NSTX TF OUTER LEG ANALYSIS

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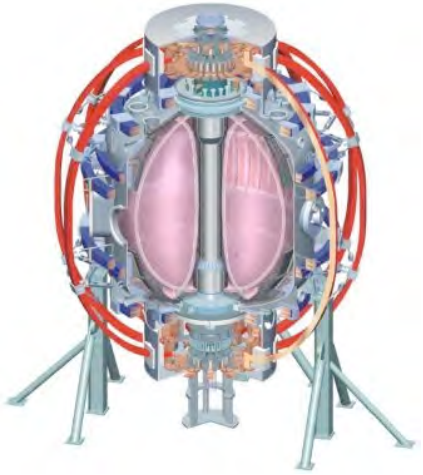
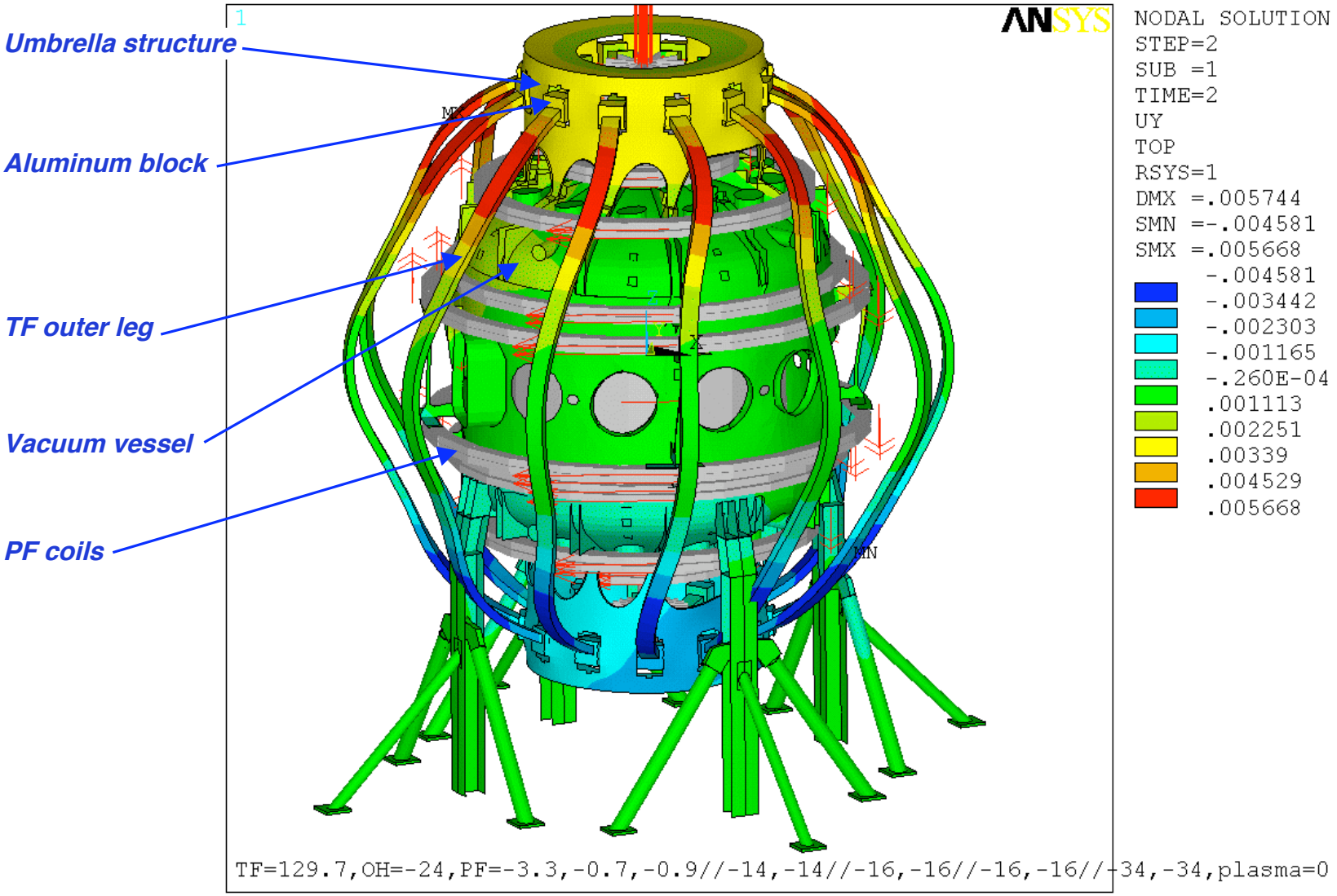
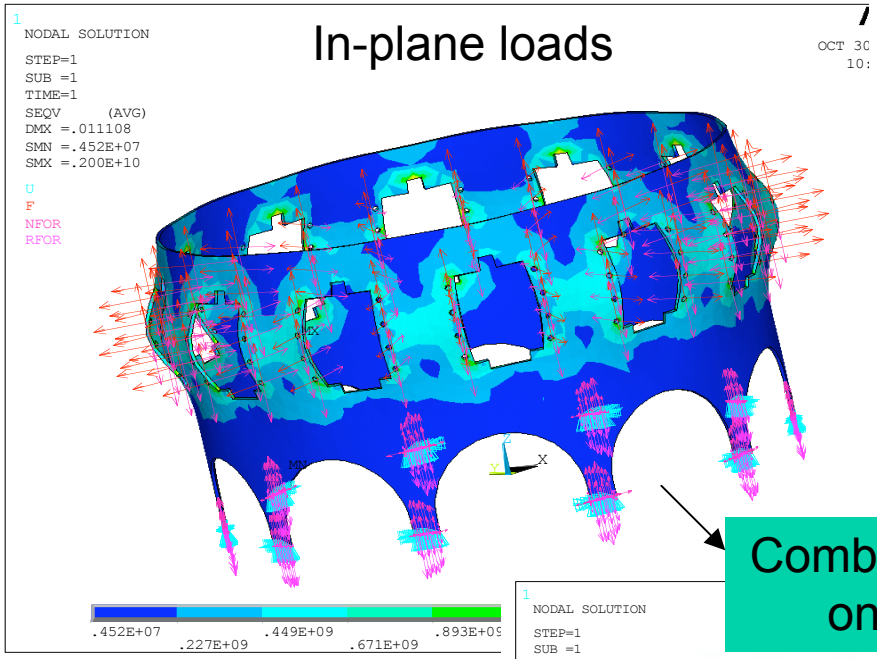
NSTX Center Stack Upgrade Peer Review
LSB, B318
August 13, 2009

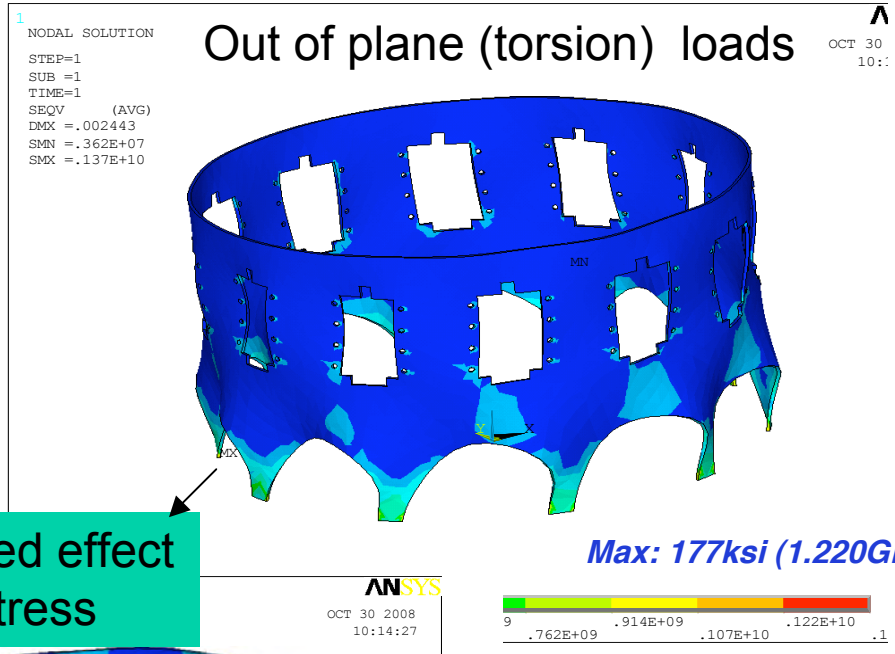



Umbrella structure
Aluminum block
TF outer leg
Vacuum vessel
PF coils
1
ANSYS
NODAL SOLUTION
STEP=2
SUB =1
TIME=2
UY
TOP
RSYS=1
DMX =.005744
SMN =-.004581
SMX =.005668
-.004581
-.003442
-.002303
-.001165
-.260E-04
.001113
.002251
.00339
.004529
.005668
MX
MN
TF=129.7,OH=-24,PF=-3.3,-0.7,-0.9//-14,-14//-16,-16//-16,-16//-34,-34,plasma=0

In-plane loads

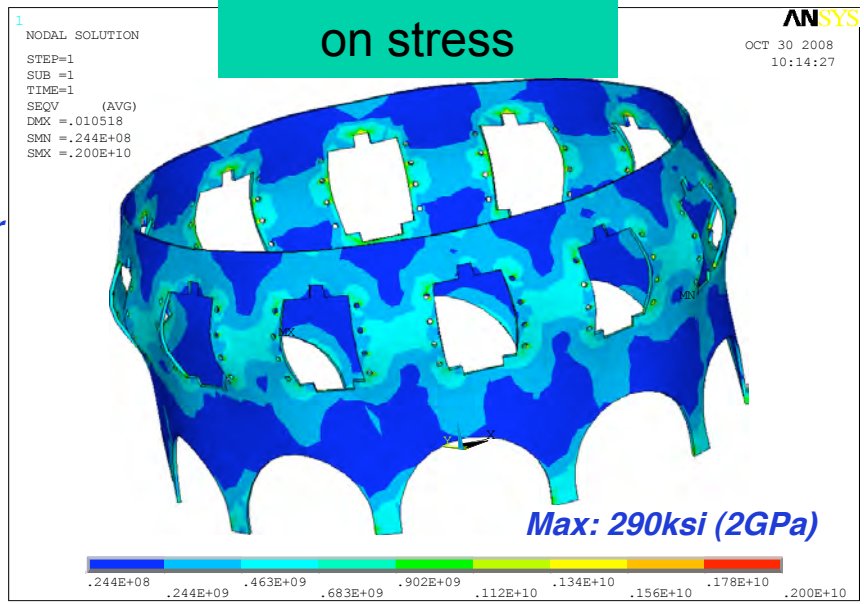


Out of plane (torsion) loads



Max: 177ksi (1.220GPa)

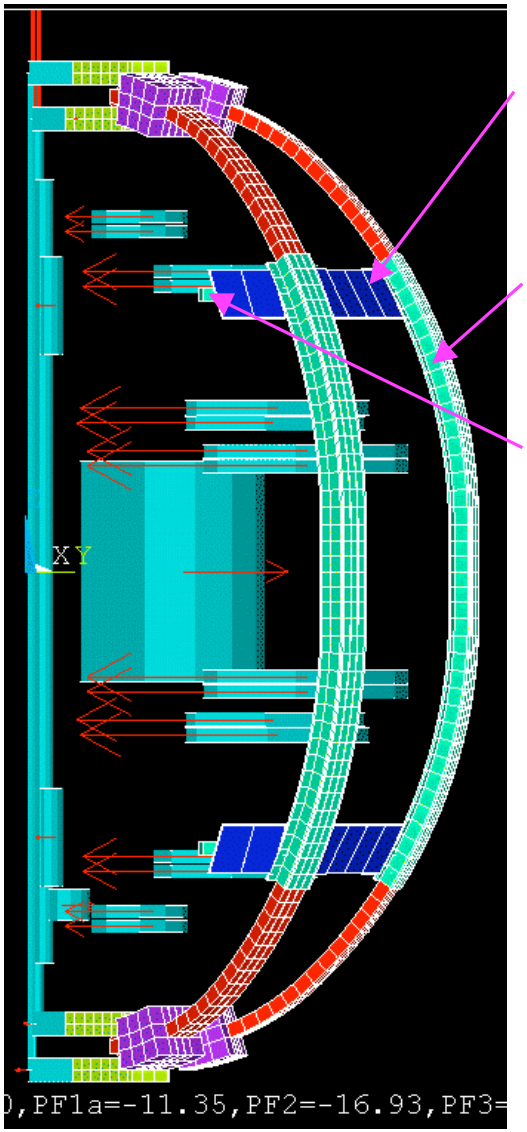
Combined effect on stress



Max: 290ksi (2GPa)

Stresses increase in the umbrella structure due to higher electromagnetic loads on the outer TF legs.

Additional truss should be added to take some in-plane and out-of-plane loads.



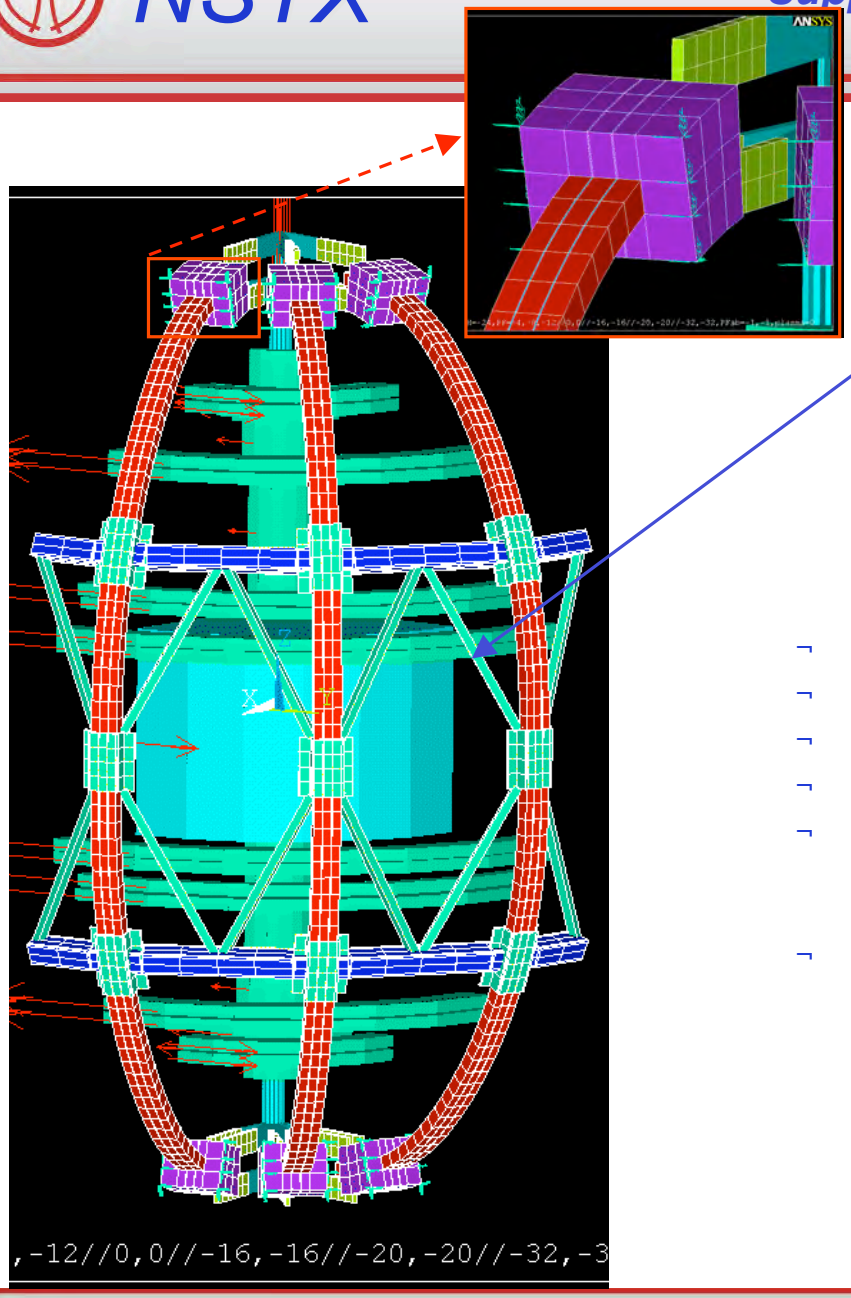
Stainless steel rings are added to take the in-plane force.

But how to take the out-of-plane load is still problematic:

Idea 1: adding stainless steel case to increase the stiffness of the TF coil and tie bars linked to vacuum vessel to take the load.

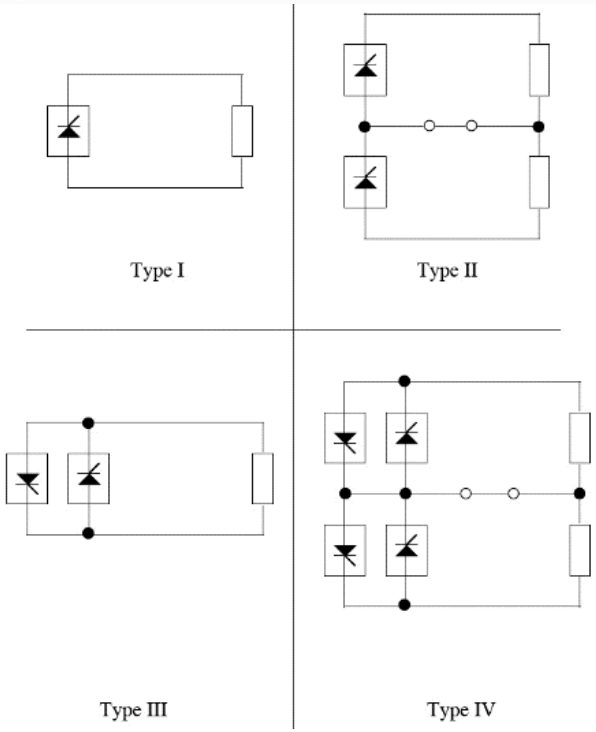
Tie bars

- *Analysis is done with symmetric PF current*
- *Stainless steel case is not effective*
- *Total force at the Al. block reduced by 20%*
- *Out-of-plane force at the Al. block reduced by 36% (from 166KN to 106KN)*
- *Vertical force increased from 11KN to 45KN.*
- *But the tie bars will constrain the coil during vacuum vessel bake out*



Idea 2: adding diamond bracing to take the out-of-plane load and there is no link to vacuum vessel.

- *Analysis is done with symmetric PF current*
- *Total force at the Al. block reduced by 17%*
- *Out-of-plane force at the Al. block reduced by 39%*
- *in-plane force increased by 7.6%*
- *However, the machine has a lot of ports and diamond bracing cannot be put everywhere. Further study with less diamond bracing is carried out*
- *Diamond bracing cannot take effect with global theta rotation. Additional structure should be added to prevent global rotation upon asymmetric PF current.*



Type I: unipolar, upper and lower coils in series (PF4, PF5)

Type II: unipolar, midpoint connection between upper and lower coils allowing difference current (PF2)

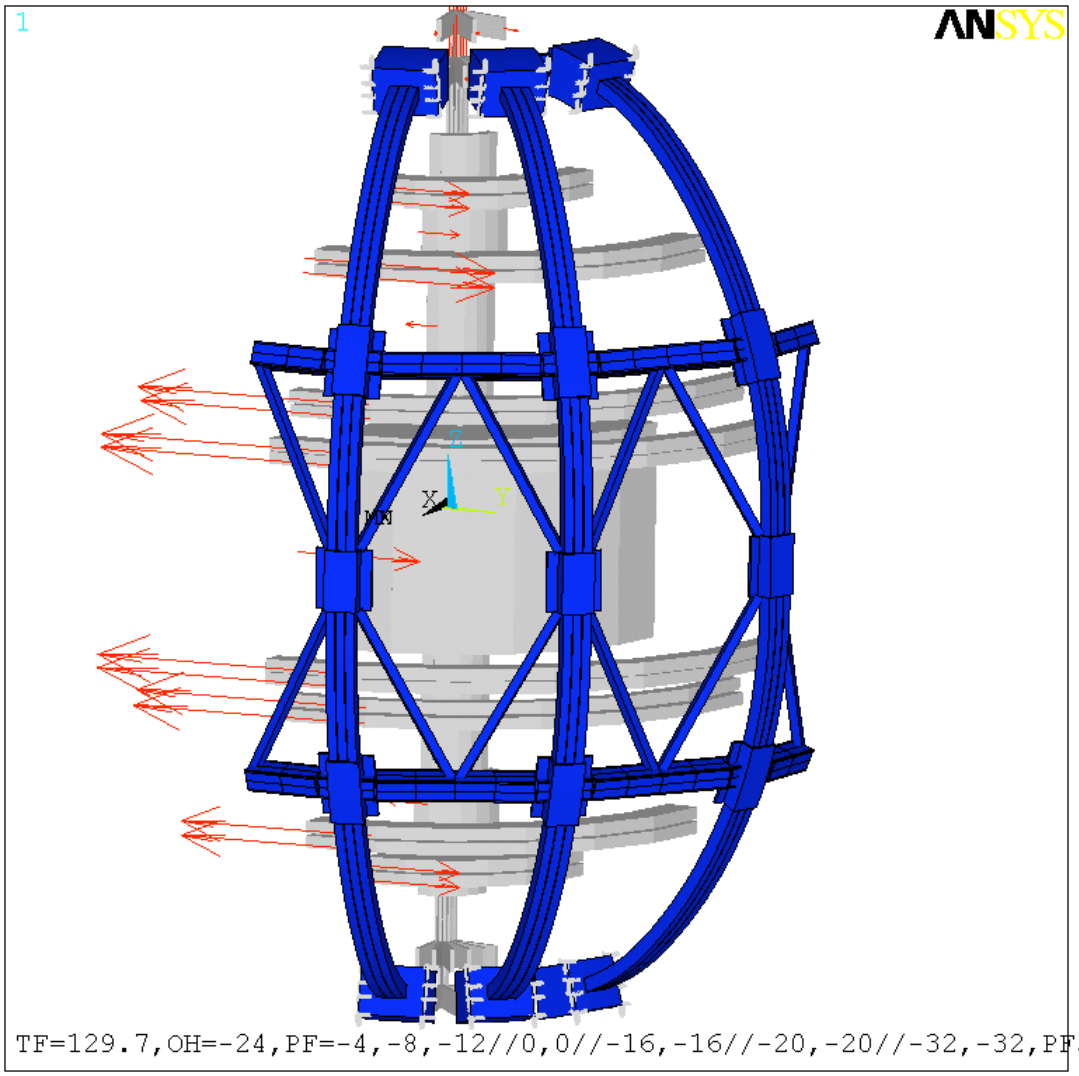
Type III: bipolar, upper and lower coils in series (OH)

Type IV: bipolar, midpoint connection between upper and lower coils allowing difference current (PF1a, PF1b, PF1c, PF3)

Worst case up-down symmetric currents (no net twist)

Worst case up-down asymmetric currents (large net twist that needs to be reacted against the vessel)

Coil	Turns	Min Curr (kA)	Min Curr (kA-Turn)	Max Curr (kA)	Max Curr (kA-Turn)	worst case symm PF curr (kA-turn)	worst case asym PF curr (kA-turn) upper	lower
OH	508	-24.0	-12191.2	24.0	12191.2	**-12191.2**	**-12191.2**	-12191.2
PF1a	88	-0.7	-58.9	8.1	715.5	**-58.9**	**-58.9**	**715.5**
PF1b	20	-3.6	-71.7	4.2	84.1	**-71.7**	**-71.7**	**84.1**
PF1c	20	-3.1	-62.4	8.2	164.1	**-62.4**	**-62.4**	**164.1**
PF2a	14	0.0	0.0	20.0	280.0	**0.0**	**0.0**	**280.0**
PF2b	14	0.0	0.0	20.0	280.0	**0.0**	**0.0**	**280.0**
PF3a	15	-16.0	-240.0	8.0	120.0	**-240.0**	**-240.0**	**120.0**
PF3b	15	-16.0	-240.0	8.0	120.0	**-240.0**	**-240.0**	**120.0**
PF4b	8	-20.0	-160.0	15.0	120.0	**-160.0**	**-160.0**	**-160.0**
PF4c	9	-20.0	-180.0	15.0	135.0	**-180.0**	**-180.0**	**-180.0**
PF5a	12	-32.0	-384.0	0.0	0.0	**-384.0**	**-384.0**	**-384.0**
PF5b	12	-32.0	-384.0	0.0	0.0	**-384.0**	**-384.0**	**-384.0**



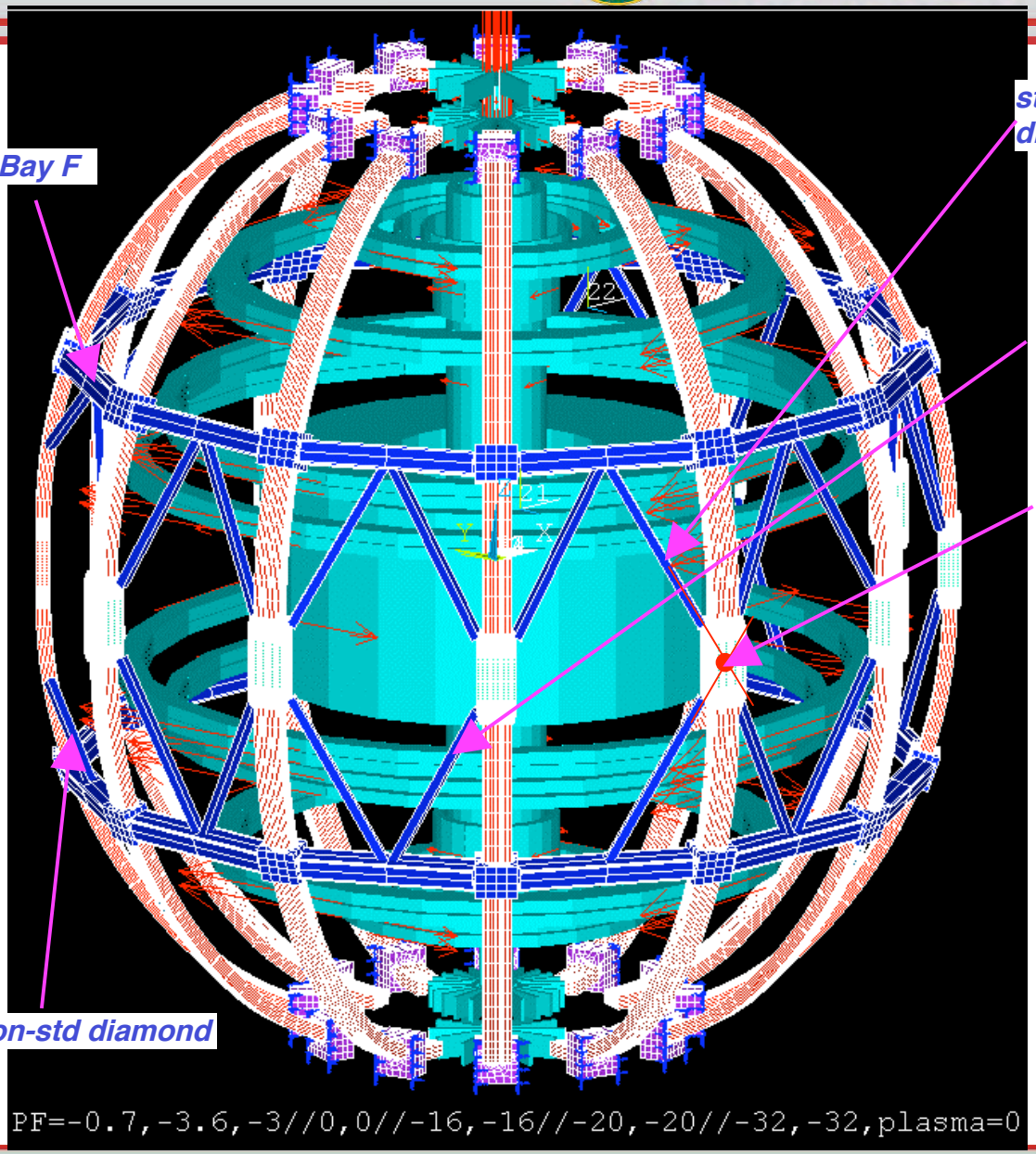
Max theta displacement: 17mm (0.67")

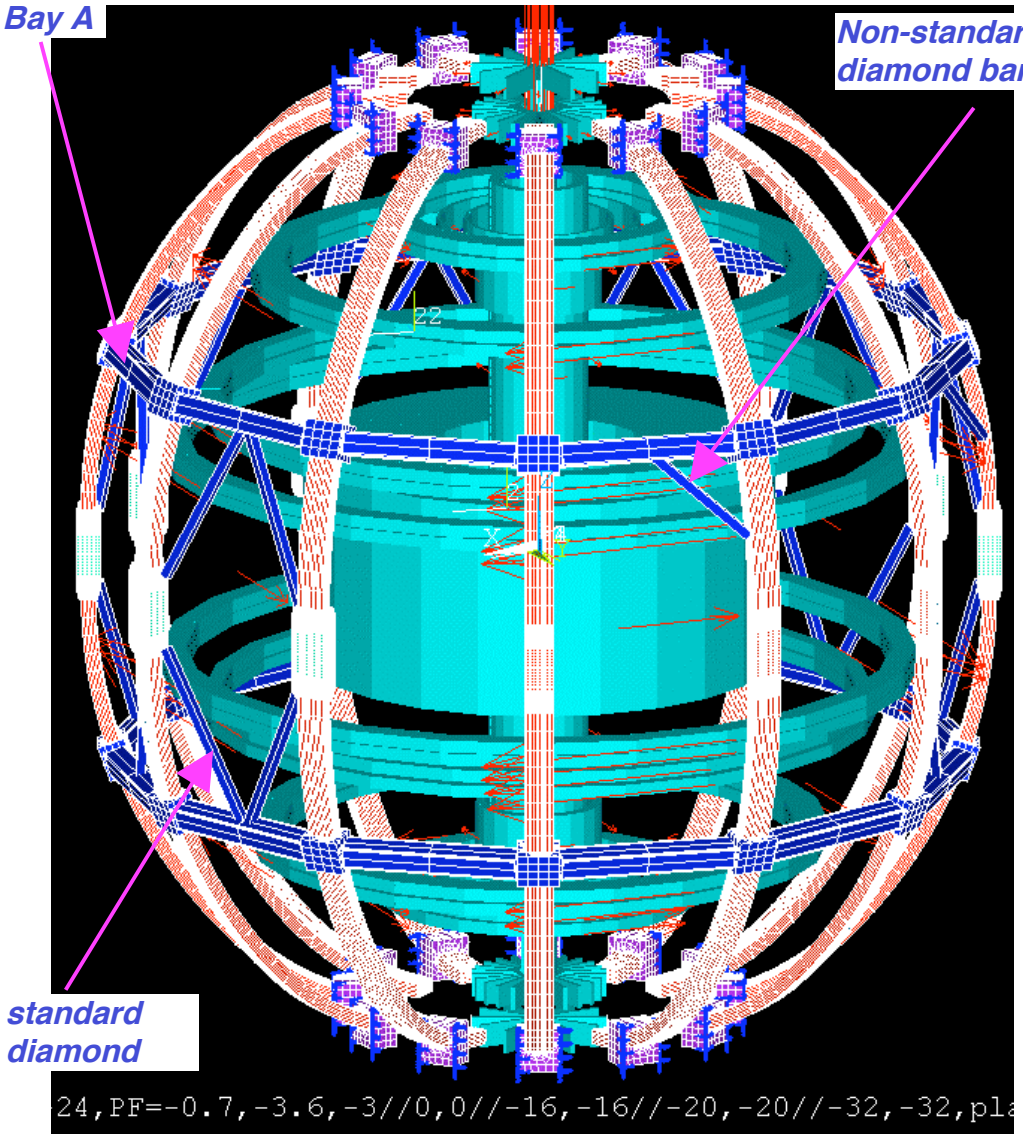
Upon the worst case asymmetric PF current, TF coils have max net twist of 17mm (0.67")

Radius (tangential) rods must be added to prevent this global rotation

Bay	Std diamond, 1,3 upper, 2,4 lower	Non-Std diamond (shorter), 1,3 upper, 2,4 lower
A	3,4	1, 2
B	Y	
C	0	
D	0	3?
E	0	
F	0	1, 3 , 2
G	Y	
H	Y	
I	1, 3, 4	2,
J	Y	
K	3	1,
L	Y	

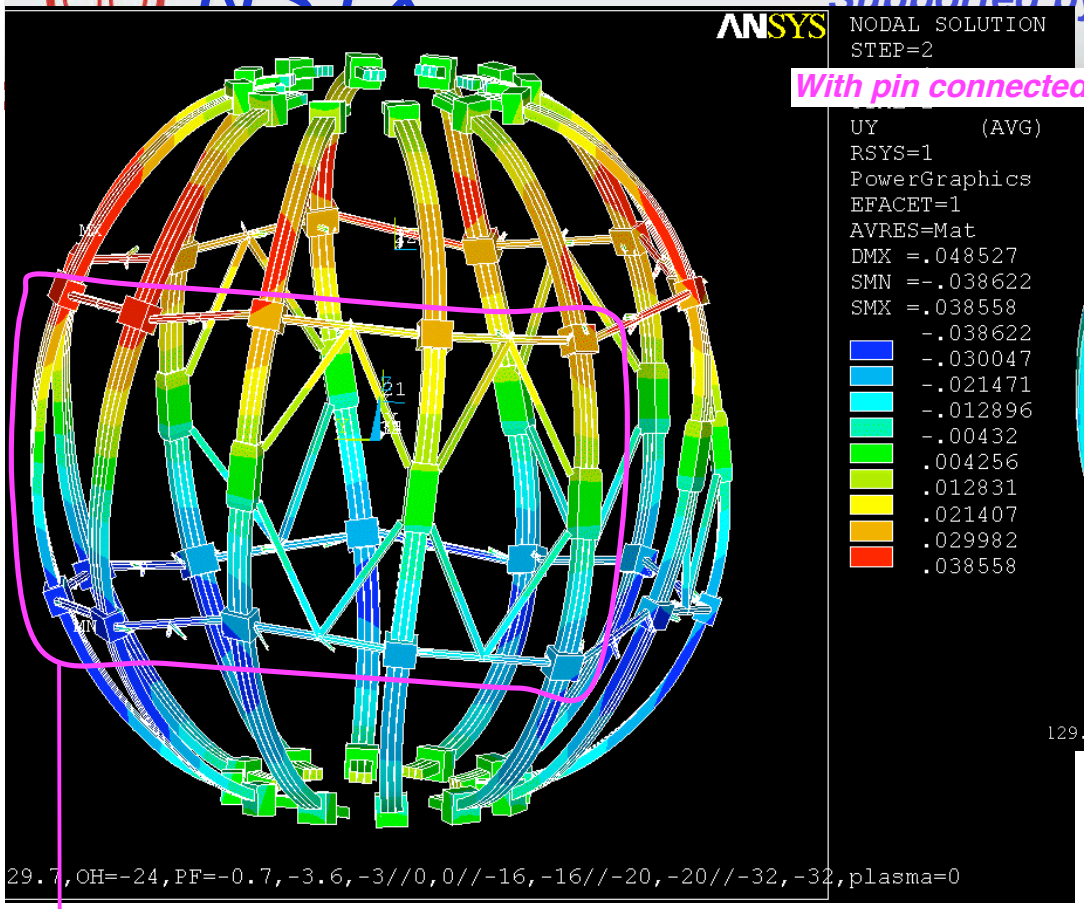
From Danny Mangra



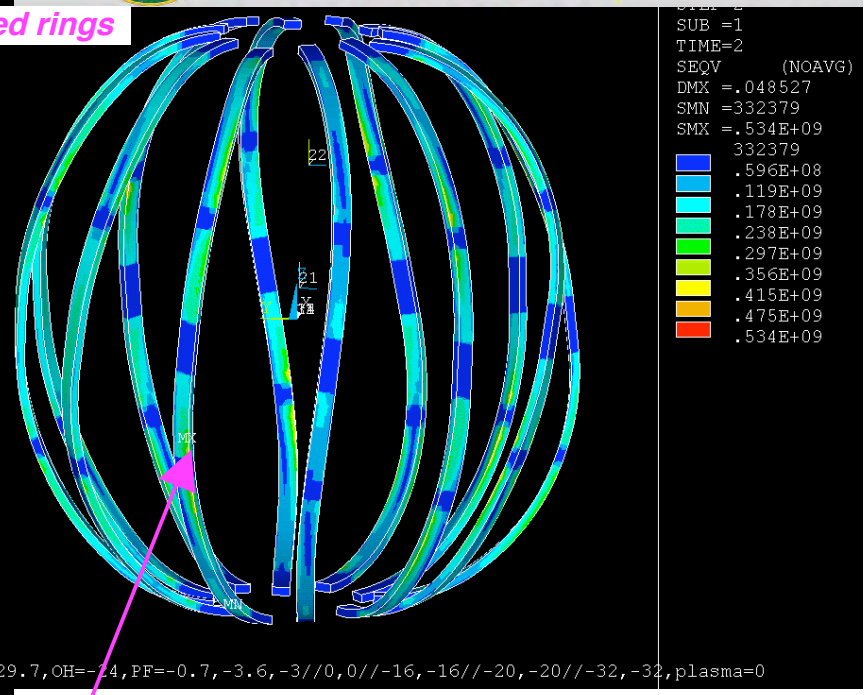


Since the machine has a lot of ports and full diamond bracing cannot be added everywhere:

- ***Full 360° model is built with diamond bracing added at the exact places***
- ***Aluminum blocks connected to springs to simulate umbrella structure***
- ***Standard (full or partial) diamonds have intersections at exactly the TF coil center. Non-standard (shorter) diamond don't.***
- ***Rings are exactly at the position of existing turn buckle.***
- ***Symmetric PF current***

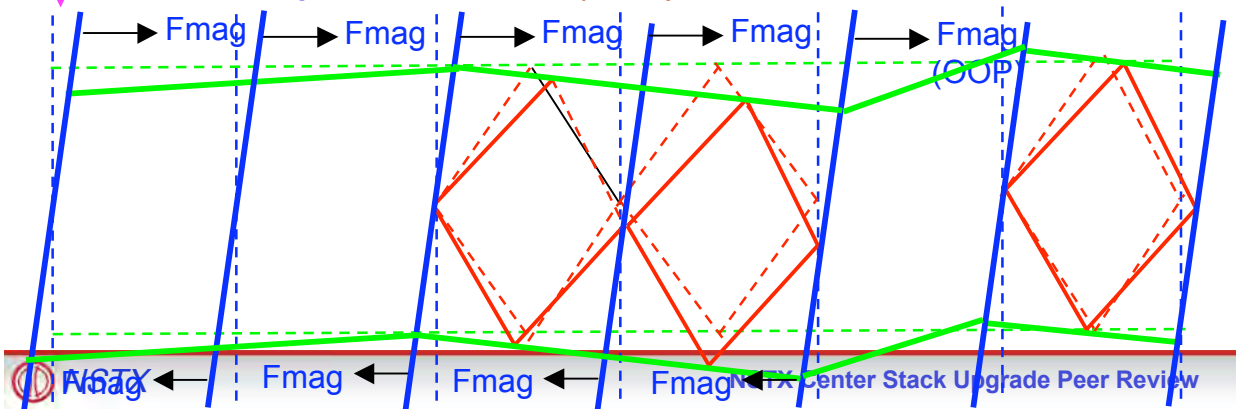


With pin connected rings



Max coil stress is ~500MPa (72.5ksi)

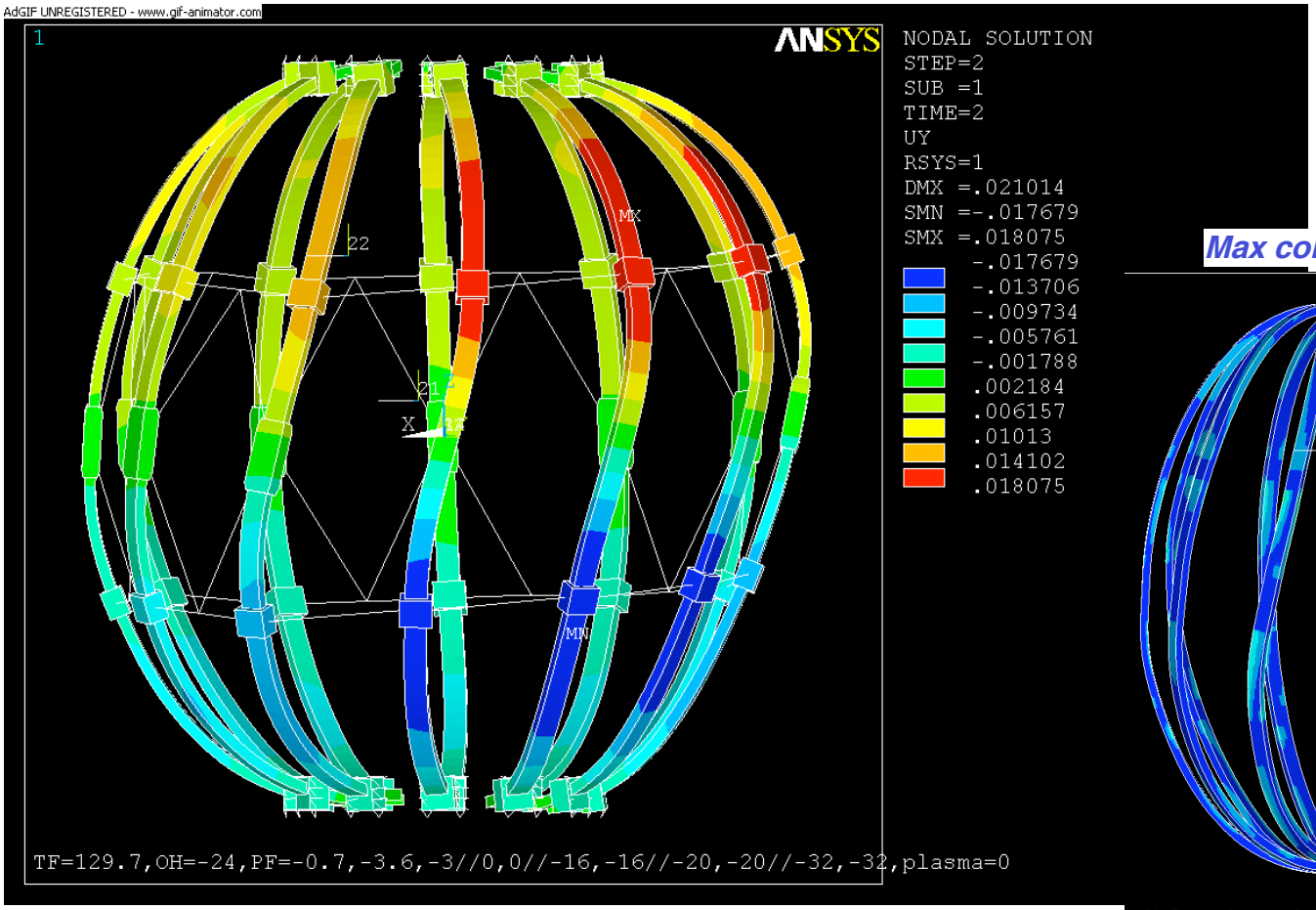
Max theta displacement=39mm (1.54")



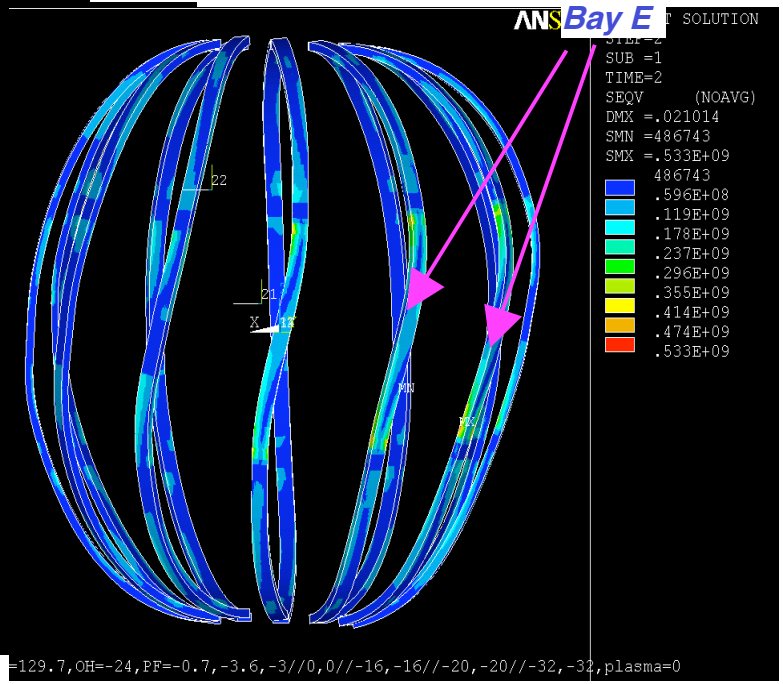
--Non-uniformly distributed diamonds cause TF coils and rings to deform

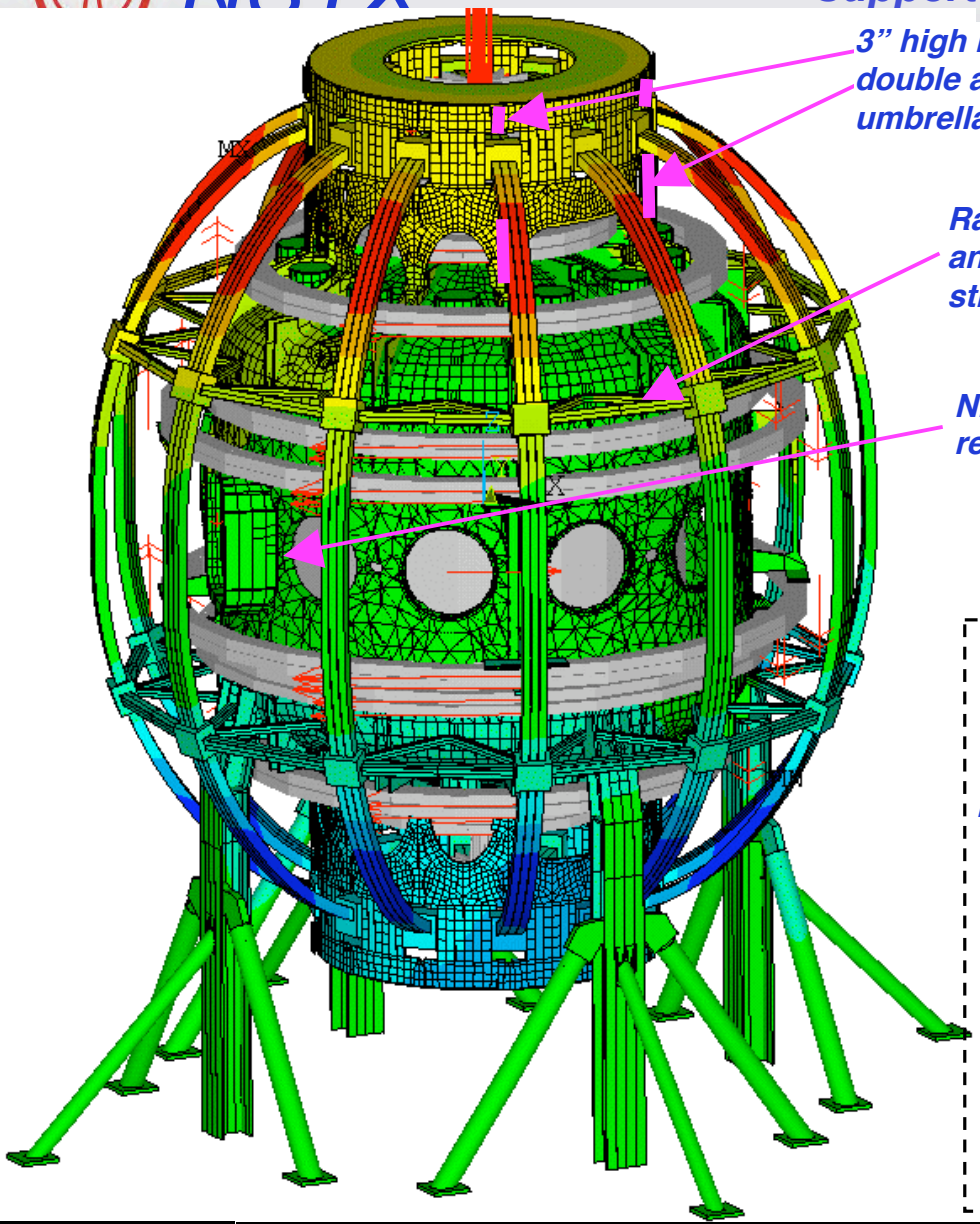
--welded rings are required to reduce the deflection in horizontal plane.

With welded rings: max theta displacement reduced to 18mm (0.7") but the non-uniform effect still exists.



Max coil stress is ~500MPa (72.5ksi)





3" high ribs welded to reinforce double arch on upper and lower umbrella structures

Radius rods and the supt structures

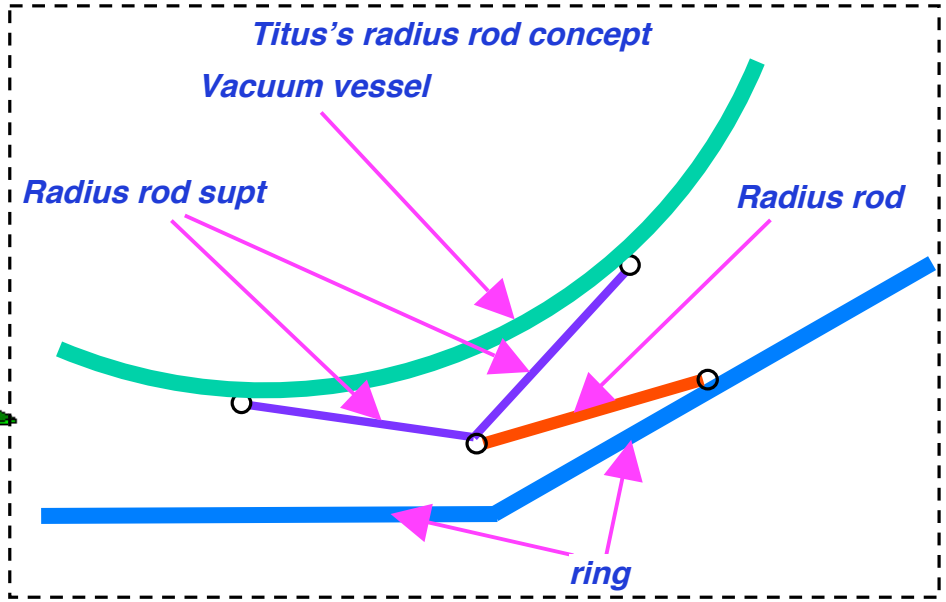
NB port area reinforced

Idea 3: adding radius (tangential) rods to take the out-of-plane load.

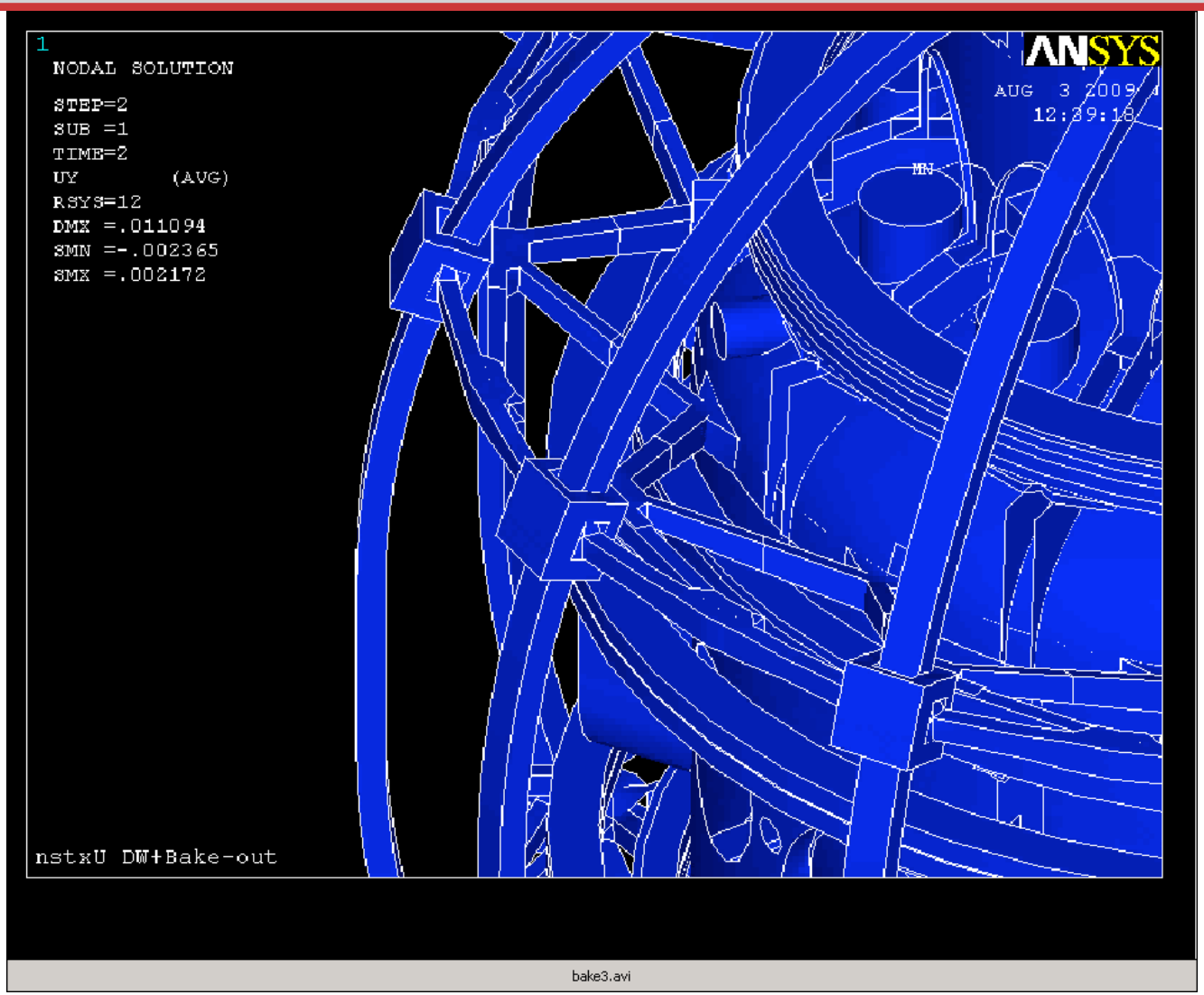
They only take effect at tangential direction.

Radius rods support structure are fixed to vacuum vessel, but they are not affected by the vessel bake out. Also no need to disconnect them during vessel bake out.

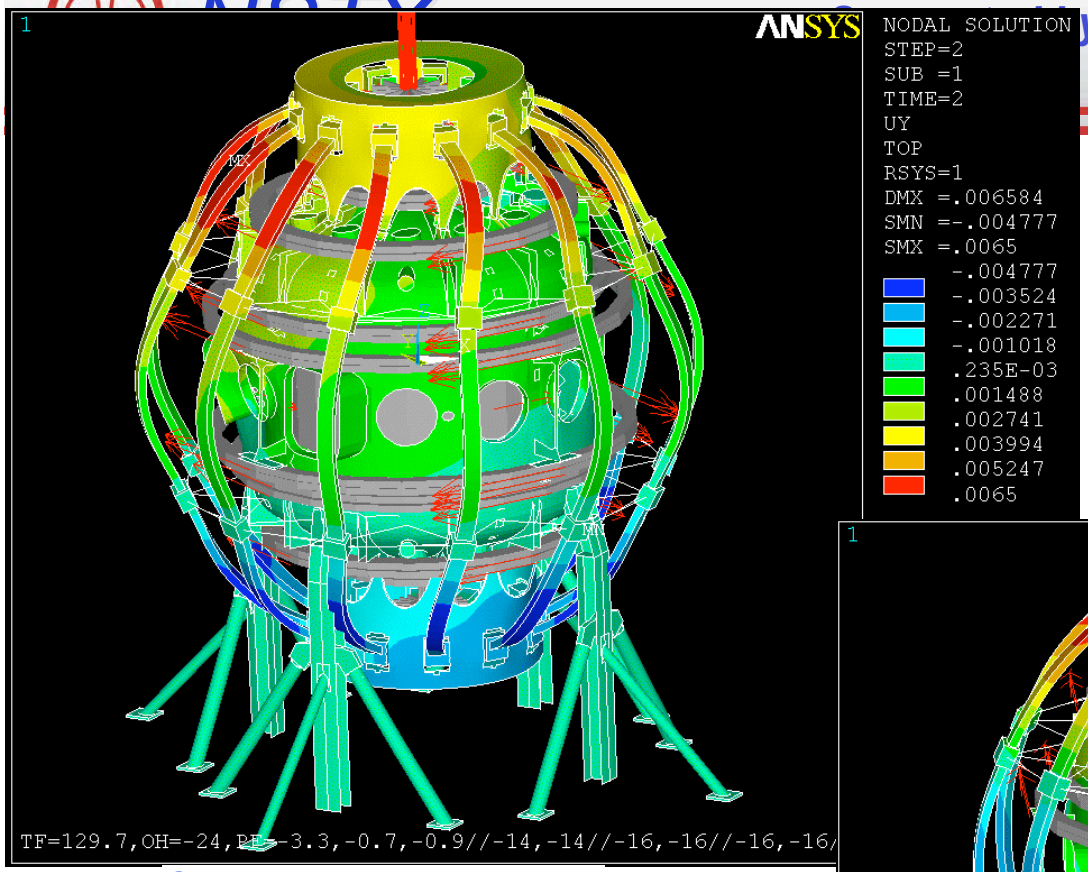
They are effective on both symmetric and asymmetric PF current.



Symm PF curr:	TF=129.7,OH=-24,PF=-0.7,-3.6,-3//0,0//-16,-16//-20,-20//-32,-32,plasma=0
Asym PF curr:	OH=-24*508,PF=716,84,164,-59,-72,-62//560,0//240,-480//-320,-320//-768,-768



Vacuum vessel bake out (from Peter Titus)

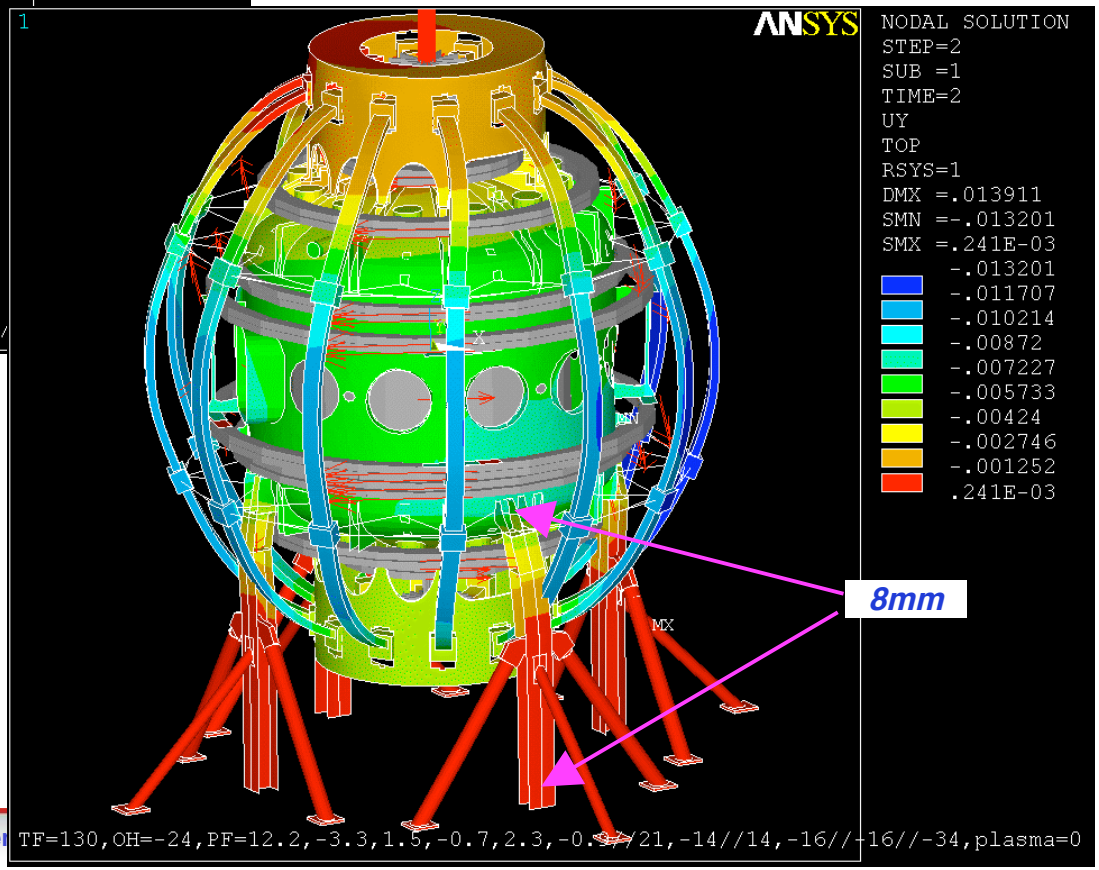


Symm PF curr: coil theta displacement (m)

welded ring (2.8x2.8" rect solid), radius rods (2"x2"), radius rods supt struct (2"x2")

Worst cases with symmetric and asymmetric PF currents are studied.

Asym PF curr: coil theta displacement (m)



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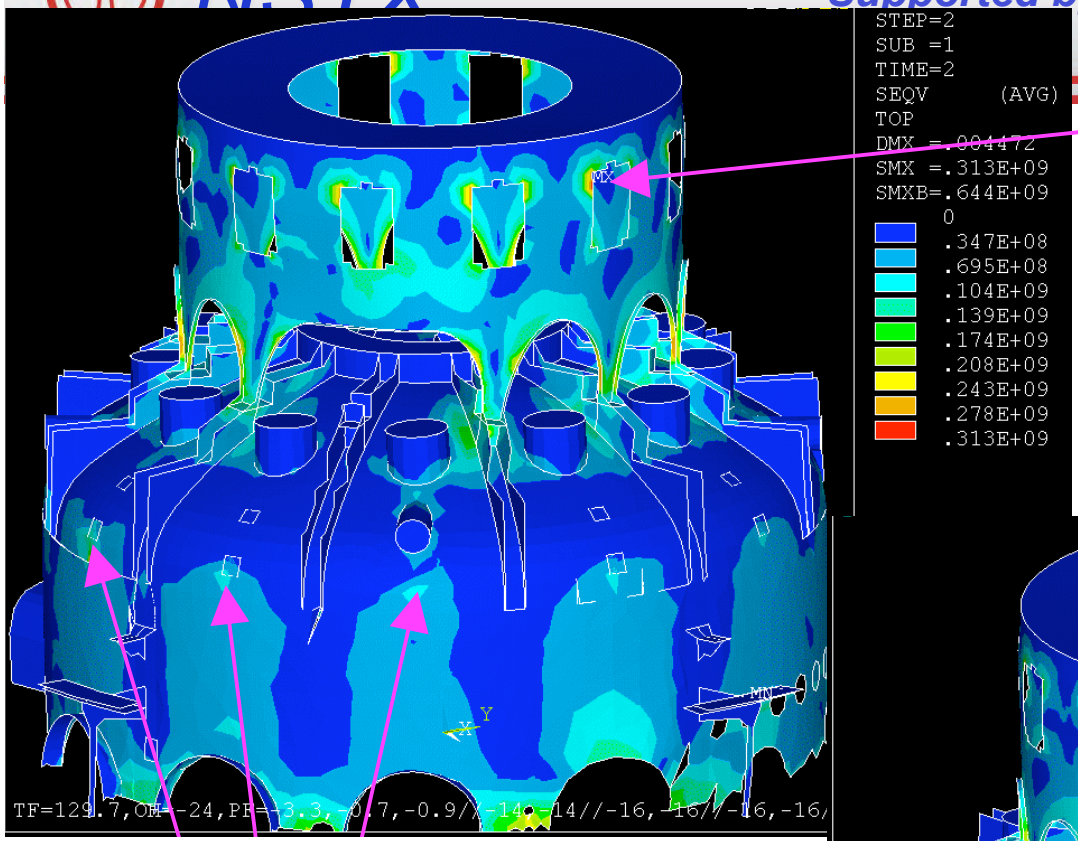
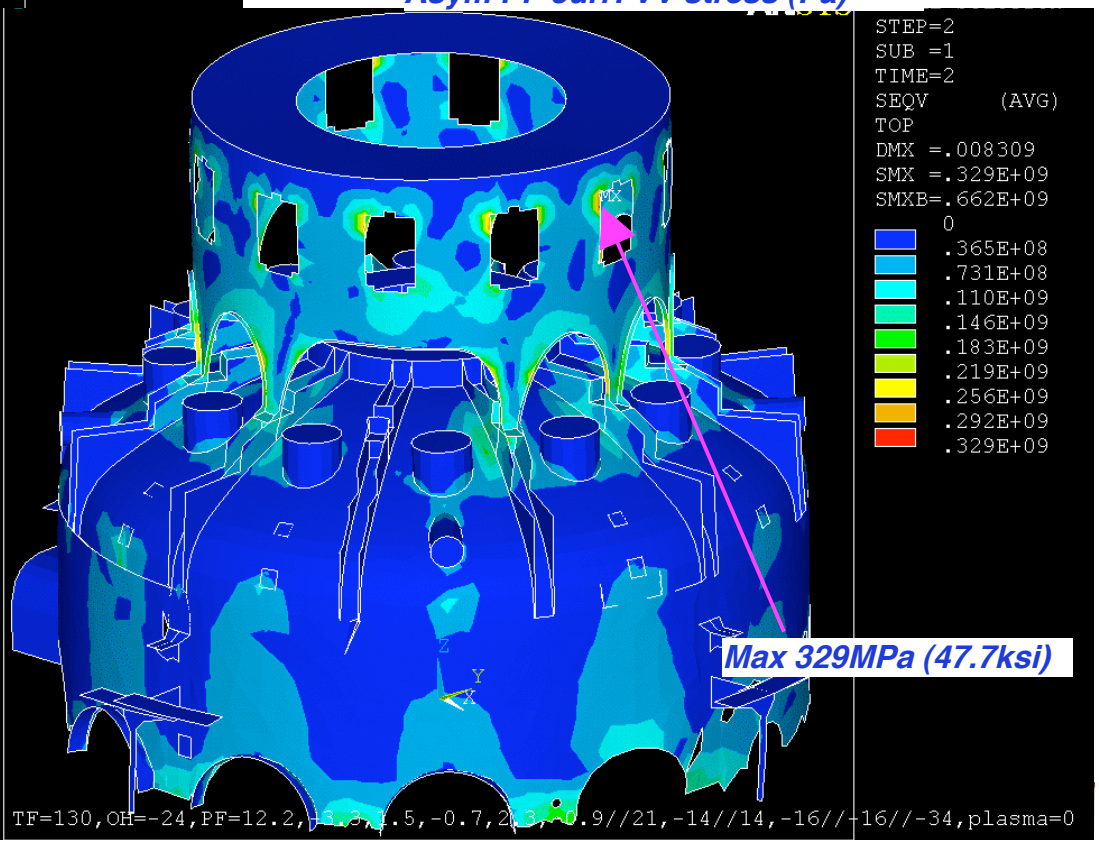


Max 313MPa (46ksi)

Due to the coupling of nodes on Al. block and umbrella structure (element discontinue here)

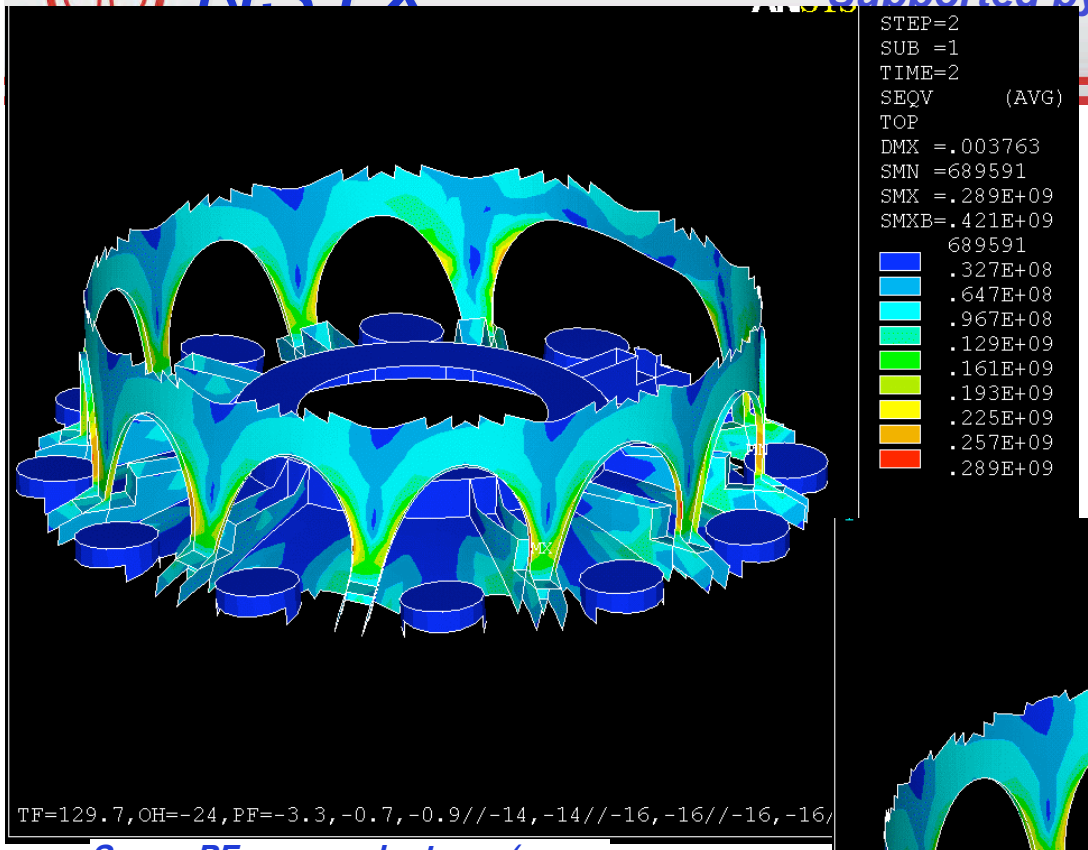
Symm PF curr: VV stress (Pa)

Asym PF curr: VV stress (Pa)



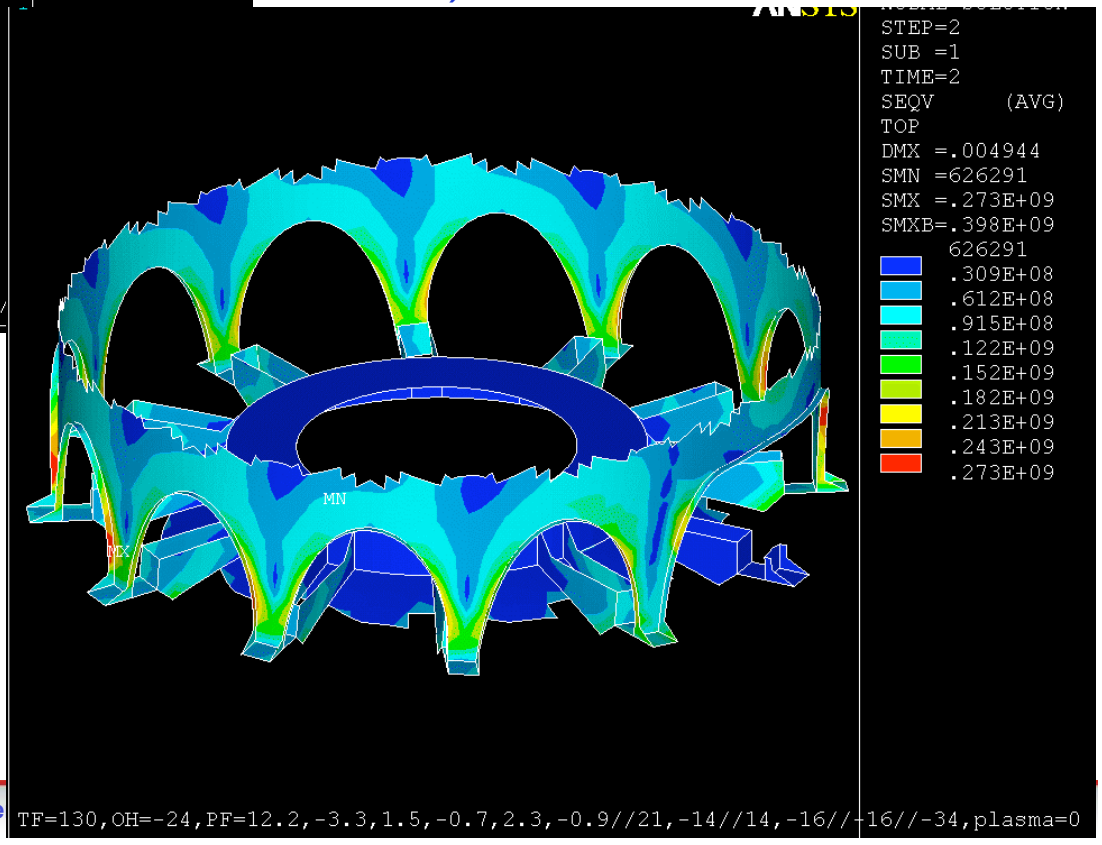
Positions of radius rod support (stress ~139MPa (20ksi)

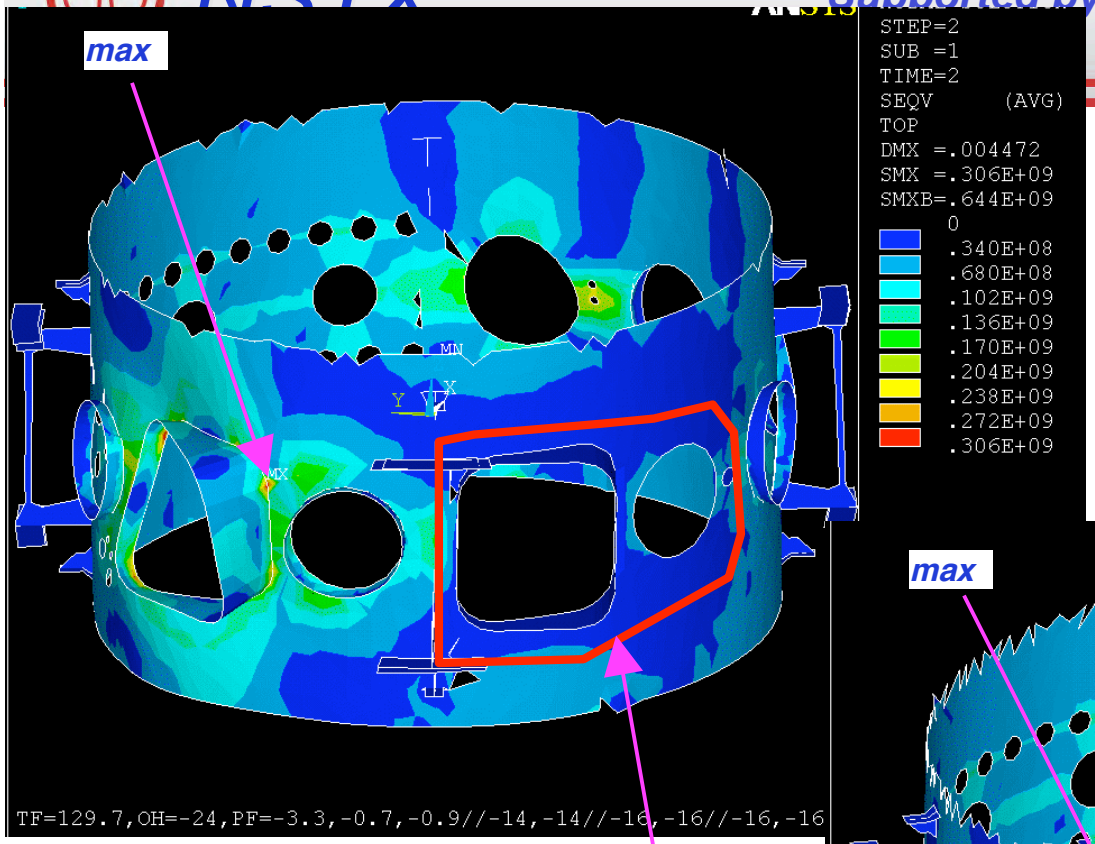
Max 329MPa (47.7ksi)



Symm PF curr: arch stress (max: 289MPa, 42ksi)

Asym PF curr: arch stress (max: 273MPa, 39.6ksi)



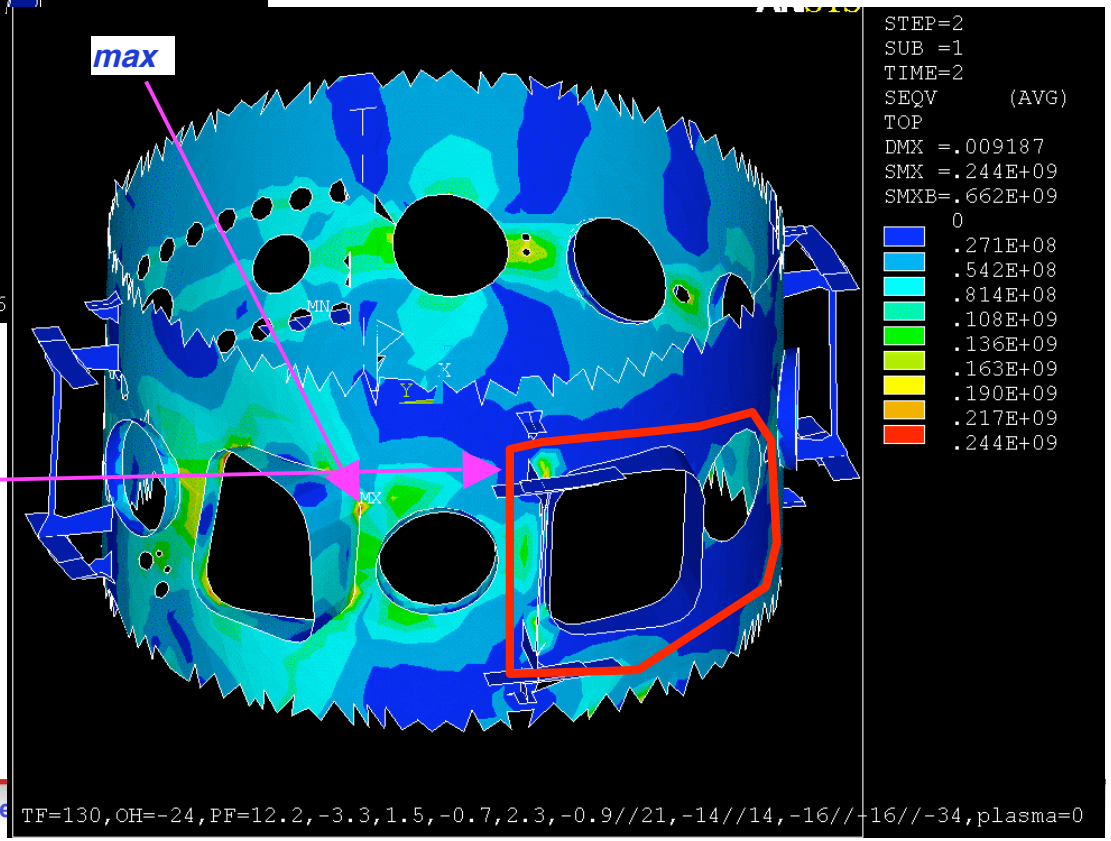


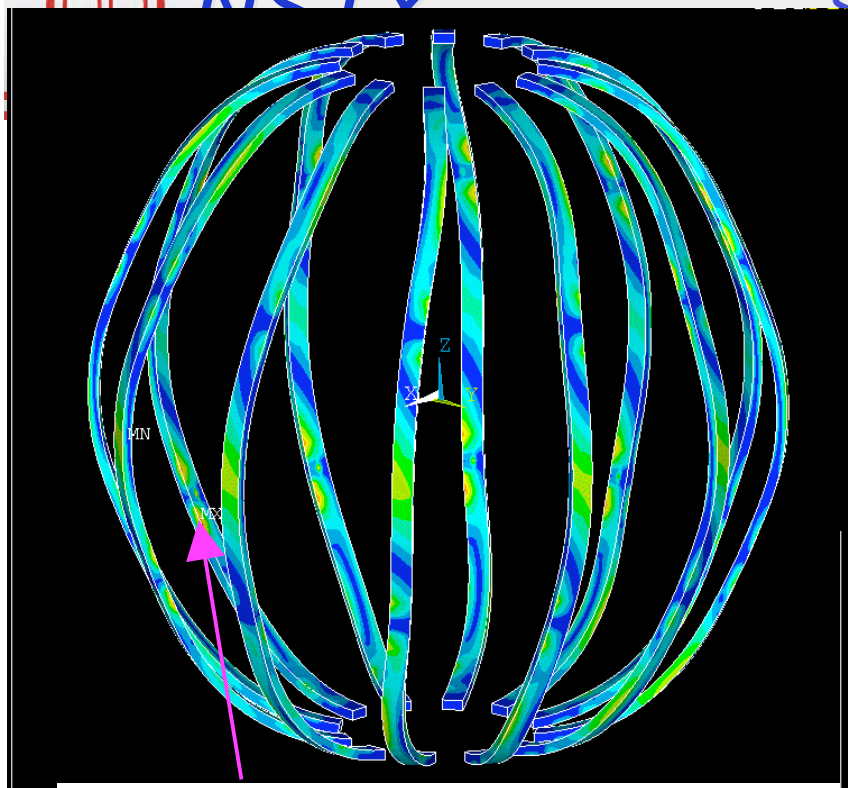
Symm PF curr: Port area stress (max: 306MPa, 44.4ksi)

Reinforcement needed at the other NB port

Asym PF curr: Port area stress (max: 244MPa, 35.4ksi)

Reinforcement needed at the other NB port



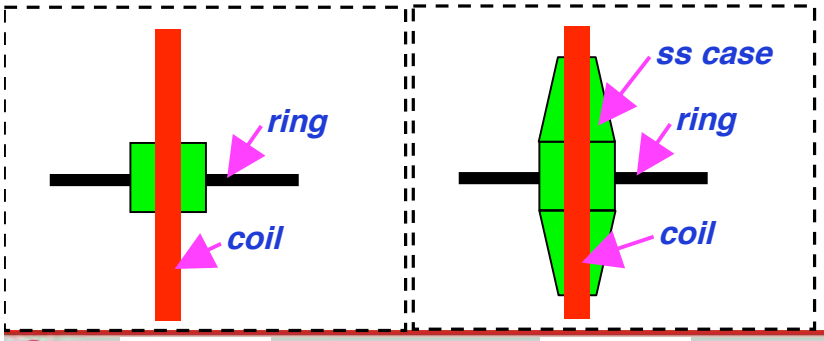


Symm PF curr: coil stress (Pa)

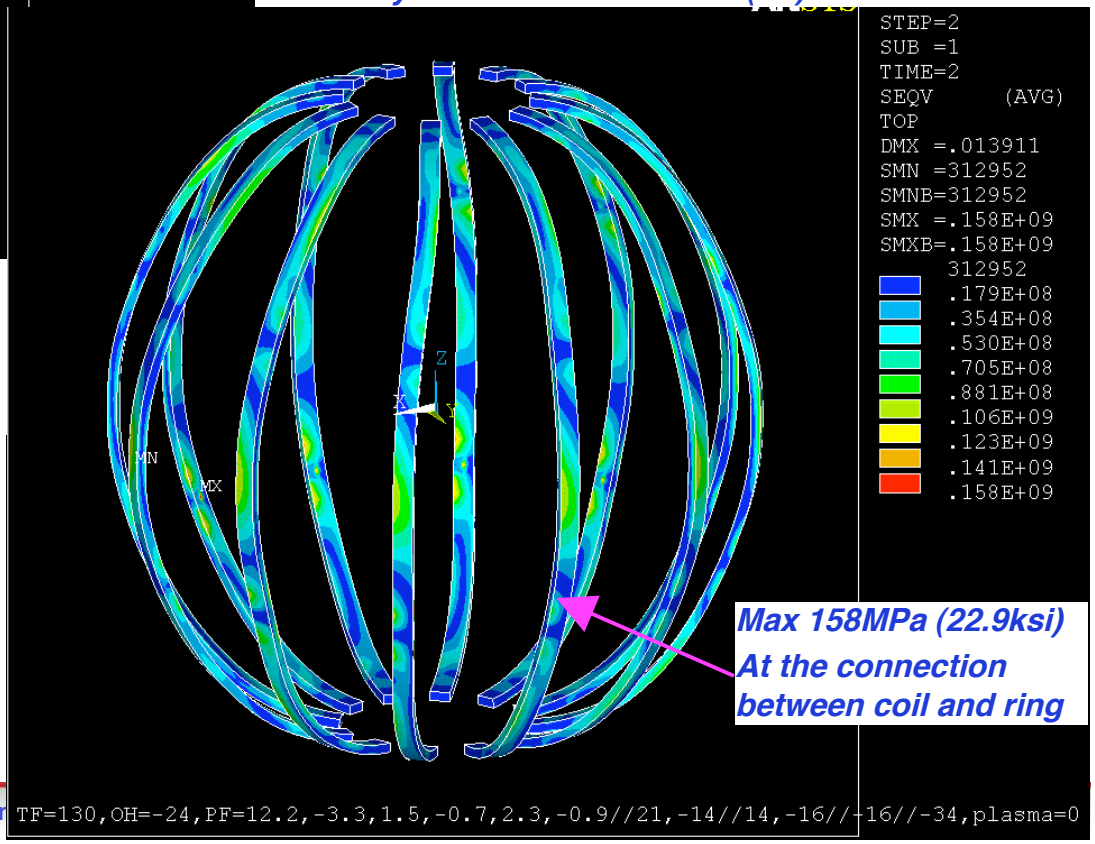
Max 147MPa (21.3ksi)

At the connection between coil and ring

Adding stainless steel case may help to reduce it

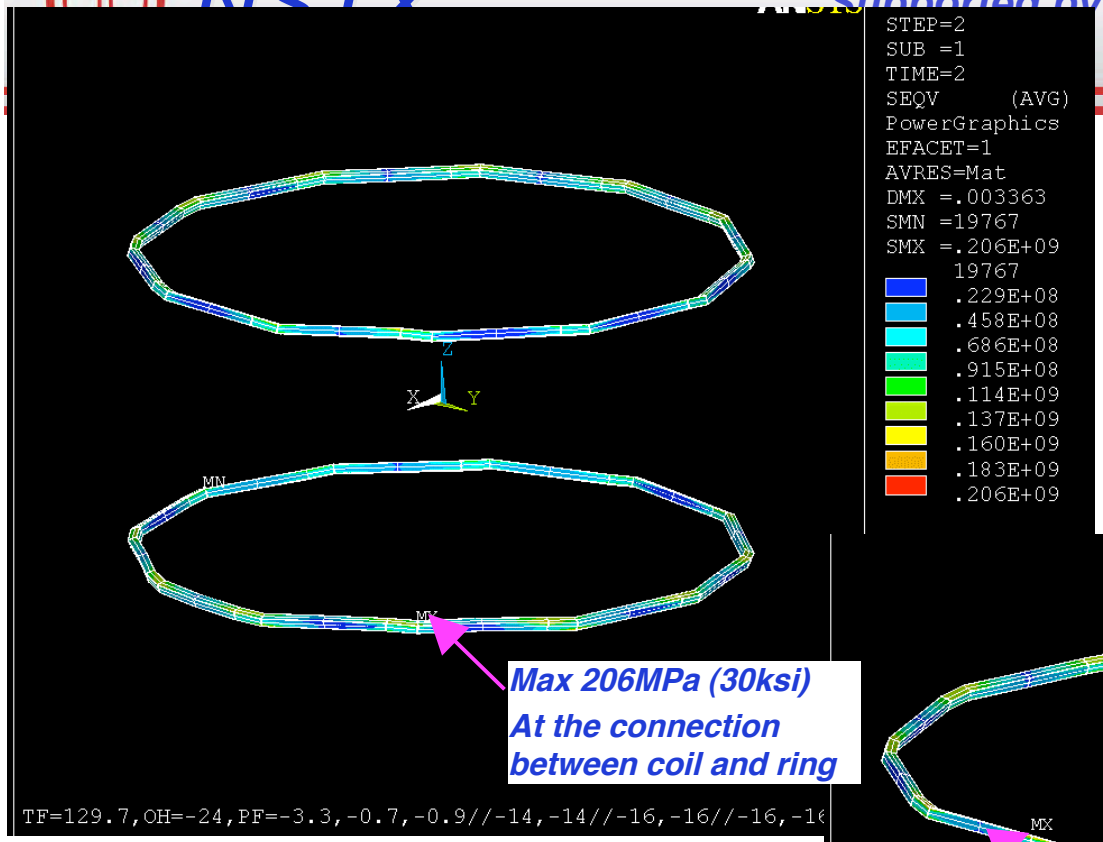


Asym PF curr: coil stress (Pa)



Max 158MPa (22.9ksi)

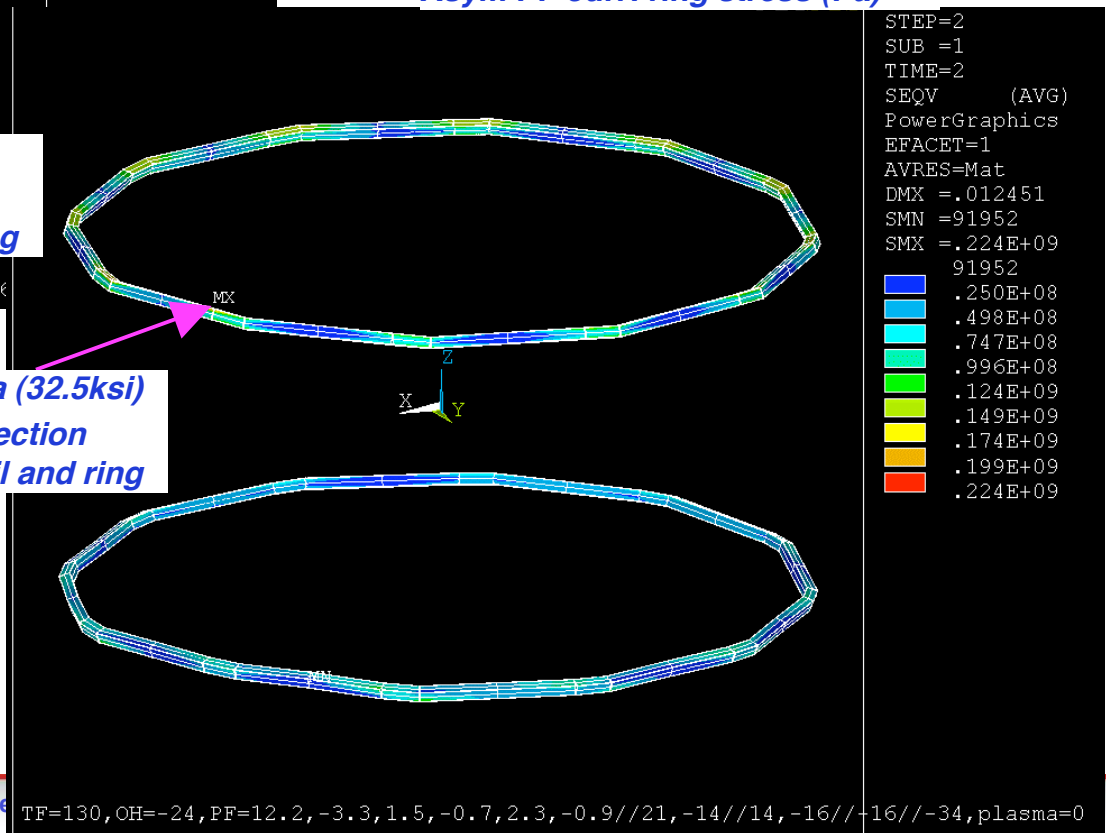
At the connection between coil and ring



Max 206MPa (30ksi)
At the connection between coil and ring

Symm PF curr: ring stress (Pa)

Asym PF curr: ring stress (Pa)



Max 224MPa (32.5ksi)
At the connection between coil and ring

Symm PF curr:

radius rod load
Max: 81.5KN (18.4 klbs)
Min: 19.8KN (4.5 klbs)

Vessel stress at the radius rod support area
139 MPa (20ksi)

Asym PF curr:

radius rod load
Max: 90.2KN (20.3klbs)
Min: 17.8KN (4klbs)

Vessel stress at the radius rod support area
146 MPa (21ksi)

Summary

- Rings were added to reduce the pull-out (in-plane) loads at the Umbrella Structure
- Various Trusses were tried to reduce Out-of-Plane Loads from the outer TF legs
- Interferences were a severe problem limiting the addition of trusses
- Up-Down Asymmetric Currents and Resulting Net Twist Required an attachment to the Vessel
- Tangential Radius Rods Took the Net Twist - and provided adequate OOP support for Symetric Case
- Tangential radius rods use the existing territory of turn buckle and there is enough room for them
- Loads in the Tangential Radius Rods Allow Attachment to the Vessel with only Modest Modifications
- Vessel Stresses in the Umbrella Structure and Equatorial Plane Port Region are Acceptable or require only Modest modification.