

DE LA RECHERCHE À L'INDUSTRIE

cea

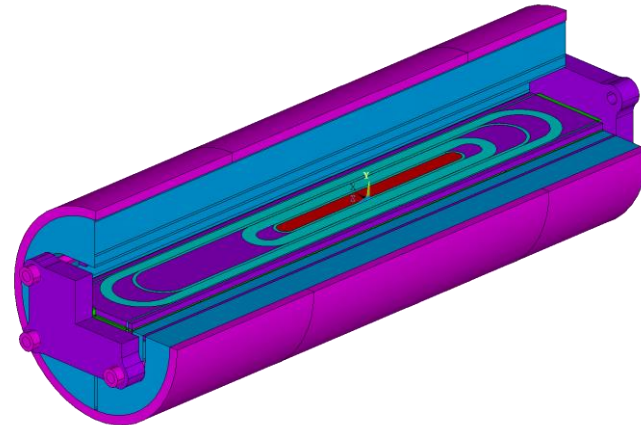


Conceptual Design Review of R2D2

3

- Mechanical Design -

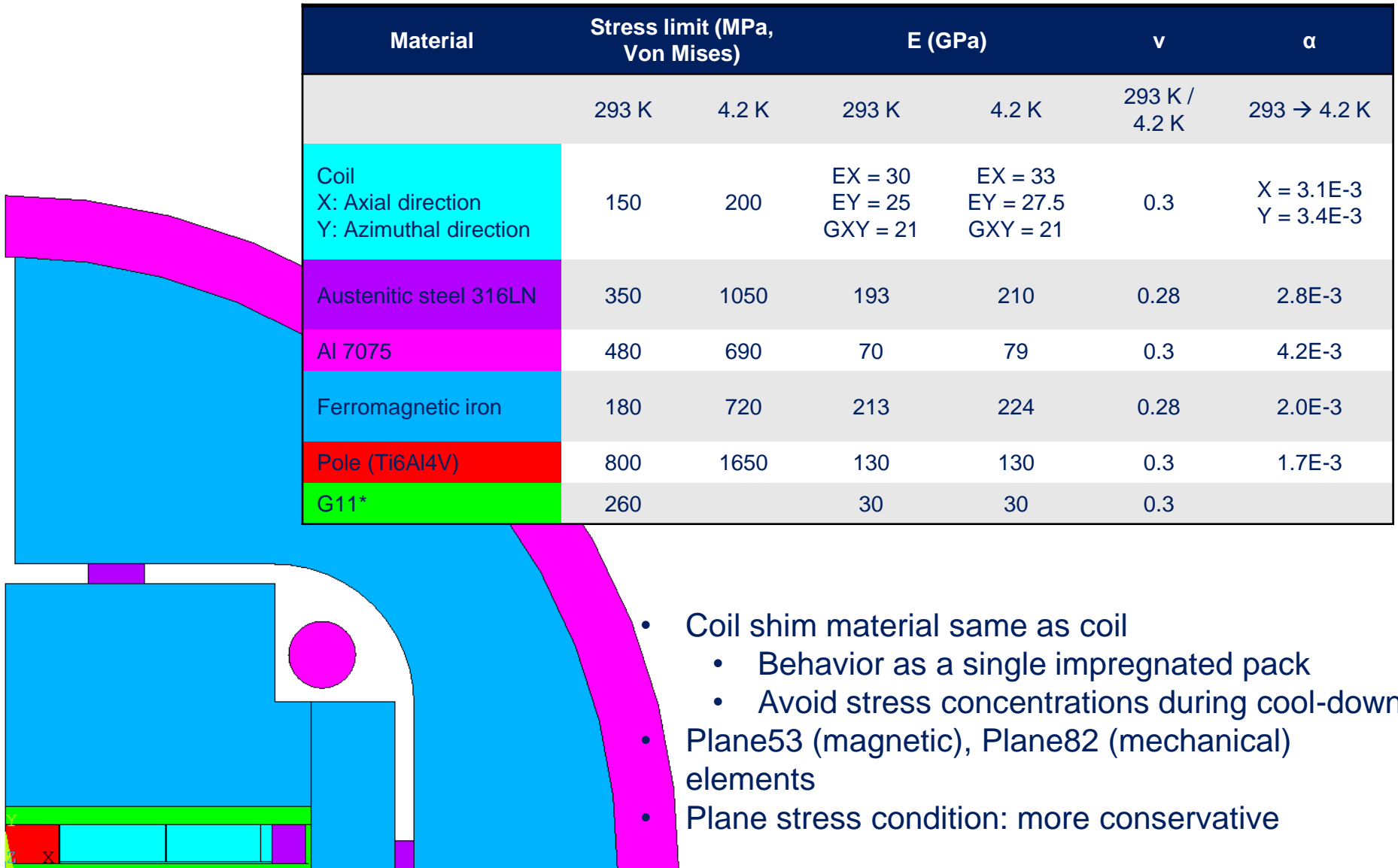
<https://indico.cern.ch/event/1003865/>



CEA: E. Rochepault, V. Calvelli, M. Durante, H. Felice, P. Mallon, P. Manil, G. Minier, G. Maitre, B. Prevet, S. Perraud, F. Rondeaux

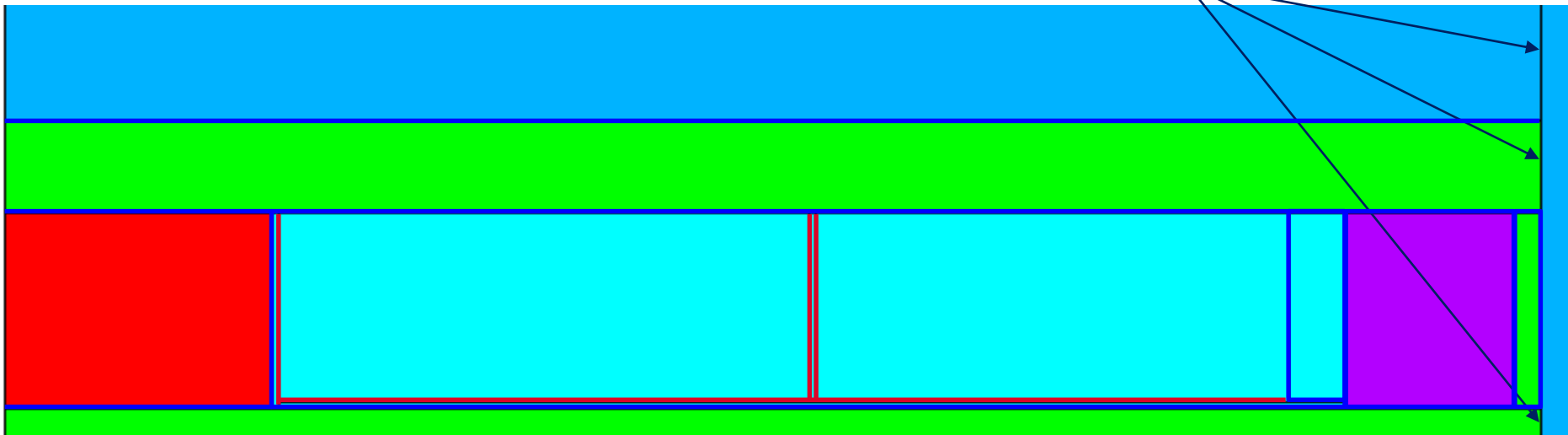
CERN: S. Izquierdo Bermudez, J.C. Perez, D. Tommasini, J. Fleiter, H. Felice

08/03/2021



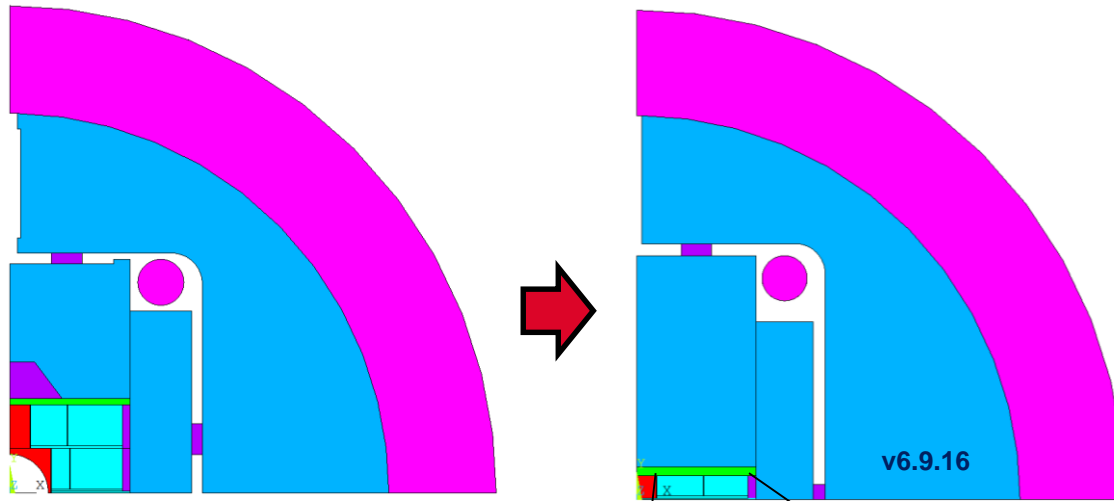
- Standard contact (Separation and Sliding permitted)
- No initial penetration or gap
- Friction coefficient = 0.2

Unprescribed interfaces



- Standard contact between all interfaces surrounding coil assembly, friction coefficient = 0.2
- Coupling between coils and their proximal shims

- Coupling used to:
 - Force coil pack to behave as a unit
 - Avoid stress concentrations during cool-down

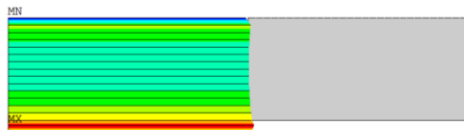


- Too much pre-load because of the thick shell
→ High peak stress
→ Need to redesign the structure
- Different fillers and pads
→ Marginal cost saving

0.10 mm Xinterf
0.05 mm Yinterf
+cool-down

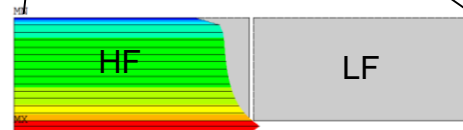
Nominal:
13.38 kA, 11T

Short sample:
16.88 kA, 11T



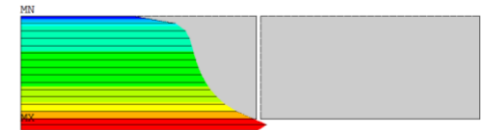
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SMN =167.191
SMX =172.982

167.191
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172.982



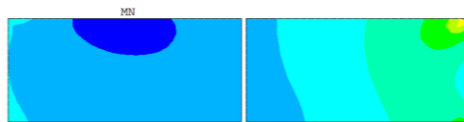
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SMX =104.244

76.8354
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89.0171
92.0625
95.1079
98.1533
101.199
104.244



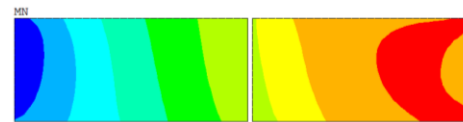
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64.3527
68.4411



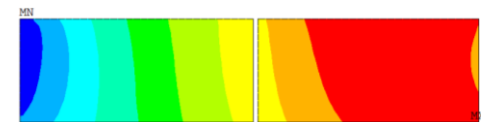
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PowerGraphics
EFACET=1
AVRES=Mat
DMX =.614933
SMN =146.778
SMX =207.867

146.778
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160.353
167.141
173.929
180.716
187.504
194.292
201.08
207.867



SEQV (AVG)
PowerGraphics
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DMX =.589787
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SMX =201.074

83.4719
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148.806
161.873
174.94
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201.074



SEQV (AVG)
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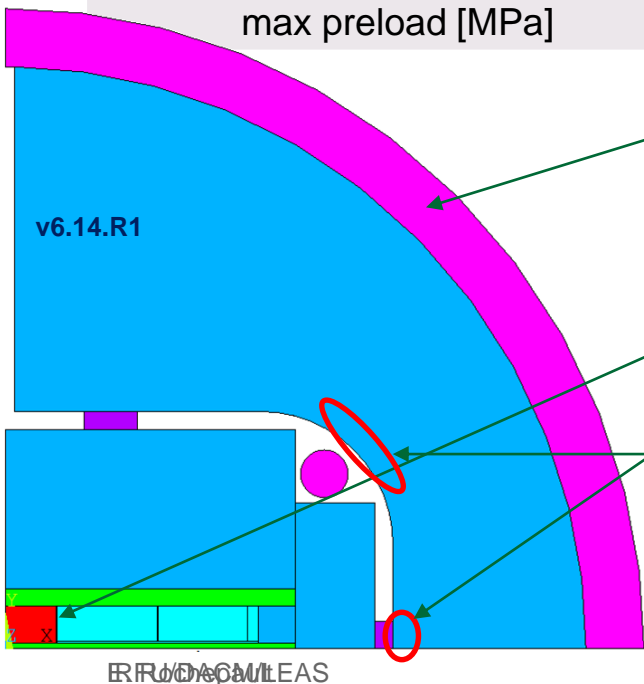
41.7951
59.9595
78.1238
96.2882
114.453
132.617
150.781
168.946
187.11
205.274

208 MPa

201 MPa

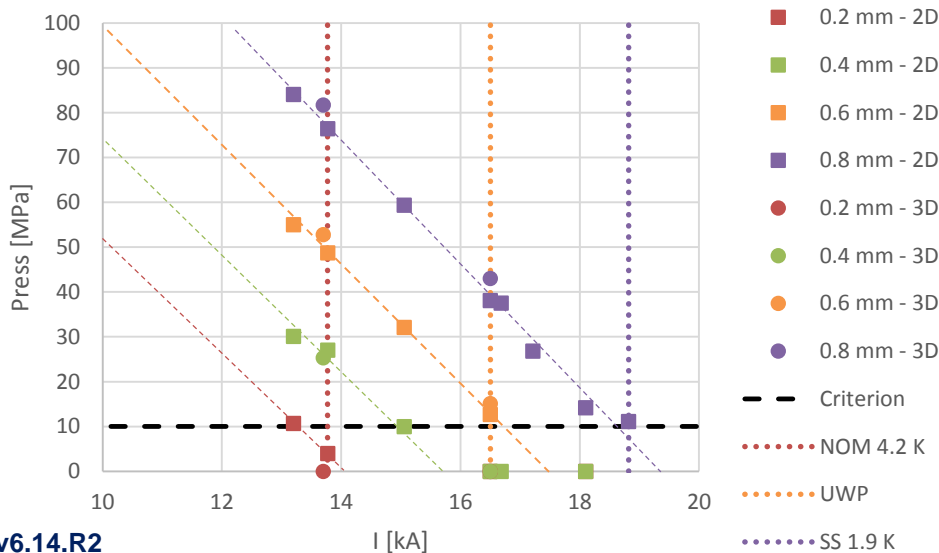
205 MPa

Parameter		Criterion	I	II	III	IV	V	VI
Shell Thick. (mm)		>15 mm	26	22	20	22	22	22
Yoke Ext. Rad. (mm)		>190 mm	190	190	190	195	210	220
Overall Rad. (mm)		>205 mm	216	212	210	217	232	242
Max. Von Mises stress in coil [MPa]	Nominal	<150 MPa	129	123	120	126	134	128
	SS 1.9K	No limit	217	247	201	211	218	222
Coil-Pole Contact [MPa]	Nominal	>10 MPa	12	7	5	9	12	13
	SS 1.9K	>10 MPa	16	8	2	10	12	12
Max. Von Mises stress in Iron at max preload [MPa]		<180 MPa	257	247	240	223	186	174



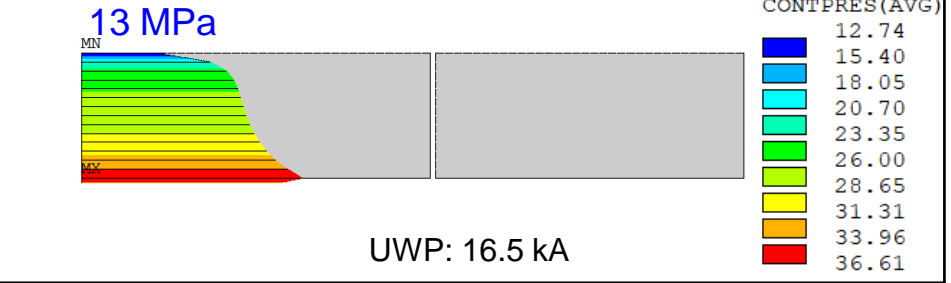
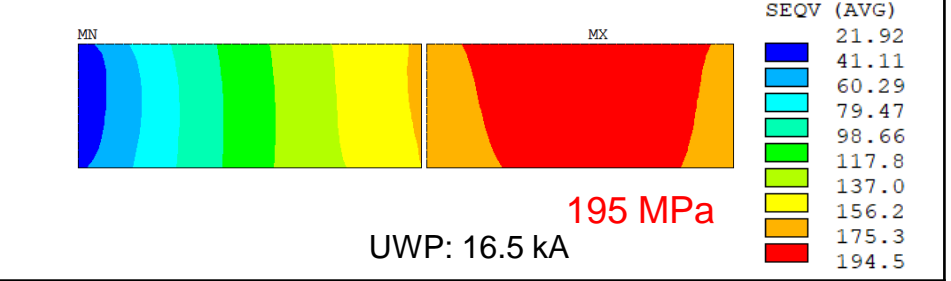
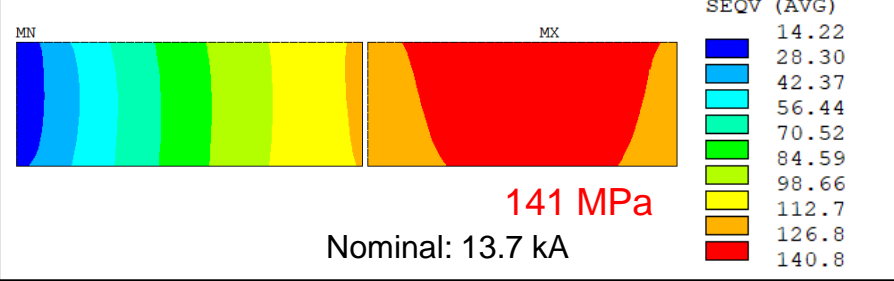
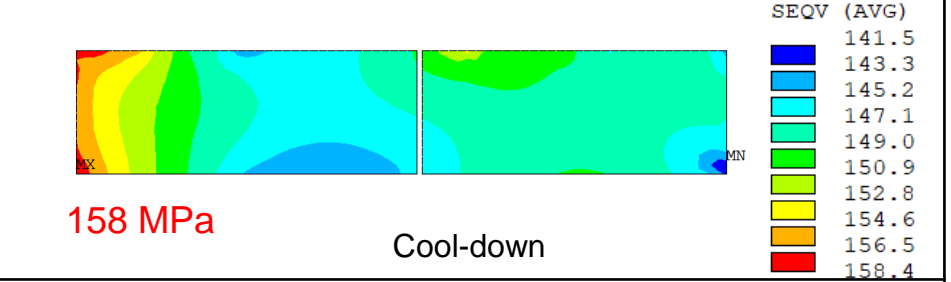
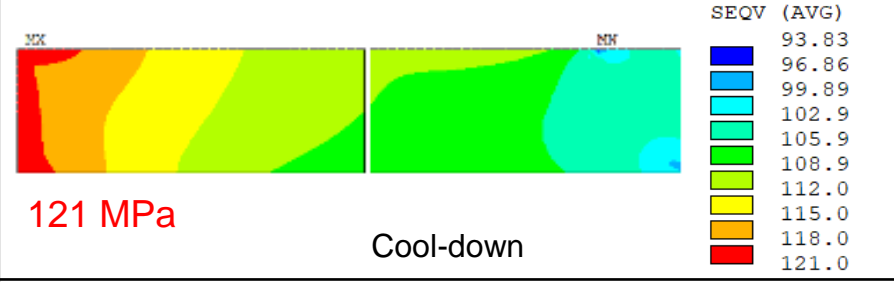
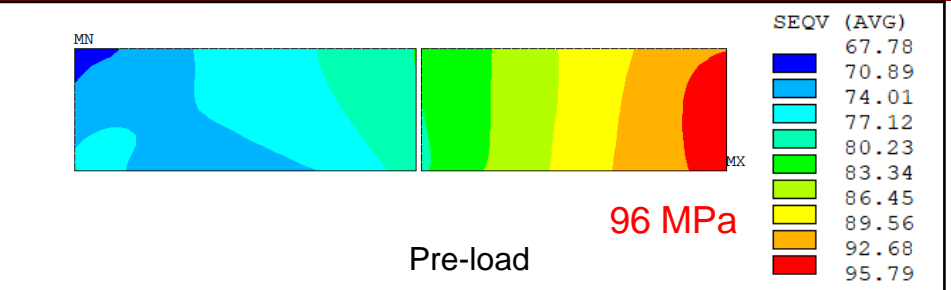
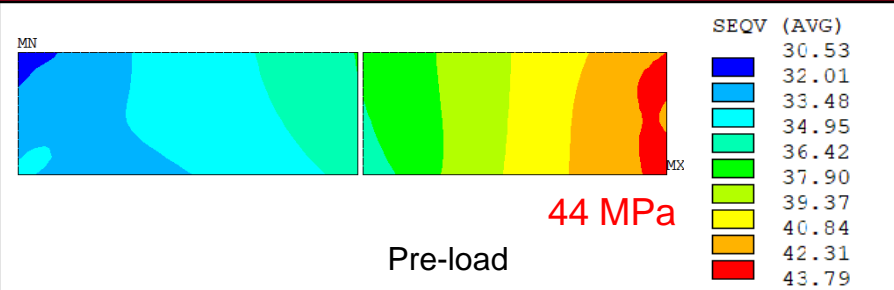
- ✓ Step 1: shell thickness/radius reduced to decrease **coil stress below 150 MPa at nominal**
- ✓ Step 2: pre-load tuned to guarantee **10 MPa contact** from nominal to SS
- ✓ Step 3: Yoke radius varied to keep **peak stress at warm below 180 MPa**

Parameter	Unit	NOM 4.2 K	NOM 1.9 K	UWP 4.2K	UWP 1.9K	SS 4.2 K	SS 1.9 K
Current	A	13772	15055	16500	16500	17215	18819
Margin HF	%	20.0	20.9	4.5	12.9	0.0	0.9
Margin LF	%	20.5	20.0	4.0	11.3	0.7	0.0
B (0,0)	T	10.42	11.15	11.98	11.98	12.46	13.29
Max. Von Mises stress in coil	MPa	141	155	195	195	204	231

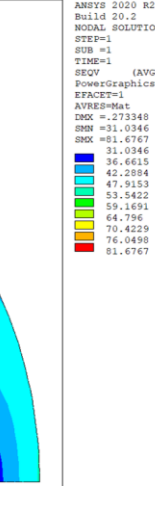
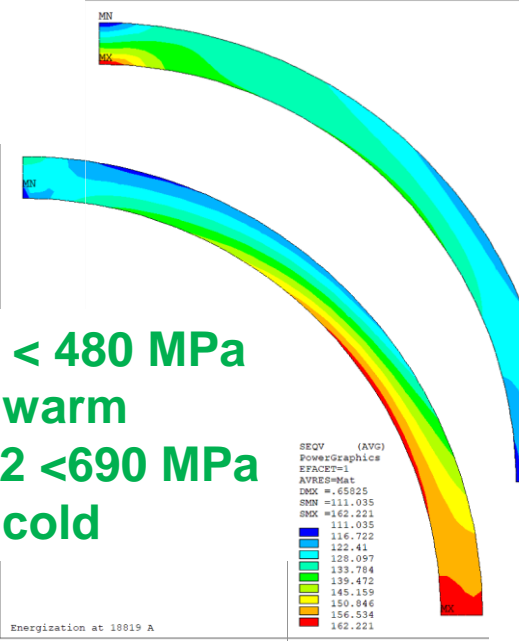
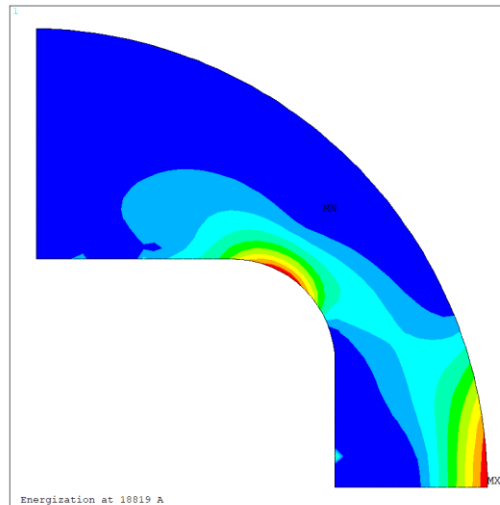
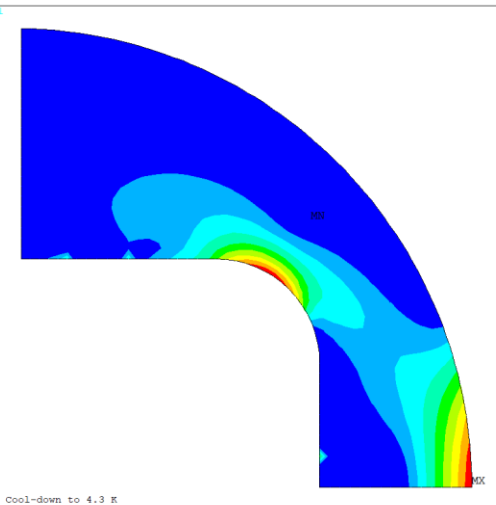
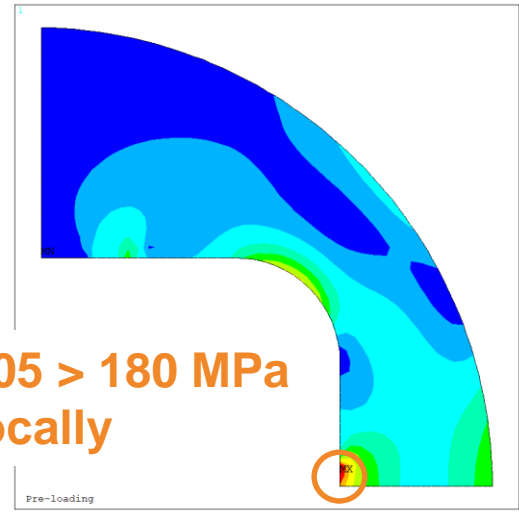
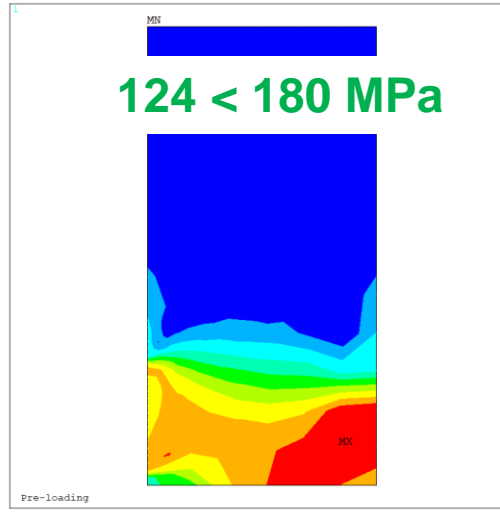
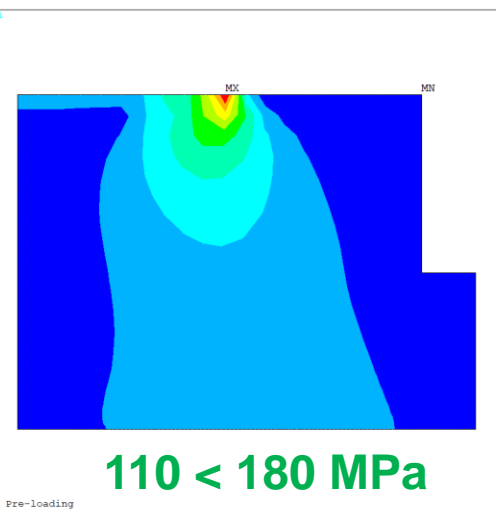


- Min. pre-load for nominal operation
- Max. pre-load for SS 1.9K
- **Structure can withstand high pre-load if required**
- **Coil should be limited to ultimate current**

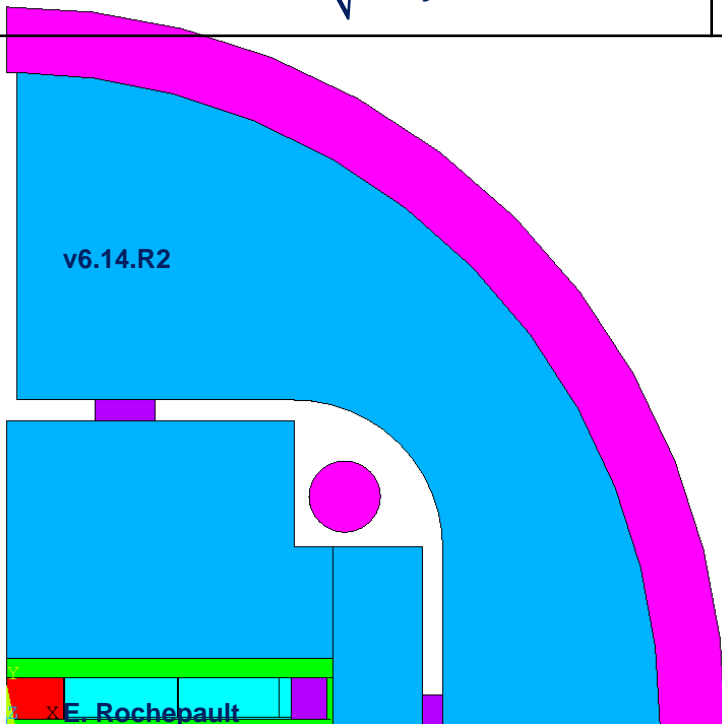
PEAK STRESS IN COIL AND CONTACTS (Nom.+UWP)



PEAK STRESSES IN STRUCTURE (SS 1.9 K)



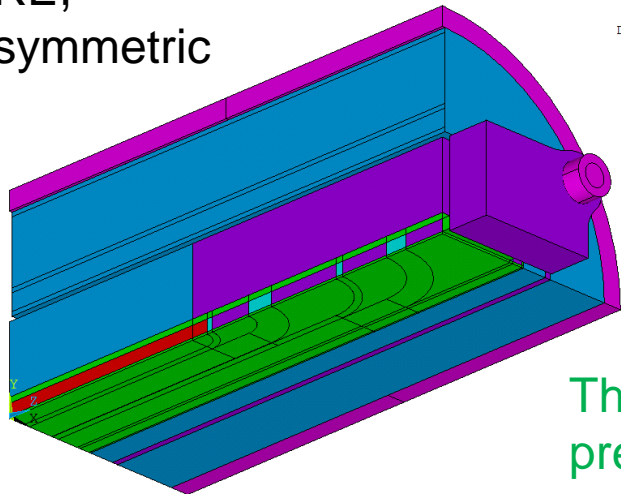
	At Room Temperature	After Cool-Down
Force/rod (4 rods)	-142.8 kN = 70 % EMF @ SS 1.9K	-204 kN = 100 % EMF @ SS 1.9K
Minimum diameter before yield: $d_{min} = \sqrt{4 \frac{F_{z,rod}}{\sigma_{yield}\pi}}$	$\sigma_{yield} = 480 \text{ MPa}$ $d_{min} = 19.5 \text{ mm}$	$\sigma_{yield} = 690 \text{ MPa}$ $d_{min} = 19.4 \text{ mm}$



- N.b.: 18 mm is minimum diameter for 16.5 kA ultimate working point condition
- 24 mm has been chosen, giving 1.5 safety factor

(see 4, P. Manil for longitudinal pre-load concepts)

RE,
symmetric



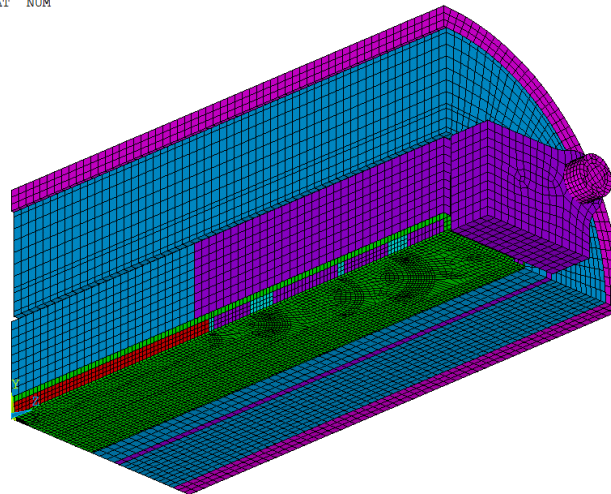
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R19.0
Academic

DEC 18 2020
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This
presentation

Version 6p14_RE_R2, 3D Mechanical

ELEMENTS
MAT NUM

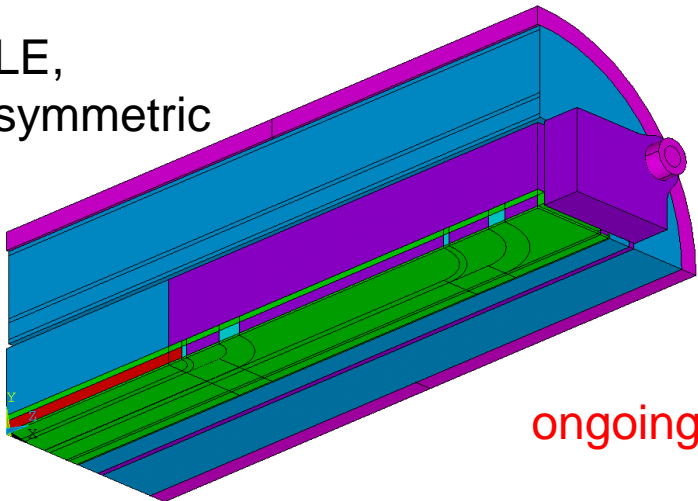


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Academic

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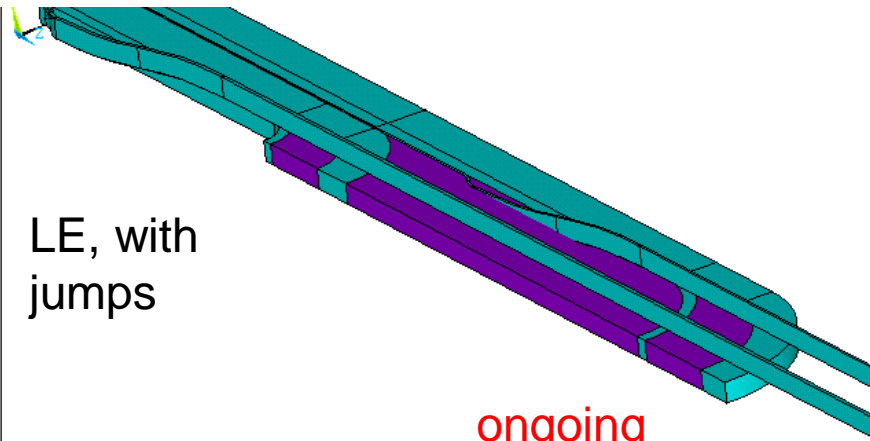
LE,
symmetric



ongoing

Version 6p14_LE_R2, 3D Mechanical

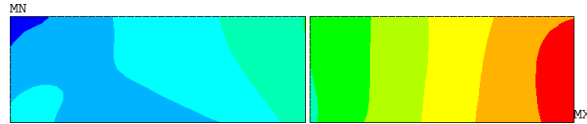
LE, with
jumps



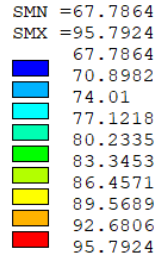
ongoing

Version 6p14_LE_R2, 3D Mechanical

2D



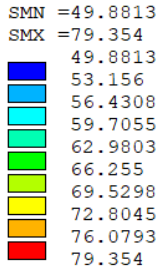
96 MPa



3D

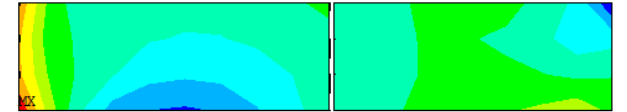


79 MPa

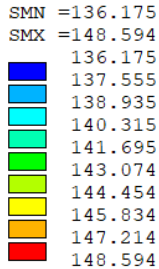


0.60 mm Xinterf
0.05 mm Yinterf

Cool-down

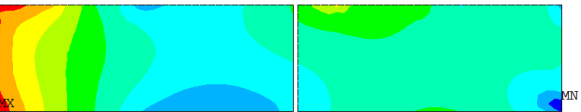
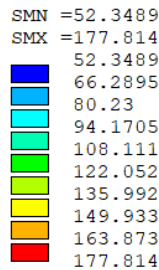
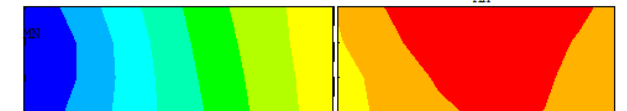


149 MPa



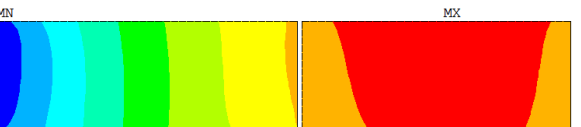
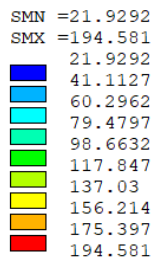
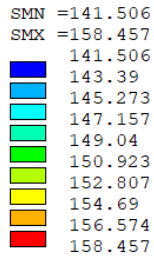
178 MPa

16.5 kA
Ultimate
current



158 MPa

195 MPa

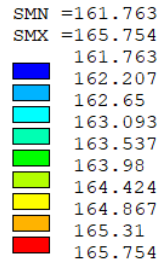
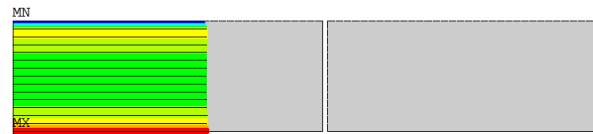


- Profile and range very similar between 2D/3D
- Difference 10-20 MPa in max. VM Stress attributed to 2D plane stress Vs 3D stress, 2D more pessimistic (conservative)
- Difference <5 MPa in X Stress

2D

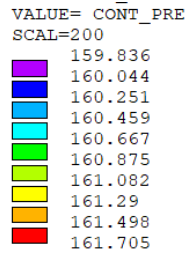
3D

162 MPa

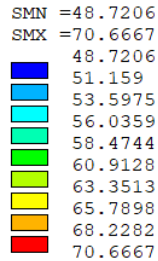
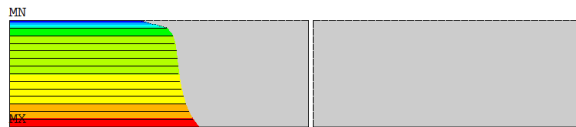


Cool-down

160 MPa

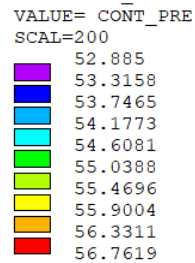


49 MPa

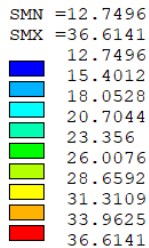
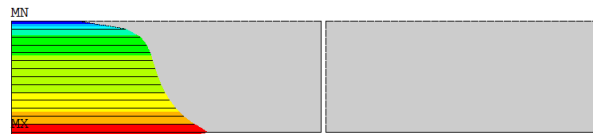


13.7 kA
Nominal
current

53 MPa

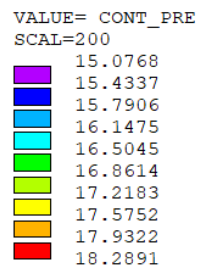
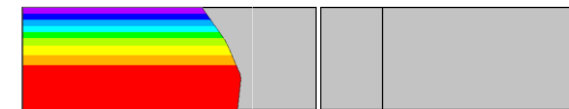


12.7 MPa



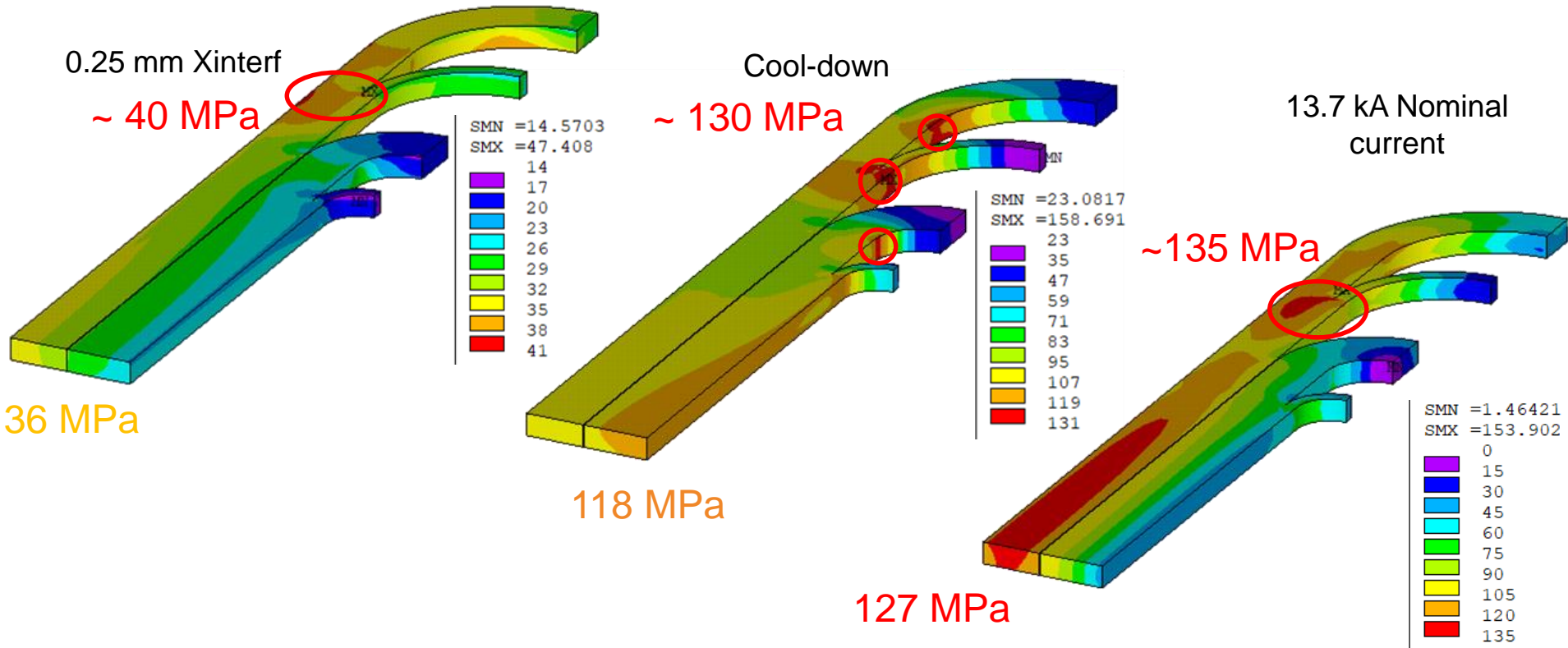
16.5 kA
Ultimate
current

15.1 MPa

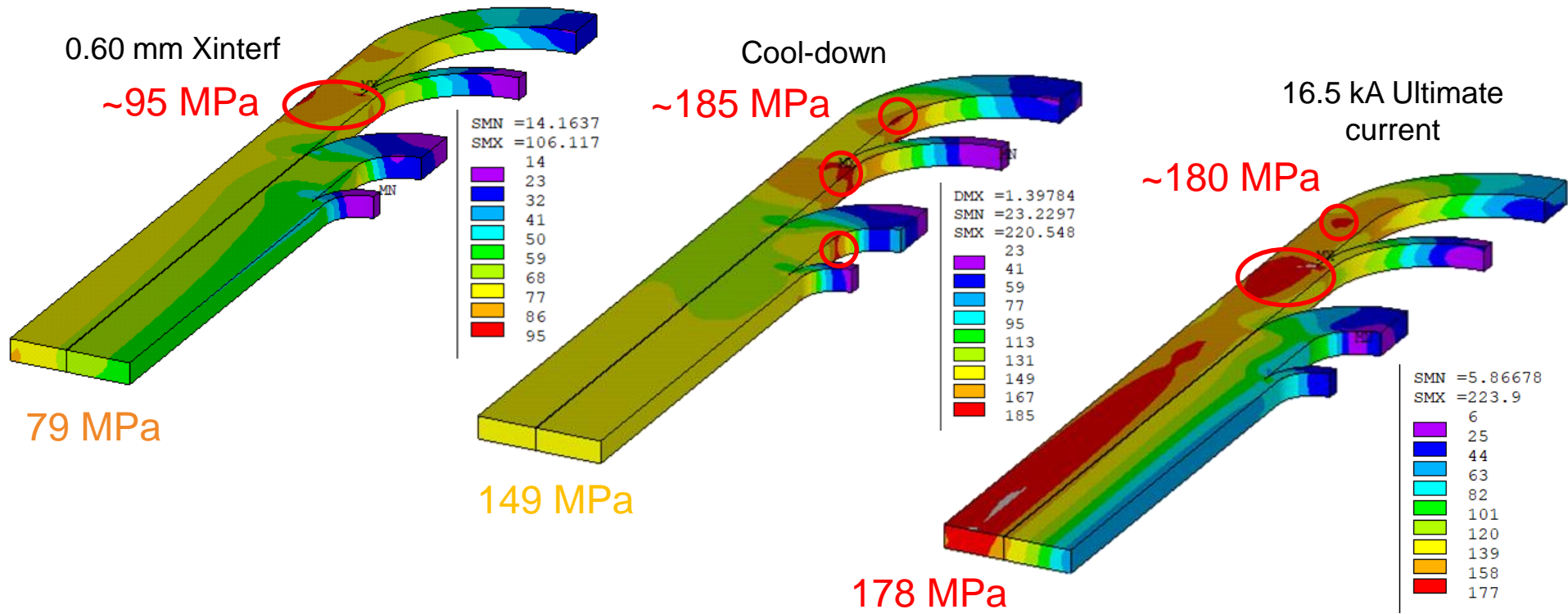


- Profile and range very similar between 2D/3D
- Difference <5 MPa in min. contact pressure

→ pre-load to be slightly corrected → +/-5 MPa on coil stress



- Higher stresses in coil-ends than in straight section
→ To be checked with longitudinal pre-load study
- Peak stress still < 150 MPa at Nominal



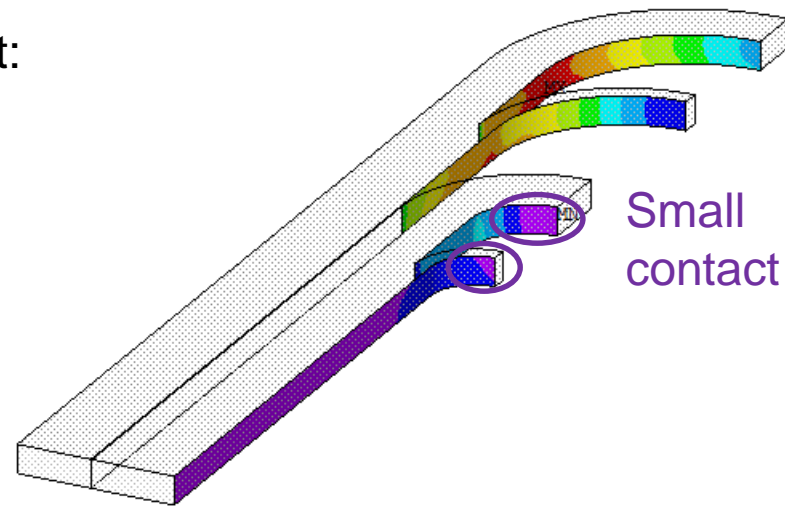
- Higher stresses in coil-ends than in straight section
→ To be checked with longitudinal pre-load study
- Peak stress still < 200 MPa at ultimate

- Lorentz forces @ **Nominal** current:
 $F_{z,mag} = 350 \text{ kN /end}$
- Xpreload: 0.25 mm interf.
- Z Preload:
 - warm: 400 kN = 115 % $F_{z,mag}$
 - Cold: 641 kN = **183 % $F_{z,mag}$**

→ **Small >0 contact in the ends with relatively high pre-load**

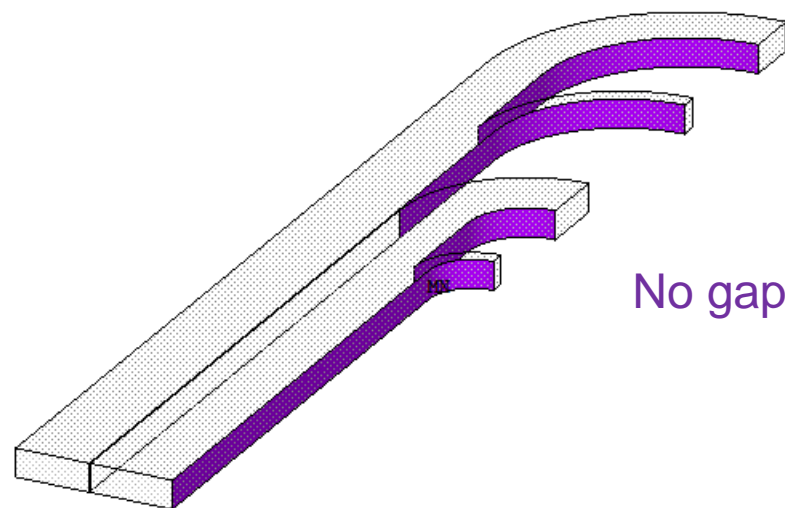
Goals of the longitudinal support:

1. Positive contact pressure
2. Stress < criteria



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PowerGraphics
EFACET=1
AVRES=Mat
DMX =1.45675
SMN =2.35584
SMX =137.868

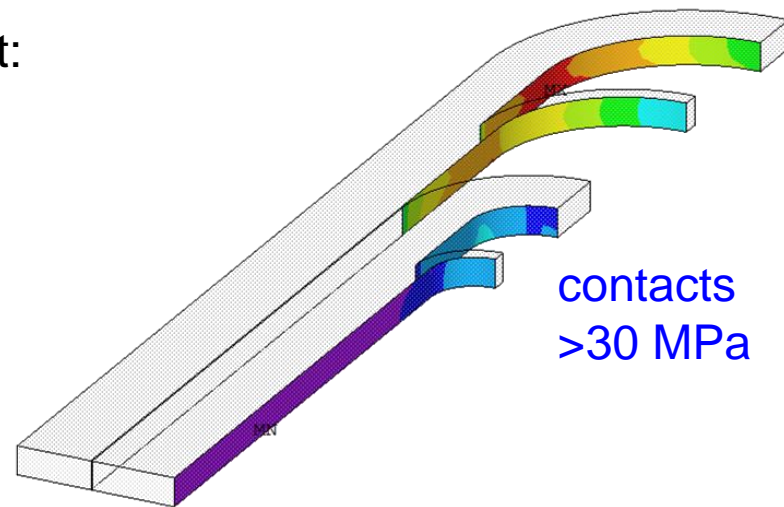
17.4127
32.4696
47.5265
62.5834
77.6403
92.6972
107.754
122.811
137.868



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AVRES=Mat
DMX =1.45675

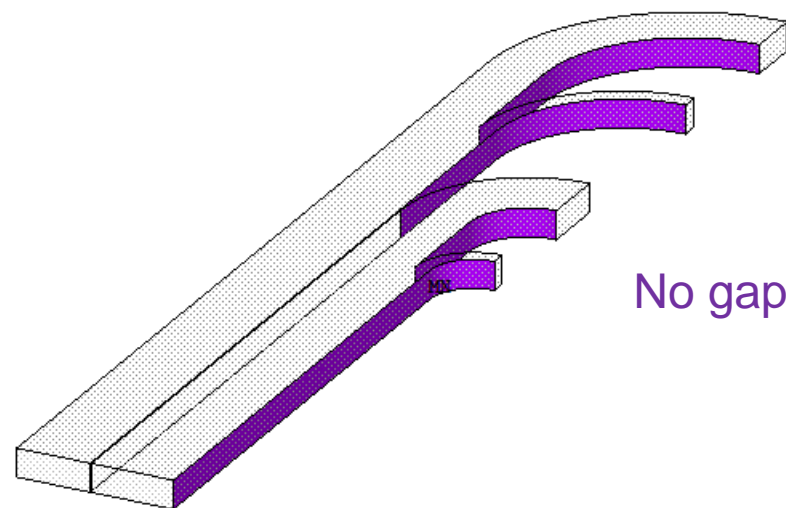
- Lorentz forces @ **Nominal** current:
 $F_{z,mag} = 350 \text{ kN /end}$
- Xpreload: 0.25 mm interf.
- **Increasing Z Preload +40%:**
 - warm: 529 kN = 151 % $F_{z,mag}$
 - Cold: 783 kN = **224 %** $F_{z,mag}$

→ contacts >0 in the ends if very high pre-load



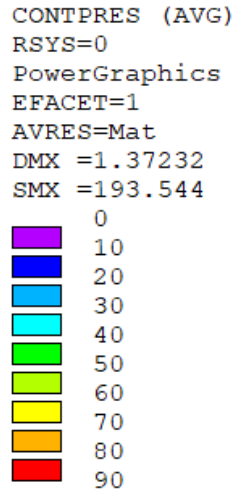
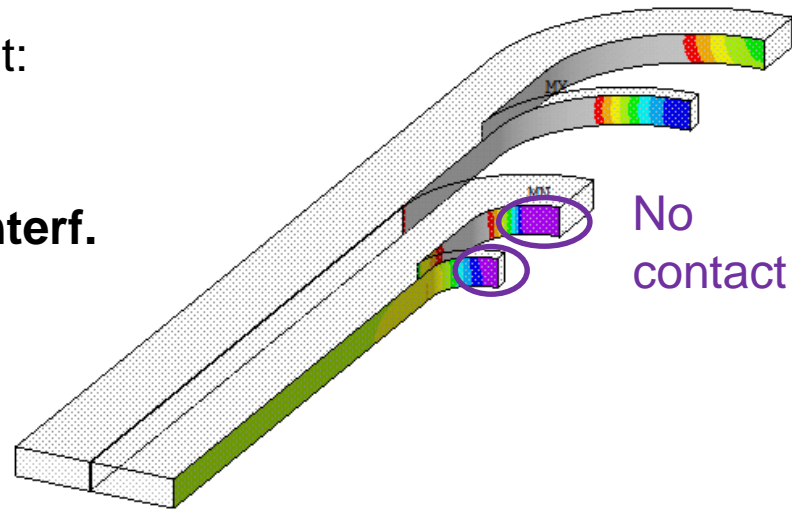
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AVRES=Mat
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SMX =143.049

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34.1318
49.6914
65.251
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96.3702
111.93
127.489
143.049

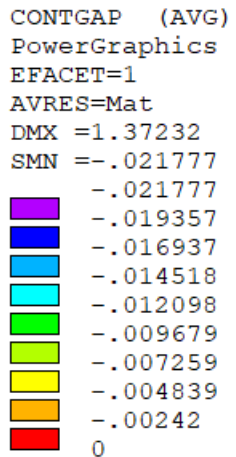
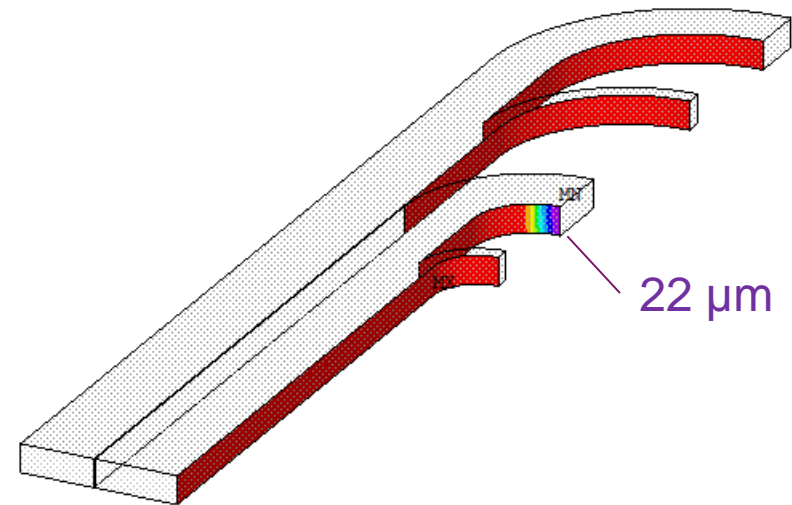


CONTGAP (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =1.45675

- Lorentz forces @ **Nominal** current:
 $F_{z,mag} = 350 \text{ kN /end}$
- **Increasing X preload: 0.6 mm interf.**
- **Increasing Z Preload:**
 - warm: 565 kN = 162 % $F_{z,mag}$
 - Cold: 831 kN = **238 % $F_{z,mag}$**



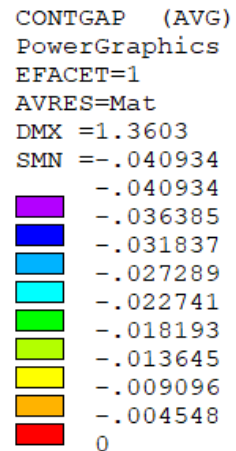
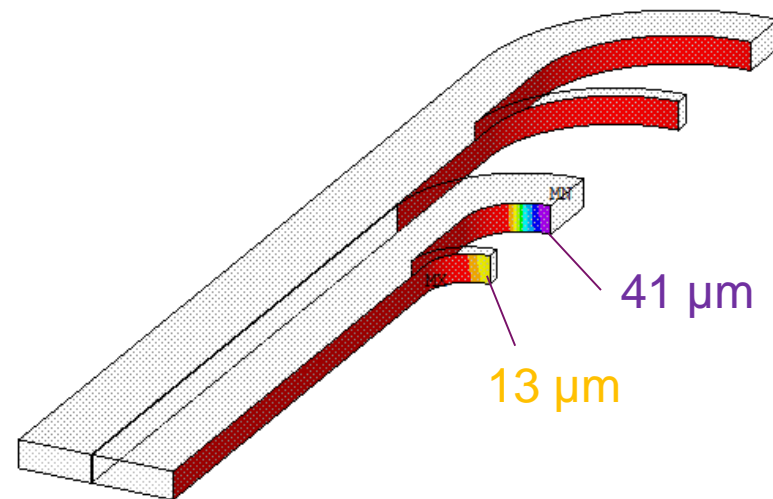
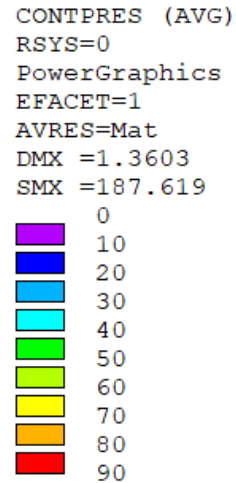
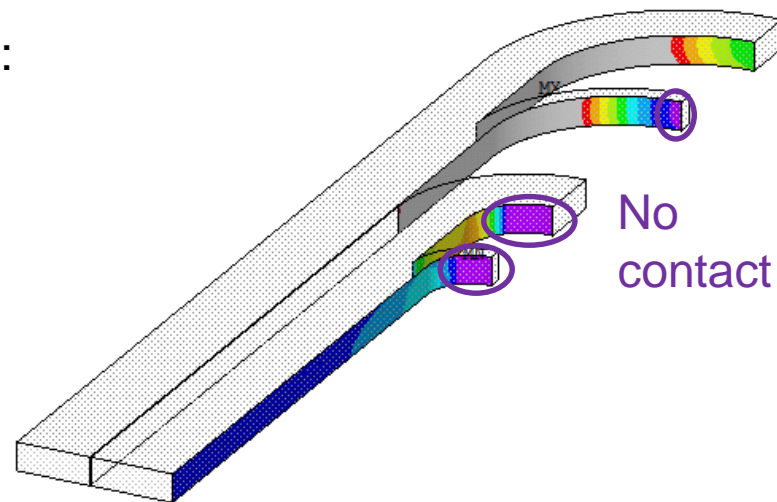
→ **But: contacts lost if transverse pre-load is too high**



- Lorentz forces @ **Ultimate** current:
 $F_{z,mag} = 477 \text{ kN /end}$
- X preload: 0.6 mm interf.
- Z Preload:
 - warm: 565 kN = 119 % $F_{z,mag}$
 - Cold: 831 kN = **174 % $F_{z,mag}$**

→ **Need to considerably increase the pre-load to guarantee full contact in the ends**

(see 4, P. Manil for longitudinal pre-load concepts)



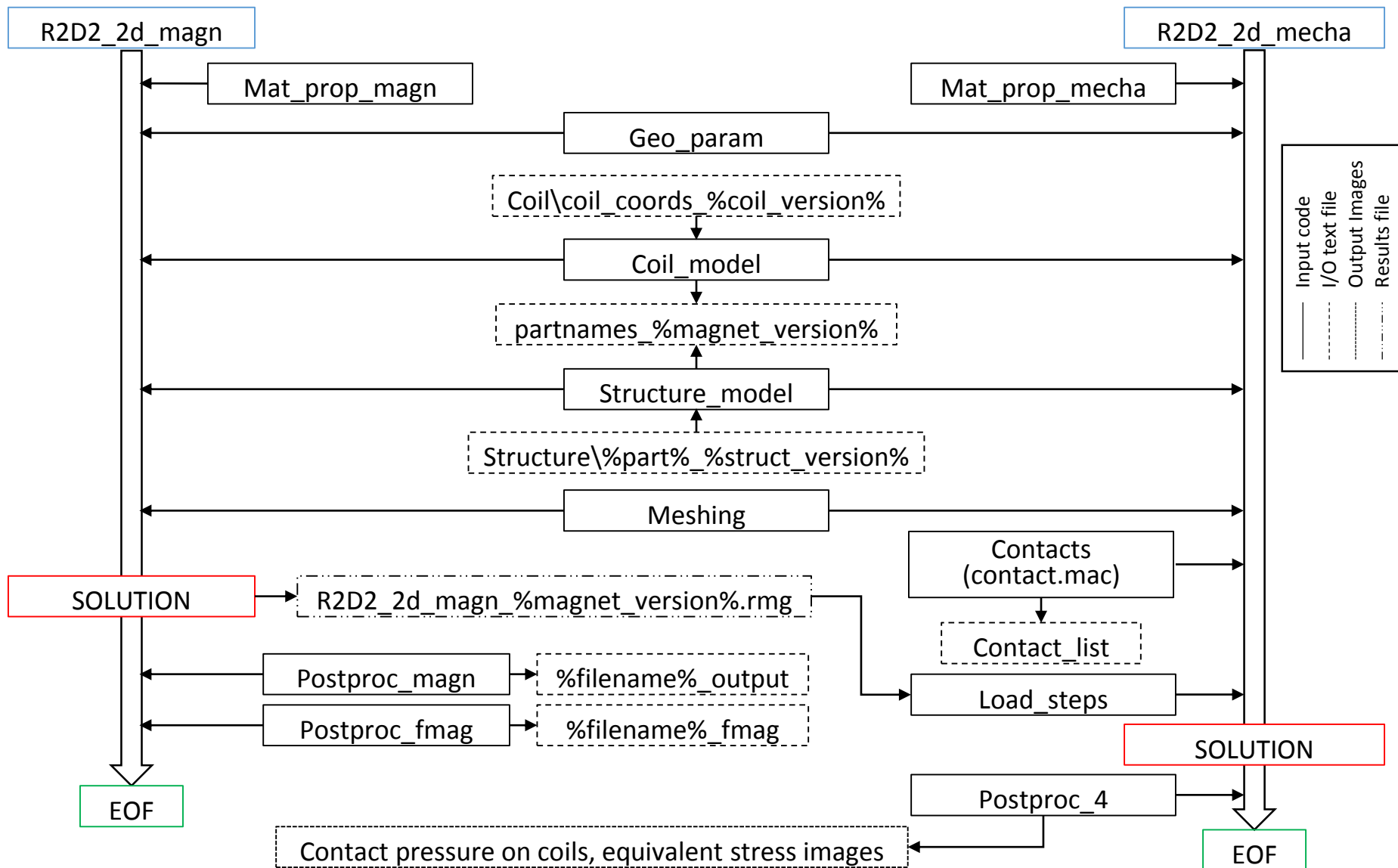
- Attempt to assemble R2D2 coils in the F2D2 structure
→ **coil stress too high >200MPa**
- 2D Parametric study to find the **adequate shell and yoke radiuses**
- Peak stress in the coil **<150 MPa at nominal, <200 at ultimate**
- Range of pre-load to guarantee **10 MPa coil-pole contact from nominal to SS operation**
- 3D model to study coil-ends:
 - Simplified RE symmetric geometry
 - 'Conventional' tie-rods + end-plates
 - **Peak stress in coil-ends, but still below criteria**
 - Possible to guarantee **full contact in the ends, but with very high forces in the rods**
 - **Further studies required with detailed models**

DE LA RECHERCHE À L'INDUSTRIE

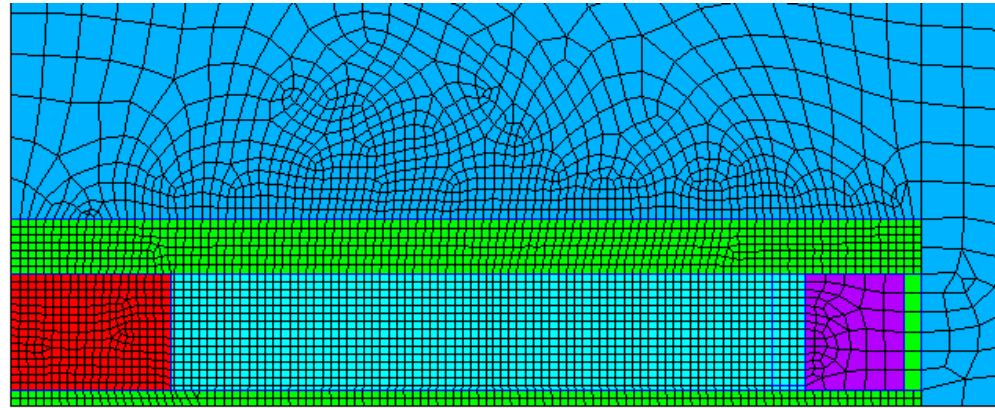
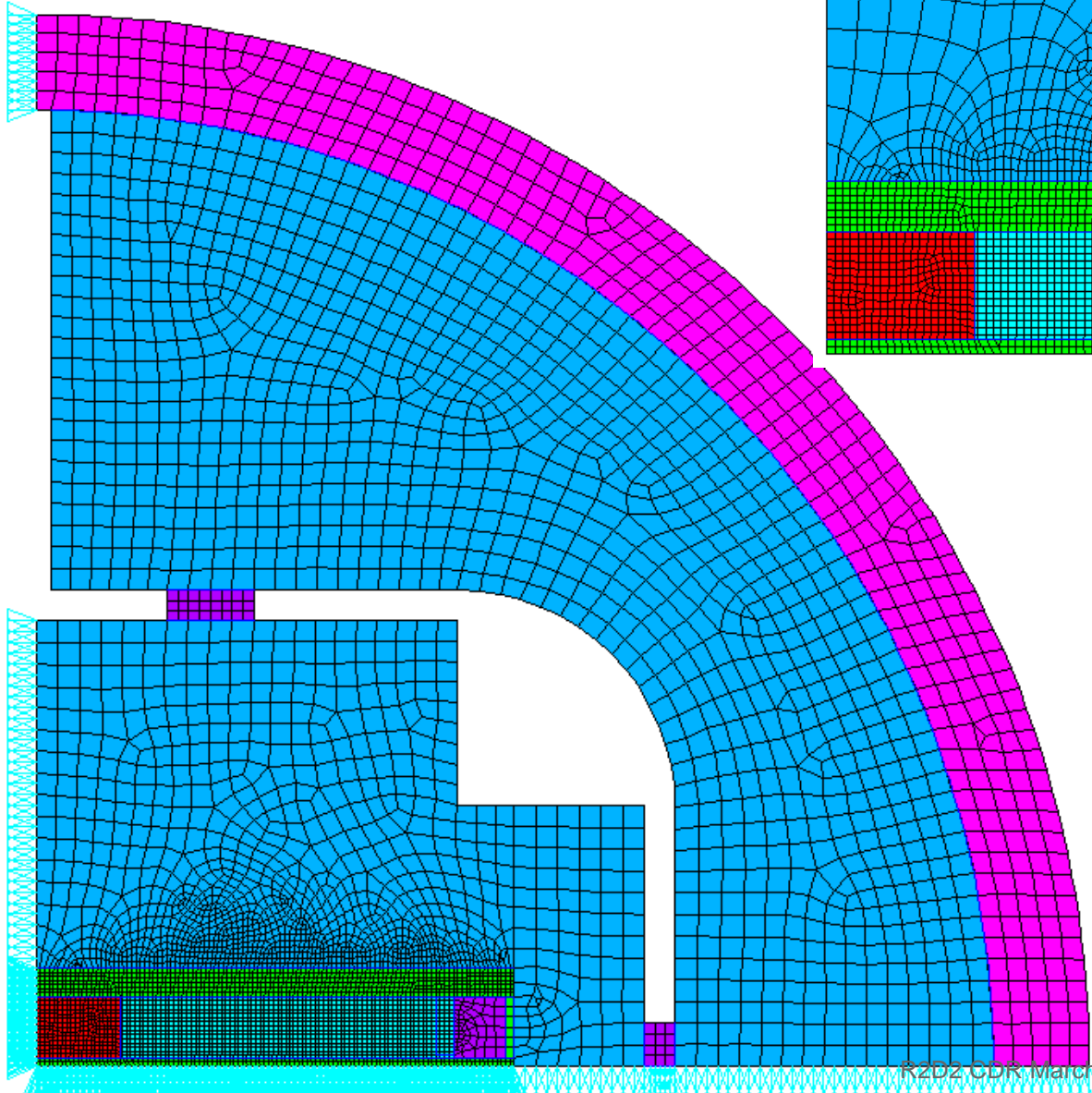
cea



THANK YOU!



SYMMETRY CONDITIONS AND MESH



- 3D Magnetic Model: Full energy/length @ 1.9 K, Short Sample (18 kA) = 204 kJ/m per quadrant

$$\mathbf{F}_{z,mag} = \mathbf{816\ kN.}$$

- Assuming resultant forces on end-shoes and end-plates are the same.
- Assuming 30 % of efforts coming from differential contraction with Al rods (to be checked with mechanical model)
- We aim at 100 % of magnetic forces in z after preload at room temperature (RT) + cool-down (CD)

$$\mathbf{F}_{z,RT+CD} = \mathbf{F}_{z,mag} = \mathbf{-816\ kN}$$

- Assumption: 70% of forces are applied at room temperature:

$$\mathbf{F}_{z,RT} = \mathbf{F}_{jack} = \mathbf{-571\ kN}$$

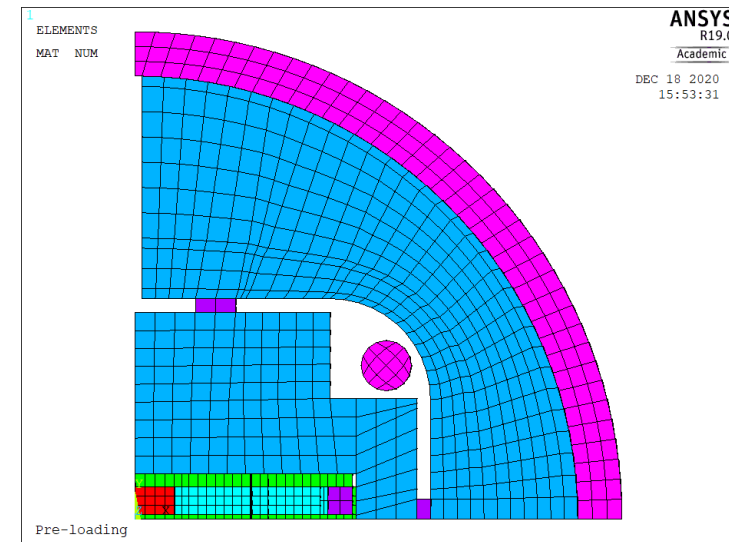
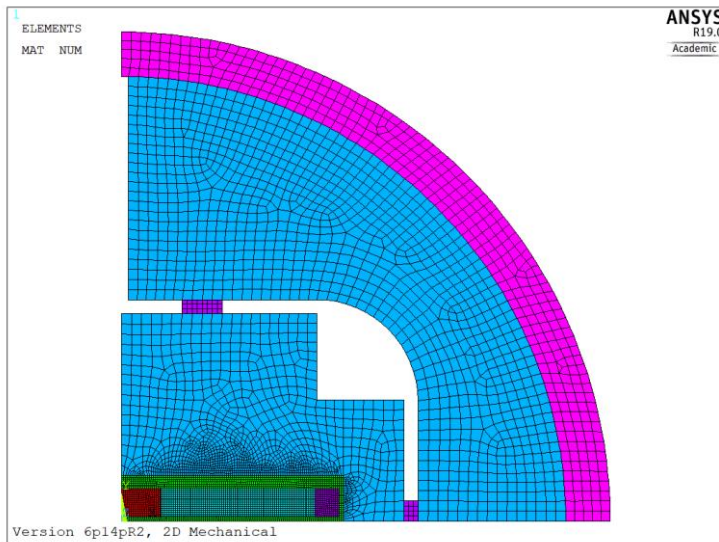
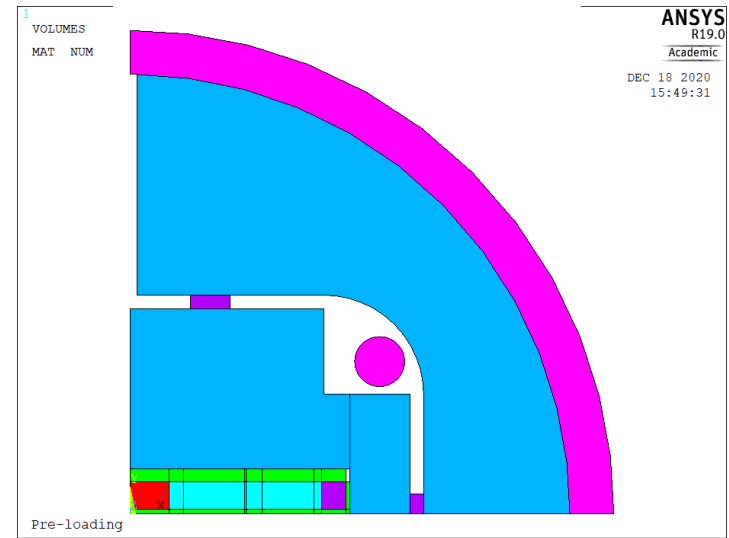
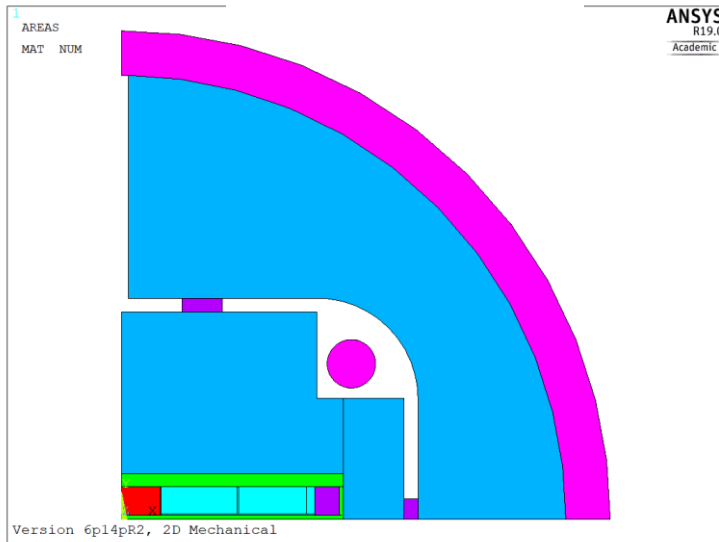
- Force on one rod:

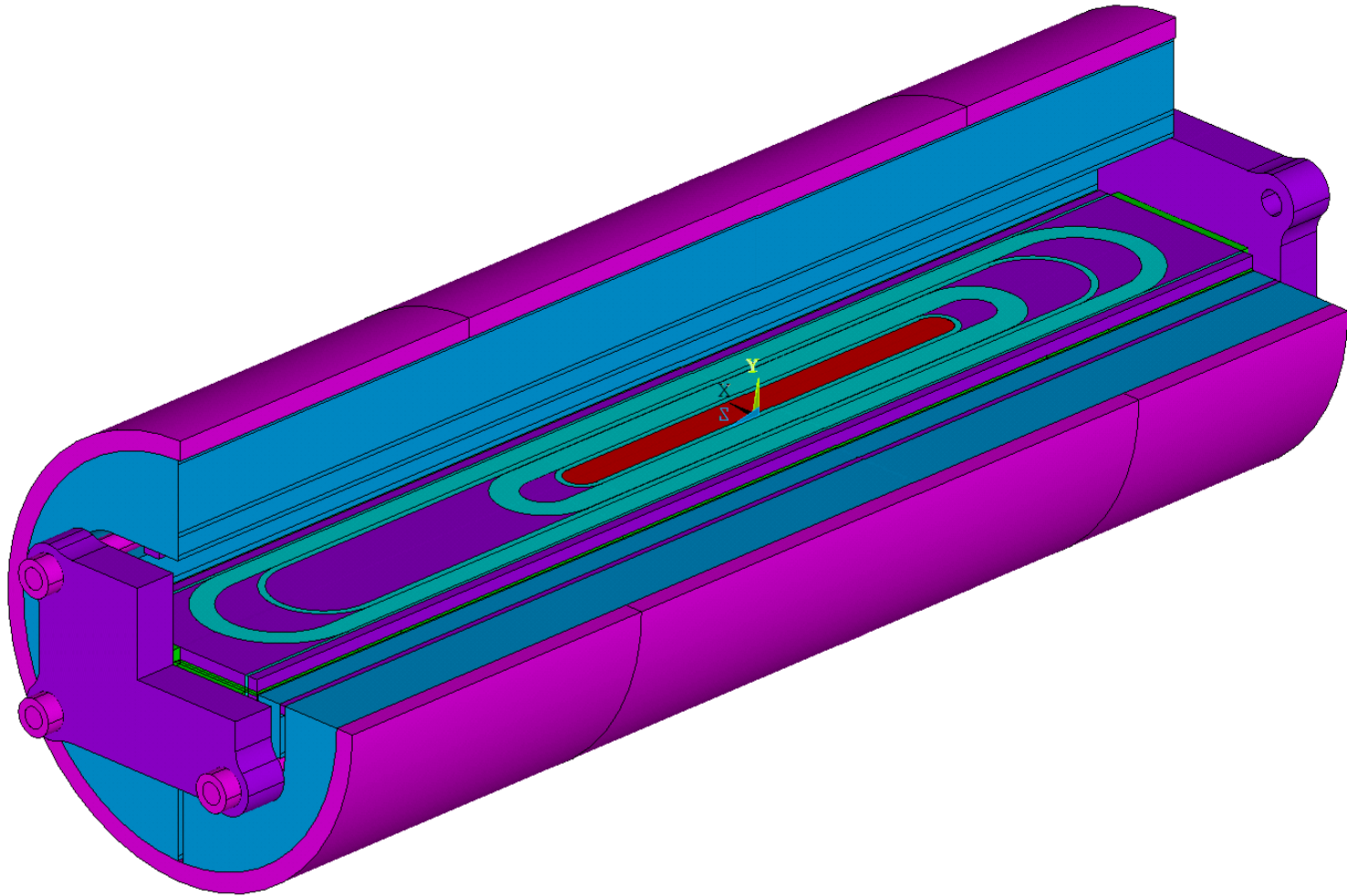
$$\mathbf{F}_{z,rod} = \mathbf{F}_{z,mag}/N_{rods} = \mathbf{\sigma \times A_{rod} = \sigma \times \pi d_{rod}^2/4}$$

COMPARISON 2D Vs 3D

2D

3D



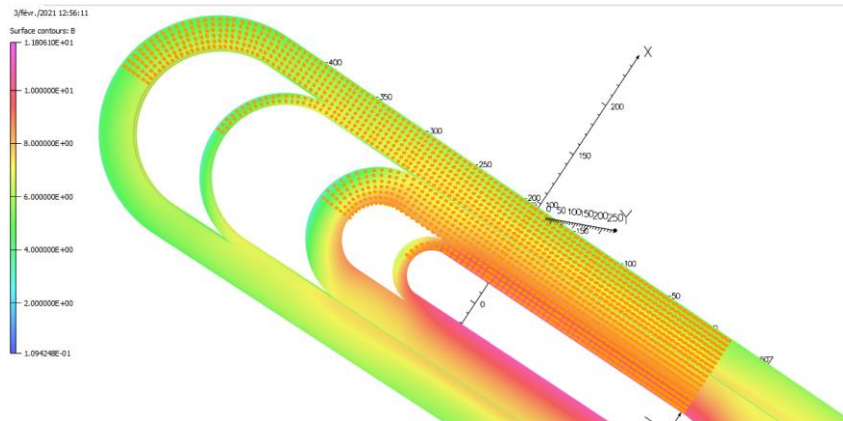


Forces imported from Opera 3D

- RE,
- nominal current 13.7 kA
- Per octant

		Fx	Fy	Fz
coil1	kN	136	-16.5	8.5
coil2	kN	415.3	-126.8	36.7
coil3	kN	150.1	-91.6	17.2
coil4	kN	28.6	-319.6	25.1
coil	kN	651.5	-518.9	87.4
Opera	kN	646	-491	-90.3

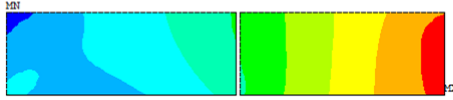
		HF	LF	total
Fx	kN/m	1698	112	1810
Fy	kN/m	-469	-752	-1221
Fz	kN/m	41	77	118



VM STRESS – 2D vs 3D (NOMINAL)

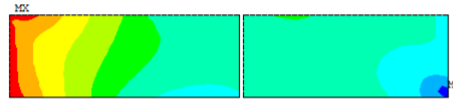


2D



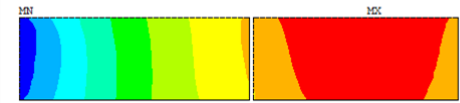
0.40 mm Xinterf
0.05 mm Yinterf

SEQV (AVG)	
PowerGraphics	
EFACET=1	
AVRES=Mat	
DMX =.175605	
SMN =46.4923	
SMX =66.1123	
46.4923	
48.6723	
50.8523	
53.0323	
55.2123	
57.3923	
59.5723	
61.7523	
63.9323	
66.1123	



Cool-down

SEQV (AVG)	
PowerGraphics	
EFACET=1	
AVRES=Mat	
DMX =.648081	
SMN =117.391	
SMX =136.691	
117.391	
119.535	
121.68	
123.824	
125.969	
128.113	
130.258	
132.402	
134.546	
136.691	



Nominal current

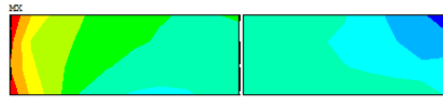
SEQV (AVG)	
PowerGraphics	
EFACET=1	
AVRES=Mat	
DMX =.613195	
SMN =37.8343	
SMX =155.693	
37.8343	
50.9298	
64.0252	
77.1207	
90.2161	
103.312	
116.407	
129.502	
142.598	
155.693	

3D



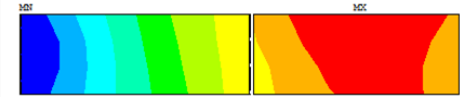
Pre-loading

SEQV (AVG)	
PowerGraphics	
EFACET=1	
AVRES=Mat	
DMX =.159914	
SMN =33.3338	
SMX =54.342	
33.3338	
35.6681	
38.0023	
40.3366	
42.6708	
45.005	
47.3393	
49.6735	
52.0078	
54.342	



Cool-down to 4.3 K

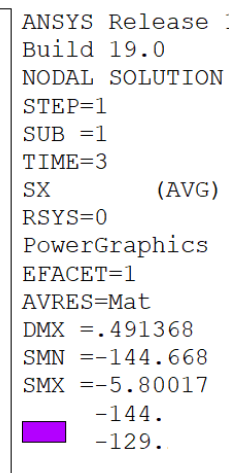
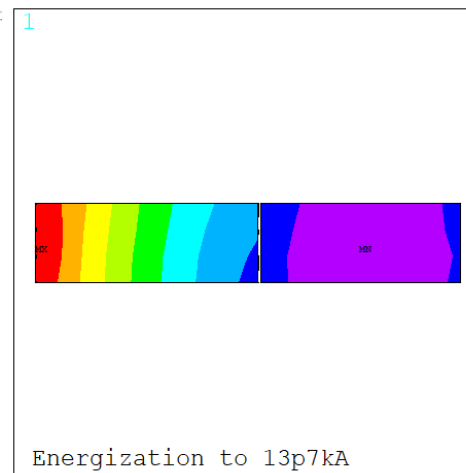
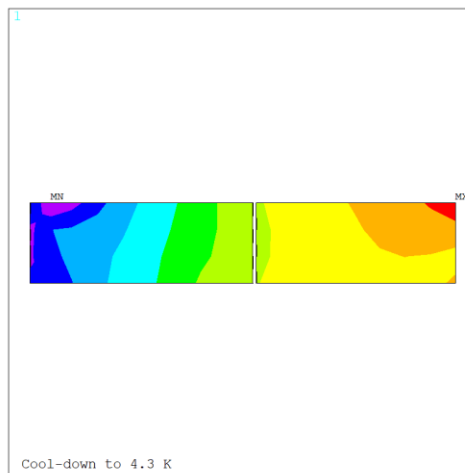
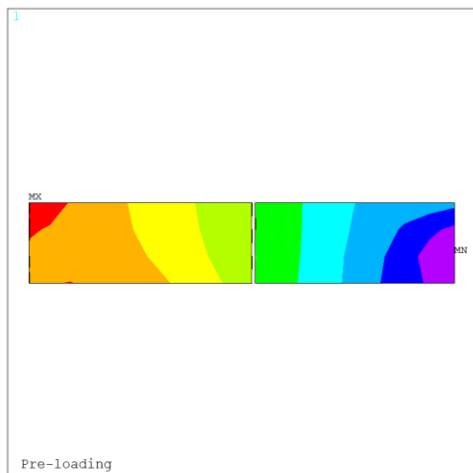
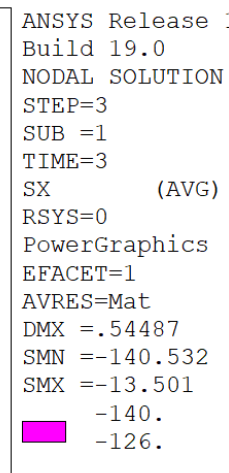
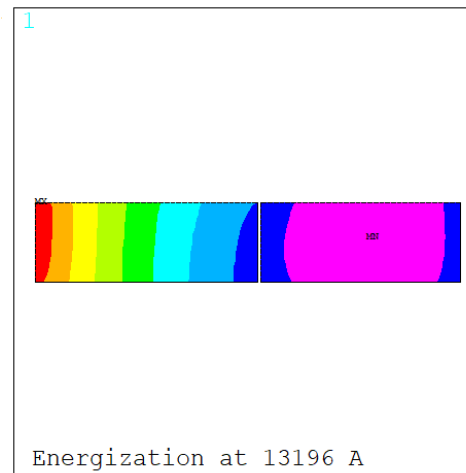
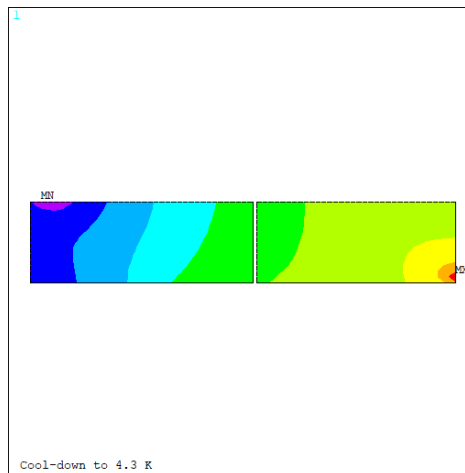
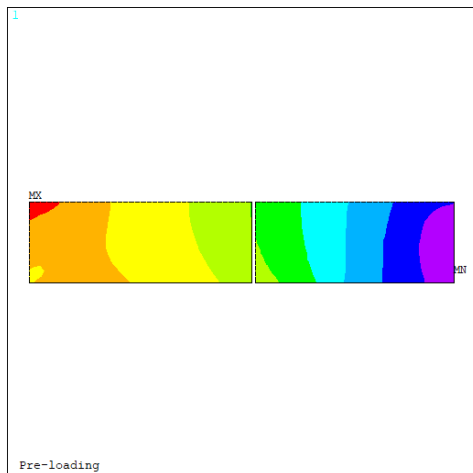
SEQV (AVG)	
PowerGraphics	
EFACET=1	
AVRES=Mat	
DMX =.652381	
SMN =113.704	
SMX =130.801	
113.704	
115.604	
117.504	
119.403	
121.303	
123.202	
125.102	
127.002	
128.901	
130.801	



Energization to 13p7kA

SEQV (AVG)	
PowerGraphics	
EFACET=1	
AVRES=Mat	
DMX =.595956	
SMN =53.0954	
SMX =144.571	
53.0954	
63.2593	
73.4232	
83.5871	
93.751	
103.915	
114.079	
124.243	
134.407	
144.571	

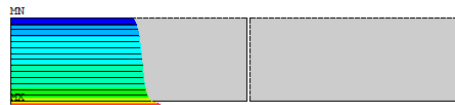
X STRESS – 2D vs 3D (0.2 MM INTERF)



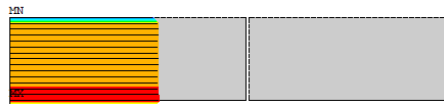
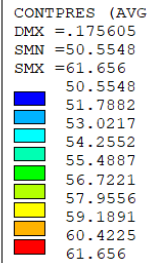
POLE CONTACTS – 2D vs 3D (NOMINAL)



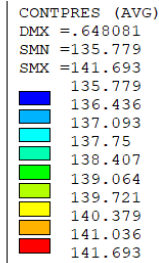
2D



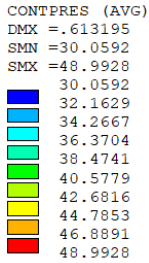
0.40 mm Xinterf
0.05 mm Yinterf



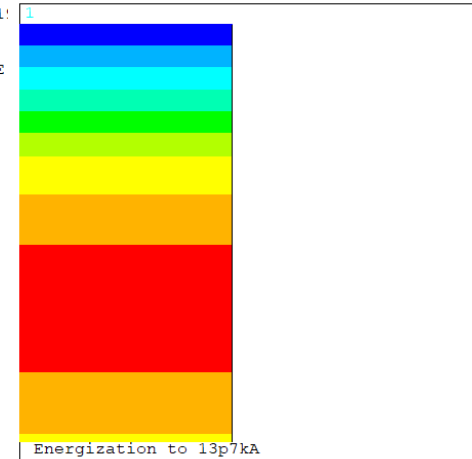
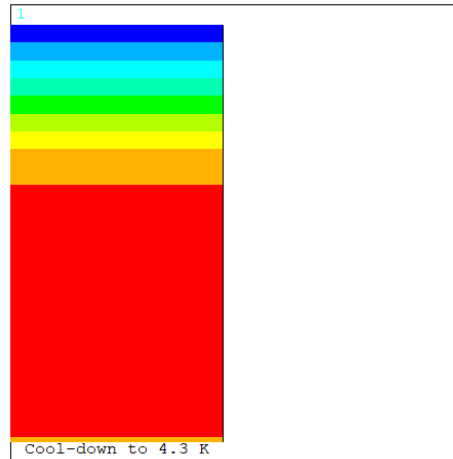
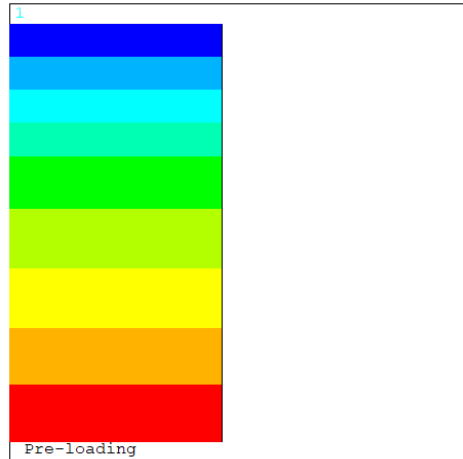
Cool-down



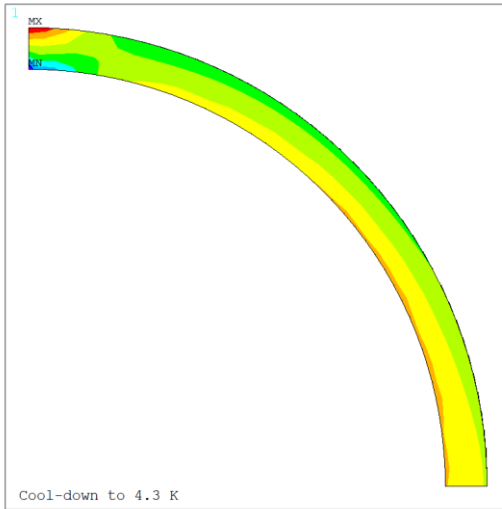
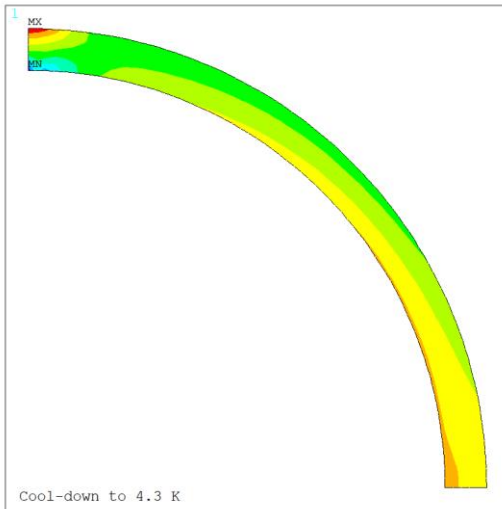
Nominal current

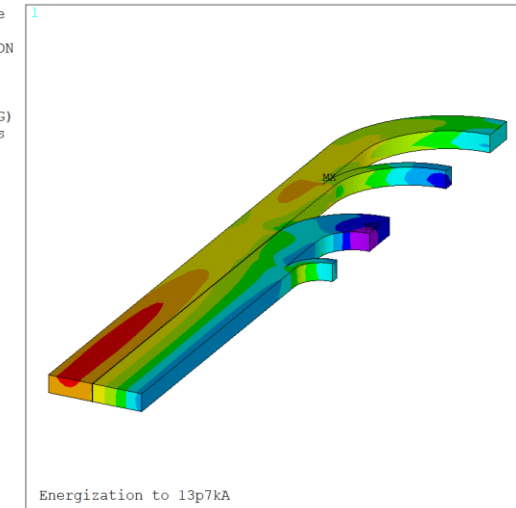
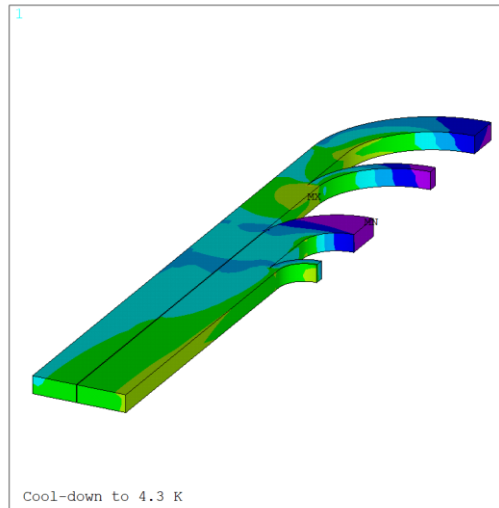
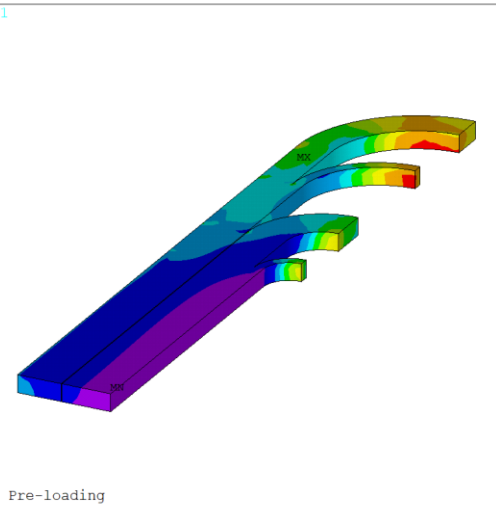


3D

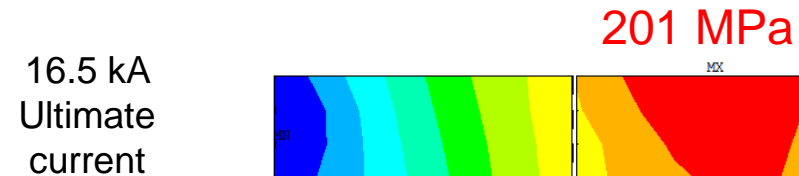
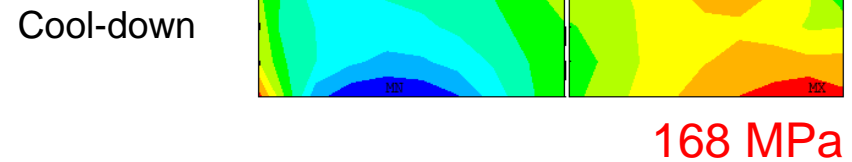
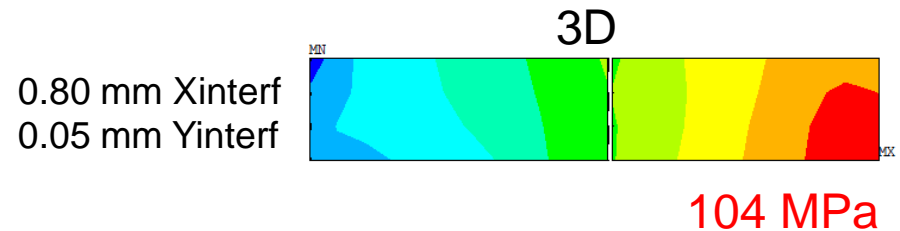


STRESSES IN STRUCTURE – 2D vs 3D (0.2 MM)

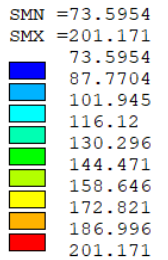
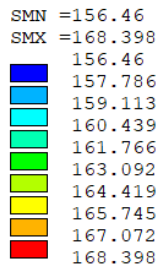
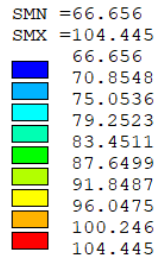


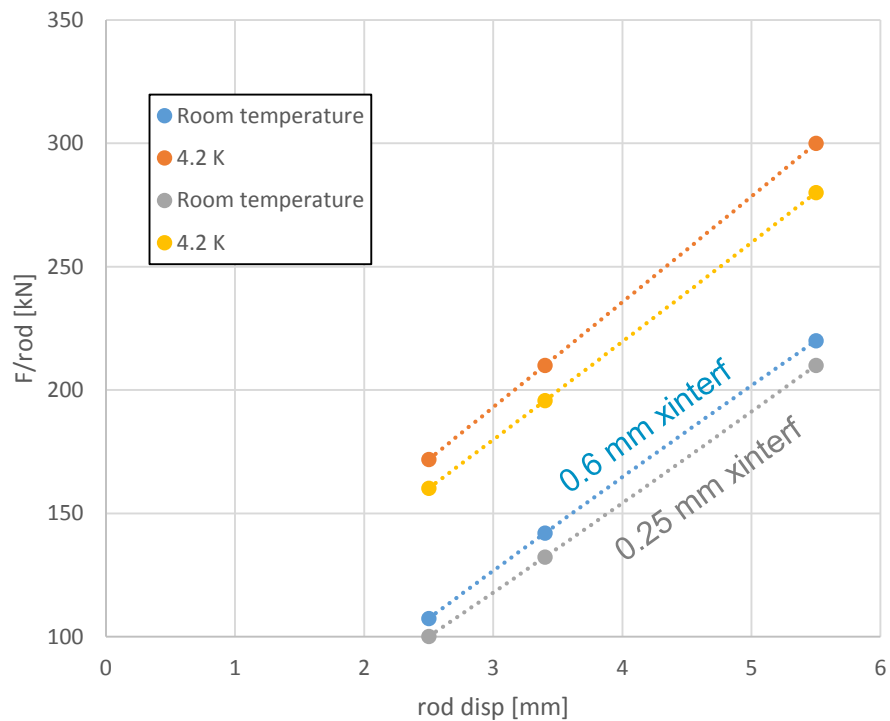


2D



3D





Nominal current

