NCSX National Compact Stellarator Experiment

PDR - NCSX PF & TF Support Structure

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20 July 2007

Charge:

The charge to the review committee is as follows:

1. Are the requirements well defined?

2. Will the design meet performance requirements?

3. Is the design adequately underpinned by analysis and testing?

4. Have design and implementation risks been identified and properly mitigated?

Requirements:

The coil support structure provides the means for accurately locating and supporting the TF and PF coils.

• It must provide adequate support for the EM loads arising from the coil operational scenarios specified in the GDR (Section 3.2.1.5.3.3.1, 3.2.1.5.3.3.1.3 to 3.2.1.5.3.3.1.6).

• It must have sufficient compliance to accommodate cooldown from room temperature to 77 deg.K

• It must be sufficiently rigid to limit coil deflections to acceptable values per field error criteria established in the GDR para. 3.2.1.5.1b.

• It must satisfy the GDRs' life cycle requirements:
"The facility shall be designed for the following maximum number of pulses when operated per the reference scenarios defined in Section 3.2.1.5.3.3.1 and based on the factors for fatigue life specified in the NCSX Structural and Cryogenic Design Criteria Document"

  • 100 per day;
  • 13,000 per year; and
  • 130,000 lifetime.

• It must have a relative magnetic permeability less than 1.02
• It must limit eddy currents to effectively limit field errors at the plasma boundary:

  GDR:"The time constant of the longest-lived eddy current eigenmode in the electrically conducting structures outside the vacuum vessel and inside the cryostat (except coils) shall be less than 20 ms."

• It must meet the NCSX seismic & Structural Design Criteria (NCSX-CRIT-CRYO-00).

Loads considered:

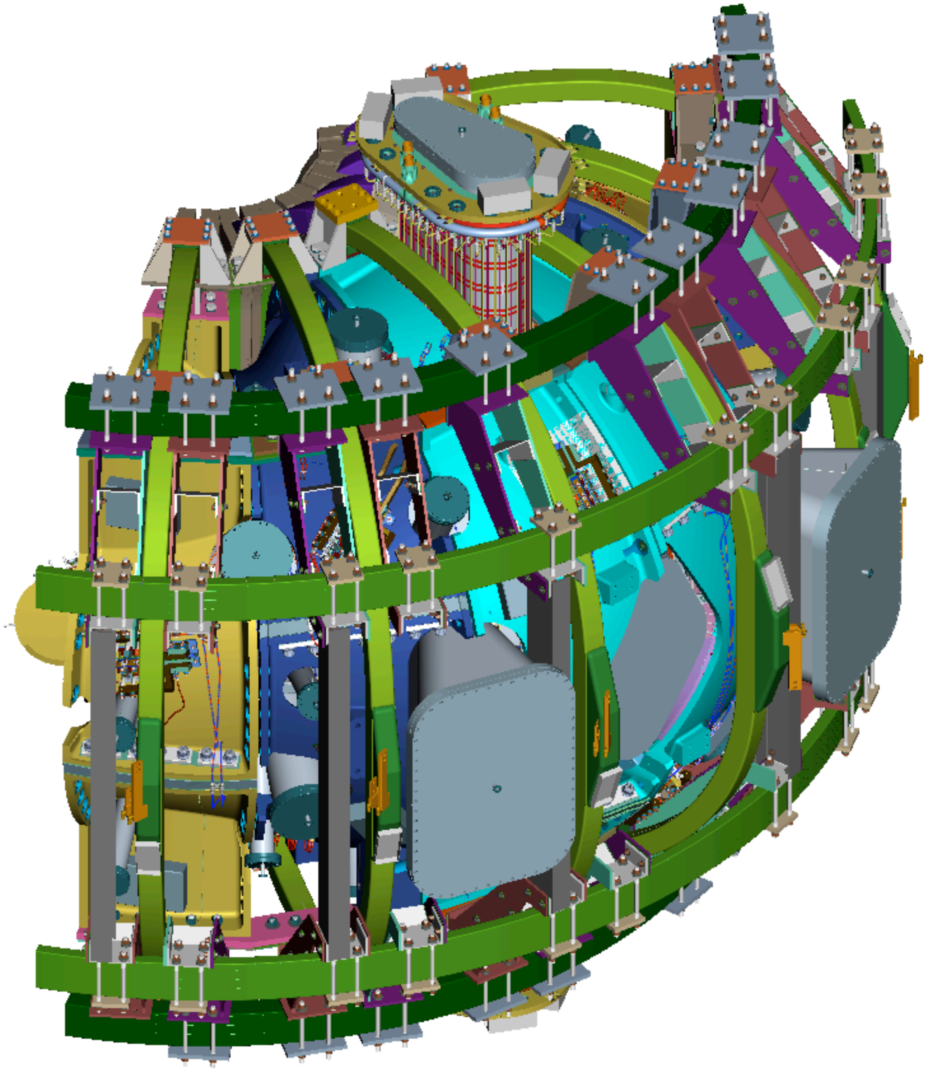
Gravity Loads with 1g & 2g vertical downward, B.C.: Symmetry & fixed @ MCWF center (attached to the inner & outer segmented casting mounts which were fixed to avoid RBM).

Horizontal seismic loading using static 0.15g acceleration per the NCSX/IBC2000 criteria (h~15ft, Fp=0.108 x 1.369 = 0.147 ~ 0.15g). B.C.: Symmetry & fixed @ MCWF Mtg.

Thermally induced stress from cool down and temperature differentials using mean CTEs from R.T. to 77 ^{o}K. B.C.: Symmetry & fixed @ MCWF Ctr. (CTE-AlAly5083 data from NIST data, CTE-316L from ITER data)

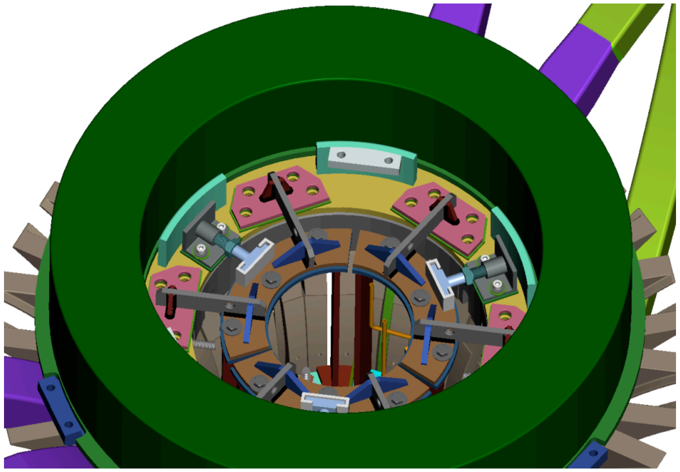
Electro-magnetic loading for defined coil scenarios (A.2.3.2):
1.7T Ohmic, 1.7T High Beta, 320kA Ohmic, (0.5T TF only-limit TBD)

B.C.: Symmetry & fixed RBM @ MCWF C.L.

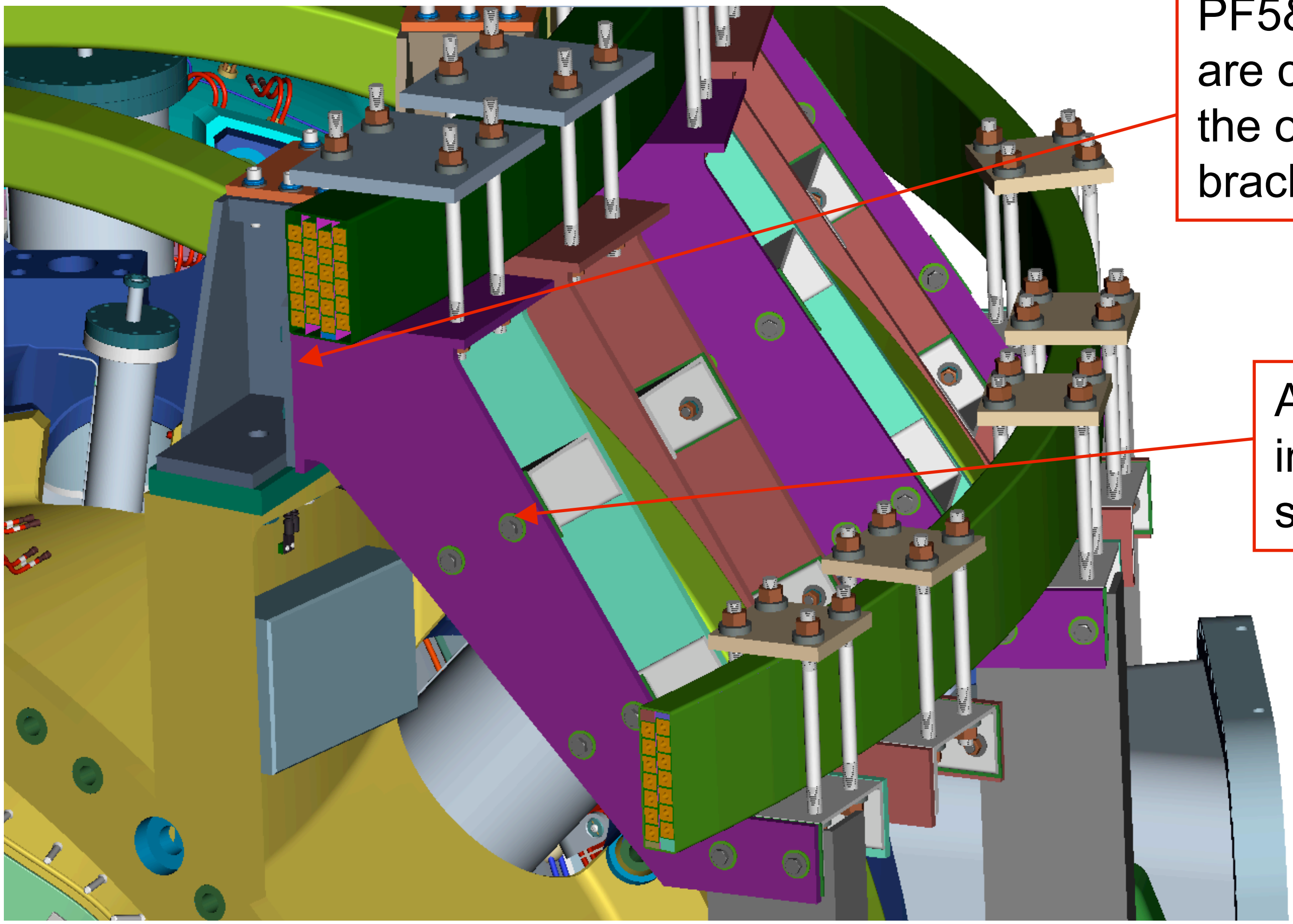


Outer PF5 & PF6 Supports

- TF support Brackets are AlAly 5083 -H32 weldments.
- Brackets are bolted directly to the MCWF shell structure or to spacers which bolt to the MCWF.
- Shims are used to provide vertical positioning of the TF coils.



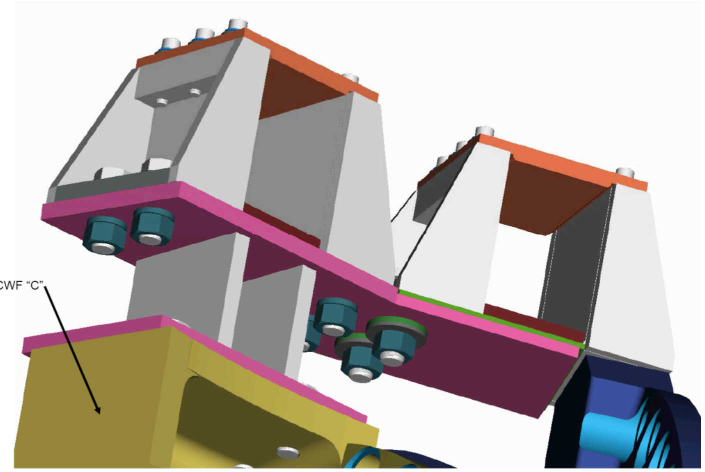
PF4 & CS support



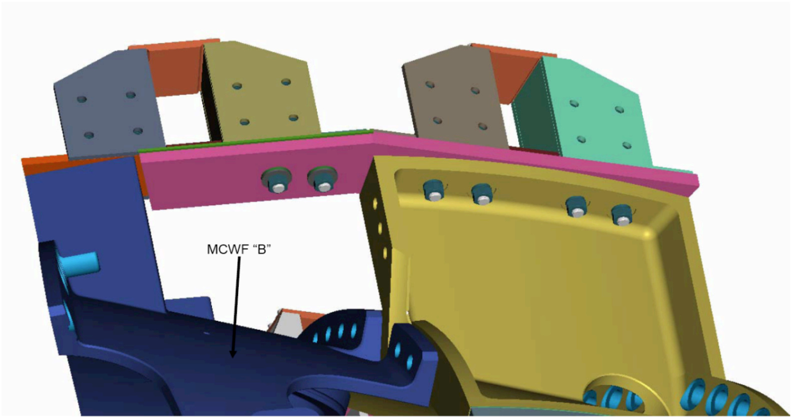
PF5&6 brackets are cantilevered off the outer TF bracket assembly

All bolted Joints are insulated with G11 sleeves & washers

PF Coils are shimmed & clamped to the support brackets



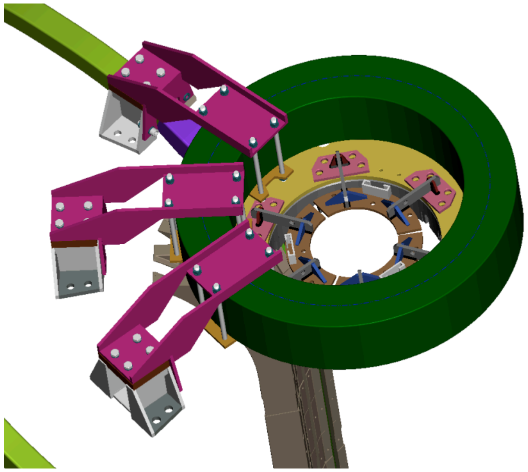
TF Inner Supports "B" to "C" Span

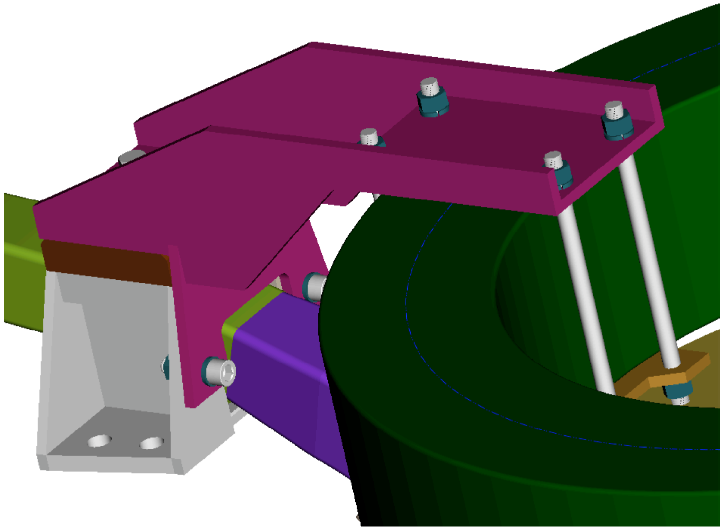


TF Outer Supports "C" to "B" Span

Inner TF coil mtg. brkts.

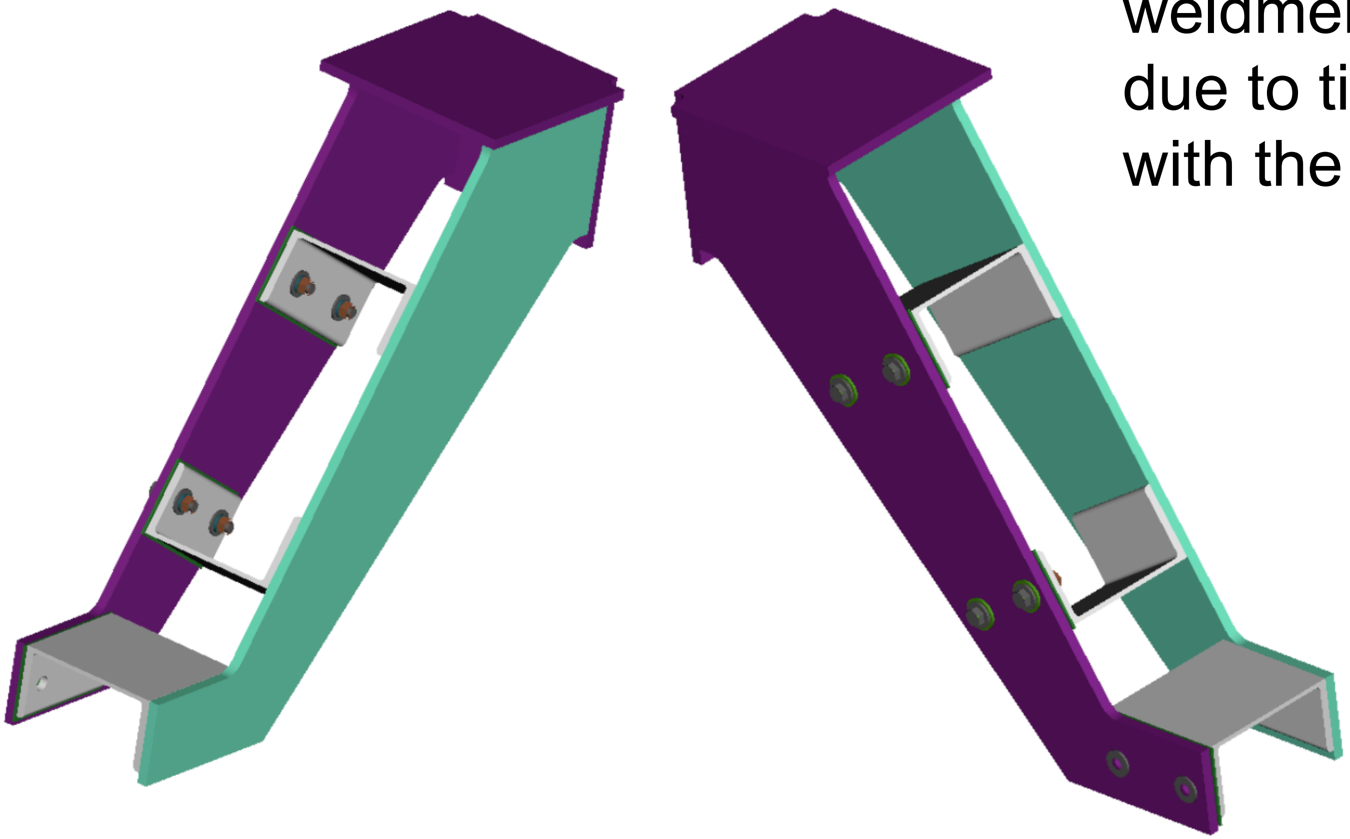
Outer TF Coil mtg. brkts.



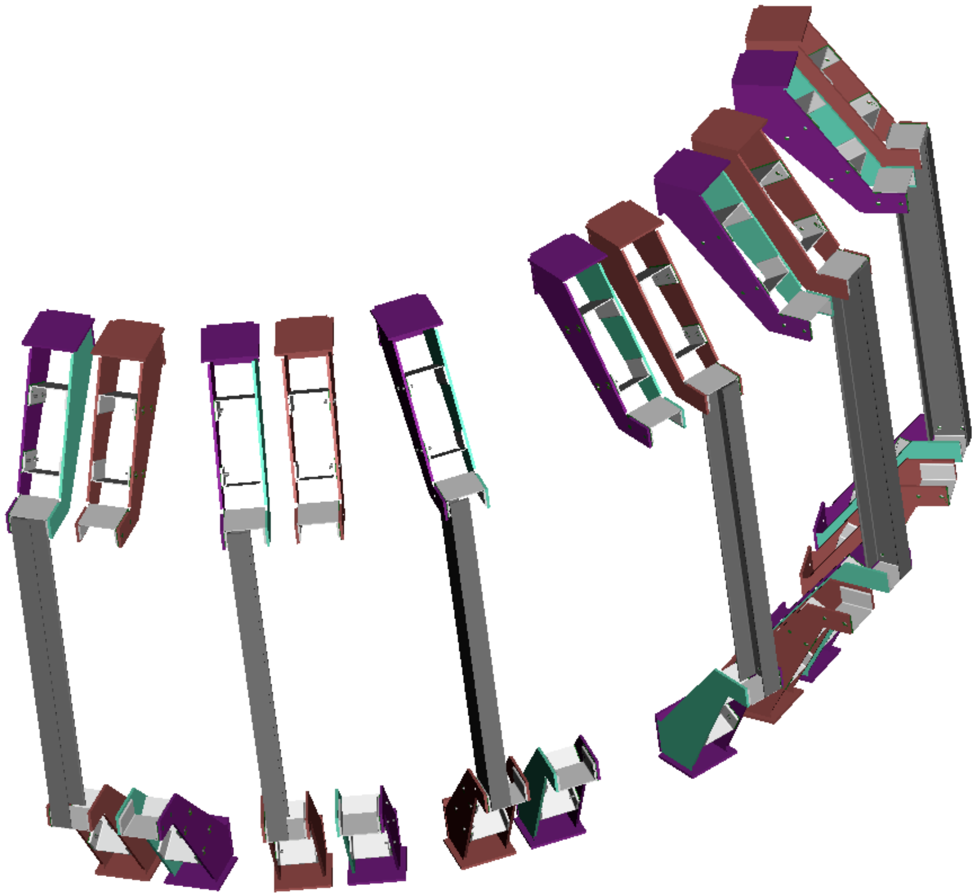


PF4 Coil Mtg. off inner TF brkts.

Left and right hand weldments required due to tight clearance with the TF coils

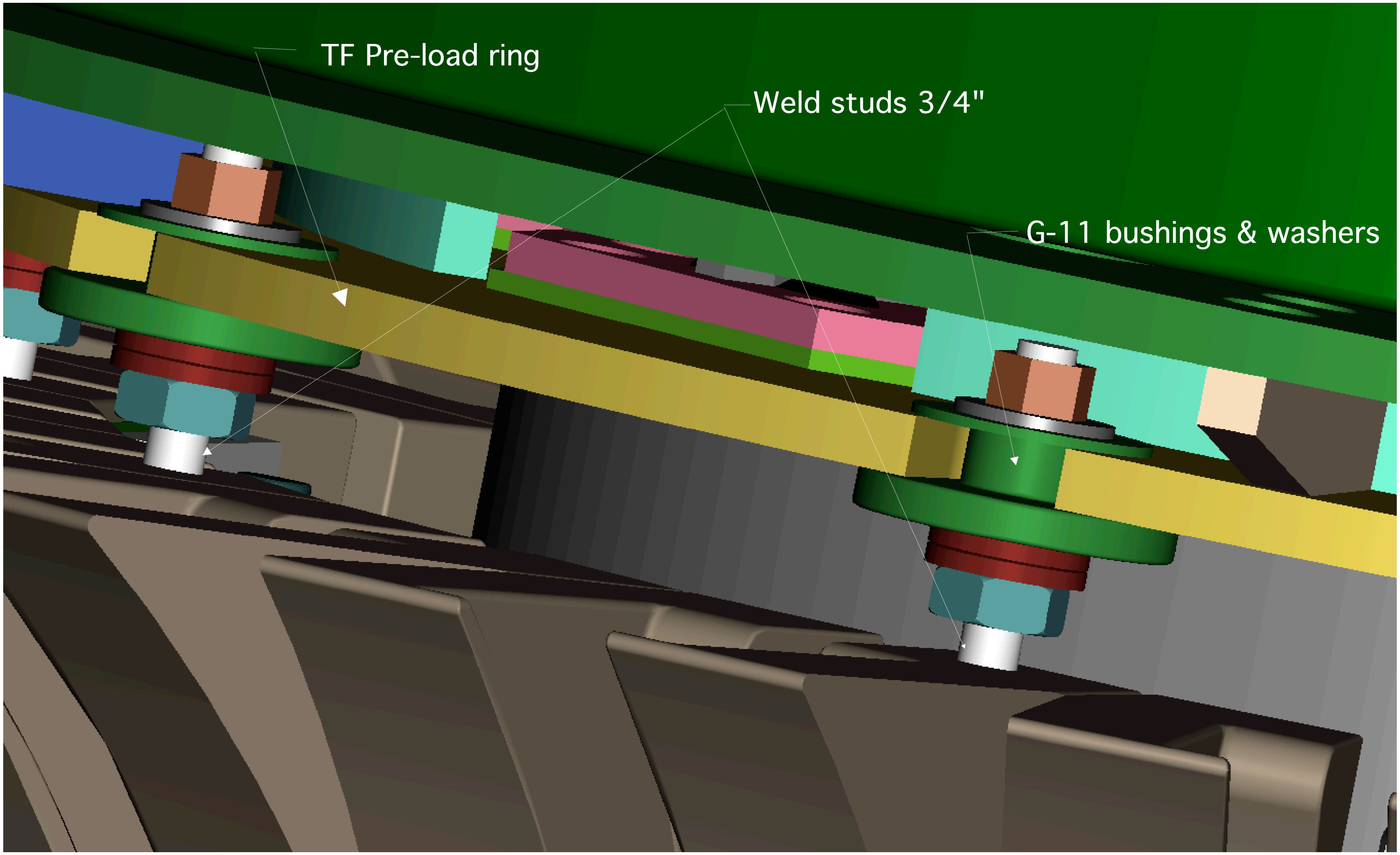


PF5 & PF6 Coil supports are welded with insulators on one side to avoid current loops



The vertical channels have been eliminated.

Vertical channels could provide an additional load path between the top and bottom PF6 coils, but CTE mismatch between Aluminum and Stellalloy produced unacceptably high stresses (316L ss still an option if needed).



The CS assembly and TF pre-load rings mount on the TF wedge castings via weld studs

E-M and Structural Analysis

Table 7: Most Significant Load Cases Analyzed for Fields Forces on Coils

Load Case	1	2	3	4	5
Scenario	0.5 T TF	1.7T Ohmic	2T High Beta	320kA Ohmic	320kA Ohmic
Time, s	0.0	0.0	0.0	0.206	0.506
M1 (A)	0	38141	40908	34200	34200
M2 (A)	0	35504	41561	32057	32057
M3 (A)	0	35453	40598	32184	32184
PF1 (A)	0	-25123	-15274	11354	21858
PF2 (A)	0	-25123	-15274	11354	21858
PF3 (A)	0	-9698	-5857	-11802	-5975
PF4 (A)	0	-7752	-9362	-13936	-9441
PF5 (A)	0	8284	1080	4563	4634
PF6 (A)	0	-8997	-24	5068	5705
TF (A)	16200	-3548	-1301	2191	2191
Plasma (A)	0	0	0	-320775	-320775

Red and blue fields represent maximum and minimum coil currents

Table 8: Maximum Net Forces on PF Coils [kN]

Coil	LC2	LC3	LC4	LC5
Central Solenoid	468 Attract	24 Attract	67 Attract	778 Attract
PF4	182 Attract	117 Attract	142 Attract	39 Repel
PF5	215 Repel	19 Repel	52 Repel	43 Repel
PF6	149 Attract	0	58 Repel	62 Repel

Load Case selection:

Based on prior PF coil analysis, the most severe loading for PF4,5,&6 is the 1.7T Ohmic scenario.

Note, these load cases use the PF1,2,&3 CS currents and therefore should be conservative for the PF1a currents for the MIE runs.

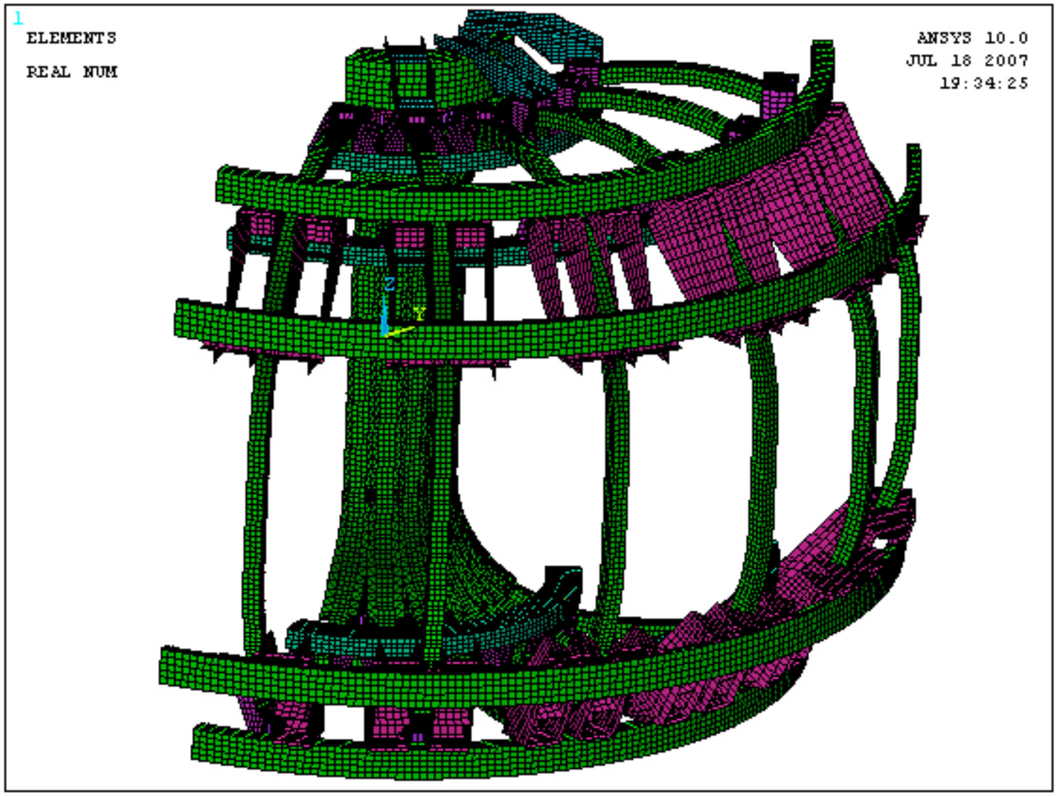
1-g loads:
PF4 - 8.3kN
PF5 - 10.5kN
PF6 - 7.6kN
Gravity loads are < 5% of EM loads

The structural FEA model:

The main structural elements include:

TF support brackets 1/2" thk. AlAly 5083 -Quadrlateral plate elements.
PF support brackets 1/2" thk. AlAly 5083 -Quadrlateral plate elements
TF coils 3x3 solid brick elements with "smeared" properties representing Cu/Insulation
PF4 coil 5x7 solid brick elements with "smeared" properties representing Cu/Insulation
PF5 coils 3x5 solid brick elements with "smeared" properties representing Cu/Insulation
PF6 coils 2x5 solid brick elements with "smeared" properties representing Cu/Insulation
TF wedge castings solid 10-node tetras with Stellalloy material props.
MCWF modeled with solid brick elements of equivalent stiffness & Stellalloy props.
Bolts as beam elements with Inconel 718 material properties.
TF pre-load rings solid brick elements with Stellalloy material properties.

Code used: ANSYS ver. 10.0 for EM & Structural analysis



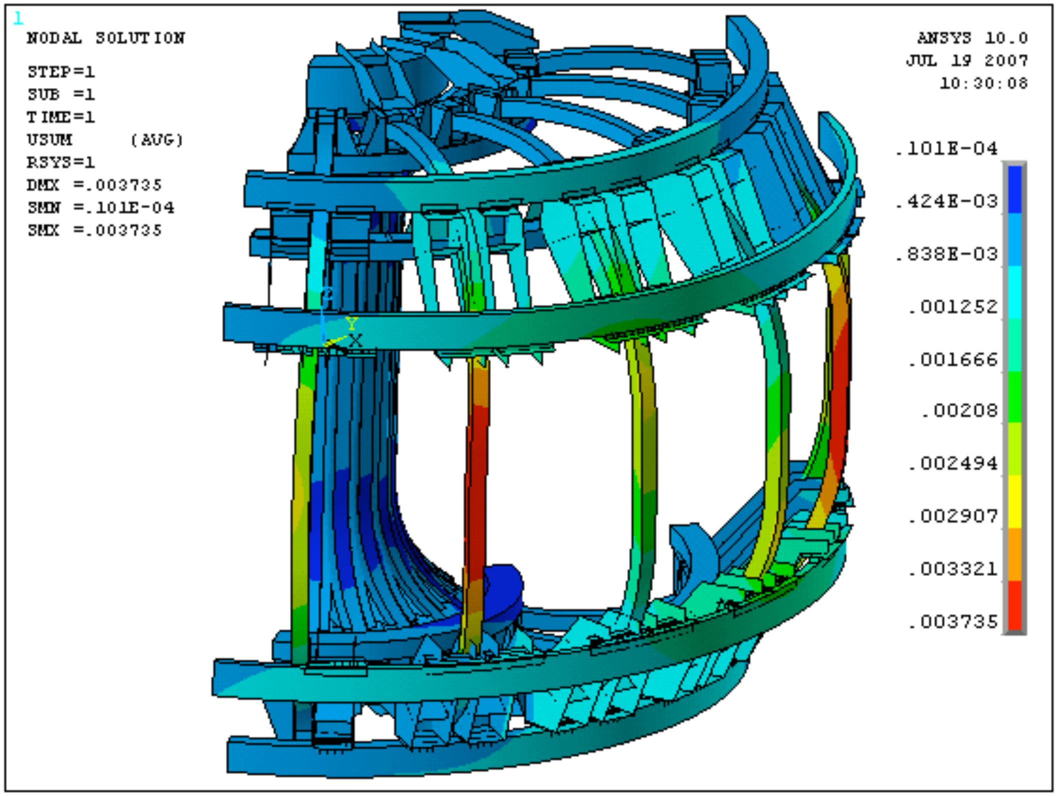
Model Details:

#Nodes	191687
#Elements	152293
#Coupled nodes	5280
#Forces	135276
Tref	20 C
Tload	-198 C
Solver	Sparse

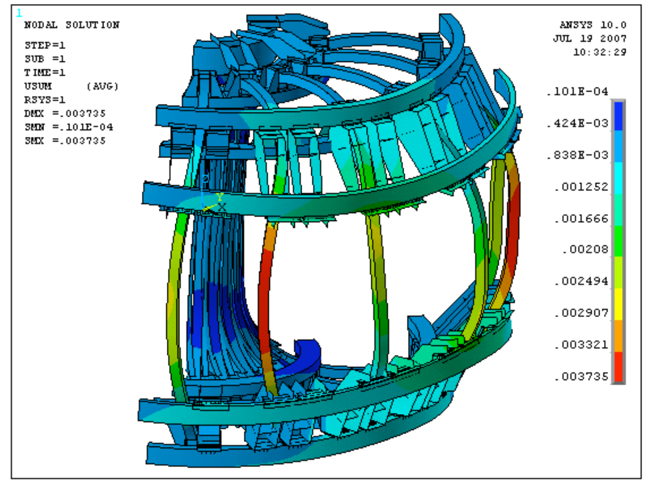
ANSYS FEA Model of PF & TF Coil supports

Files: pf456_tf3-1.7T-Ohmic-0.100b4d EM loads

pf456_tf3-1.7T-Ohmic-0.100b4dT EM+Thermal loads

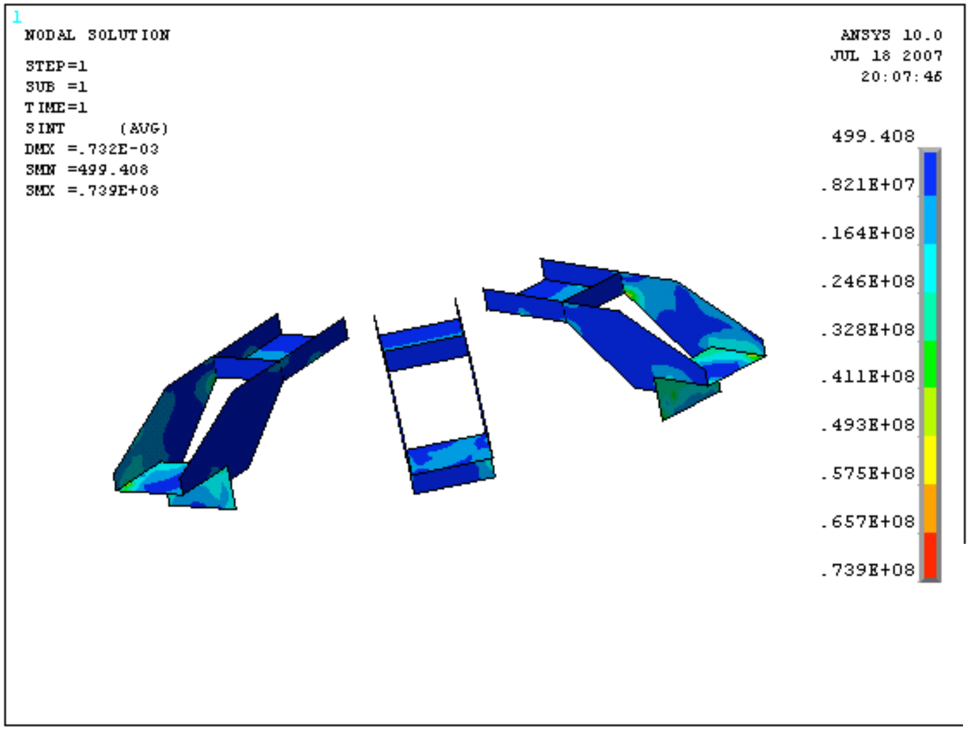


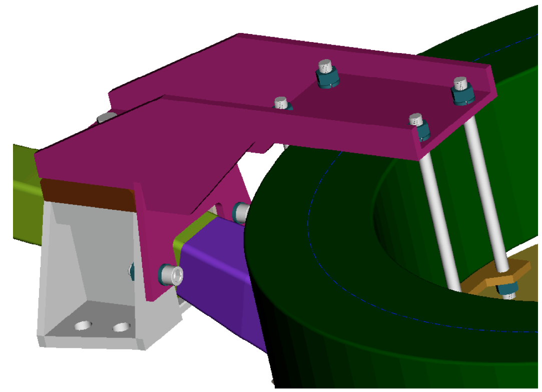
Peak EM driven displacements ~4mm on TF outer leg

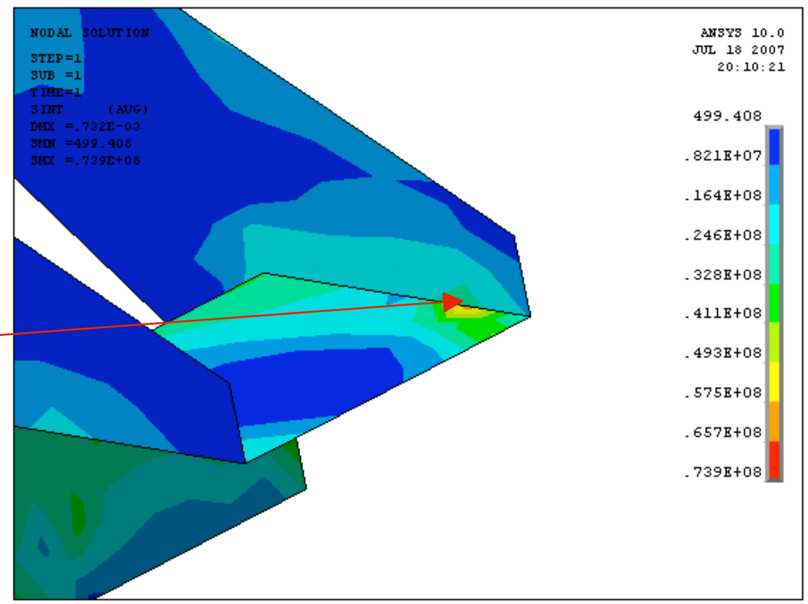


SRSS-Deformed shape x100

Results: LC1-1.7T Ohmic EM loads only

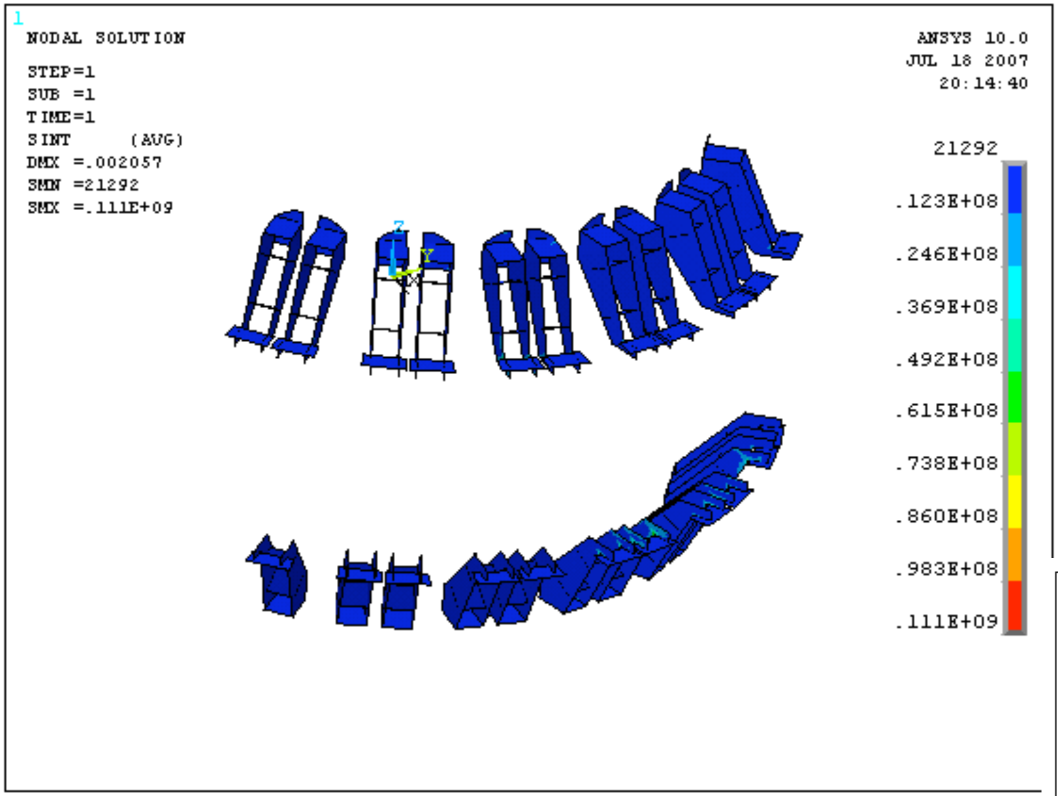






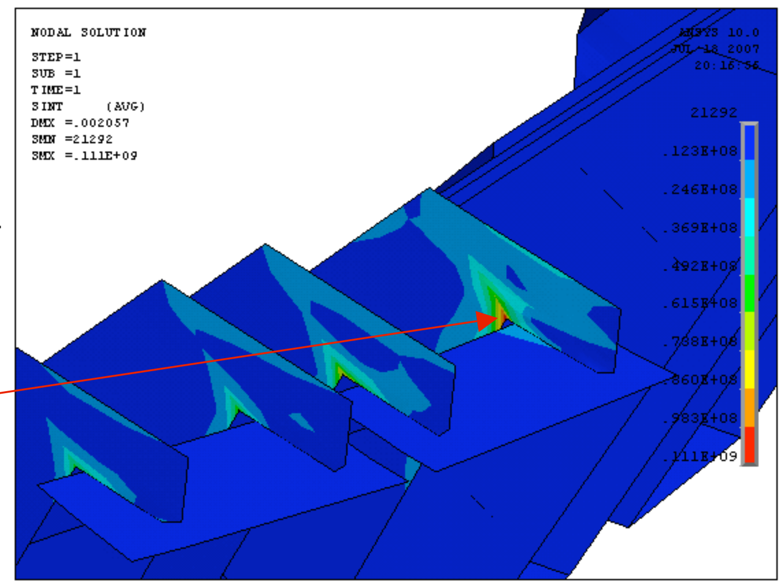
Peak Tresca Stress in PF4 support brackets is ~74 MPa

Results: LC1-1.7T Ohmic EM loads only



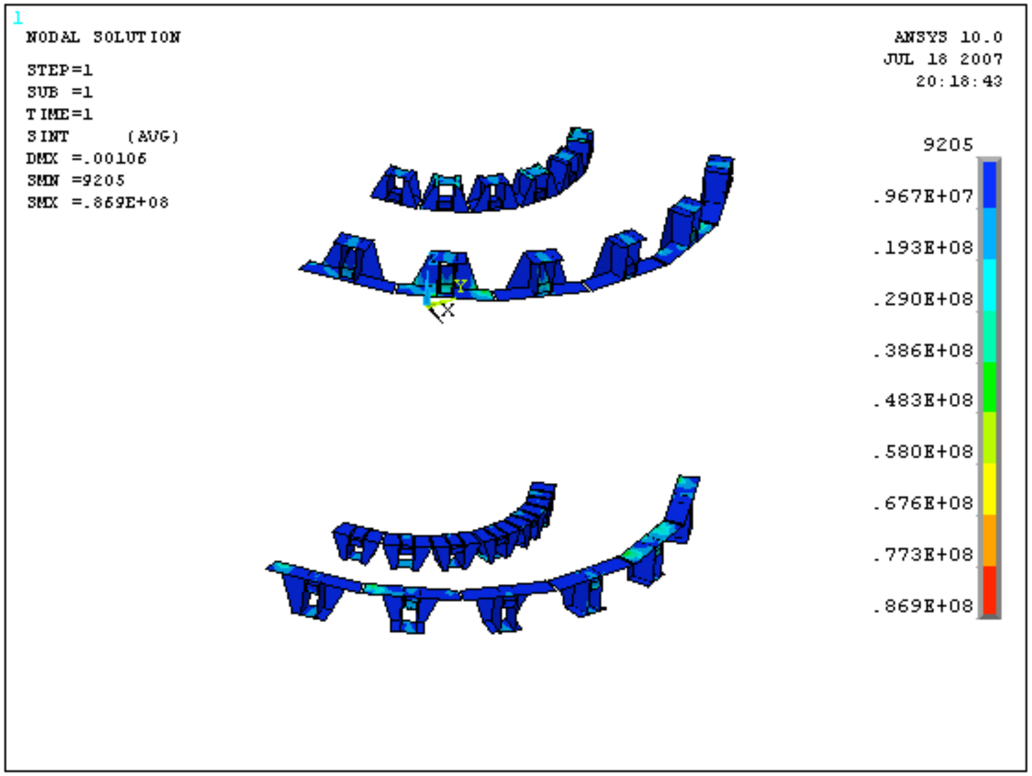
Results: LC1-1.7T
Ohmic EM loads only

This is the highest EM induced stress in the coil support structure



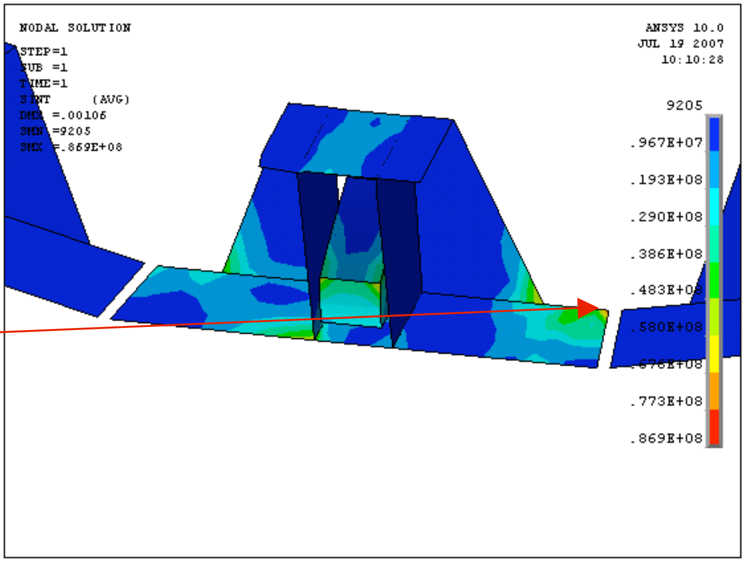
Peak Tresca Stress in PF5&6 Supports is 111 Mpa

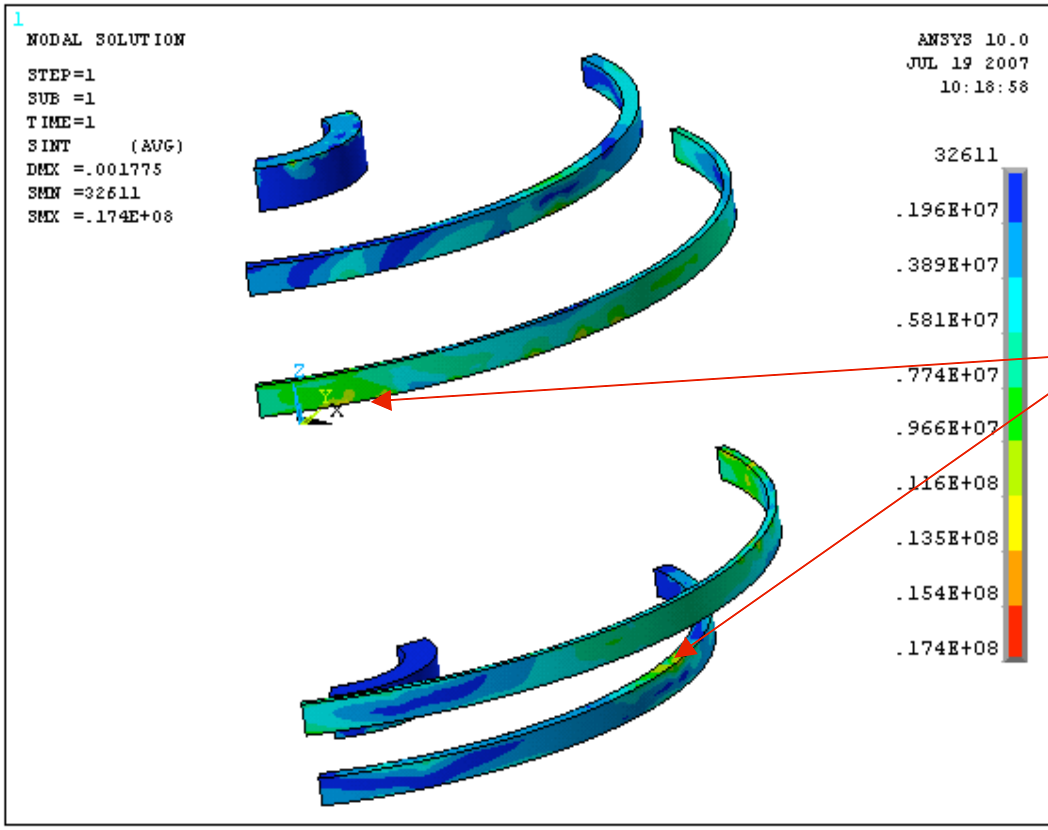
(somewhat artificial due to sharp corner in model)



Results: LC1-1.7T Ohmic EM loads only

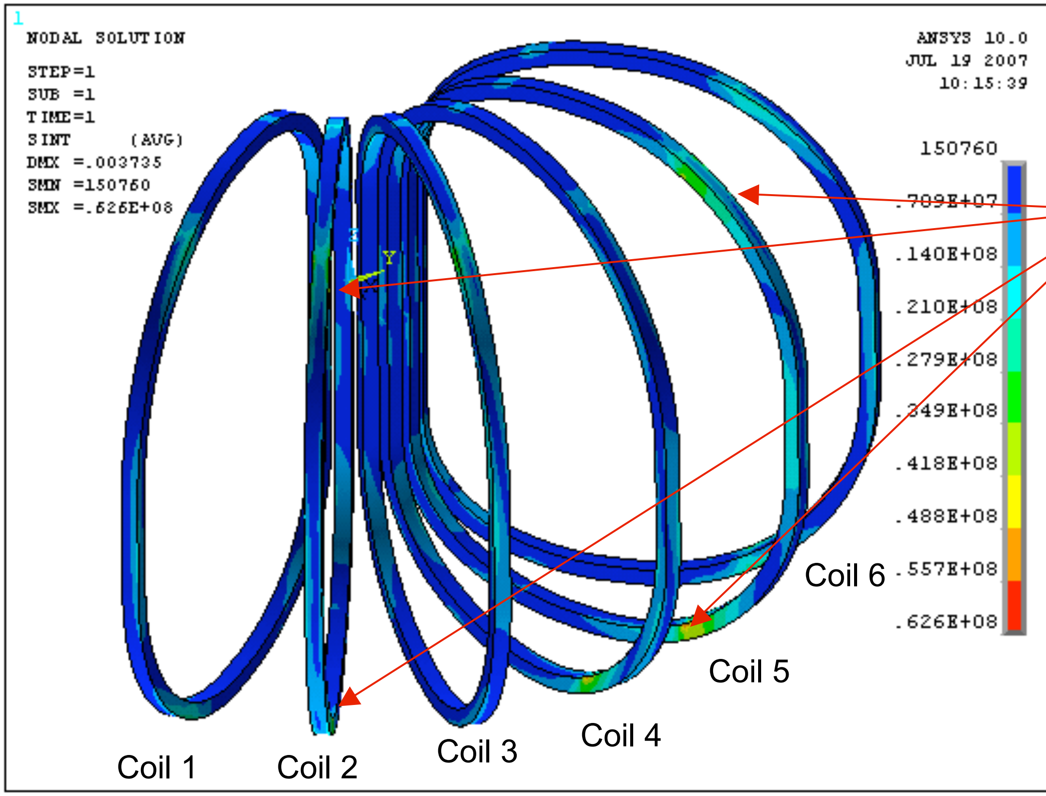
Peak Tresca Stress in the TF coil Support brackets is ~ 87 Mpa @ corners of base.





Peak Tresca Stress In the PF coils is only 17.4 Mpa @ the PF5 & 6 support clamps

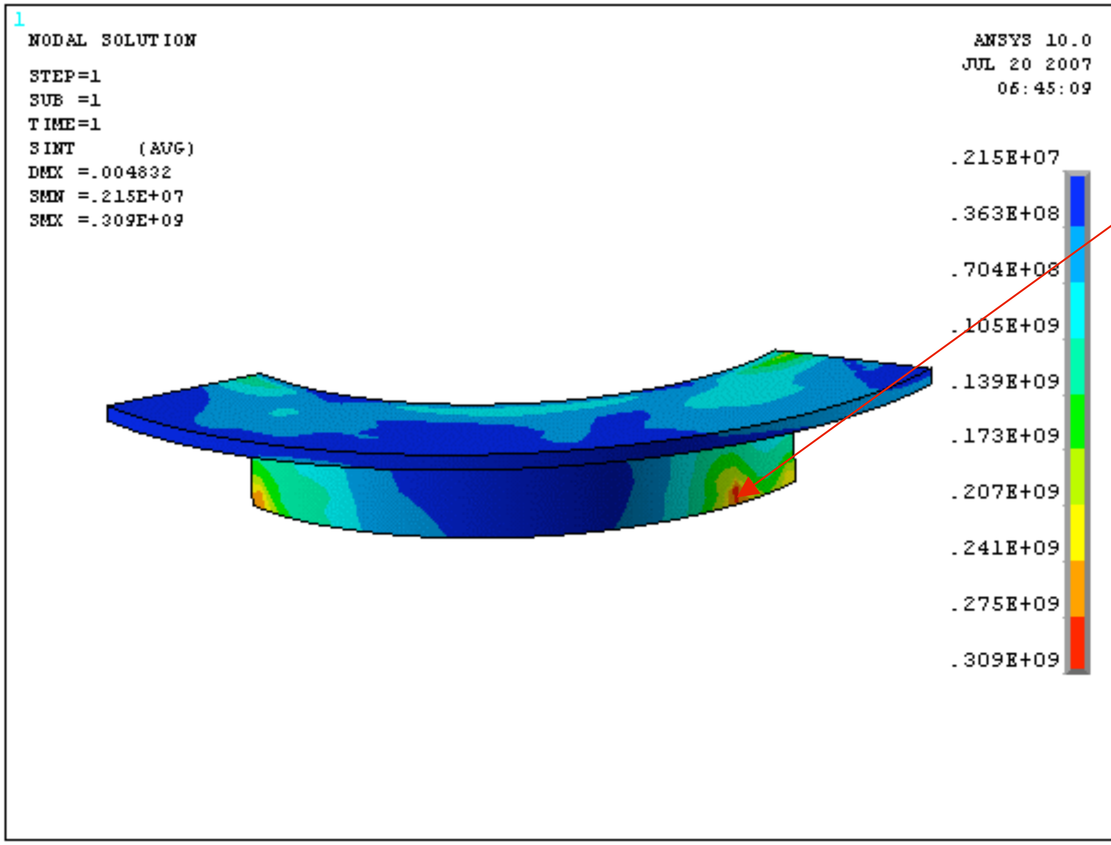
Results: LC1-1.7T Ohmic EM loads only



Peak Tresca Stress in the TF coils is 63 Mpa @ the outer brackets

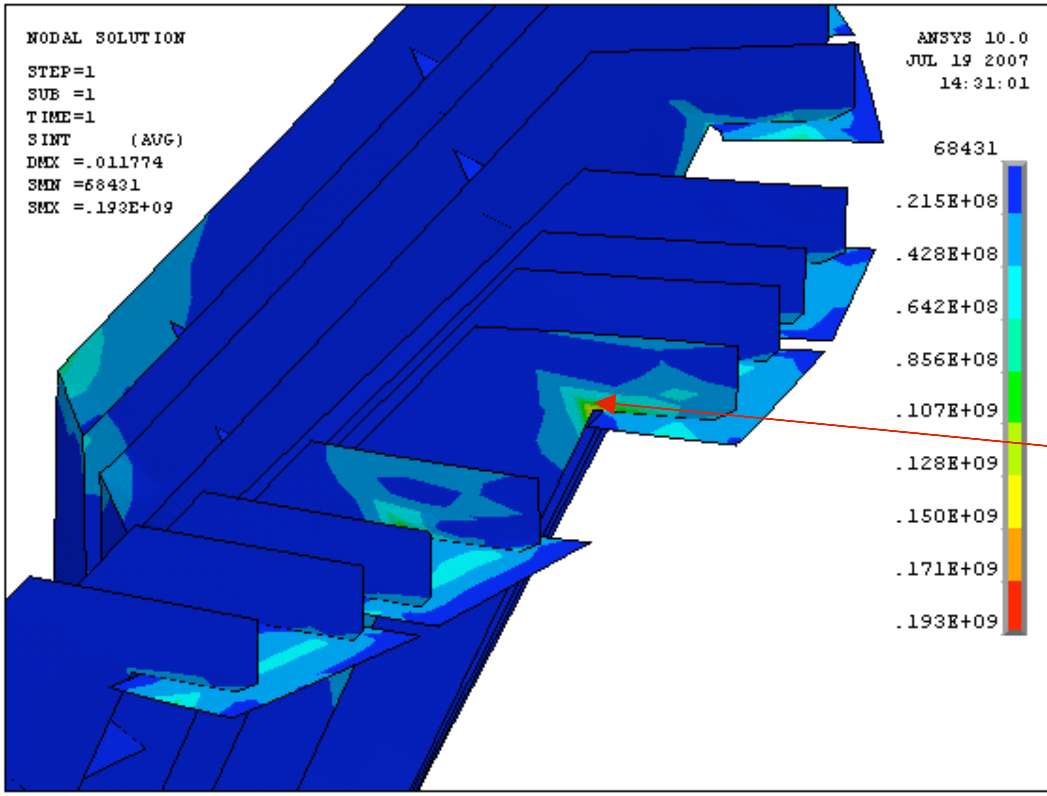
Note: Maximum stresses and displacements are in coils 2 & 5

Results: LC1-1.7T Ohmic EM loads only



Peak Tresca stress in the TF pre-load ring is 309MPa

Results: LC1-1.7T Ohmic EM + thermal loads



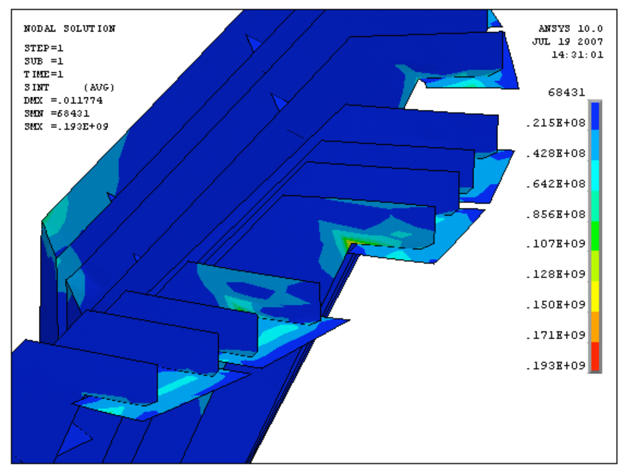
90% < 21.5MPa Primary Stress

~8% < 107 Mpa Primary + bending

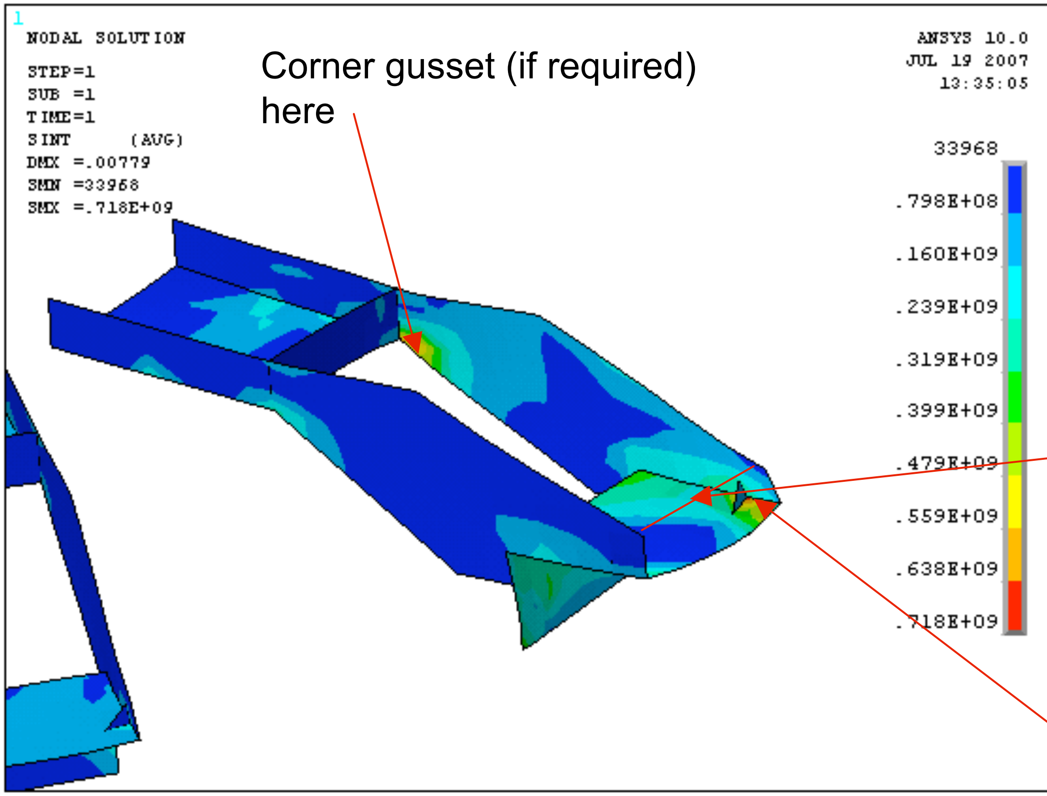
~2% 107 to 193 MPa peak

secondary stress

Peak Tresca stress 193 MPa



Results: LC1-1.7T Ohmic EM + thermal loads



~60% < 160 MPa Primary Stress

~95% < 319 Mpa Primary + bending

~5% 319 to 718 MPa peak

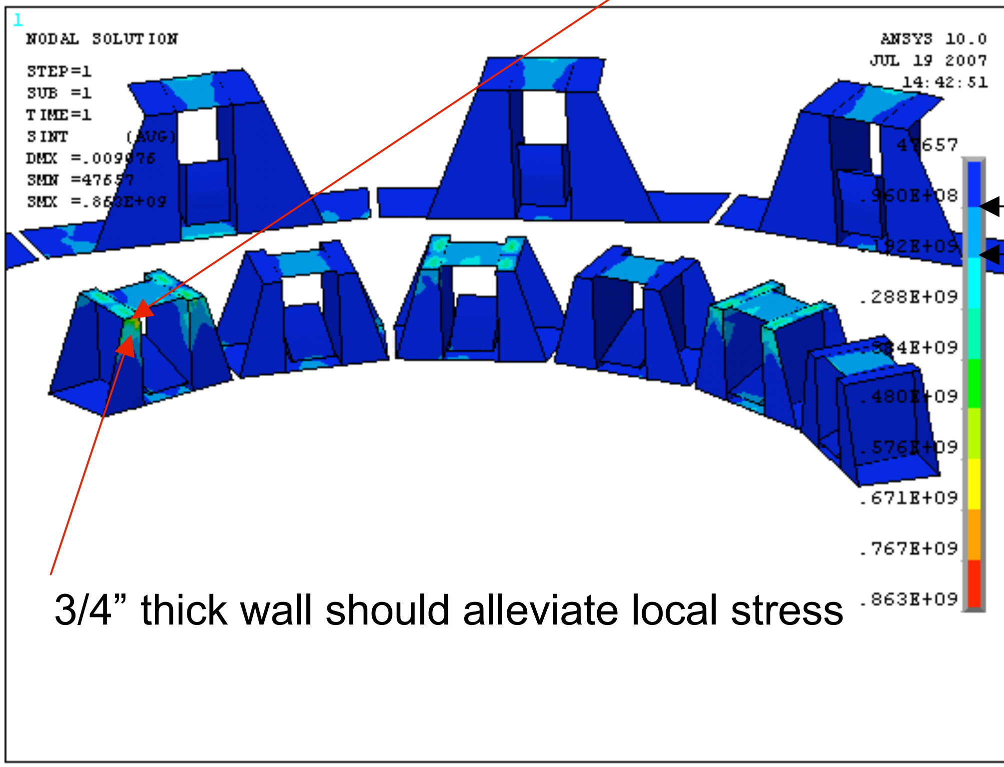
secondary stress

This area will be reinforced with An additional 1/2" thk. gusset

Peak Tresca stress 718 MPa

Results: LC1-1.7T Ohmic EM + thermal loads

Peak Tresca stress 863 MPa



3/4” thick wall should alleviate local stress

.960E+08 Pa

.192E+09 Pa

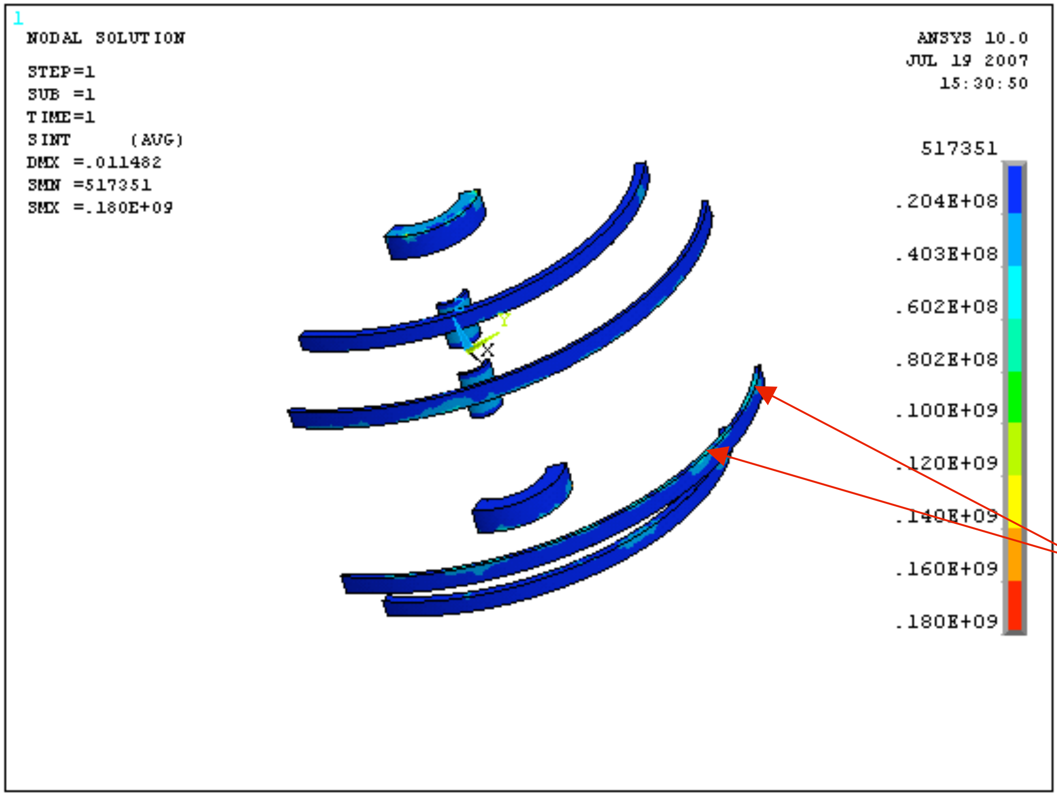
~75% < 96 MPa Primary Stress

~15% < 192 Mpa Primary + bending

~5% < 288 MPa

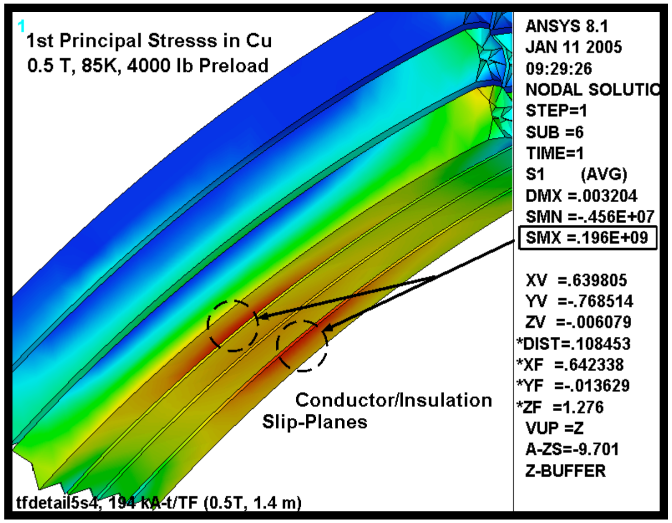
~5% 288 to 863 MPa peak secondary stress

Results: LC1-1.7T Ohmic EM + thermal loads

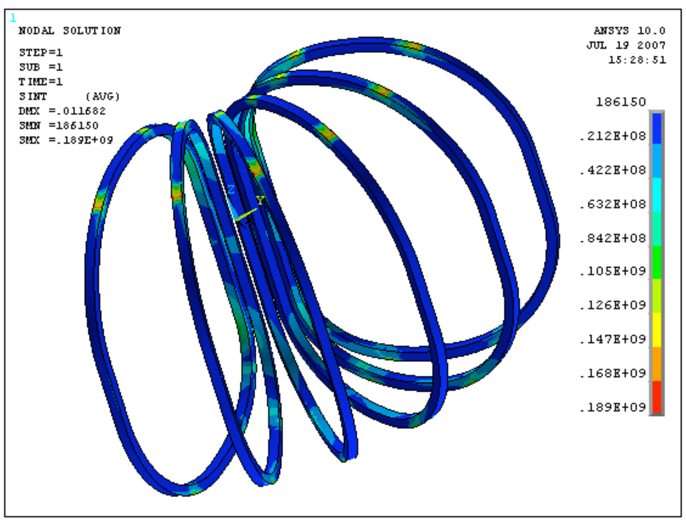


Peak Tresca stress 180 Mpa @ support bracket interfaces

Results: LC1-1.7T Ohmic EM + thermal loads



Stress in TF from Myatt hybrid model analysis



Peak Stress in TF from current (EM+Cooldown) analysis 189MPa

Table 10 Design Stress Values at 80K, Metallic

Material	Yield, σ_y [MPa]	Ultimate, σ_u [MPa]	Design Stress, S_m ($2/3\sigma_y$ or ½σ_u) [MPa]	Fatigue Stress
Stainless Steel	410	1300	270	Design-Basis Curve
Cu (1/4-Hard)	290	360	180	Design-Basis Curve

Table 11 Design Stress Values at 80K, Epoxy-Glass Insulation

Material	Flat-Wise Compression [Mpa]	Normal Tension [MPa]	In-Plane Tension/Compression [MPa]	Shear/Compression τ_o and c_2
VPI'd S-2 Glass + Kapton	2/3(600)=400	0.02% Strain 0.0002 x 19 GPa = 3.8 MPa	0.5% Strain 0.005 x 26 GPa = 130 MPa	40 MPa and 0.32
VPI'd S-2	Better Than VPI'd S-2 Glass + Kapton			

Design Stress values for PF & TF coils

NCSX National Compact Stellarator Experiment

5083-O			
Temp	Tensile Strength (ksi)		Elongation
°F	Ultimate	Yield	% in 2"
-320	59	24	36
-112	43	21	30
-18	42	21	27
75	42	21	25
212	40	21	36
300	31	19	50
400	22	17	60
500	17	11	80
600	11	7.5	110
700	6	4.2	130

Sm = 2/3 Sy = 16 ksi (110 Mpa) in weld and haz.

Aluminum Association Data (Typical values - NOT FOR DESIGN)

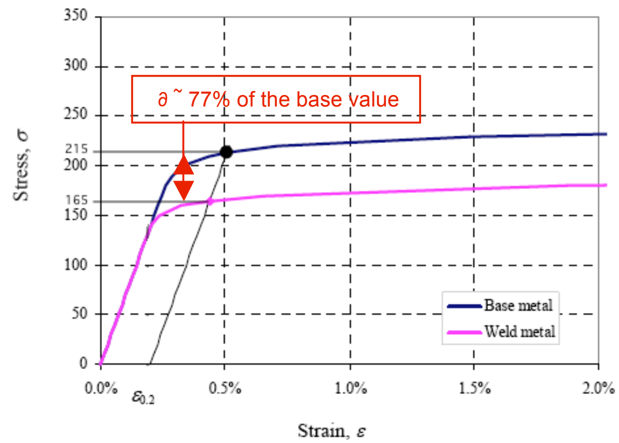


Fig.1 Stress-strain curves of base metal and weld metal of 5083-H116

Table 1

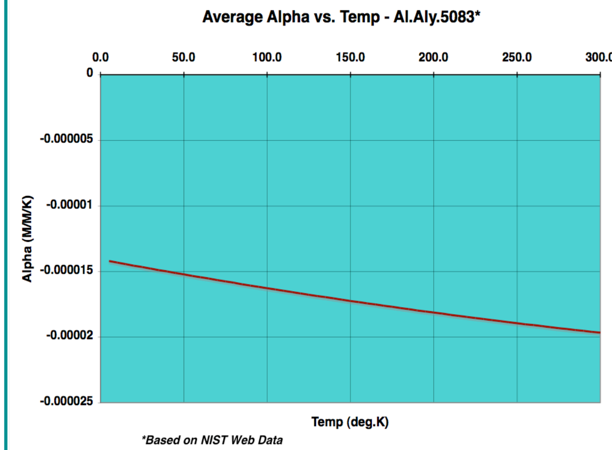
Typical Tensile Strength Properties of Groove Welds

Non-Heat Treatable Alloys

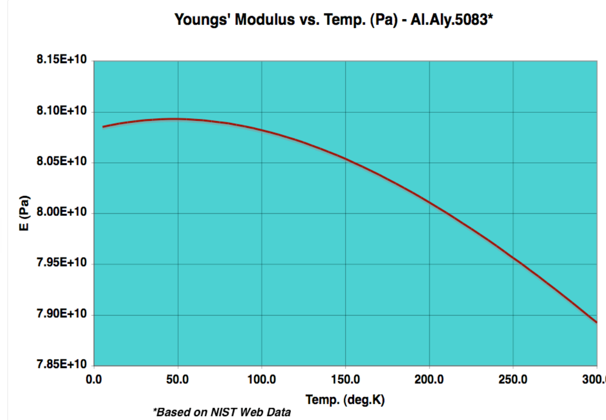
Base Alloy & Temper	Base Alloy Tensile Strength - ksi	As welded Tensile Strength - ksi
1060-H18	19	10
5052-H32	33	27
5052-H39	42	27
5086-H34	47	38
5086-H38	53	38
5083-H116	46	43
3003-H34	35	16
3004-H38	41	24

Weld efficiencies for 5083 are generally >75%

Material Properties @77 K



Alpha (secant) = 1.63E-5 /deg.K



E = 80.8 Gpa -Youngs' modulus

Sm = 12.0ksi (82.7MPa) for R.T. H0 or H112 per ASME Section II-Table 2B (1992)

-code based on a very low minimum yield of only 18 ksi

Minimum R.T. yield for Al.Aly. 5083-H32 is 31 ksi (213 Mpa) with 10% minimum elongation per the ABS* Table 1

Minimum R.T. yield strength for welds (using 5183 filler rod) is 24 ksi (165 Mpa)

TABLE 1
Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys (6, 7)

Mechanical test specimens are taken as detailed in 2-5-5/5.

Designations based on the Aluminum Association. Temper conditions are defined in EN515 or ANSI H35.1

Alloy and Temper	*Thickness* (1)		*Ultimate Tensile Strength kgf/mm² (ksi)*		*Yield Strength 0.2% Offset kgf/mm² (ksi)*		*Minimum Elongation* (2) *in 50 mm (2 in.)*
	millimeters	*(inches)*	*minimum*	*maximum*	*minimum*	*maximum*	*percent*
5052-O	3.0–6.4 6.6–75.0	(0.114–0.249) (0.250–3.000)	17.6 (25.0) 17.6 (25.0)	21.8 (31.0) 21.8 (31.0)	6.7 (9.5) 6.7 (9.5)		20 18
5052-H32	3.0–6.5 6.6–12.5 12.6–51.0	(0.114–0.249) (0.250–0.499) (0.500–2.000)	21.8 (31.0) 21.8 (31.0) 21.8 (31.0)	26.7 (38.0) 26.7 (38.0) 26.7 (38.0)	16.2 (23.0) 16.2 (23.0) 16.2 (23.0)		9 11 12
5052-H34	3.0–6.5 6.6–25.0	(0.114–0.249) (0.250–1.000)	23.9 (34.0) 23.9 (34.0)	28.8 (41.0) 28.8 (41.0)	18.3 (26.0) 18.3 (26.0)		7 10
5052-H112	6.5–12.5 12.6–51.0 51.1–75.0	(0.250–0.499) (0.500–2.000) (2.001–3.000)	19.7 (28.0) 17.6 (25.0) 17.6 (25.0)		11.2 (16.0) 6.7 (9.5) 6.7 (9.5)		7 12 16
5059-0	3.0–50	(0.114–1.968)	33.6 (47.7)		16.3 (23.2)		24
5059 H111	3.0–50	(0.114–1.968)	33.6 (47.7)		16.3 (23.2)		24
5059-H116	3.0–20 20.1–50	(0.114– 0.787) (0.788–1.968)	37.7 (53.5) 36.7 (52.1)		27.5 (39.1) 26.5 (37.6)		10 10
5059-H321	3.0–20 20.1–50	(0.114–0.787) (0.788–1.968)	37.7 (53.5) 36.7 (52.1)		27.5 (39.1) 26.5 (37.6)		10 10
5083-O	1.3–38.0 38.1–76.5	(0.051–1.500) (1.501–3.000)	28.1 (40.0) 27.4 (39.0)	35.9 (51.0) 35.2 (50.0)	12.7 (18.0) 12.0 (17.0)	20.4 (29.0) 20.4 (29.0)	16 16
5083-H112	6.5–38.0 38.1–76.5	(0.250–1.500) (1.501–3.000)	28.1 (40.0) 27.4 (39.0)		12.7 (18.0) 12.0 (17.0)		12 12
5083-H116 (3)	1.6–38.0 38.1–76.5	(0.063–1.500) (1.501–3.000)	30.9 (44.0) 28.8 (41.0)		21.8 (31.0) 20.4 (29.0)		10 10
5083-H321)	1.6–38.0 38.1–76.5	(0.063–1.500) (1.501–3.000)	30.9 (44.0) 28.8 (41.0)		21.8 (31.0) 20.4 (29.0)		10 10
5083-H323	1.5–3.0 3.1–6.5	(0.051–0.125) (0.126–0.249)	31.6 (45.0) 31.6 (45.0)	38.0 (54.0) 38.0 (54.0)	23.9 (34.0) 23.9 (34.0)	30.9 (44.0) 30.9 (44.0)	8 10
5083-H343	1.5–3.0 3.1–6.5	(0.051–0.125) (0.126–0.249)	35.2 (50.0) 35.2 (50.0)	41.5 (59.0) 41.5 (59.0)	27.4 (39.0) 27.4 (39.0)	34.4 (49.0) 34.4 (49.0)	6 8
5383-O	3.0–50	(0.114–1.968)	29.0 (42.1)		14.5 (21.0)		17
5383-H111	3.0–50	(0.114–1.968)	29.0 (42.1)		14.5 (21.0)		17
5383-H116	3.0–50	(0.114–1.968)	30.5 (44.2)		22.0 (31.9)		10
5383-H321	3.0–50	(0.114–1.968)	30.5 (44.2)		22.0 (31.9)		10
5383-H34	3.0–25	(0.114–1.000)	34.0 (49.3)		27.0 (39.2)		5
5086-O	1.5–6.5 6.5–51.0	(0.051–0.249) (0.250–2.000)	24.6 (35.0) 24.6 (35.0)	30.9 (44.0) 30.9 (44.0)	9.8 (14.0) 9.8 (14.0)		18 16
5086-H112	4.5–12.5 12.6–25.5 25.6–51.0 51.1–76.5	(0.188–0.499) (0.500–1.000) (1.001–2.000) (2.001–3.000)	25.3 (36.0) 24.6 (35.0) 24.6 (35.0) 23.9 (34.0)		12.7 (18.0) 11.2 (16.0) 9.8 (14.0) 9.8 (14.0)		8 10 14 14
5086-H116 (3)	1.5–6.5 6.6–51.0	(0.063–0.249) (0.250–2.000)	28.1 (40.0) 28.1 (40.0)		19.7 (28.0) 19.7 (28.0)		8 10
5454-O	3.0–76.5	(0.114–3.000)	21.8 (41.0)	28.8 (41.0)	8.4 (12.0)		18
5454-H32 (4,5)	1.5–6.5 6.6–51.0	(0.051–0.249) (0.250–2.000)	25.3 (36.0) 25.3 (36.0)	30.9 (44.0) 30.9 (44.0)	18.3 (26.0) 18.3 (26.0)		8 12
5454-H34 (4,5)	4.0–6.5 6.6–25.5	(0.162–0.249) (0.250–1.000)	27.4 (39.0) 27.4 (39.0)	33.0 (47.0) 33.0 (47.0)	20.4 (29.0) 20.4 (29.0)		7 10
5454-H112 (5)	6.5–12.5 12.6–51.0 51.1–76.5	(0.250–0.499) (0.500–2.000) (2.001–3.000)	22.5 (32.0) 21.8 (31.0) 21.8 (31.0)		12.7 (18.0) 8.4 (12.0) 8.4 (12.0)		8 11 15
5456-O	1.5–38.0 38.1–76.5	(0.051–1.500) (1.501–3.000)	29.5 (42.0) 28.8 (41.0)	37.3 (53.0) 36.6 (52.0)	13.4 (19.0) 12.7 (18.0)	21.1 (30.0) 21.1 (30.0)	16 16

ABS RULES FOR MATERIALS AND WELDING – ALUMINUM AND FIBER REINFORCED PLASTICS (FRP) • 2006 21

Table 1 Mechanical property of aluminum alloys, ref. ABS (2003)

TABLE 2
Minimum Mechanical Properties for Butt-Welded Aluminum Alloys

The adoption of test values higher than given in this table will be subject to special consideration. Filler wires are those recommended in 2-5-A1/Table 3. Values shown are for welds in plate thicknesses up to 38 mm (1.5 in.) unless otherwise noted.

Alloy	*Ultimate Tensile Strength* (U_{al})	*Yield Strength* (Y_{al}) (2)	*Shear Strength* (τ_{al}) (2)
	N/mm² (psi)	*N/mm² (psi)*	*N/mm² (psi)*
5083-H111	269 (39000)	145 (21000)	83 (12000)
5083-H116, H321	276 (40000)	165 (24000)	96 (14000)
5083-H323, H343	276 (40000)	165 (24000)	96 (14000)
5086-H111	241 (35000)	124 (18000)	69 (10000)
5086-H112 6 mm (0.25 in.) –12 mm (0.50 in.)	241 (35000)	117 (17000)	65 (9500)
5086-H112 12 mm (0.5 in.) –25 mm (1.0 in.)	241 (35000)	110 (16000)	62 (9000)
5086-H112 Greater than 25 mm (1.0 in.)	241 (35000)	96.5 (14000)	55 (8000)
5086-H32, H34, H116	241 (35000)	131 (19000)	76 (11000)
5383-O, H111	290 (42000)	145 (21000)	83 (12000)
5383-H116, H321	290 (42000)	165 (24000) (3)	83 (12000)
5383-H34	290 (42000)	145 (21000)	83 (12000)
5454-H111	214 (31000)	110 (16000)	65 (9500)
5454-H112	214 (31000)	83 (12000)	48 (7000)
5454-H32, H34	214 (31000)	110 (16000)	65 (9500)
5456-H111	283 (41000)	165 (24000)	96 (14000)
5456-H112	283 (41000)	131 (19000)	76 (11000)
5456-H116, H321	290 (42000)	179 (26000)	103 (15000)
5456-H323, H343	290 (42000)	179 (26000)	103 (15000)
6061-T6(1) under 9.5 mm (0.375 in.)	165 (24000)	138 (20000)	83 (12000)
6061-T6(1) over 9.5 mm (0.375 in.)	165 (24000)	103 (15000)	62 (9000)

Notes:

1 Values when welded with 4043, 5183, 5356 or 5556 filler wire.

2 Yield and shear strength is not required for weld procedure qualification.

3 Yield strength values as high as 185 N/mm² (27000 psi) have been satisfactorily demonstrated and statistically verified.

19% increase in base metal yield

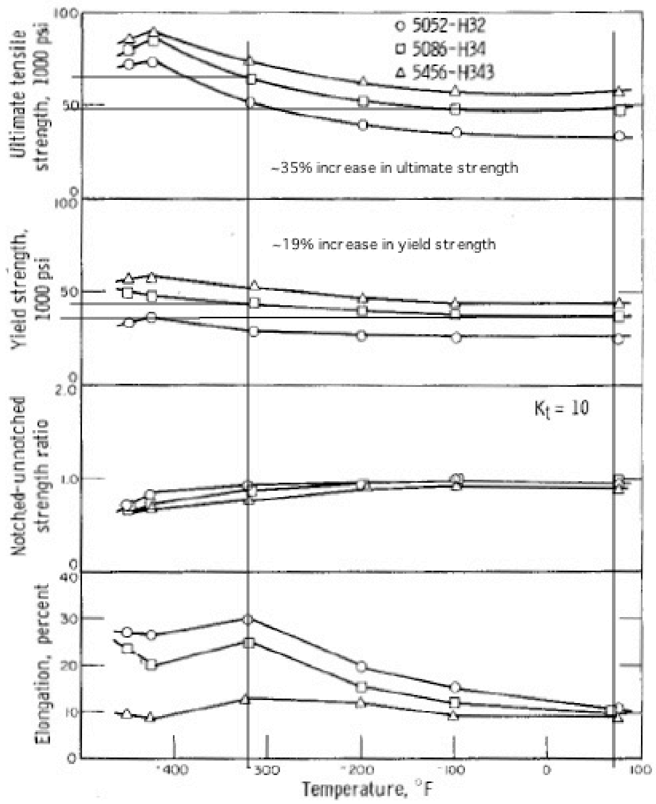


FIGURE 9.—Tensile properties of 5000 series aluminum alloys in the H3X condition.
From NASA Sp-5012 "Effects of Low Temperature on Structural Metals"

12% increase in weld yield strength

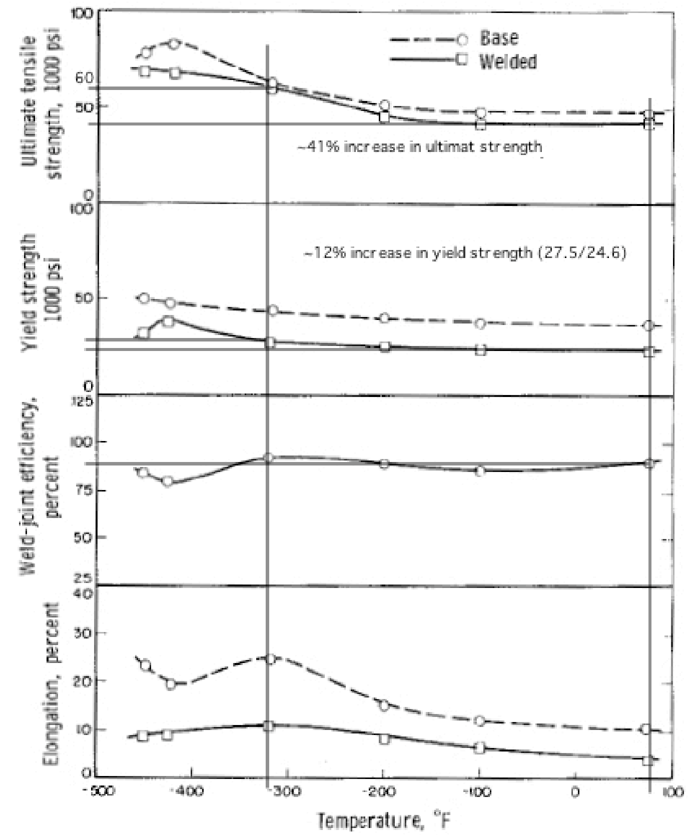


FIGURE 11.—Effect of welding on the tensile properties of 5086 aluminum alloy in the H34 condition.
From NASA SP-5012 "Effects of Low Temperatures on Structural Metals"

Data Comparison of R.T. to 77 K material properties for 5xxx series Aluminum

B 209M – 06

TABLE 2 *Continued*

Temper	Specified Thickness, mm		Tensile Strength, MPa		Yield Strength (0.2 % offset), MPa		Elongation, min, %[C]		Bend Diameter Factor, *N*
	over	through	min	max	min	max	in 50 mm	in 5× Diameter ($5.65\sqrt{A}$)	
					Alloy 5083				
O	1.25	6.30	275	350	125	200	16	...	...
	6.30	80.00	270	345	115	200	16	14	...
	80.00	120.00	260	...	110	...	...	12	...
	120.00	160.00	255	...	105	...	...	12	...
	160.00	200.00	250	...	100	...	...	10	...
H112	6.30	12.50	275	...	125	...	12	...	...
	12.50	40.00	275	...	125	...	...	10	...
	40.00	80.00	270	...	115	...	...	10	...
H32	3.20	5.00	305	385	215	295	10	...	...
	5.00	12.50	305	385	215	295	12	...	...
	12.50	40.00	305	385	215	295	...	10	...
	40.00	80.00	285	385	200	295	...	10	...
F[E]	6.30	200.00	...	...	...	...	...	...	...

Proposed* 77 deg.K allowable based on 10% increase in yield strength:

Sy-base-min. = 236MPa ---> Sm = 157 Mpa (2/3rd min. spec. yield @temperature)

Sy-weld/haz = 153MPa ---> Sm = 110 Mpa (using 70% efficiency of base value)

* To be confirmed by tensile test specimens

Based on NCSX design criteria, using Sm = 157 Mpa, Cooldown + EM stresses

PF 5&6 brackets:

- Primary Membrane Stress for 1.7T EM + thermal = 21.4MPa < Sm (157 MPa)
- Primary + bending for 1.7T + thermal = 107 MPa < 1.5 x Sm (236 MPa)
- Primary + bending + secondary = 193 MPa < 3 x Sm (472 MPa)

PF 4 brackets:

- Primary Membrane Stress for 1.7T EM + thermal = 160 Mpa slightly > Sm
- Primary + bending for 1.7T + thermal = 319 Mpa > 1.5 x Sm (236 Mpa)
- Primary + bending + secondary = 717 Mpa* > 3 x Sm (472 Mpa)

TF brackets:

- Primary Membrane Stress for 1.7T EM + thermal = 96 Mpa < Sm (157 Mpa)
- Primary + bending for 1.7T + thermal = 192 Mpa < 1.5 Sm (236 Mpa)
- Primary + bending + secondary = 863 Mpa* > 3 x Sm (472 Mpa)

* At a weld location

Conclusion of stress analysis:

All supports within allowables for most severe EM operational loads.

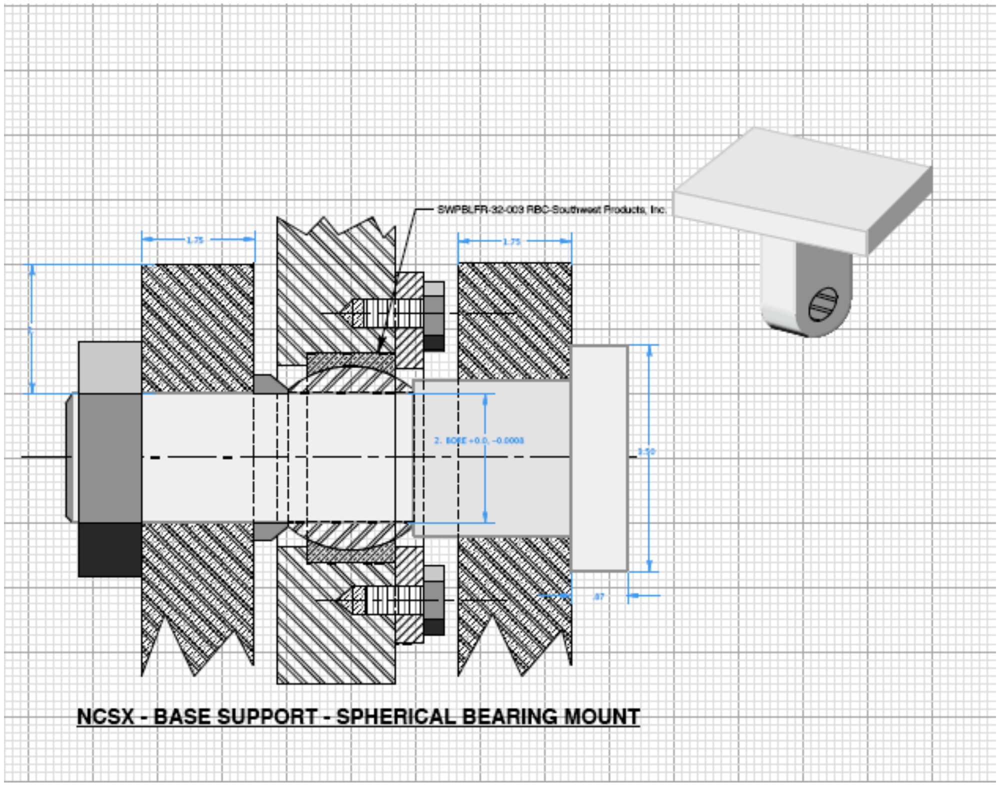
Thermally induced stresses are considered as secondary stresses (ie. Self limiting) and are permitted to reach but not exceed 3 x Sm. Small areas of structure are exceeding secondary stress limits and require further analysis to determine whether they are just an artifact of the FEA model or require more local reinforcement.

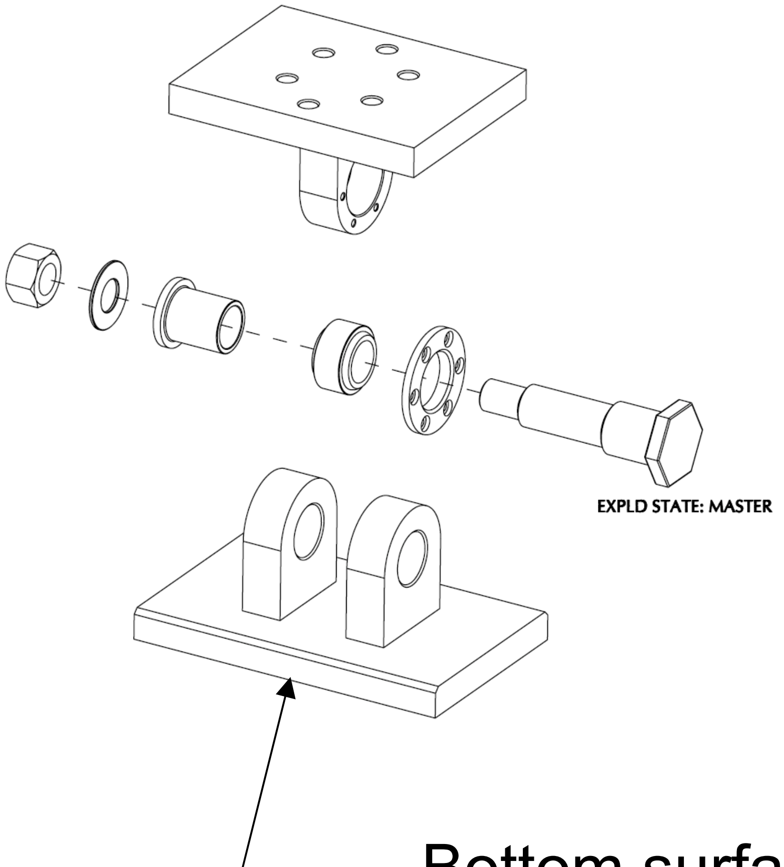
In general, the PF & TF supports are not severely challenged by the highest EM loading.

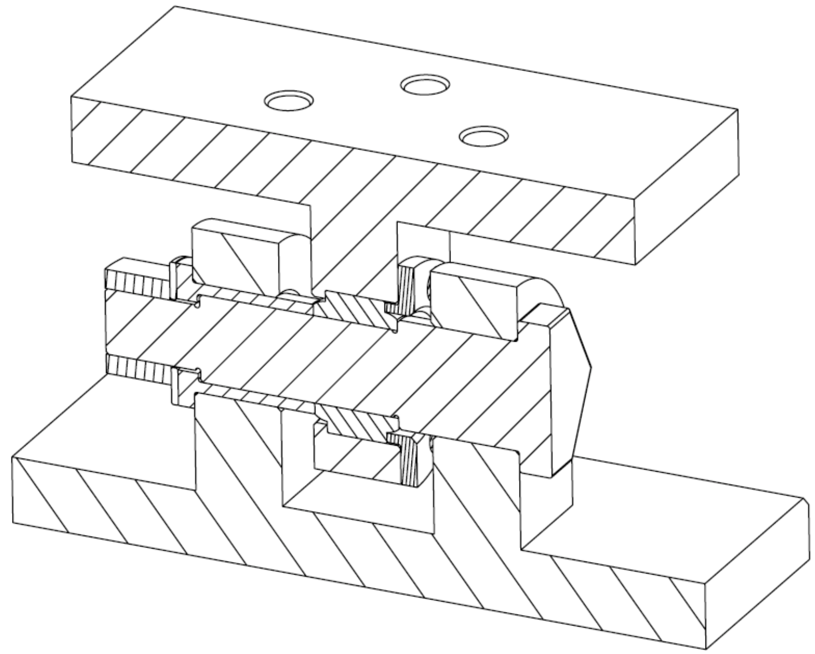
Analysis of the .5T TF only must still be performed to determine the maximum safe operating current for the TF system.

MCWF-Base Support Interface

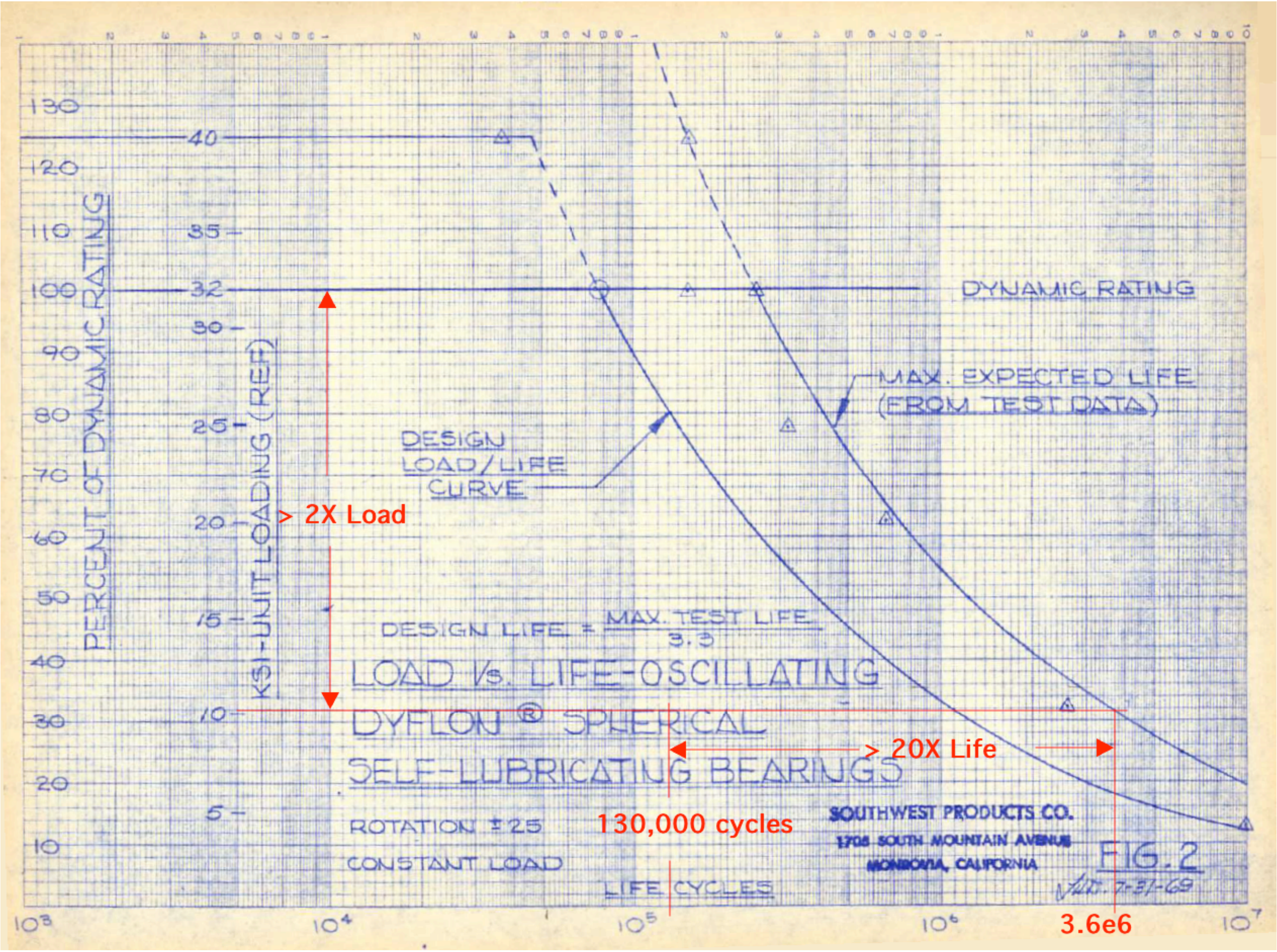
- Clevis - Spherical Bearing Mounts
- Provides 3-axis rotational compliance for MCWF
- Provides radial compliance via radially guided lower clevis/PFTE sliding surfaces
- Carries gravity load to Base Support Structure
- Reacts Seismic Loads
- Non-magnetic (Inconel & Monel materials)
- No lubrication required - Dyflon coat
- Good cryogenic properties (used in NASA space vehicles)
- Dynamic load Limit: 117 kip
- Ult. Static load: 338 kip
- Static Load limit: 270 kip
- Thrust Load Limit: 39 kip





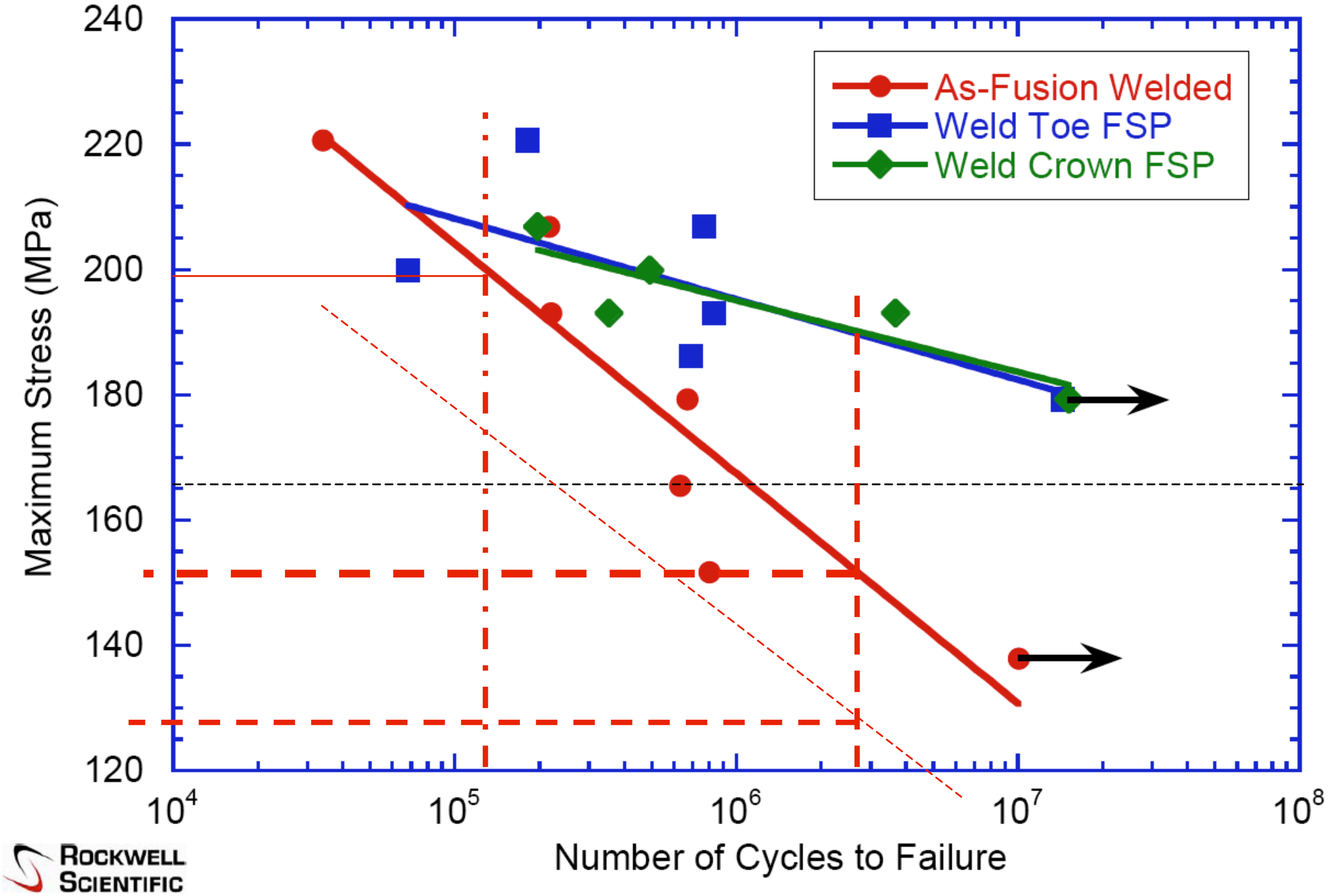


Bottom surface slides on Teflon sheet



Bearing Design Life: Meets GDR-Design Criteria: 2X/20X Requirements

Fatigue Properties-5083/5356



Fatigue Strength (base) 159 Mpa (23000 psi) AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen

Design risks & uncertainties:

• Small risk of cost escalation - bugetary estimates, within budget, are in hand for a majority of parts - no state of the art requirements in this job.

• Small risk of hot cracking welds - specify weld rod, inspections, dye penetrant, repair procedures, etc.

• Must resolve (possible) high thermally induced stress in localized areas of brackets - additional gussets and ribs may be necessary.

WBS Number: 15
WBS Title: Coil Support Structures
Job Number: 1501/1550
Job Title: Coil Support Structures Design
Job Manager: Fred Dahlgren

Uncertainty of the Estimate

	High	Medium	Low	Uncertainty Range (%)	Comments/Other Considerations
Job 1501				-10%/+15%	
Design Maturity		X			Only now approaching PDR stage, however nothing exotic.
Design Complexity			X		Standardized components.
Job 1550				-10%/+15%	
Design Maturity		X			Only now approaching PDR stage, however nothing exotic.
Design Complexity			X		Standardized components.

Other Comments:

There is a finite likelihood of material costs increasing, but already assumed an escalation of ~5%/year for Inconel, HOWEVER, recent history indicates much higher escalation (see Table V)

Possibility that vendor will not deliver on time, however, significant float (~4 months exist off critical path) - however, could impact half-period and full-period assembly schedule if TF brackets delayed => other vendors could be identified.

Note: High/Medium/Low uncertainty assessment from Job Manager. Uncertainty range based on AACEI recommended practice 18R-97 as amended for NCSX.

Schedule Risk:

Procurement of parts not scheduled to start until mid FY'08

Possible long lead items:

RBC-SW spherical bearings (12 months ARO)cost 2.5k$ x 6 = 15k$

Activity ID	MILE-stones (level 2 & 3)	Activity Description	Duration (work days)	Baseline Start	Baseline Finish	Shifts	Total Float	% cmplt	Proposed Budgeted	FY07 FY08 FY09 FY10
Job: 1550 - Coil Struct. Procurement -DAHLGREN										
1501-245		Prep Spec,Solicit Bids, and Evaluate Bids	30	05MAY08	16JUN08		28		0.00	
162-036.9	2	Award Coil Support Structure	0		16JUN08*		28		0.00	
162-037	2	Fabricate TF/MCWF mounting Components	260	17JUN08	01JUL09		28		328,830.26	41=239.73
162-038		Fabricate PF Mounting components	260	17JUN08	01JUL09		28		268,267.82	48=257.06
162-039		Fabricate Final TF Assy components Components	260	17JUN08	01JUL09		28		83,133.18	48=79.657
162-040		Fabricate Machine/base support interface	260	17JUN08	01JUL09		28		92,713.42	48=88.84k ;
162-050		Prep req, bid and award G11/Teflon parts	20	16JUN08*	14JUL08		69		0.00	
162-051		Deliver G11/Teflon parts	90	15JUL08	18NOV08		69		155,701.41	48=150.42$k ;
162-052		Prep req, bid and award Inconnel hardware	20	16JUN08*	14JUL08		69		0.00	
162-053		Deliver Inconnel hardware	90	15JUL08	18NOV08		69		107,848.23	48=104.19$k ;
162-055		Prep req, bid and award Belleville Washers	20	16JUN08*	14JUL08		69		0.00	
162-057		Deliver Belleville Washers	90	15JUL08	18NOV08		69		25,106.83	41=18.695$k ;
162-031		Title III engr WBS 151	260	17JUN08*	01JUL09		813	LOE	14,151.47	EA/EM =75hr ;
Subtotal			290	05MAY08	01JUL09		813		1,075,752.62	

Schedule - design activities:

Activity ID	MILE-stones (level 2 & 3)	Activity Description	Duration (work days)	Baseline Start	Baseline Finish	Shifts	Total Float	% cmplt	Proposed Budgeted	FY07 FY08 FY09
15 - Coil Structures										
Job: 1501 - Coil Structures Design-DAHLGREN										
1501-521		Complete Preliminary Stress analysis	11	04JUN07*	18JUN07		171		12,196.10	EA//EM =70hr ;
1501-522		Prelim CAD models & Dwgs	30	04JUN07*	16JUL07		149		27,876.80	ea//dm=160
1501-525		PDR Prep	3	17JUL07	19JUL07		149		3,484.60	EA//EM =10hr ; EA//DM =10 ;
1501-525P	3	PDR	1	20JUL07*	20JUL07		149		1,393.84	EA//EM =04hr ; EA//DM =04 ;
1501-533		Detail CAD Drawings,BOM	40	23JUL07	17SEP07		149		59,238.20	EA//EM =20hr ; EA//DM =320 ;
1501-533F		Integrated Stress Analysis	40	23JUL07	17SEP07		149		41,815.20	EA//EM =240hr ;
1501-537		FDR Prep	3	18SEP07	20SEP07		149		2,613.45	EA//EM =10hr ; EA//DM =05 ;
1501-541	3	FDR Coil Structures	1	21SEP07	21SEP07		149		1,393.84	EA//EM =04hr ; EA//DM =04 ;
1501-545		Resolve Chits	20	24SEP07	19OCT07		149		7,315.10	EA//EM =20hr ; EA//DM =20 ;
1501-549		Update C.S.Support Design	10	24SEP07	05OCT07		154		10,799.70	EA//EM =20hr ; EA//DM =40 ;
1501-550		Peer Review Updated C.S.Design	3	08OCT07	10OCT07		154		1,486.08	EA//EM =04hr ; EA//DM =04 ;
1501-554		Resolve Chits from peer review	2	11OCT07	12OCT07		154		7,430.40	EA//EM =08hr ; EA//DM =08 ;
1501-558		Prepare requisition for Coil Structure & CSS h/w	10	22OCT07	02NOV07		149		743.04	EA//EM =04hr ;
1501-562		Prepare Specs for Coil Structure & CSS h/w	10	15OCT07	26OCT07		154		1,857.60	EA//EM =10hr ;
ECP53RBX09		FY07 Rebaseline exercise	22*	01MAY07*	31MAY07		1,333	LOE	6,969.20	ORNLEM =40hr ;
Subtotal			131	01MAY07	02NOV07		1,224		186,613.15	

Chits from peer review:

1	Coil structure rests on cover plate for an existing building penetration. A structure will be needed to carry loads to the building structure [Perry] A: out of scope – to be addressed at base support structure review
2	New design of coil structures will increase cost and schedule required for final assembly due to the extra steps required. These increases should be estimated and added to project plans. 1) more coil handling at final assembly, 2) FPA sled supports removed during final assembly and replaced by new design. 3) many of the new supports will need additional structures to bridge existing floor penetrations. [Perry] A: out of scope – to be addressed at base support structure review
3	Interface with base support structure (p13) should have sliding joints at tops of columns. Columns pinned top and bottom will change elevation when lateral motion occurs. [Perry] A: The present base support interface has sliding surfaces & rotational compliance.
4	For tension ring allow access to TF coil radial pre-load nuts after assembly. [Kalish] A: There is access until the CS assembly is in place.
5	TF coil analysis had different restraints revisit analysis stress, deflection, error field, and fatigue. [Kalish] A: Myatts' analysis must be re-visited
6	This design seems to provide less toroidal stiffness than the original design. It may increase the shear loadings at the modular coil bolted joints. [HM Fan] A: This should be addressed with the full integrated machine model (HMFan)

7	Consider whether it is advantageous to incorporate the new PF ring support as part of the PF coil case. [Kalish] A: Not necessary
8	Vertical restraint of the TF coils is important to reduce coil stress with combined field, My memory of the earlier analysis is that this is required for the TF to give significant flexibility. [Zarnstorff] A: Vertical restraints are provided via brackets attached to the MCWF
9	Consider supporting PFS CFF more than C-Feet only, to reduce ˜ 80º separation between supports. [Zarnstorff] A: Additional supports have been provided where no interferences with bus leads exist
10	Examine earlier analysis of field errors. Due to vertical asymmetric TF mounting. [Zarnstorff] A: ?
11	Vertical alignment of the CS to the MC's must be controlled, suggest aligning it after cooldown using magnetic measurements and adjusting the height of the post. [Zarnstorff] A: CS assembly is mounted on top of TF wedges & shim washers are adjustable
12	What aligns CS and structure to MC and TF's in radial direction? Possible solution align CS and PF's to TF structure, and the TF Array to the MC's. [Zarnstorff] A: All structural brackets will be aligned to fiducials on MCWF
13	How will the TF array stay aligned with the MC array? By sticking of the sliding joints during pulses, the coils could wedge in the "key-ways" allowing the TF array to mis-align due to bending of the coils, recommend adding mechanism to control position of TF reaction ring to MC's [Zarnstorff] A: The TF coils mount directly on the MCWF which, once tightened, will not permit any slippage.

14	New TF reaction ring shorts the full OH flux swing. How much current flows due to the Loop Voltage ~ 1V? How much heating of the ring? Make of highest resistivity material or introduce breaks. [Zarnstorff] A: TF Pre-load ring is Inconel 601 with high resistivity. A.Brooks determined that the eddy currents were acceptable.
15	Stresses and deflections of the TF coil shall be checked again because the support conditions are slightly different and the PF's and PF-6 loads are conditions added on the TF coils. [HM Fan] A: The present analysis suggests lower TF stresses with this support configuration. A detailed re-visit of Myatts' hybrid model will be needed to insure this. The PF6 loads are now transmitted to the MCWF through the brackets not through the TF coils.
16	Control coils need to be considered. 2) Utility headers need to be mounted somewhere else now that structure is eliminated. [Brown] A: out of scope
17	Consider coil fault conditions in the design of the structure. [Dudek] A: Fault conditions need to be defined by the project & addressed at the FDR

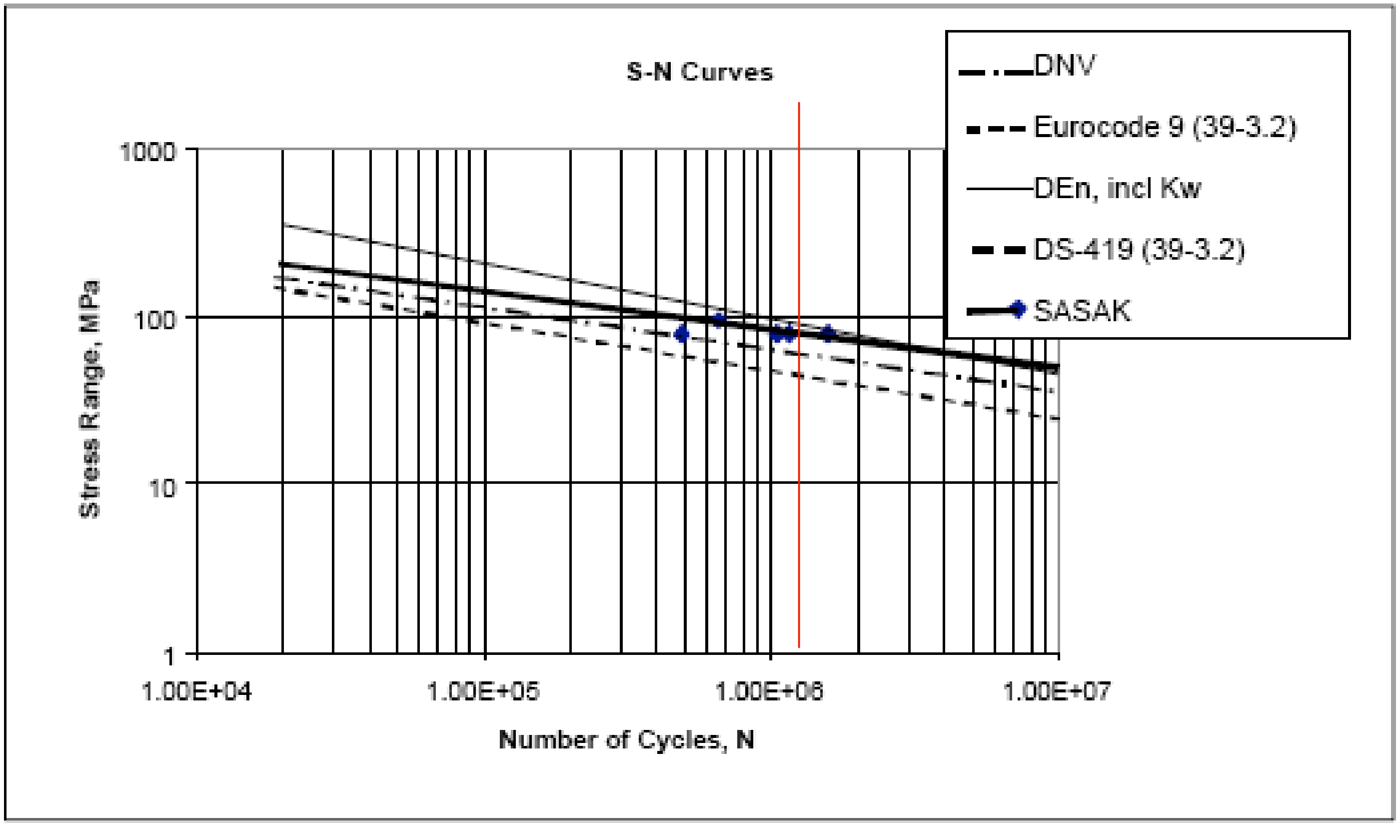


Figure 12: SN-curves obtained by DNV, Eurocode , curve form UK Department of Energy (DEn), DS-419 and the curve obtained by the present experiments.
Please note that Eurocode and DS-419 are coincidenting.

The Eurocode gives HAZ softening factors. For a “H” hardened 5XXX alloy the reduction is 0.86 for MIG welding.

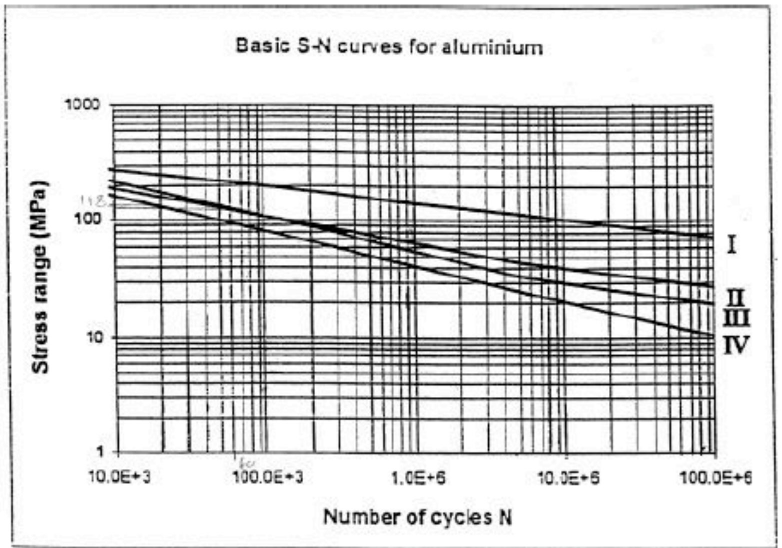


Figure C1: The DNV SN curve for aluminium [4]

S-N Curve	Material	N≤5 10⁶		N>5 10⁶	
		log a	m	log a	m
I	Base Material*	21.1	7	21.10	7
II	Welded joint*	13.82	4.32	17.12	6.32
III	Welded joint*	11.87	3.37	14.94	5.37
IV	Welded joint in corrosive enviroment	11.44	3.37	11.44	3.37

** Non corrosive enviroment*

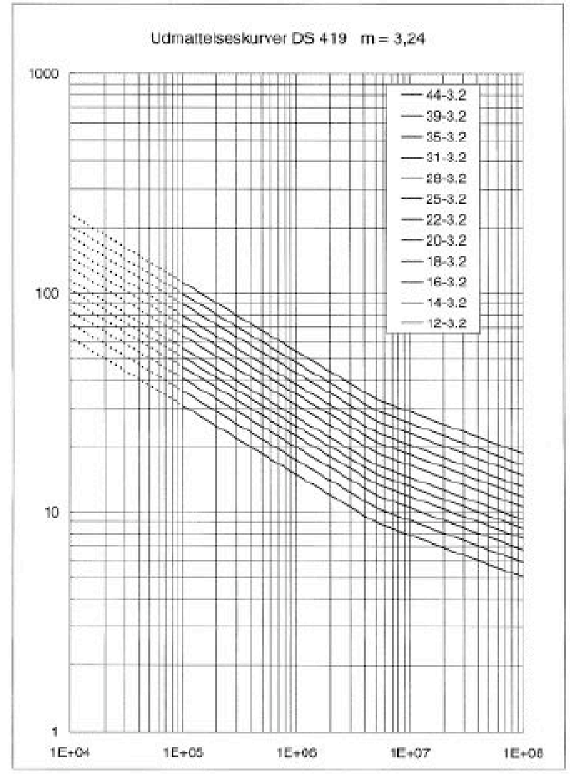


Figure C5: SN curve from DS 419, the Danish aluminium Standard.

The numbers in Figure C5 relates to Reference fatigue strength at 2 million cycles (normal stress) and Inverse slope of the log-log fatigue strength curve. For the Detail category please refer to Eurocode 9, [6].