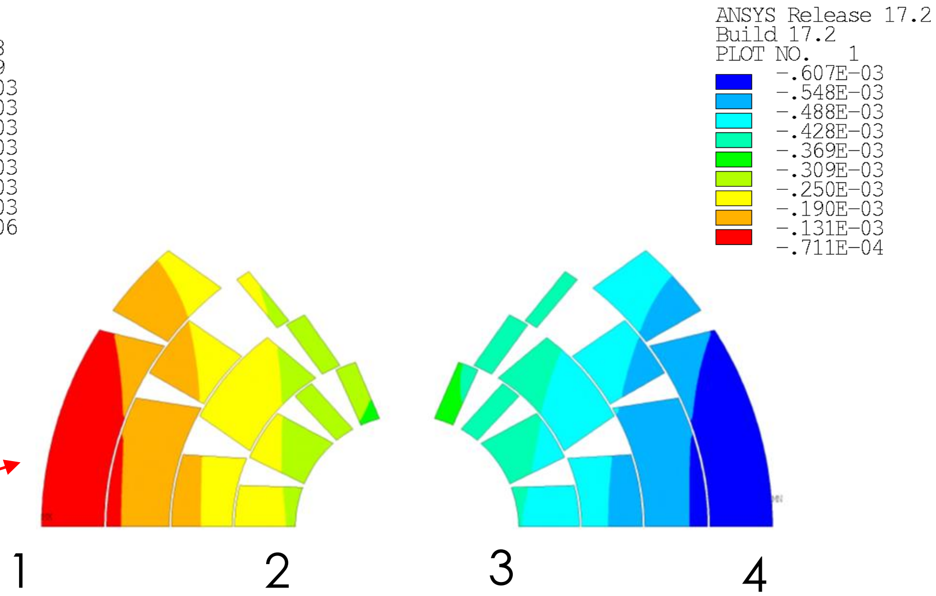




point	Disp$_x$ [μm]
1	390
2	370
3	-40
4	-60
5	727
6	715
7	690

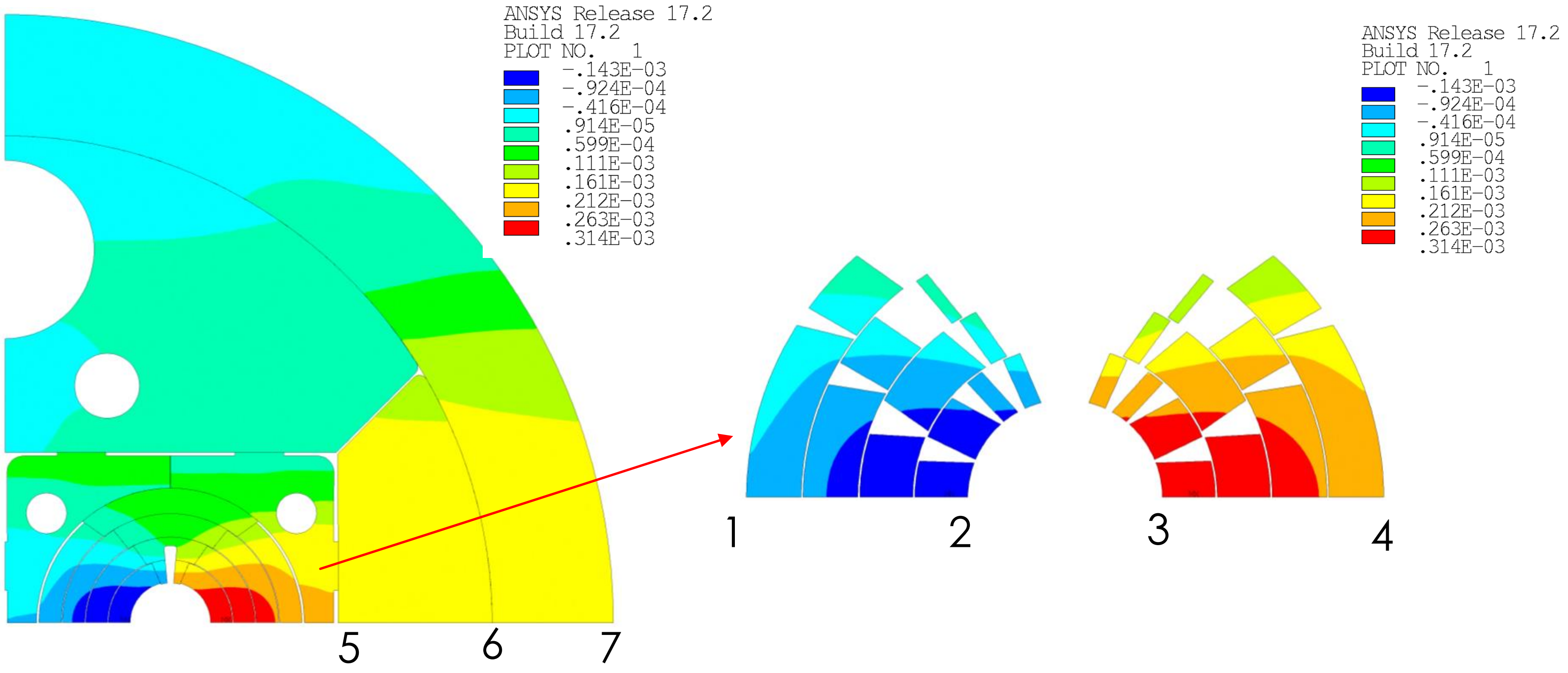
Displacements
Cool Down- Assembly





point	$Disp_x$ [µm] CD -ASS	$Disp_x$ [µm] CD - 0
1	-71	315
2	-250	120
3	-430	-470
4	-607	-670
5	-700	27
6	-900	-175
7	-1250	-560

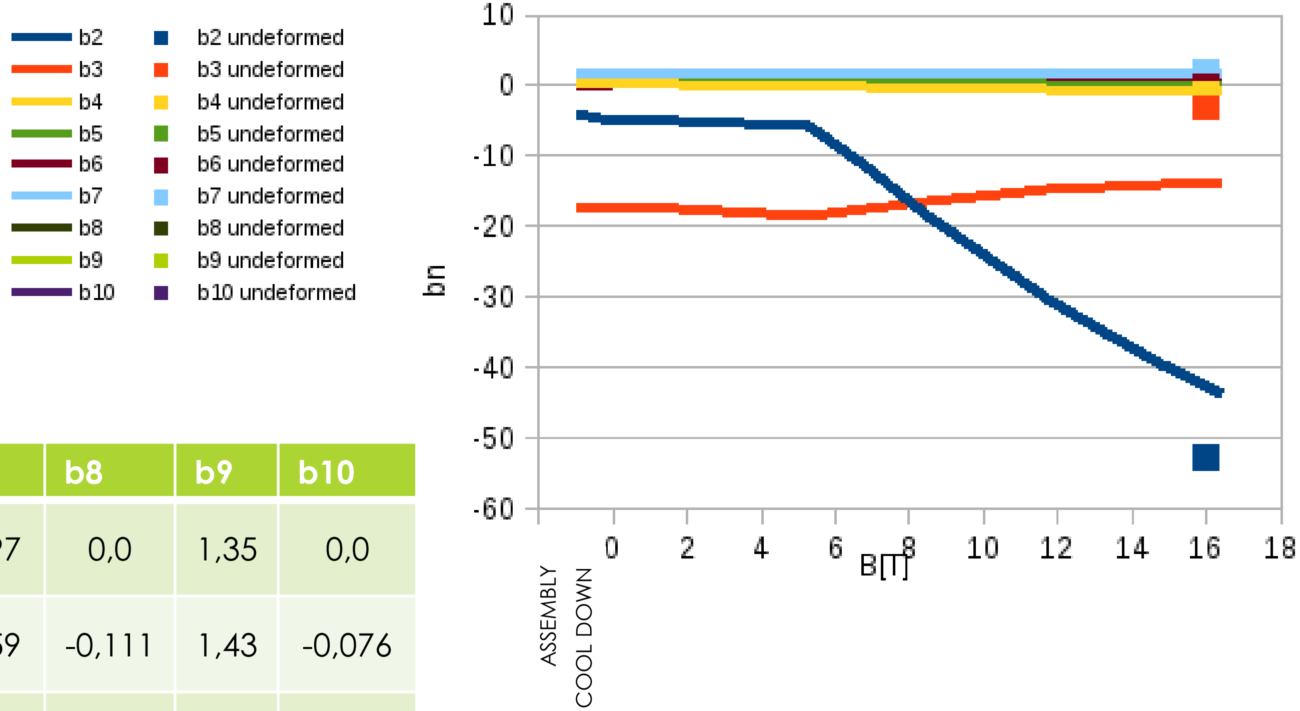
Displacements
Energization 16T –Cool Down



point	$Disp_x$ [μm] 16T -CD	$Disp_x$ [μm] 16T - 0
1	-40	280
2	-143	-20
3	314	-160
4	220	-450
5	200	225
6	195	18
7	190	-370

Effect of displacement on field quality

- Field harmonics calculation was iterated at increasing currents values, taking into account the mechanical deformation induced by assembly, cool down and energization.
- b3 is worsen by up to 10 units
- very preliminary results, further analysis are required



	B[T]	b2	b3	b4	b5	b6	b7	b8	b9	b10
Undeformed geometry	16	-52,7	-3,21	-1,220	-1,830	-0,009	1,97	0,0	1,35	0,0
Assembly	-	-3,96	-17,3	-0,002	0,185	-0,078	1,59	-0,111	1,43	-0,076
Cool down	-	-4,96	-17,3	0,083	0,237	0,114	1,62	0,127	1,47	0,085
Energization	16,444	-43,7	-13,6	-0,883	-0,247	0,062	1,71	0,062	1,33	0,057

Conclusions

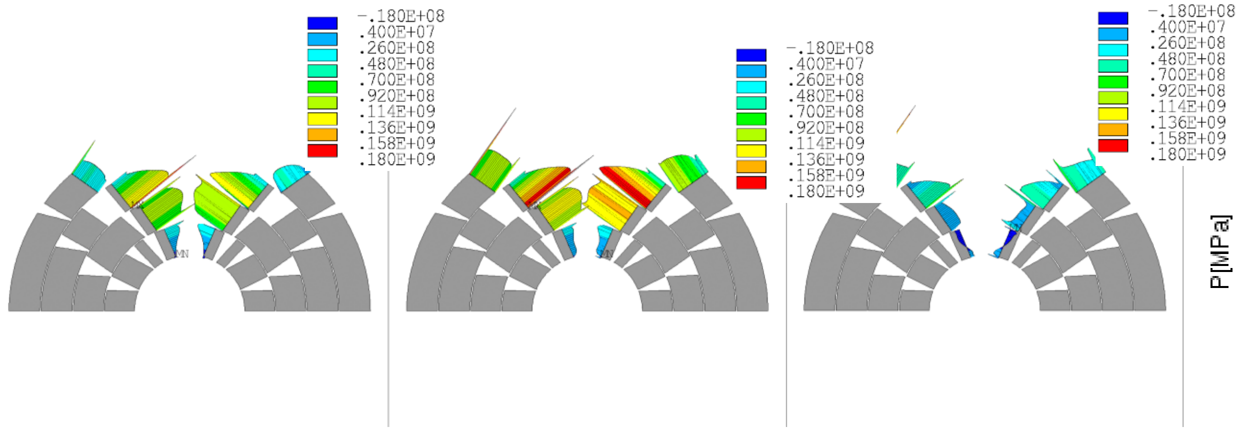
- The 16 T cosθ mechanical model was updated in order to account for:
  - cooling channels
  - iron rods for b3 correction
- Mechanical analysis on the new optimized model shown that:
  - requirements on VM stress on conductors are almost fulfilled (localized edge effect due to wedges after cool down);
  - requirements on VM stress on contact pressure are almost fulfilled ($P_{cont} \rightarrow 0$ for 1° layer after energization at 16T, but still not negative)
  - requirements on VM stress on mechanical structures are almost fulfilled (localized hot spot under keys and in the notch in the Ti pole);
- Mechanical deformation and displacements due to mechanical stress and Lorentz forces do affect field quality and must be investigated further.

Thank you

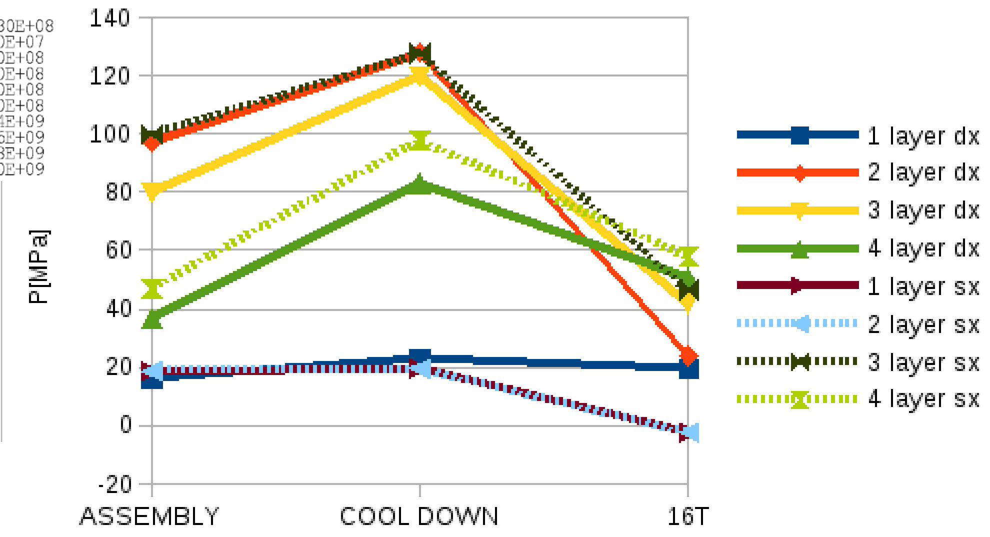
Back-up slides

Contact Pressure – Glued contact

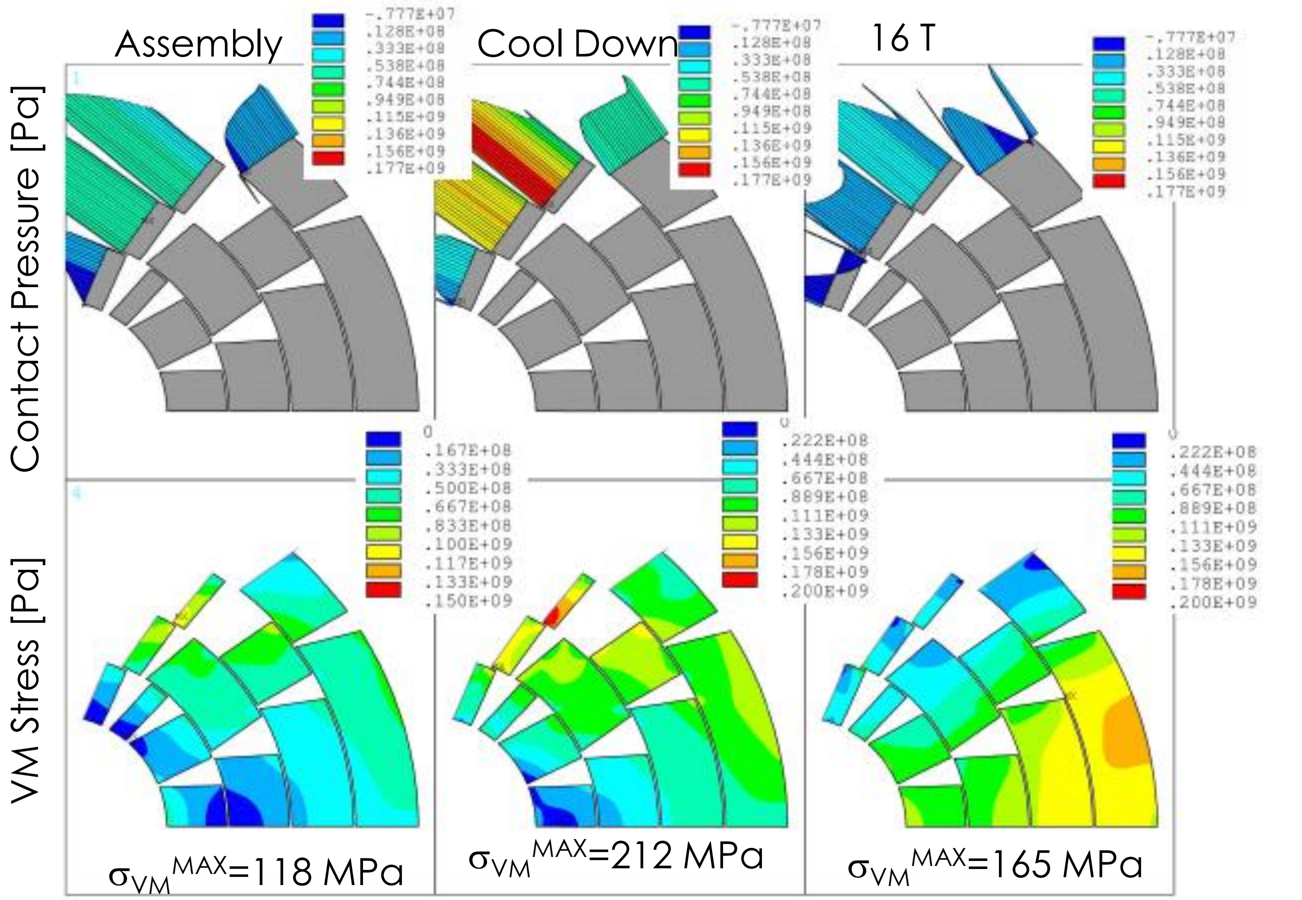
Contact Pressure [Pa]



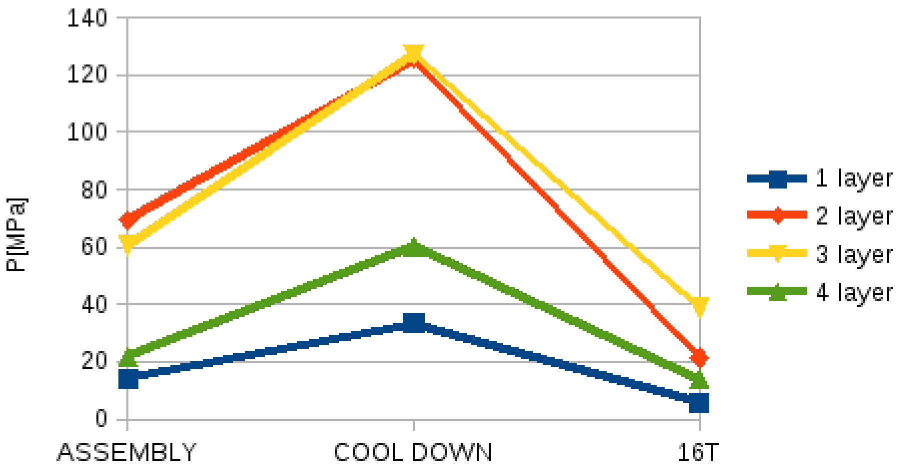
Average contact pressure per layer



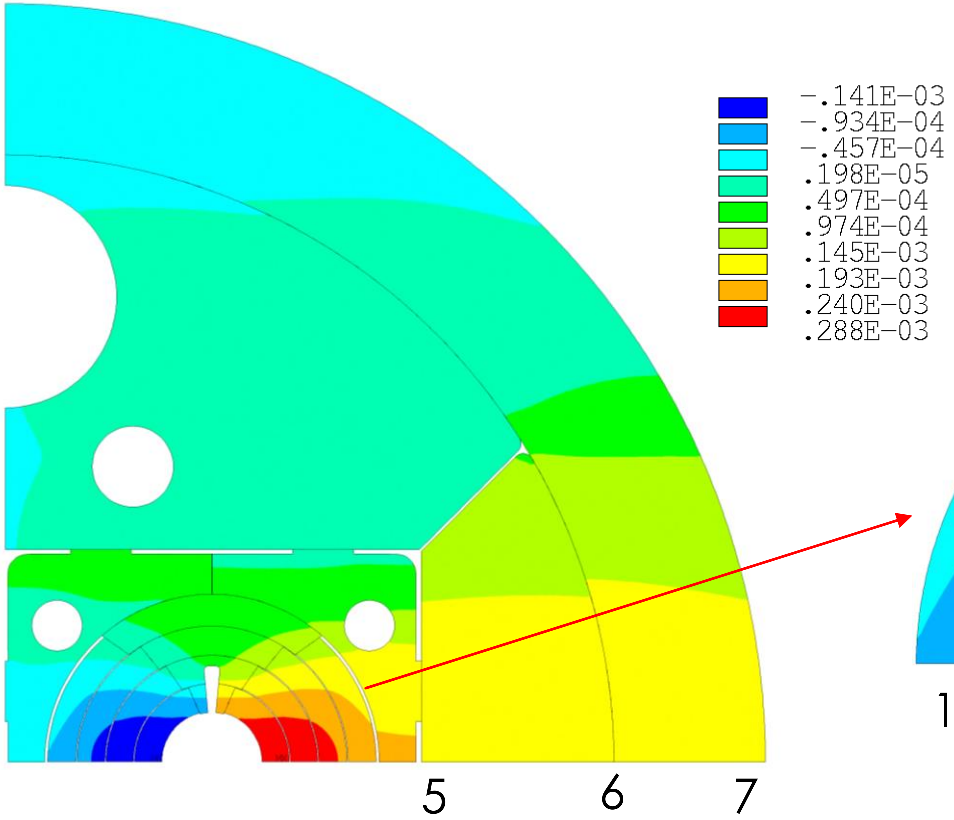
Contact Pressure – Single aperture

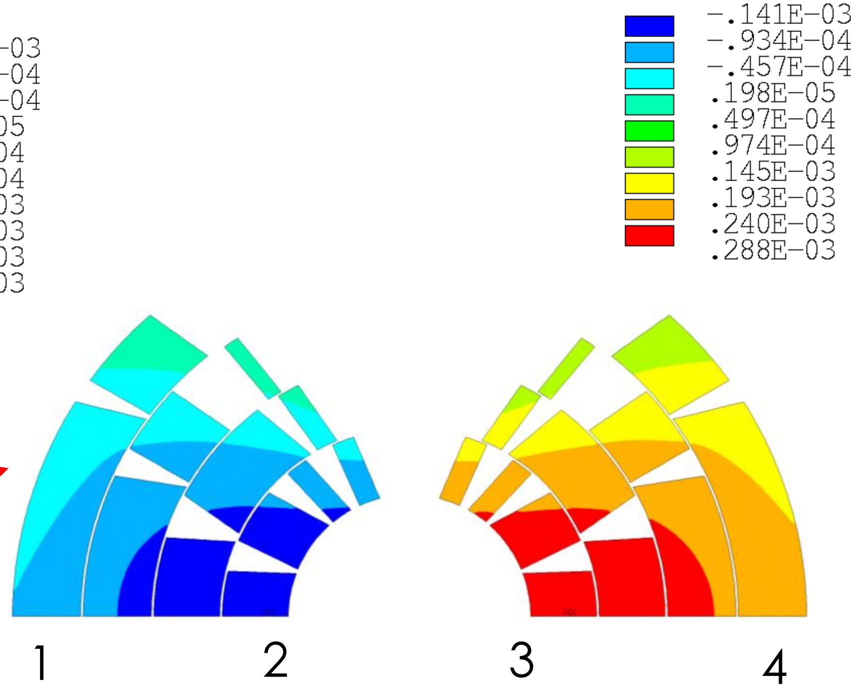


Average contact pressure per layer



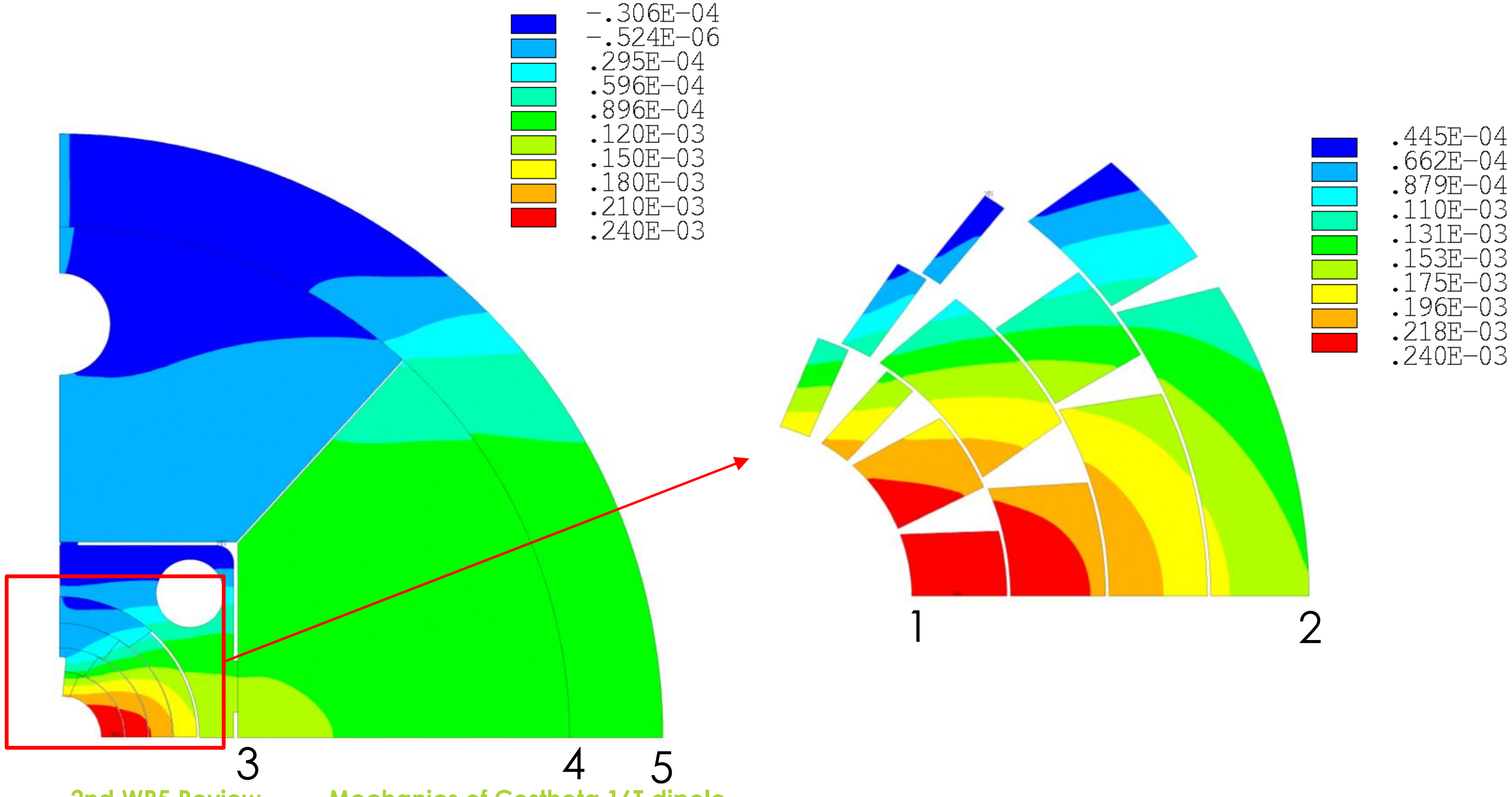
Displacements – glued contact Energization 16T –Cool Down





point	$Disp_x$ [μm]
1	-50
2	-141
3	288
4	206
5	203
6	165
7	160

Displacements – single apertures Energization 16T –Cool Down



point	Disp$_x$ [μm]
1	240
2	150
3	120
4	115
5	117

Effect of displacement on field quality

	B[T]	b2	b3	b4	b5	b6	b7	b8	b9	b10
Undeformed geometry	16	-52,7	-3,21	-1,220	-1,830	-0,009	1,97	0,0	1,35	0,0
Assembly		-3,96	-17,3	-0,002	0,185	-0,078	1,59	-0,111	1,43	-0,076
Cool down		-4,96	-17,3	0,083	0,237	0,114	1,62	0,127	1,47	0,085
Energization	1,77	-4,98	-17,3	0,081	0,234	0,112	1,62	0,126	1,46	0,084
	5,254	-5,8	-18,5	-0,029	0,255	0,109	1,63	0,124	1,45	0,085
	6,875	-11,7	-17,4	-0,302	0,190	0,104	1,67	0,111	1,46	0,082
	8,480	-18,6	-16,3	-0,489	0,126	0,101	1,69	0,112	1,46	0,082
	11,688	-30,2	-14,8	-0,700	-0,003	0,090	1,70	0,095	1,43	0,076
	13,293	-35,2	-14,3	-0,772	-0,076	0,083	1,71	0,085	1,41	0,071
	14,84	-39,7	-13,9	-0,833	-0,156	0,073	1,72	0,074	1,38	0,062
	16,444	-43,7	-13,6	-0,883	-0,247	0,062	1,71	0,062	1,33	0,057