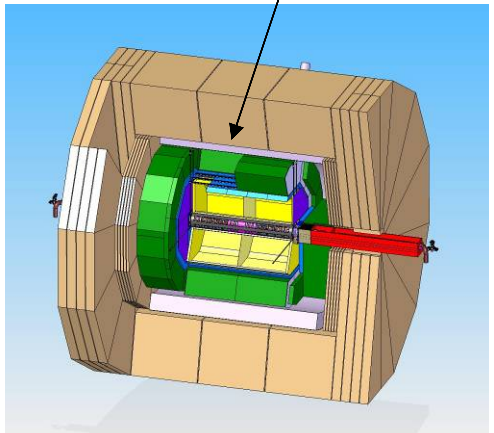
Rigidness of the cryostat

KEK Hiroshi Yamaoka

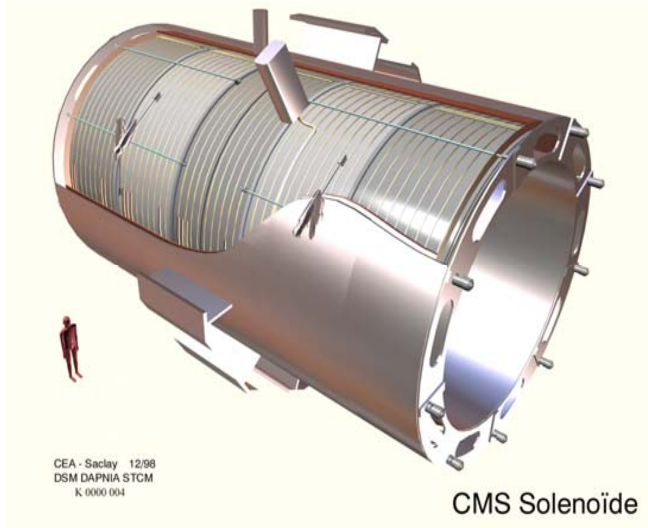
<u>Contents</u>

Introduction

Mechanical strength of the cryostat and the support system has been studied.



The support system of the CMS solenoid was referred in this calculation.



Load condition against;

1. Thermal shrinkage: dt=300K
2. Cold mass: 180tonnes
3. Vacuum pressure: 1atm
4. H-Cal. Weight: 701tonnes
5. Unbalanced force: 840kN in Z-dir.
   → Not calculated. Referred from the CMS.
6. Combined calculation with above forces

B. 0.15G of horizontal force.

Referred parameters (Old version)

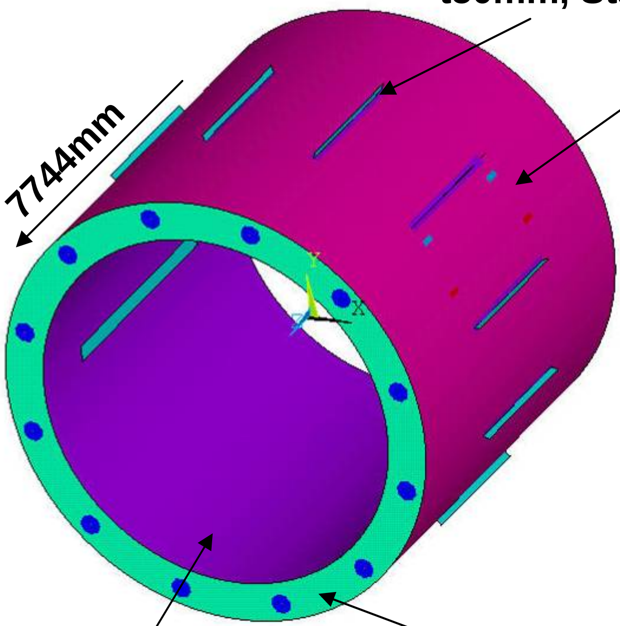
2			ILD0	ILD
3	magnet		4T, 1,7 GJ	
4		Barrel Y Rin	4270	
5		Barrel Y Rout	6420??	
6		Barrel 1/2 length	4647	
7		thick.	2150??	
8		Yoke plug front	3922	
9		Yoke plug back	4022	
10		Yoke plug Rin	350	
11		Yoke plug Rout	3190	
12		thick.	100	
13		Yoke nose front	4022	
14		Yoke nose back	4672	
15		Yoke nose Rin	350	
16		Yoke nose Rout	4070	
17			650	
18		Yoke endcap front	4672	
19		Yoke endcap back	6362	
20		Yoke endcap Rin	350	
21		Yoke endcap Rout	6420??	
22				
23		Coil cryostat		
24		Rin	3440	
25		Rout	4190	
26		cryo 1/2 length	3872	
27		thick.	750	
28		Coil Rin	3590	
29		Coil Rout	3940	
30		coil 1/2 length	3672	
			SS/Scinti, 5.3 λ, max 48 layers barrel, ,48	

FEM model

Cryostat

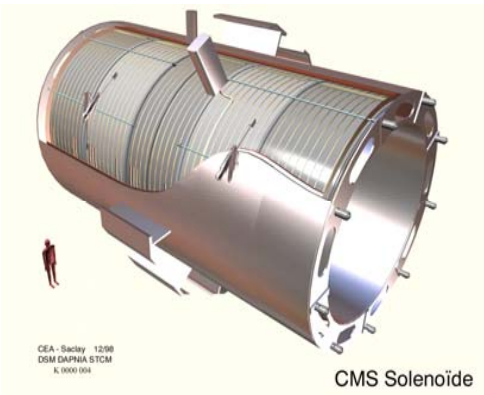
Solenoid support:
t50mm, Stainless

Outer vac. Wall:
t50mm, Stainless
→ R4190mm



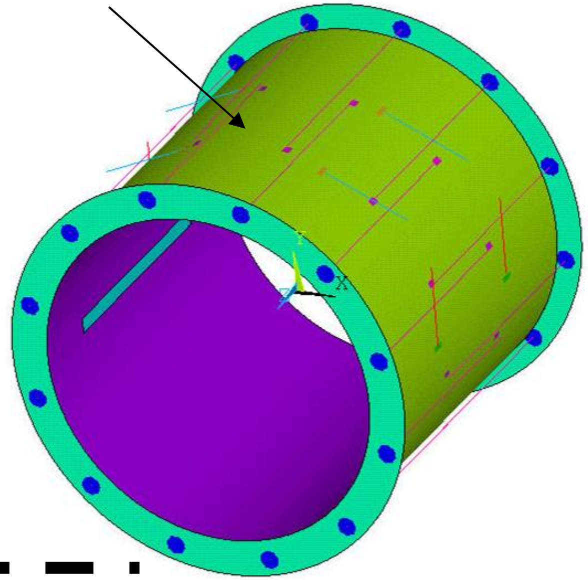
Inner vac. wall:
t60mm, Stainless
→ R3440mm

Bulk head: t50mm
(Stainless steel)

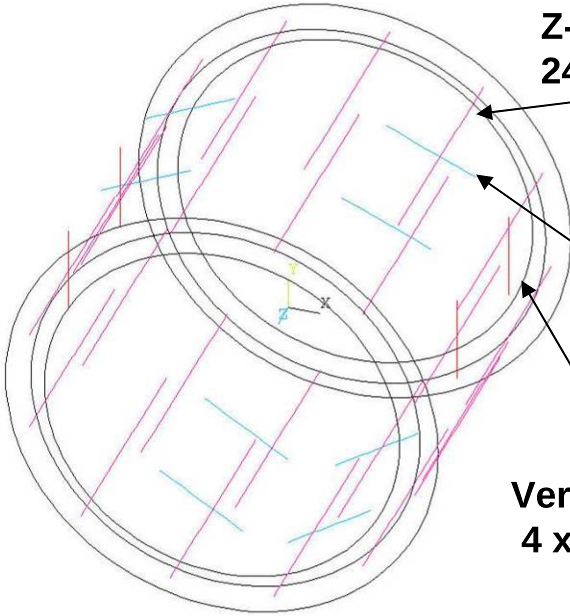


Coil:

t350mm, Al-alloy
→ R3765mm, L= 7344mm



Support rods

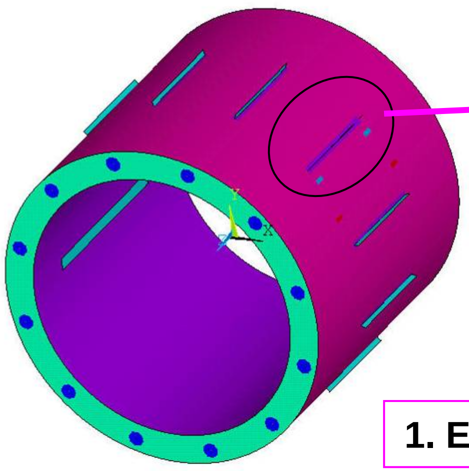


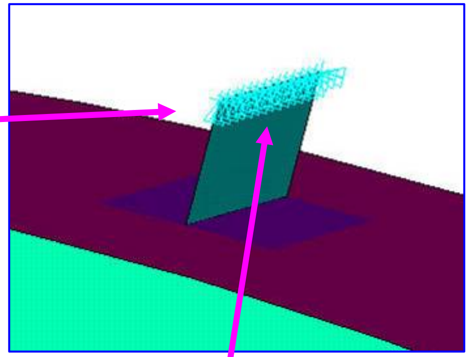
Z-support rods:
24 x dia.45mm, Titanium alloy

Radial support rods:
8 x dia.35mm, Ti-alloy

Vertical support rods:
4 x dia.60mm, Ti-alloy

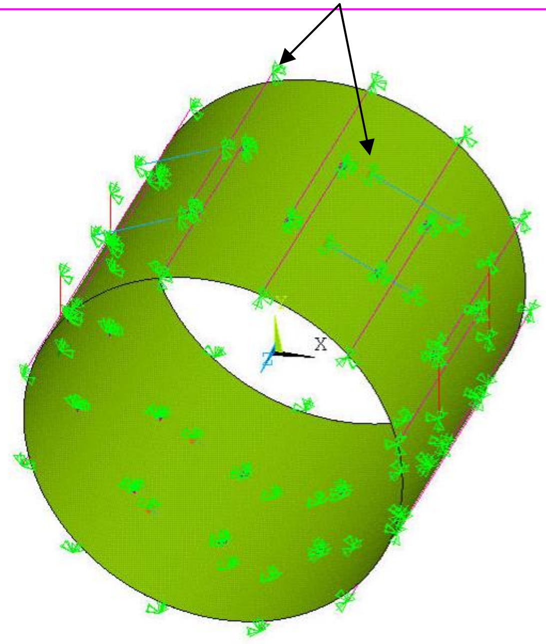
Constraints positions





1. End of the solenoid support is fixed.

2. Free rotation between the support rod and the coil/cryostat



Load conditions

1. Thermal shrinkage: dt=300K
2. Cold mass: 180tonnes
3. Vacuum pressure: 1atm
4. H-Cal. Weight: 701tonnes
5. Unbalanced force: 840kN in Z-dir.
   → Not calculated. Referred from the CMS.
6. Combined calculation with above forces

B. 0.15G of horizontal force.

Material properties

1. Stainless steel
   E=210GPa, ν=0.3, γ=7.85, α=10e-5/K

2. Coil
   E=77GPa, ν=0.3, γ= 3.0, α=14e-5/K

3. Ti-alloy
   E=133GPa, ν=0.33, γ=4.5, α=6e-5/K

Calculation-1

Condition: The Coil is cooling down to LHe temp.

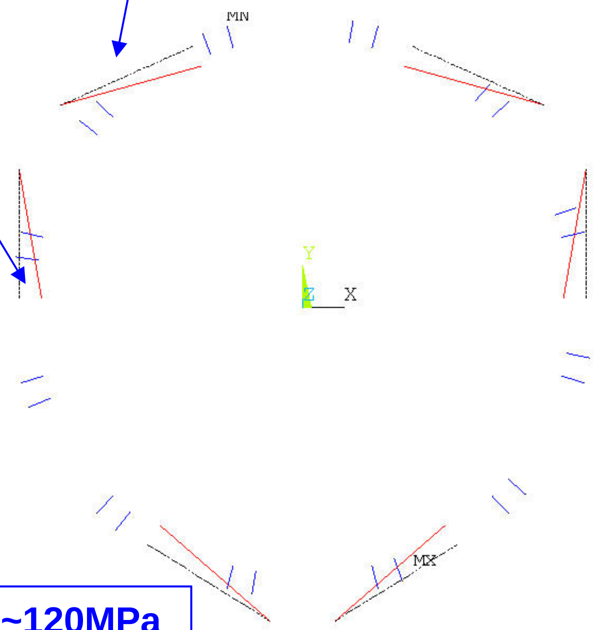
→ dt= 300K

$$dR = \alpha \cdot dt \cdot R = 14\times10^{-6} \cdot 300 \cdot 3765 = 16mm$$

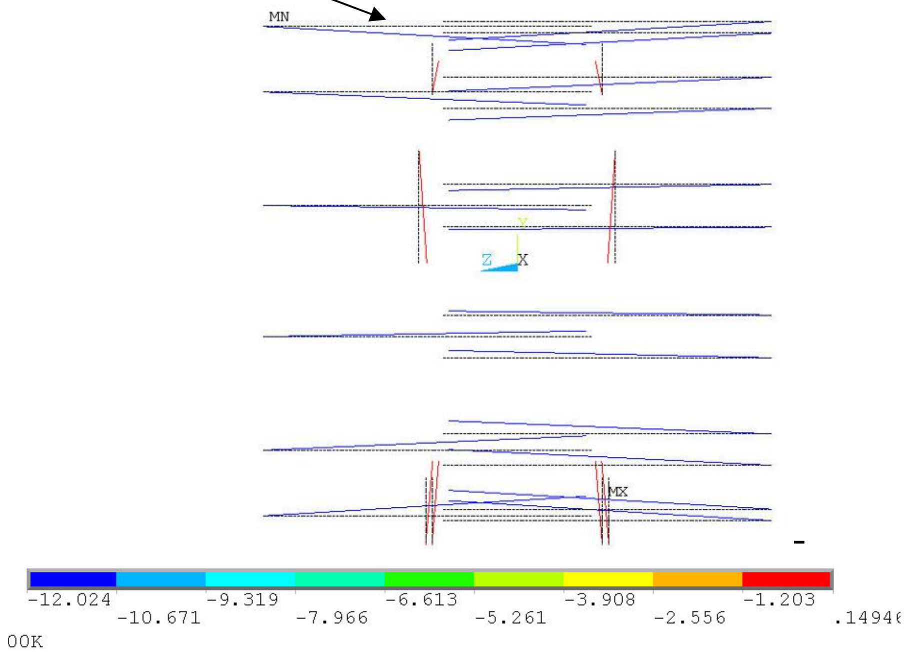
$$dL = \alpha \cdot dt \cdot L = 14\times10^{-6} \cdot 300 \cdot 3672 = 15mm$$

Radial support rods: ~0MPa

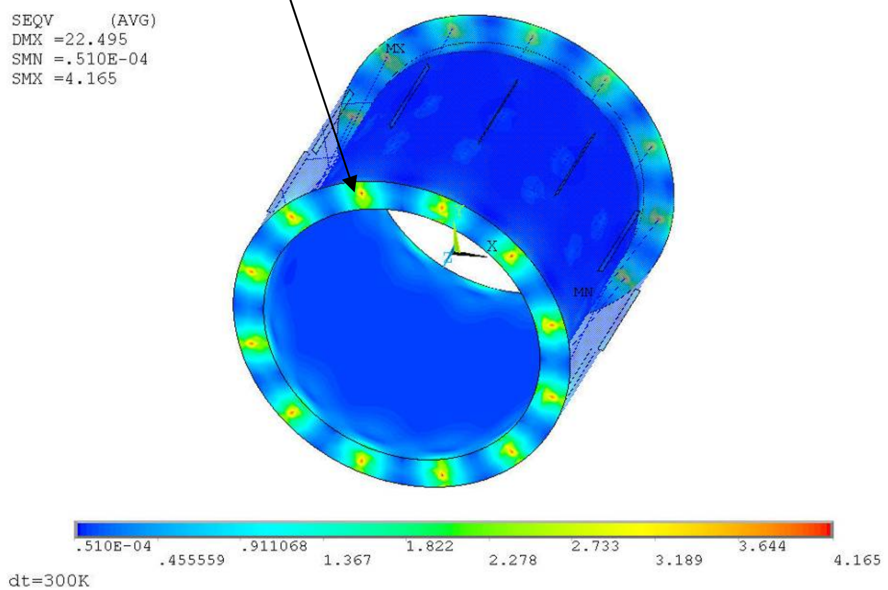
Vertical support rods: ~0MPa



Z-support rods: ~120MPa



Von. M Stress : 41MPa

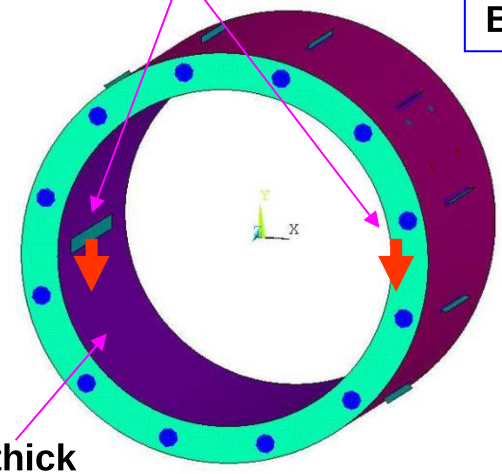


Calculation-2

Condition: Cal-weight on the inner wall.

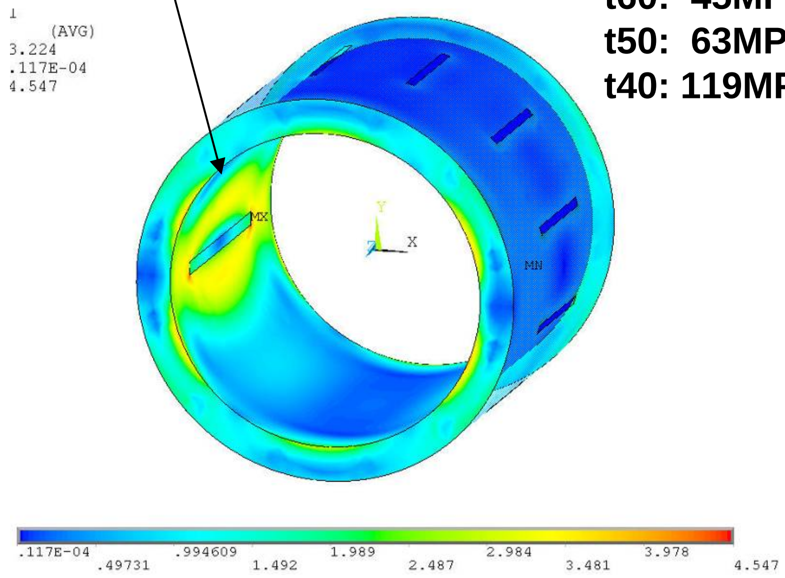
→ W_{cal}= 701tonnes

B. Hcal=626tonnes
B. Ecal= 75tonns



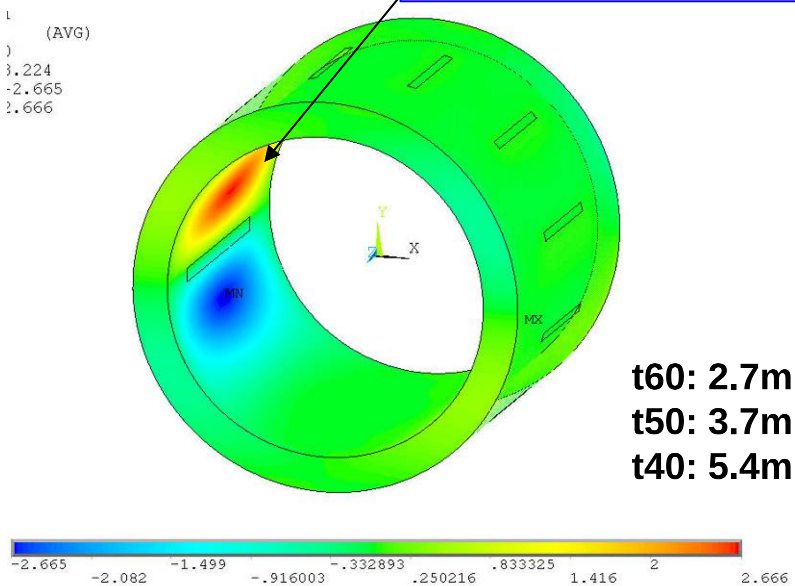
60mm-thick
Stainless steel

Von. M Stress : 45MPa



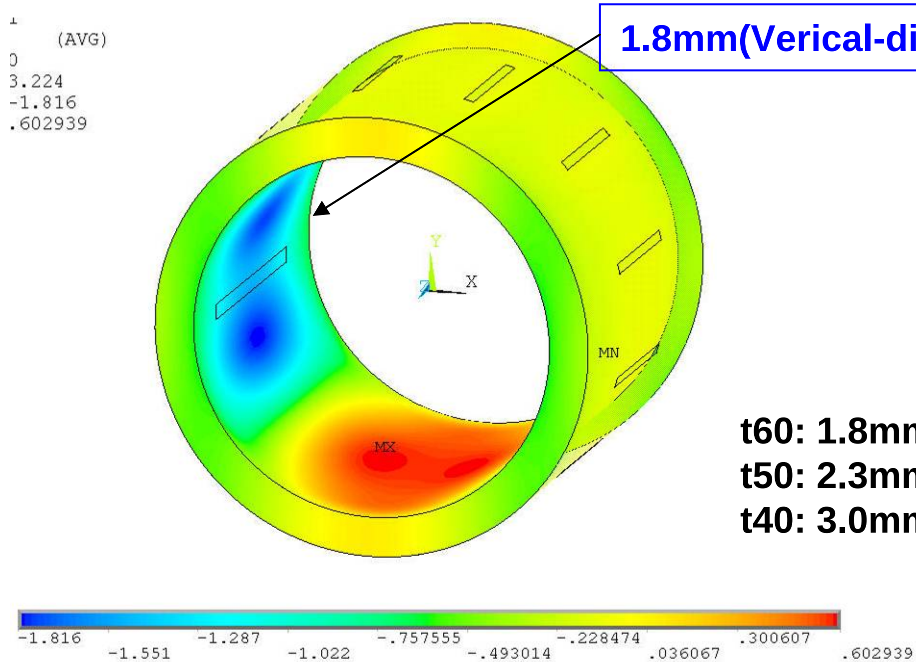
t60: 45MPa
t50: 63MPa
t40: 119MPa

2.7mm(Horizontal-dir.)



t60: 2.7mm
t50: 3.7mm
t40: 5.4mm

1.8mm(Verical-dir.)



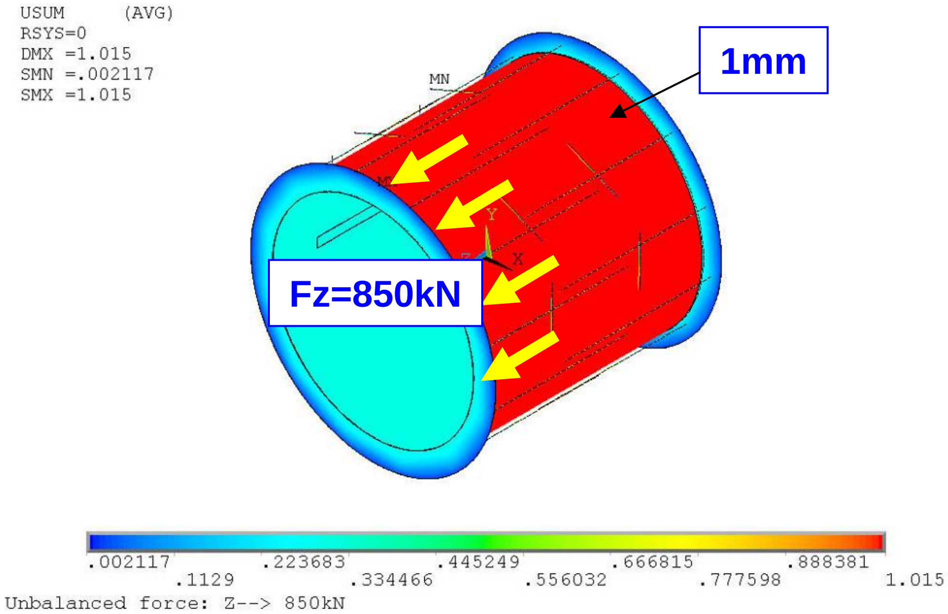
t60: 1.8mm
t50: 2.3mm
t40: 3.0mm

Calculation-3

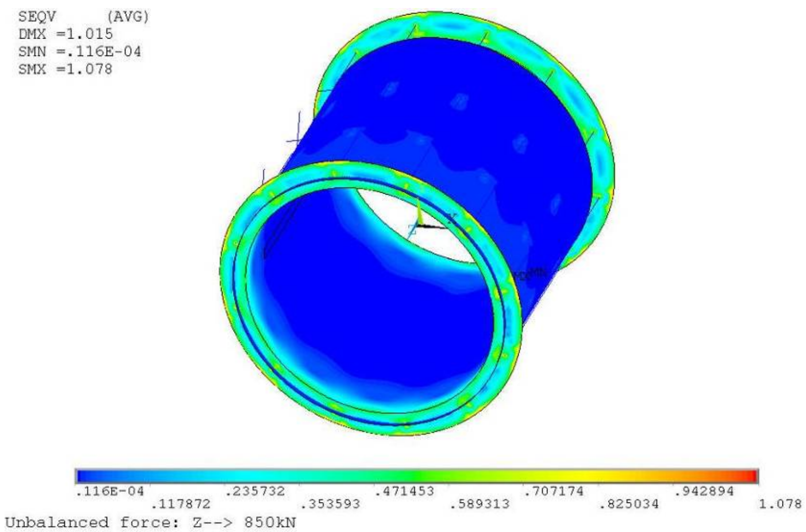
Condition: Unbalanced force in Z-direction

→ F_Z= 850kN

Deformation of the coil

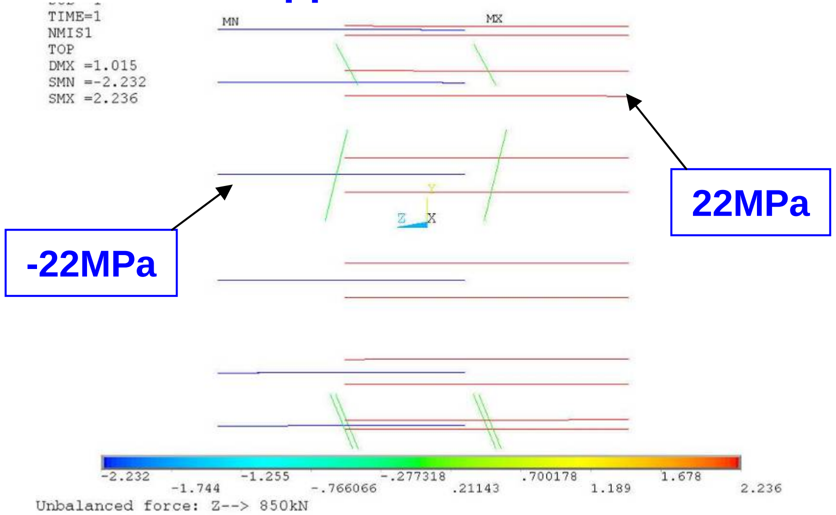


Von. M Stress on the bulkheads: 10MPa



*) The unbalanced force of the ILD solenoid has not been calculated yet.
A 850kN was taken from calculation results of the CMS solenoid.

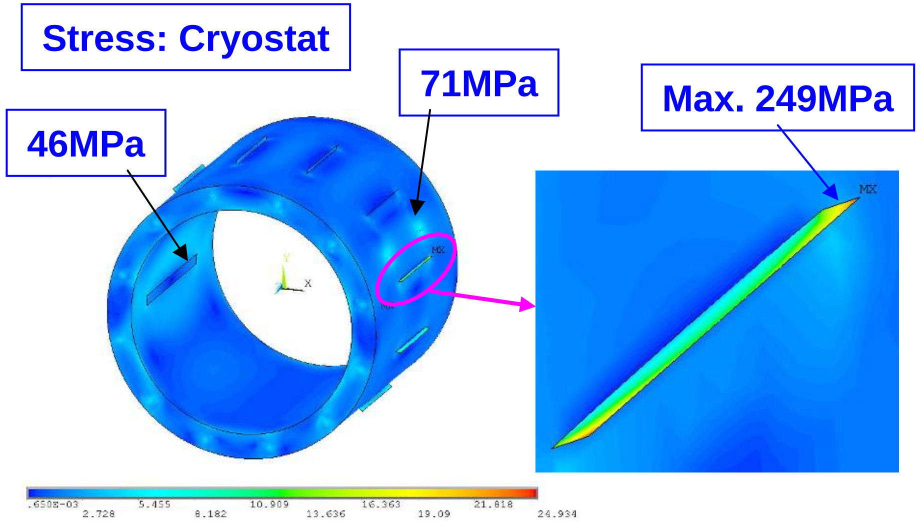
Stress in the support rods.



Calculation-4

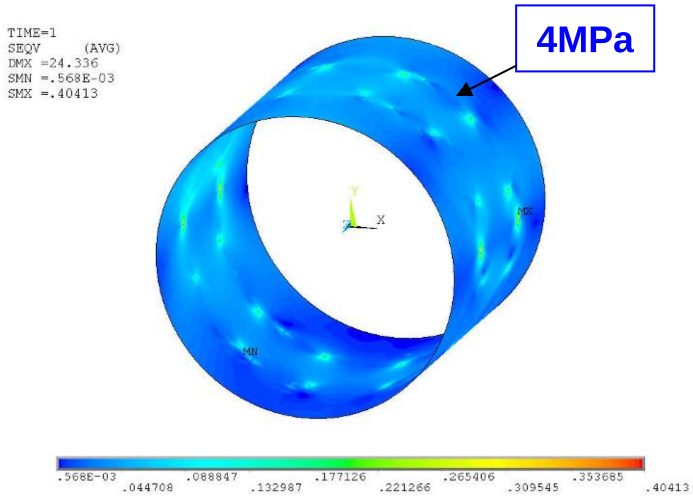
Condition: *Combined with all forces*

Stress: Cryostat

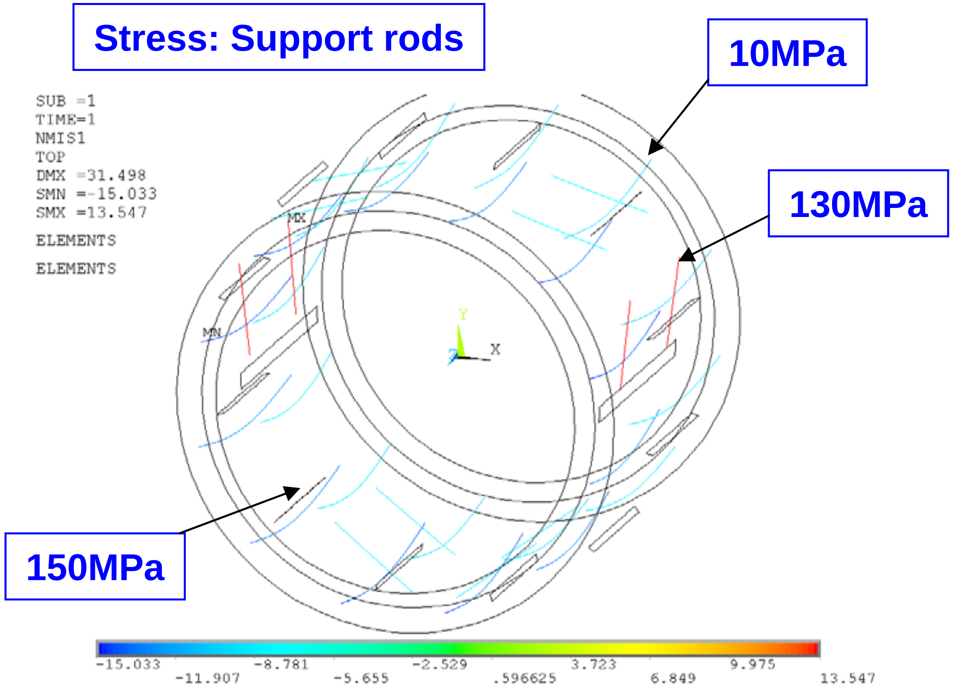


Stress on the coil: Small enough

***) Stress due to the excitation is not included.**



Stress: Support rods

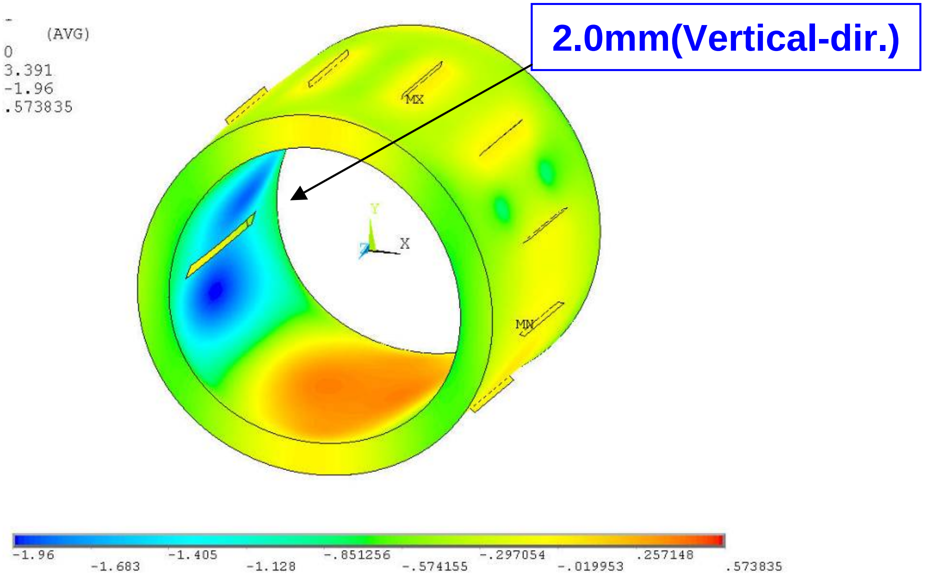


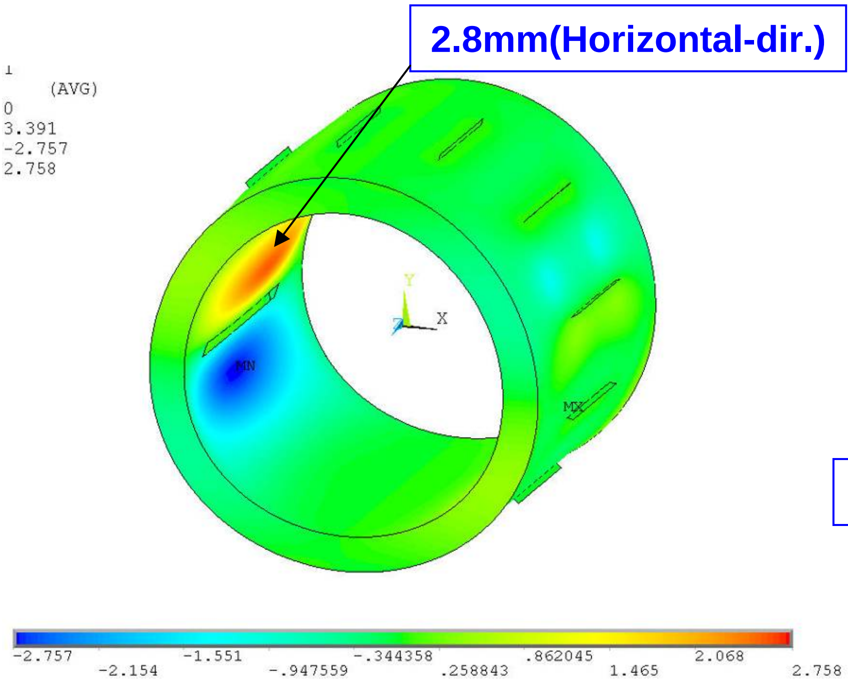
Combined with the below forces;

1. Thermal shrinkage: dt=300K
2. Cold mass: 180tonnes
3. Vacuum pressure: 1atm
4. H-Cal. Weight: 701tonnes
5. Unbalanced force: 840kN in Z-dir.
   → Not calculated. Referred from the CMS.

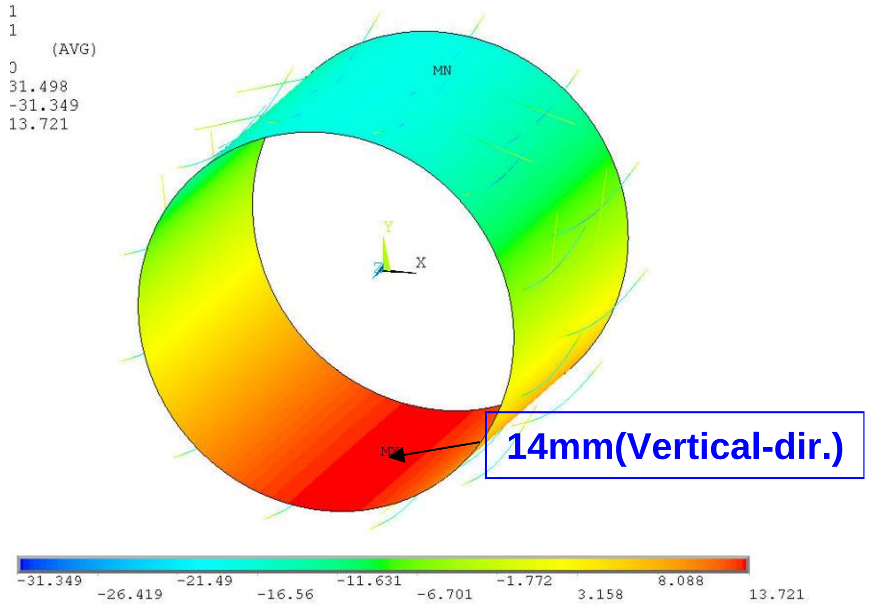
Calculation-4 Condition: *Combined with all forces*

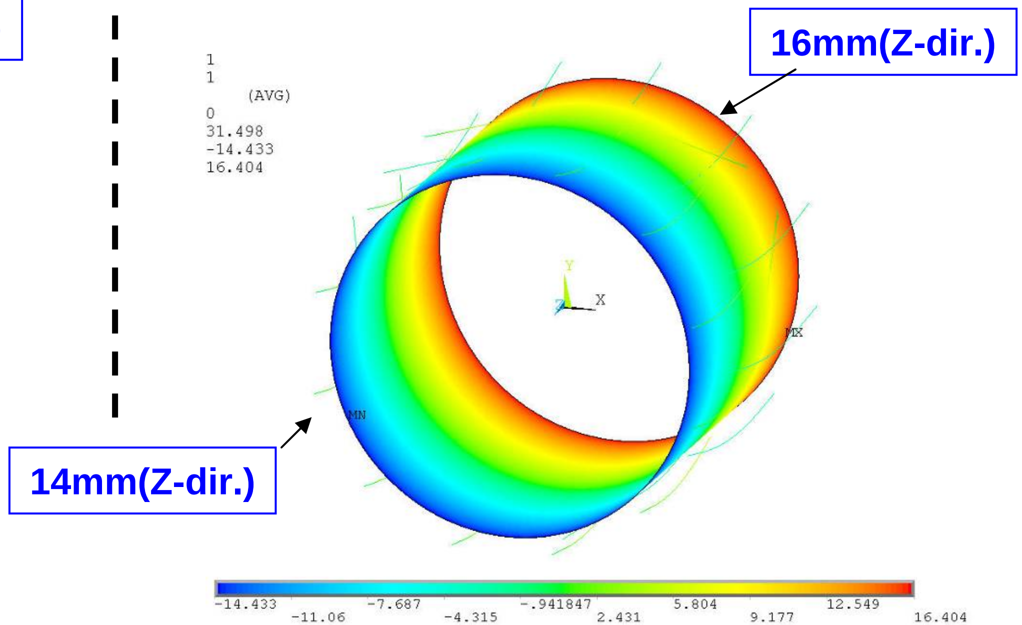
Deformation of the cryostat





Deformation of the coil

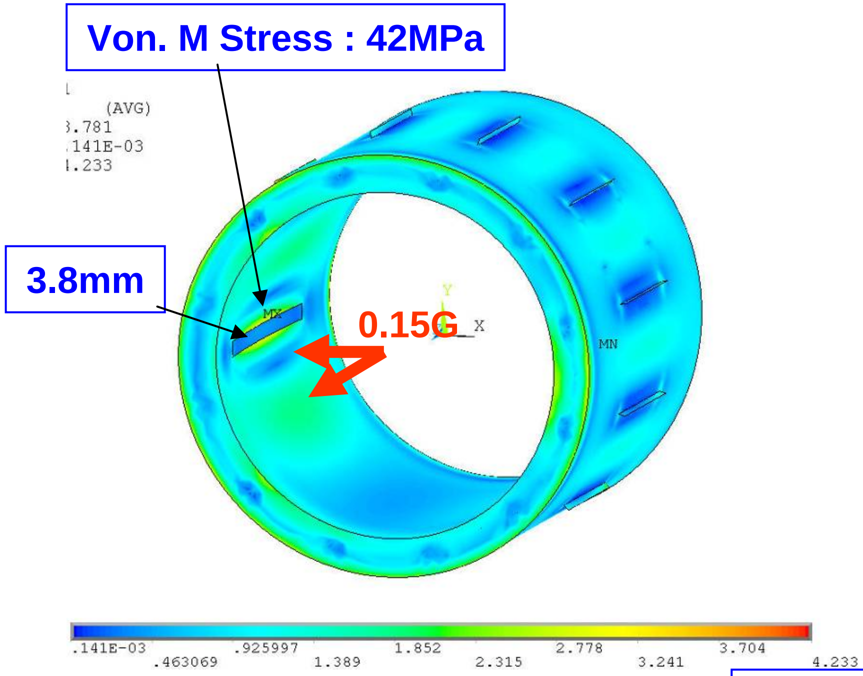


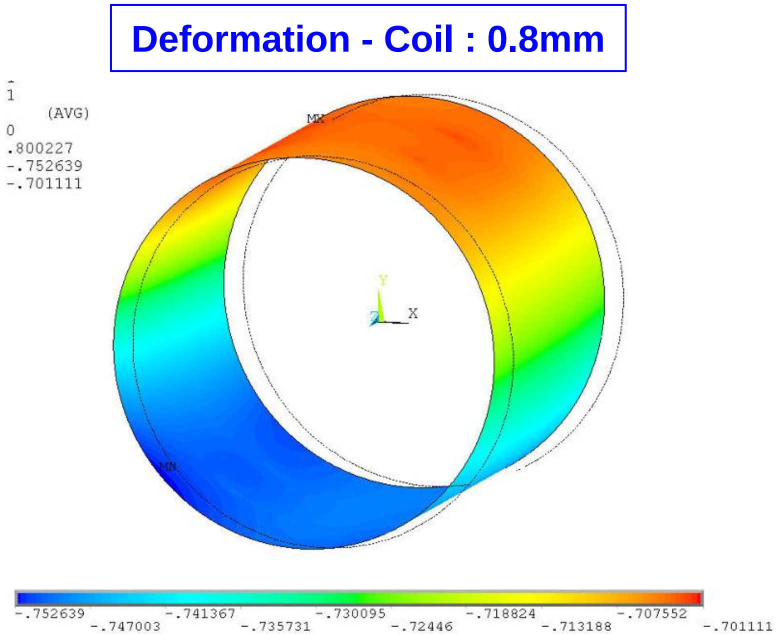


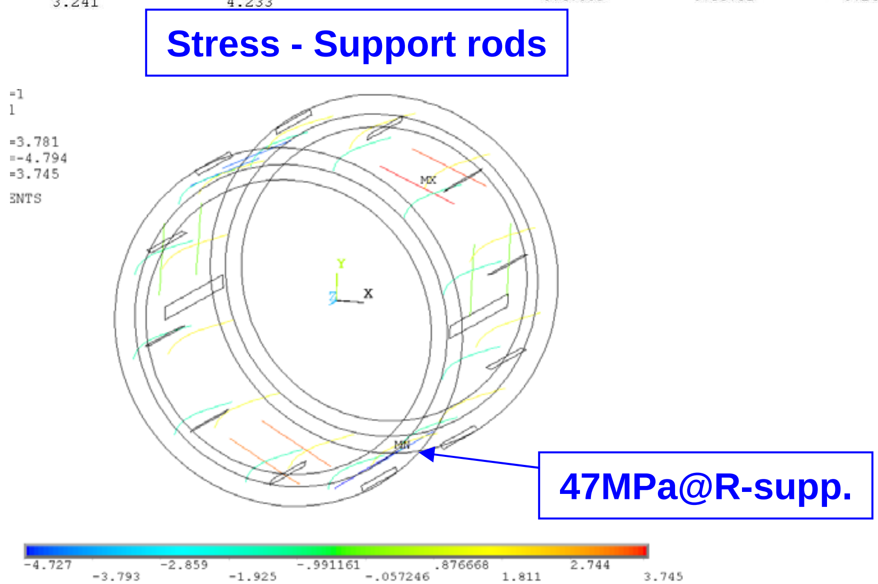
Calculation-5

Condition: 0.15G in the horizontal direction.

) Effect of the thermal shrinkage is not included.

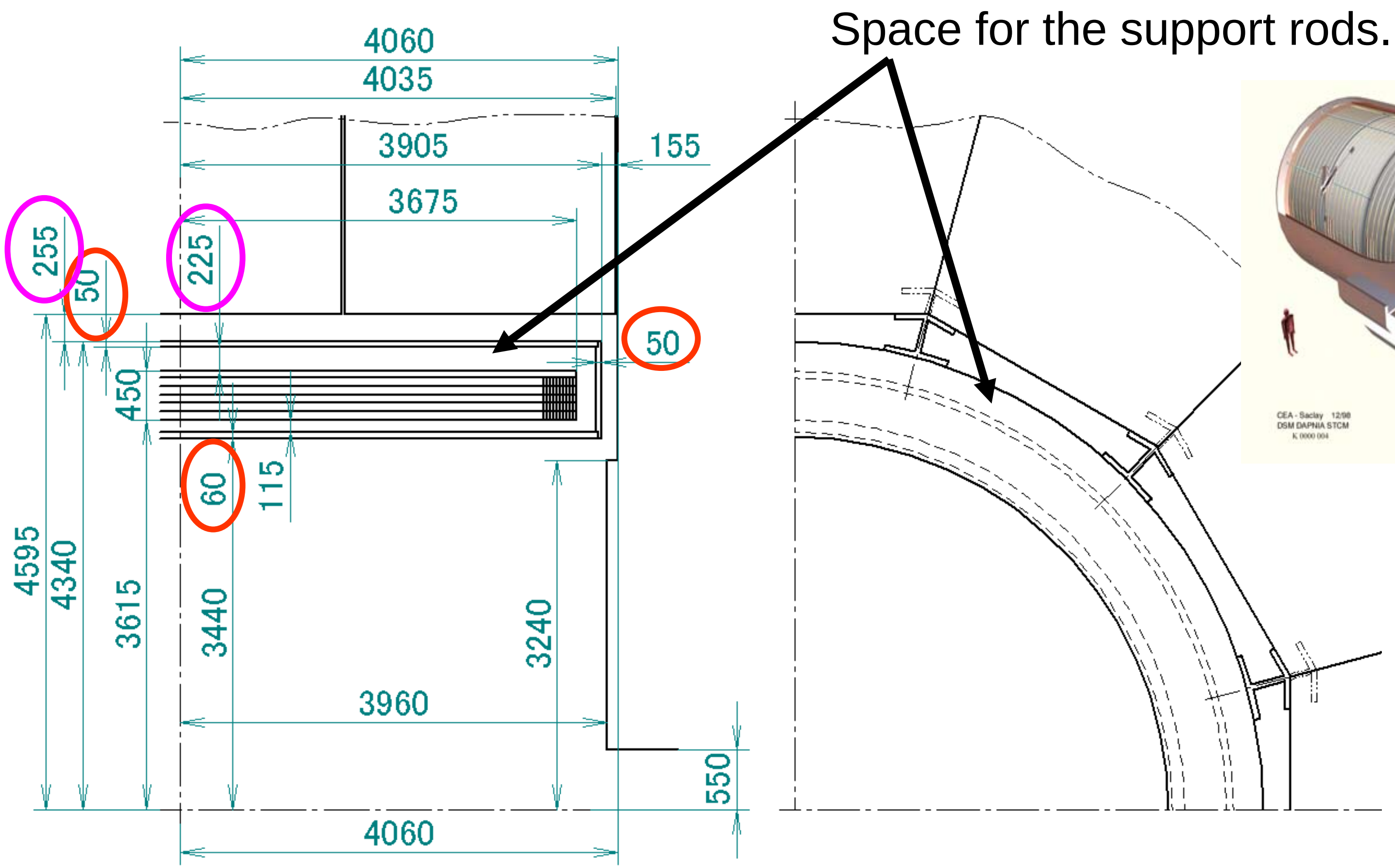


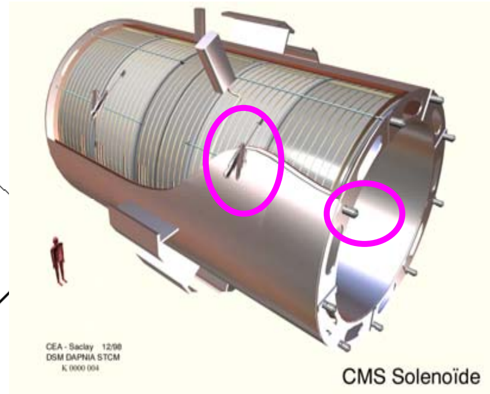




Conclusion

		Cryostat (MPa)	Coil (MPa)	R-supp. (MPa)	V-supp. (MPa)	Z-supp. (MPa)	Cryostat Hori.(mm)	Cryostat UD(mm)	Coil Hori.(mm)	Coil UD(mm)	Coil Z-dir.(mm)
Thermal shrinkage	dt=300K	41.0		0.0	0.0	120.0		0.0	−16.0	−16.0	−15.0
Cold mass	180tonnes	64.0		0.0	138.0	0.0		0.0	2.3	2.4	
Vac. Pressure	1atm	14.0					0.3	0.3			
Cal.weight	701tonnes	45.0					2.7	1.8			
Shifted force(Z-dir.)	850kN	10.0		0.0	0.0	22.0	0.0	0.0	0.0	0.0	1.0
Combined force		96.0	4.0	10.0	130.0	150.0	2.8	2.0	−14.0	−14.0	−16.0
0.15G (horizontal)		42.0		47.0		18.0	3.8		0.8	0.3	−16.0





END

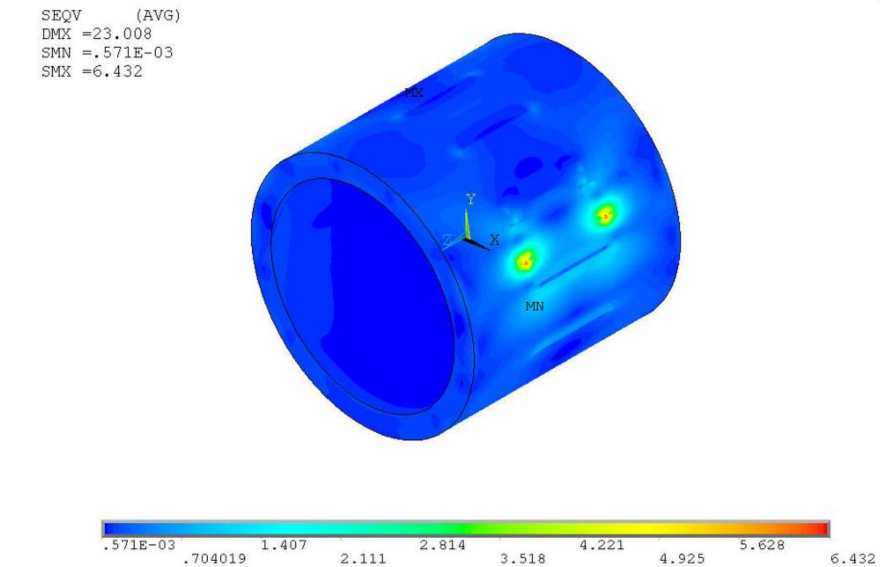
Ref.

Calculation-2

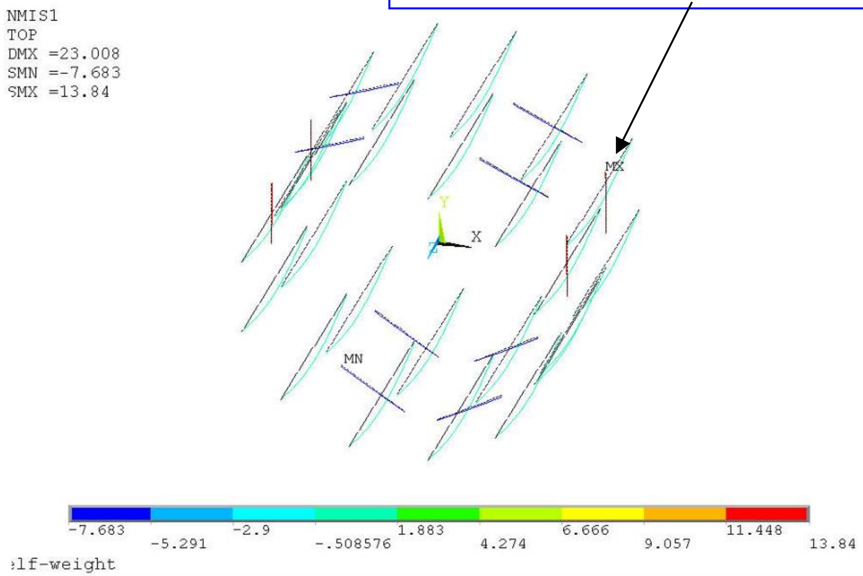
Condition: Self-weight of the coil.

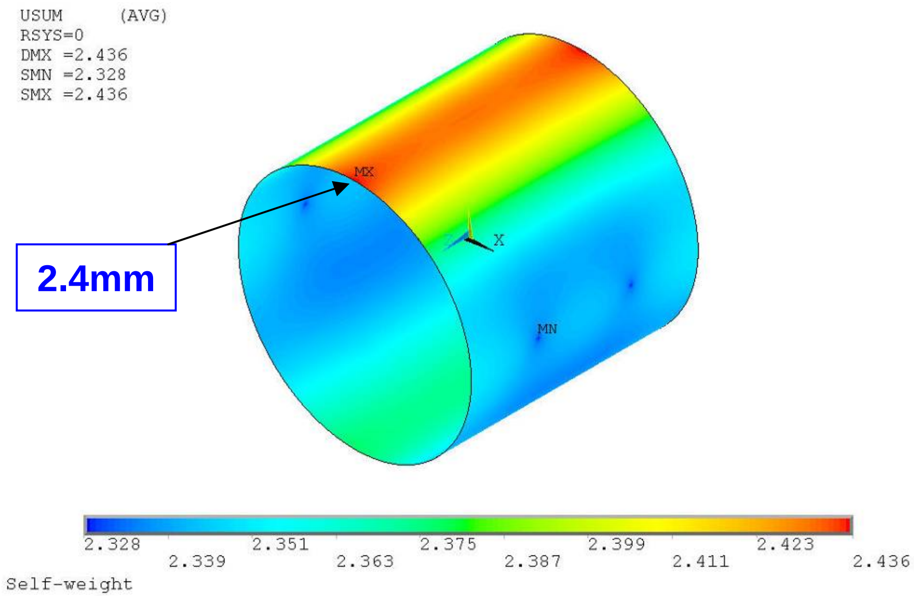
→ W_{coil}=180tonnes(Coil-thick=350mm)

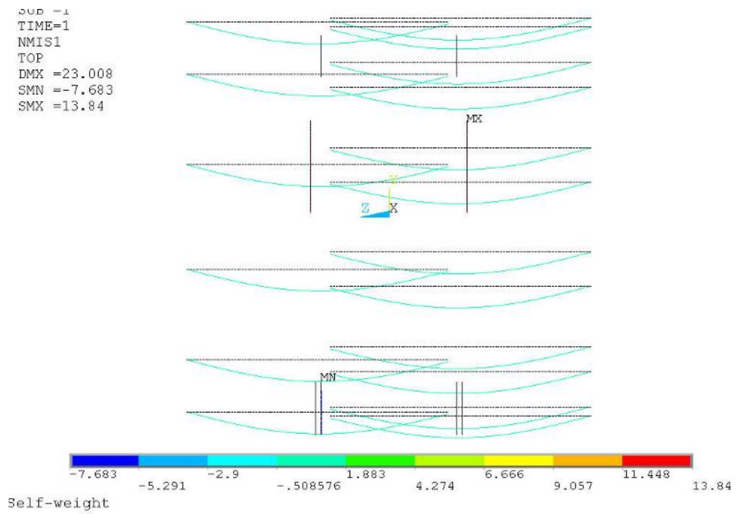
Von. M Stress : 64MPa



Verical support rods: 138MPa



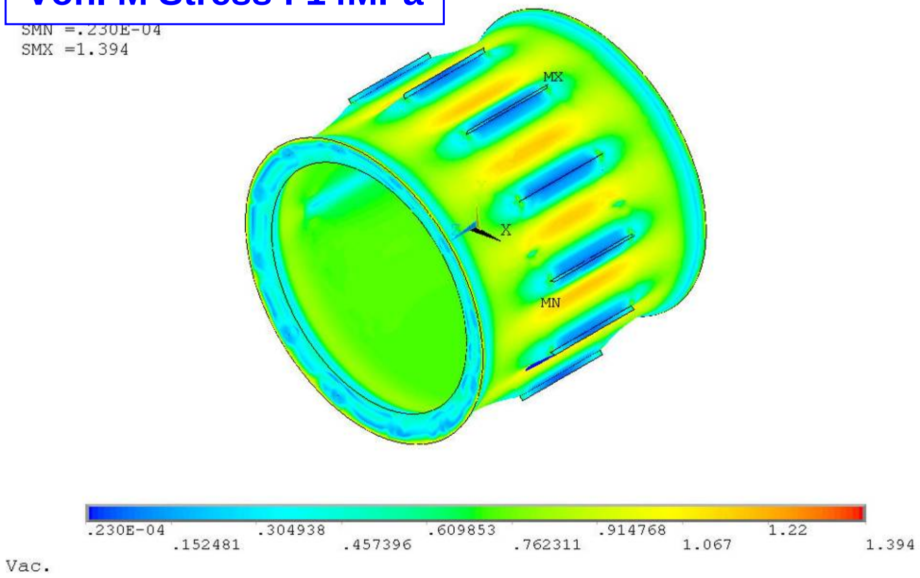


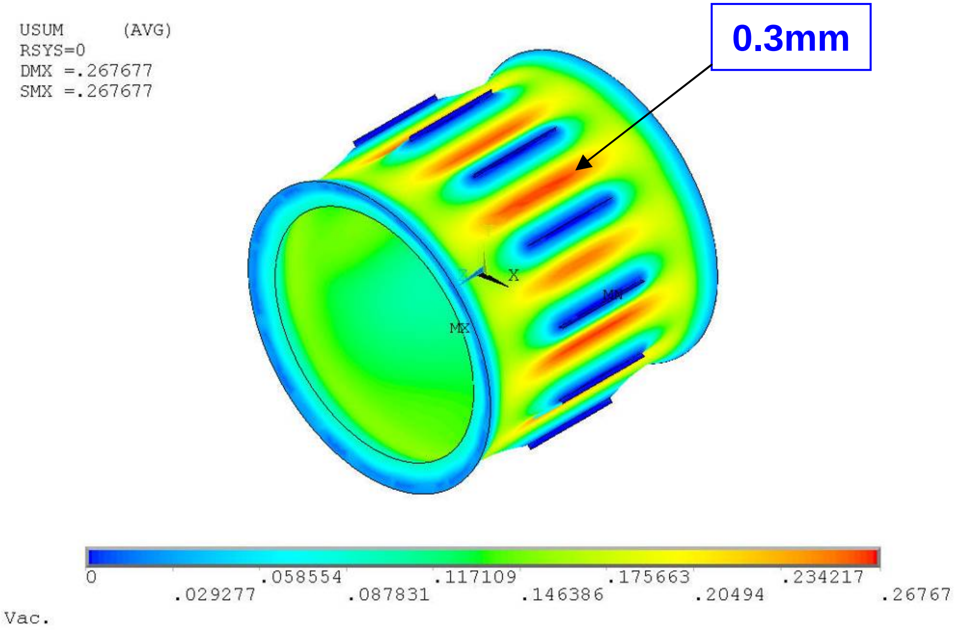


Calculation-3

Condition: Under Vacuum pressure

Von. M Stress : 14MPa





Required thickness of the outer vacuum wall to withstand buckling pressure

Ref.: NASA SP8007

$$p_{cr} = \frac{0.855}{\left(1-\mu^2\right)^{\frac{3}{4}}} \cdot \frac{E\sqrt{\gamma}}{\left(\frac{r}{t}\right)^{\frac{5}{2}}\left(\frac{L}{r}\right)}$$

$$t = \frac{r}{\left\{\dfrac{0.855E\cdot\sqrt{\gamma}}{p_{cr}\left(1-\mu^2\right)^{\frac{3}{4}}\cdot\left(\frac{L}{r}\right)}\right\}^{\frac{2}{5}}}$$

If $P_{cr} = 2atm, \sqrt{\gamma} = 0.75,$

$$t = \frac{4190}{\left\{\dfrac{0.855\cdot 2.1\times10^4\cdot 0.75}{0.02\cdot\left(1-0.3^2\right)^{\frac{3}{4}}\cdot\left(\frac{7744}{4190}\right)}\right\}^{\frac{2}{5}}}$$

$$= 24.3mm$$

→ Thicker than 24.3mm is required.

Coefficient of thermal expansion

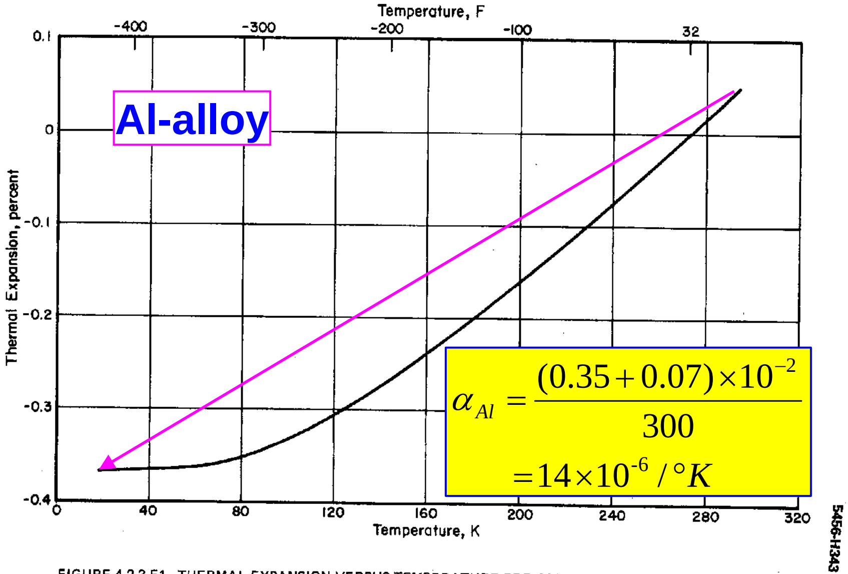


FIGURE 4.2.3-E1. THERMAL EXPANSION VERSUS TEMPERATURE FOR ALUMINUM ALLOY 5456-H343

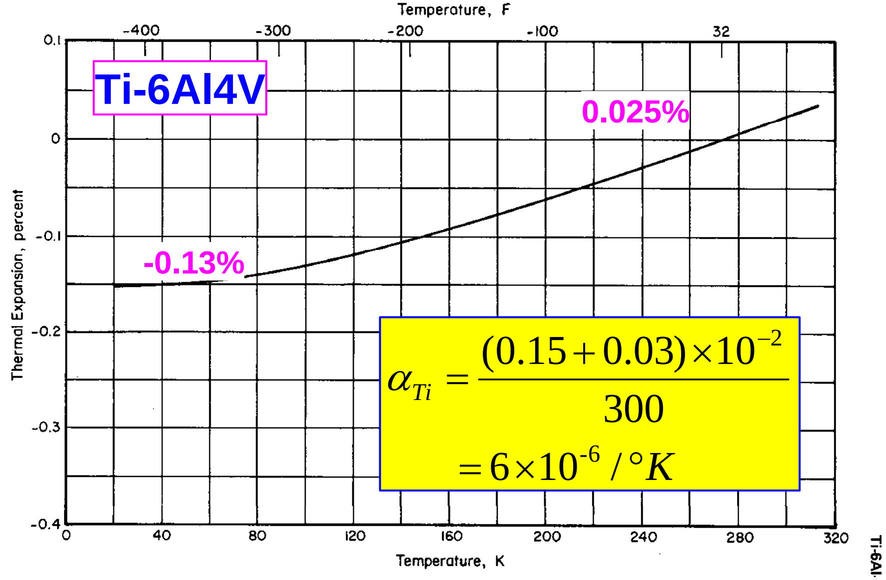


FIGURE 9.3.2-E1. THERMAL EXPANSION VERSUS TEMPERATURE FOR Ti-6 Al-4 V ALLOY

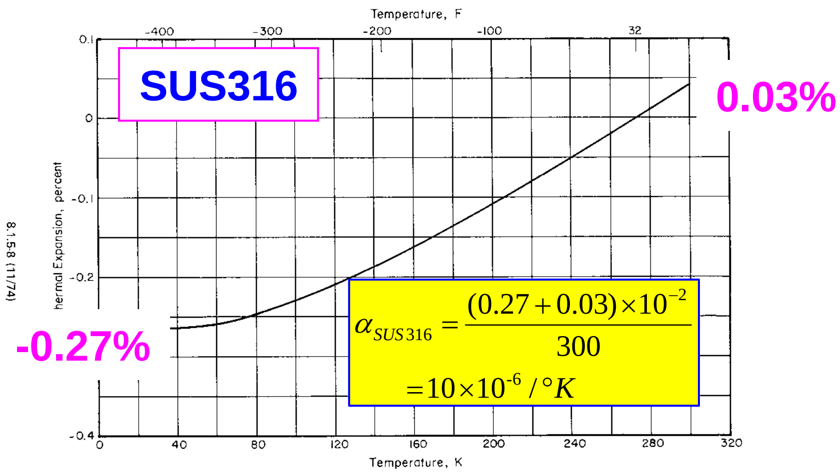


FIGURE 8.1.5-E1. THERMAL EXPANSION VERSUS TEMPERATURE FOR TYPE 316 STAINLESS STEEL

Ref.: HANDBOOK ON MATERIALS FOR SUPERCONDUCTING MACHINERY, MCIS-HP-04, Jan. 1977