Analysis and Qualification Documentation

The NSTX Upgrade Team

Presented By Peter H. Titus

NSTX Center Stack Upgrade Peer Review
LSB B318
May 18, 2011

Columbia U
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General Atomics
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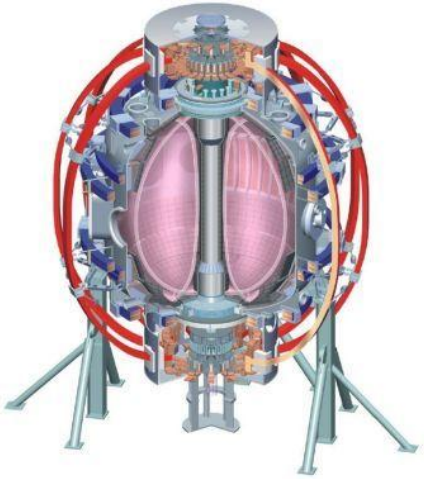
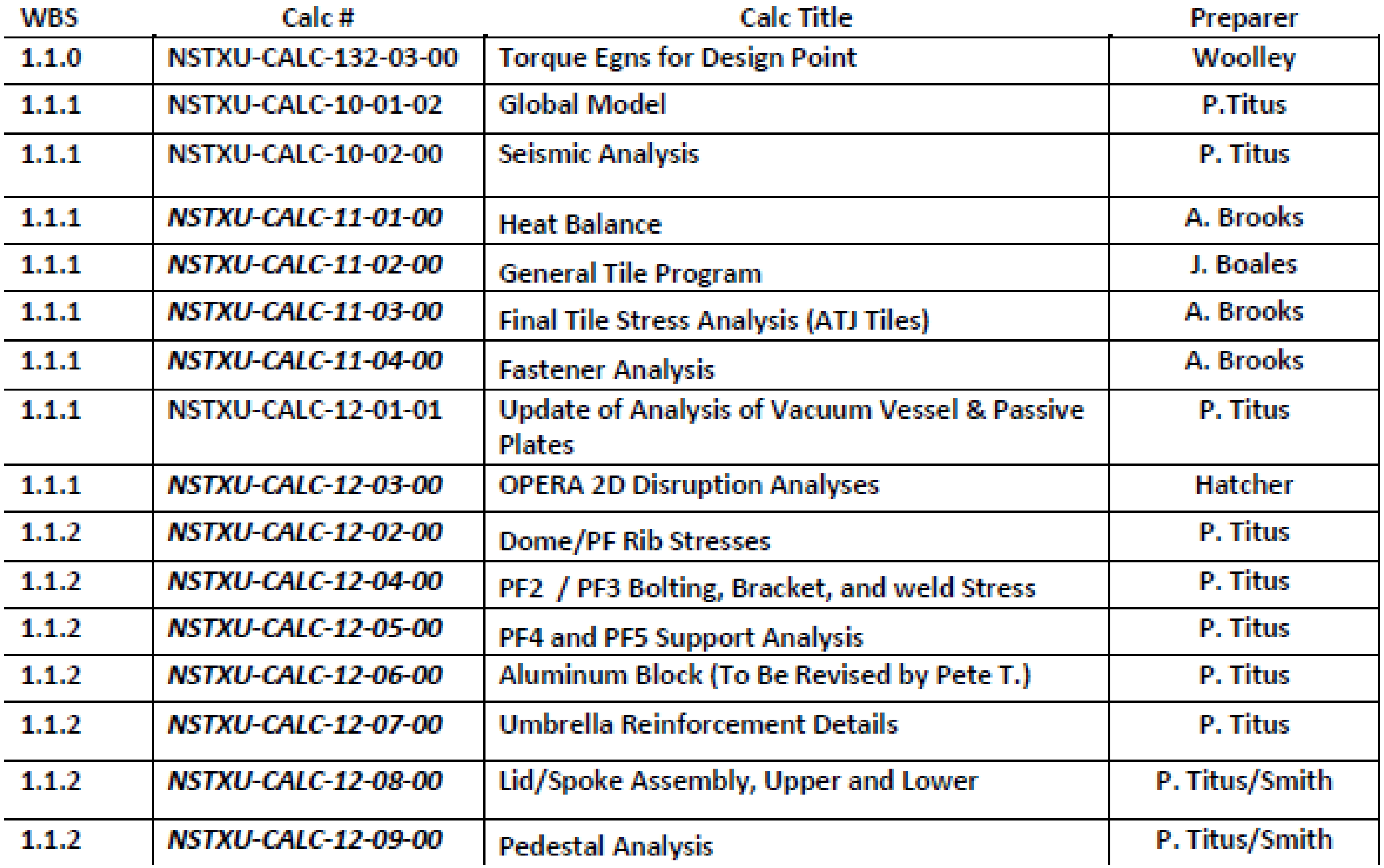


Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Historically What is Available – Aside from a Wealth of Operating Experience

NSTX CSU Calculation Index



WBS	Calc #	Calc Title	Preparer
1.1.0	NSTXU-CALC-132-03-00	Torque Egns for Design Point	Woolley
1.1.1	NSTXU-CALC-10-01-02	Global Model	P.Titus
1.1.1	NSTXU-CALC-10-02-00	Seismic Analysis	P. Titus
1.1.1	*NSTXU-CALC-11-01-00*	Heat Balance	A. Brooks
1.1.1	*NSTXU-CALC-11-02-00*	General Tile Program	J. Boales
1.1.1	*NSTXU-CALC-11-03-00*	Final Tile Stress Analysis (ATJ Tiles)	A. Brooks
1.1.1	*NSTXU-CALC-11-04-00*	Fastener Analysis	A. Brooks
1.1.1	NSTXU-CALC-12-01-01	Update of Analysis of Vacuum Vessel & Passive Plates	P. Titus
1.1.1	*NSTXU-CALC-12-03-00*	OPERA 2D Disruption Analyses	Hatcher
1.1.2	*NSTXU-CALC-12-02-00*	Dome/PF Rib Stresses	P. Titus
1.1.2	*NSTXU-CALC-12-04-00*	PF2 / PF3 Bolting, Bracket, and weld Stress	P. Titus
1.1.2	*NSTXU-CALC-12-05-00*	PF4 and PF5 Support Analysis	P. Titus
1.1.2	*NSTXU-CALC-12-06-00*	Aluminum Block (To Be Revised by Pete T.)	P. Titus
1.1.2	*NSTXU-CALC-12-07-00*	Umbrella Reinforcement Details	P. Titus
1.1.2	*NSTXU-CALC-12-08-00*	Lid/Spoke Assembly, Upper and Lower	P. Titus/Smith
1.1.2	*NSTXU-CALC-12-09-00*	Pedestal Analysis	P. Titus/Smith

1.1.3	NSTXU-CALC-133-03-00	Center Stack Casing Disruption Inductive and Halo Current Loads	P. Titus
1.1.3	NSTXU-CALC-133-04-00	OH Preload System and Belleville Spring Design ✓	Peter Rogoff
1.1.3	*NSTXU-CALC-133-05-00*	CS Casing Halo Ind and Res Cur	A. Brooks
1.1.3	*NSTXU-CALC-133-06-00*	OH Coolant Hole Optimization	A. Zolfaghari
1.1.3	*NSTXU-CALC-133-07-00*	OH Coax Lead Analysis	M. Mardenfeld
1.1.3	*NSTXU-CALC-133-08-00*	OH Stress Analyses	A. Zolfaghari
1.1.3	*NSTXU-CALC-133-09-00*	OH Fatigue and Fracture Mechanics ✓	P. Titus
1.1.3	*NSTXU-CALC-133-10-00*	Center Stack Casing Bellows	Peter Rogoff
1.1.3	*NSTXU-CALC-133-11-00*	OH & PF1 Electromagnectic Stability Analysis	P. Titus/Zolfaghari
1.1.4	*NSTXU-CALC-133-12-00*	Centerstack Manufacturing Fixtures	

1.1.2	NSTXU-CALC-132-04-00	Analysis of TF Outer Leg	Han Zhang
1.1.2	*NSTXU-CALC-132-09-00*	Analysis of Knuckle Clevis	P. Titus
1.1.2	*NSTXU-CALC-132-11-00*	Ring Bolted Joint	Peter Rogoff
1.1.3	NSTXU-CALC-131-01-00	Analysis of CSU Poloidal Field Coils	Woolley
1.1.3	NSTXU-CALC-131-02-00	Poloidal Magnetic Quantities for the Feb 2010 Provisional Design	Woolley
1.1.3	NSTXU-CALC-131-03-00	Poloidal Magnetic Quantities for the May 2010 Design Point	Woolley
1.1.3	NSTXU-CALC-132-05-00	Coupled EM-Thermal Analysis ✓	Han Zhang
1.1.3	NSTXU-CALC-132-06-00	TF Flex Joint and Bundle Stub ✓	T. Willard
1.1.3	NSTXU-CALC-132-07-00	Maximum Torsional Shear Stress	P. Titus
1.1.3	NSTXU-CALC-132-08-00	Determination of shear Forces Between the TF conductors and Insulation and the G-10 Insulating Crown.	A. Zolfaghari
1.1.3	*NSTXU-CALC-132-10-00*	TF Cool-down using FCOOL	A. Zolfaghari
1.1.3	NSTXU-CALC-133-01-01	Structural Analysis of the PF1 Coils, leads and Supports, Rev 1	L. Myatt
1.1.3	NSTXU-CALC-133-02-00	Thermal Stresses on OH-TF Coils	S. Avasarala

1.2.3	*NSTXU-CALC-40-01-00*	Diagnostics Review and Database	J. Boales
1.2.4	*NSTXU-CALC-24-01-00*	Vessel Port Re-Work for NB and Thompson Scattering Port ✓	T. Willard
1.2.4	*NSTXU-CALC-24-02-00*	Armor Plate Backing Plate ✓	L. Bryant
1.2.4	*NSTXU-CALC-24-03-00*	HHFW Antenna (needs to be modified for upgrade loads)	Han Zhang/Ellis
1.2.4	*NSTXU-CALC-24-04-00*	Magnetic Shielding Calculation ✓	L. Bryant
1.5.2	NSTXU-CALC-13-03-01	DCPS Force Influence Coefficients	Hatcher
1.5.2	*NSTXU-CALC-13-05-00*	DCPS Moment Influence Coefficients	Woolley/Titus
1.5.5	*NSTXU-CALC-55-01-00*	Bus Bar Analysis	A. Khodak

Available Documentation:

47 Calculations Total

NSTXU Calculation Web page (http:/nstx-upgrade.pppl.gov/Engineering/Calculations/index_Calcs.htm/>)

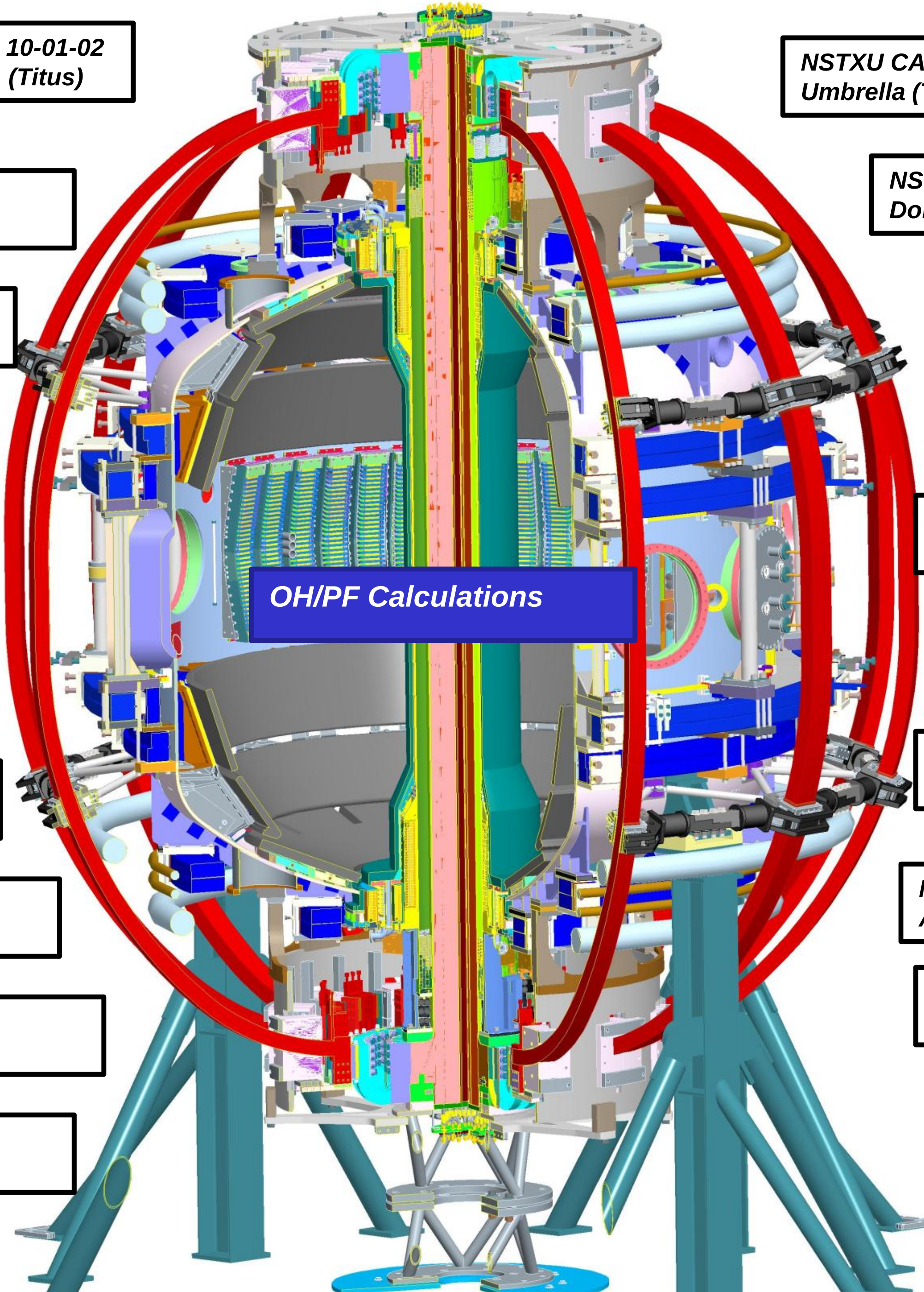
All are Prepared and Reviewed in Accordance with ENG-033

NSTX Upgrade

FDR Calculation Executive Summaries

May 2011

Prepared By:
the NSTX Upgrade Team



OH/PF Calculations

NSTXU CALC 10-01-02
Global Model (Titus)

NSTXU CALC 13-03-01
DCPS Influence
Coef(Hatcher/Titus)

NSTXU CALC 13-03-01
DCPS Moment
Coef(Titus/Woolley)

NSTXU CALC 131-01-01
PF Coils (Woolley)

NSTXU CALC 131-01-01
PF Coils (Woolley)

ISTXU CALC 133-05-00
CS Casing Halo(Brooks/Titus)

NSTXU CALC 133-06-00
OH
Cooling(Zolfaghari/Mardenfeld)

NSTXU CALC 133-06-00
OH Stress(Zolfaghari/HM Fan?
Dahlgren?)

NSTXU CALC 132-11-00
CS Casing
Stresses(Titus/Unassigned)

NSTXU CALC 12-07-00
Umbrella (Titus/Zhang)

NSTXU CALC 12-02-00
Dome Rib (Titus)

NSTXU CALC 133-01-
01
PF 1 abc(Myatt)

NSTXU CALC 12-05-00
PF2 and 3 Coil
&Sup(Titus/Zatz)

NSTXU CALC 133-04-00
OH Preload
Bellevilles(Rogoff/Zatz)

NSTXU CALC 12-05-00
PF4and 5 Coil
&Sup(Titus/Zatz)

NSTXU CALC 132-04-00
TF Outer Leg Support(Zhang)

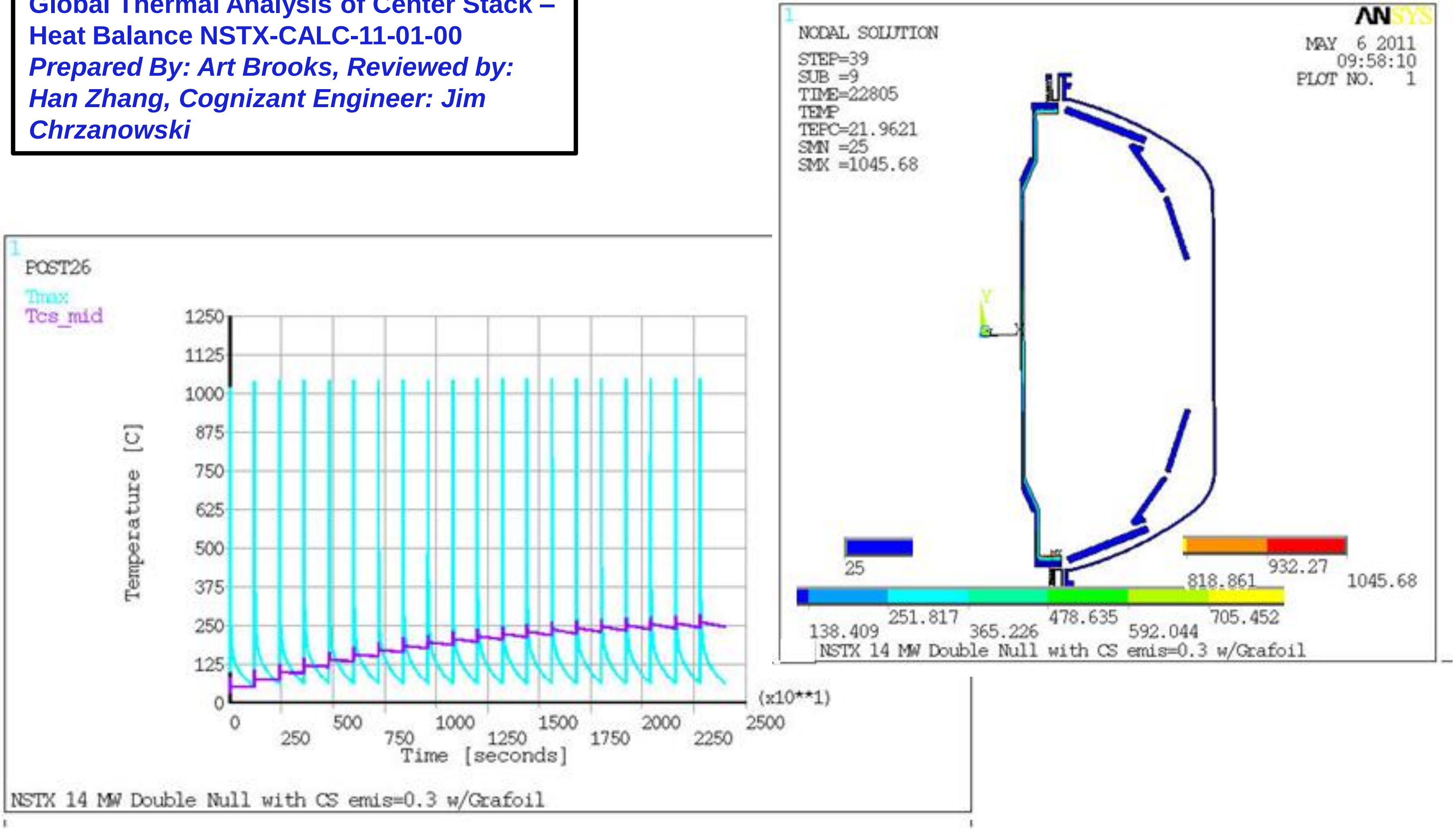
NSTXU CALC 12-06-00
Alum Block(Titus/Smith)

NSTXU CALC 133-07-
00
OH Coax (Mardenfeld)

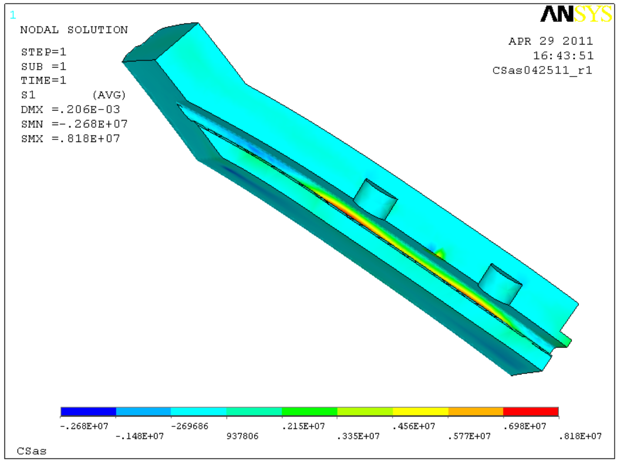
NSTXU CALC 55-01-
00
BusBar Khodak

Longer Pulse, More Neutral Beam Power, More Plasma Current, Increases Heat Load on Vessel Components

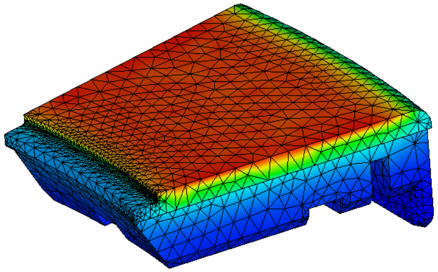
WBS 1.1.1 Plasma Facing Components, Global Thermal Analysis of Center Stack – Heat Balance NSTX-CALC-11-01-00
Prepared By: Art Brooks, Reviewed by: Han Zhang, Cognizant Engineer: Jim Chrzanowski

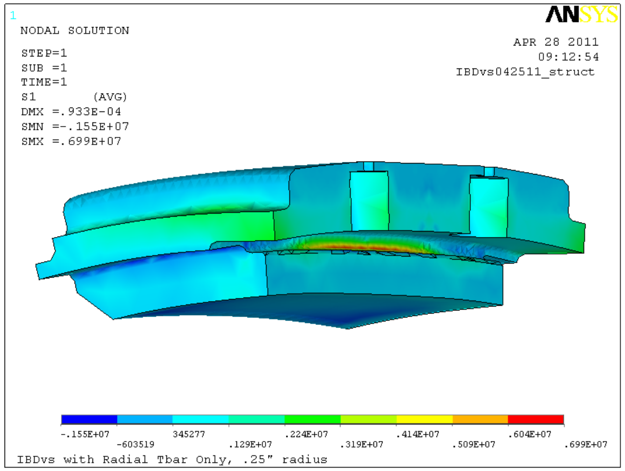


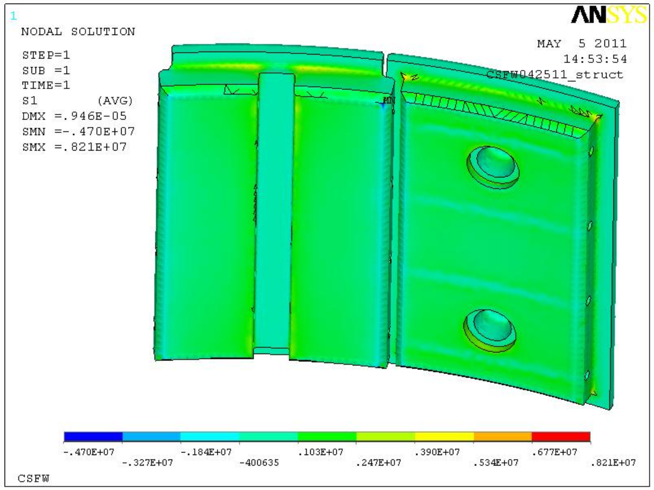
Longer Pulse, More Neutral Beam Power, More Plasma Current, Increases Heat Loads on Tiles, Increased Disruption and Halo Specs Increase Mechanical Loads on Tiles



WBS 1.1.1 Plasma Facing Components, Stress Analysis of Tiles
NSTXU-CALC-11-03-00
Prepared By: Art Brooks,
Reviewed by: TBD, Cognizant Engineer: Kelsey Tresemer







WBS 1.1.1 Basic Tile Analysis Qualification December 2010 NSTX-CALC-11-02-00 Prepared By: Joe Boales, Reviewed By: Art Brooks
Cognizant Engineer: Kelsey Tresemer

Sources of Lorentz Loading – The Design Point Spreadsheet

Qualification is based on Max and Min loads and load combinations for the 96 Equilibria from the Design Point :

With and Without Plasma

Circular or Shaped Plasma

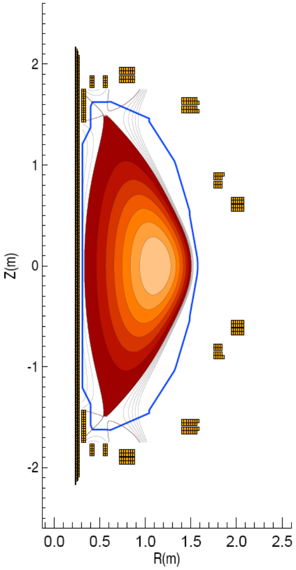
With Inductively Driven Currents from the Disruption

Max and Min Loads for the Scenarios are Tabulated

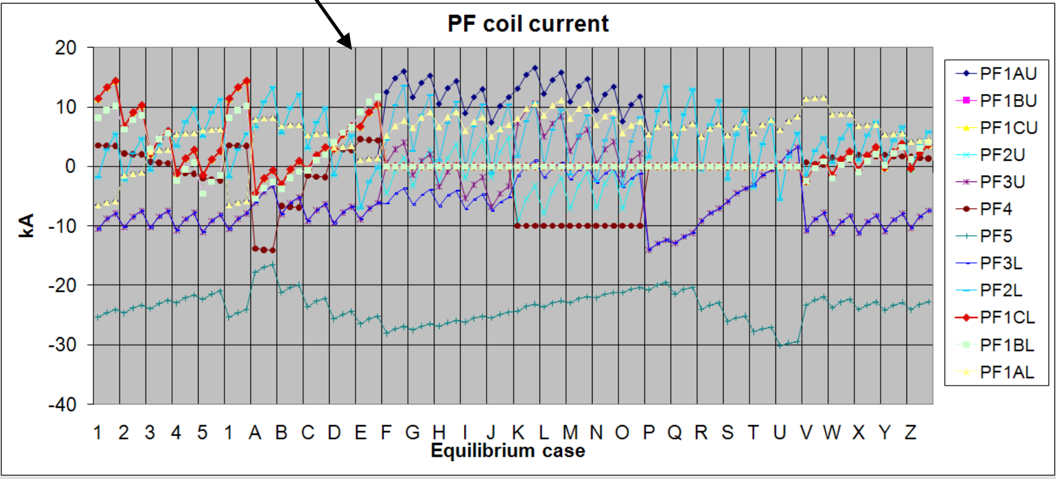
Worst Case Power Supply Loads are Tabulated

Very few areas are being qualified using maximum power supply loads from the design point. They were "Onerous"

- Loads
  - Equilibria –Jon Mennard
  - 10% "Headroom" – Charlie Neumeyer
  - Power Supply Maxima and Minima – Charlie N

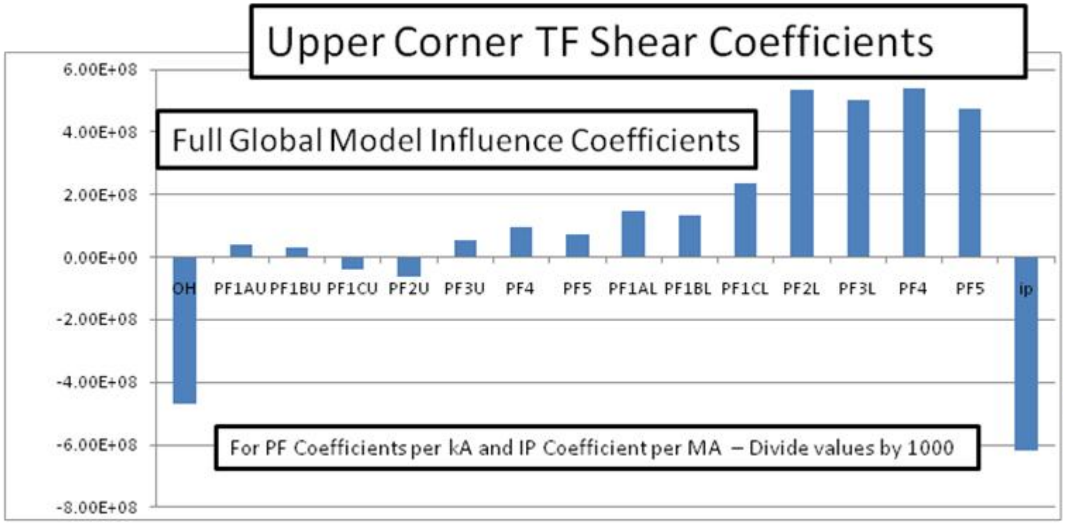


WBS 1.5.2 Force Influence Matrix Coefficients NSTXU-CALC-13-03-01 Prepared by Ron Hatcher, Review by: Peter Titus, Cognizant Engineer: Ron Hatcher



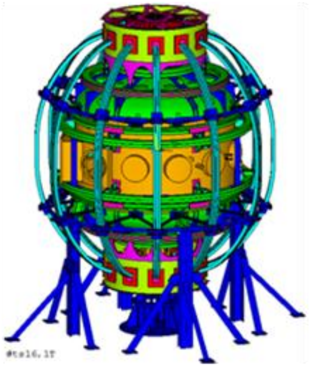
What do We Do If We Compute the Loads In the Analysis Models?

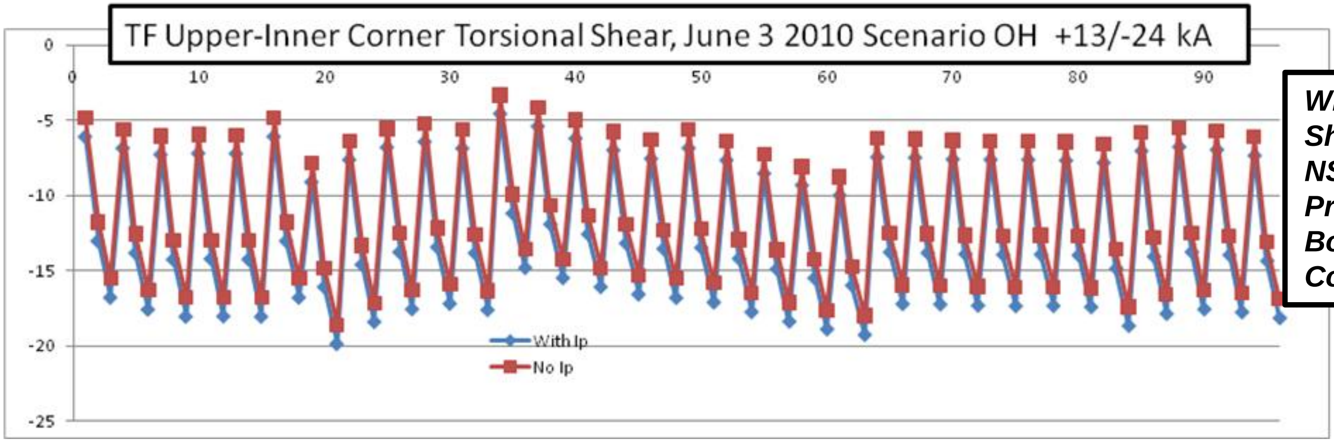
One Way is to Compute the Influence Coefficients as you Would For the DCPS and Calculate the Stress in a Spreadsheet. The Plasma can be Turned On and Off in the Spreadsheet – Remember to add 10% Headroom


Upper Corner TF Shear Coefficients

Full Global Model Influence Coefficients

For PF Coefficients per kA and IP Coefficient per MA – Divide values by 1000

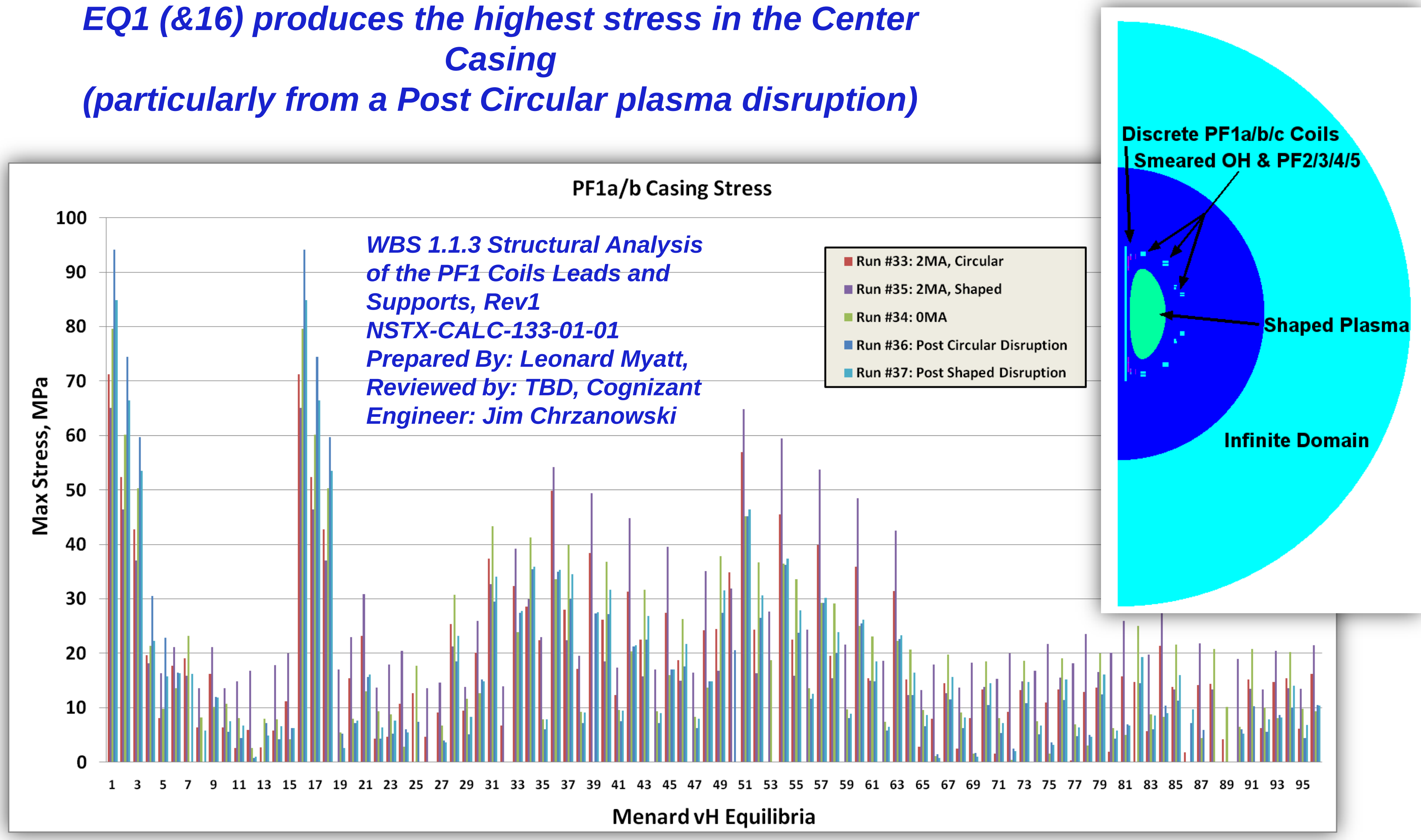



TF Upper-Inner Corner Torsional Shear, June 3 2010 Scenario OH +13/-24 kA

WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS NSTXU-CALC-132-07-00,
Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski

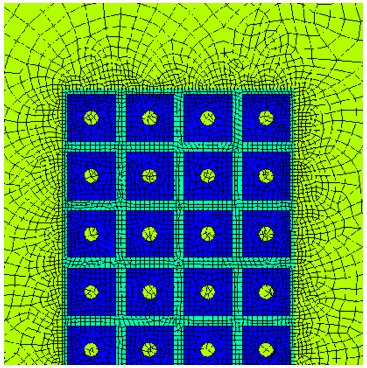
Screening Results for All 96 Scenaios, With 10% Headroom, Shaped and Circular Plasmas

EQ1 (&16) produces the highest stress in the Center Casing
(particularly from a Post Circular plasma disruption)

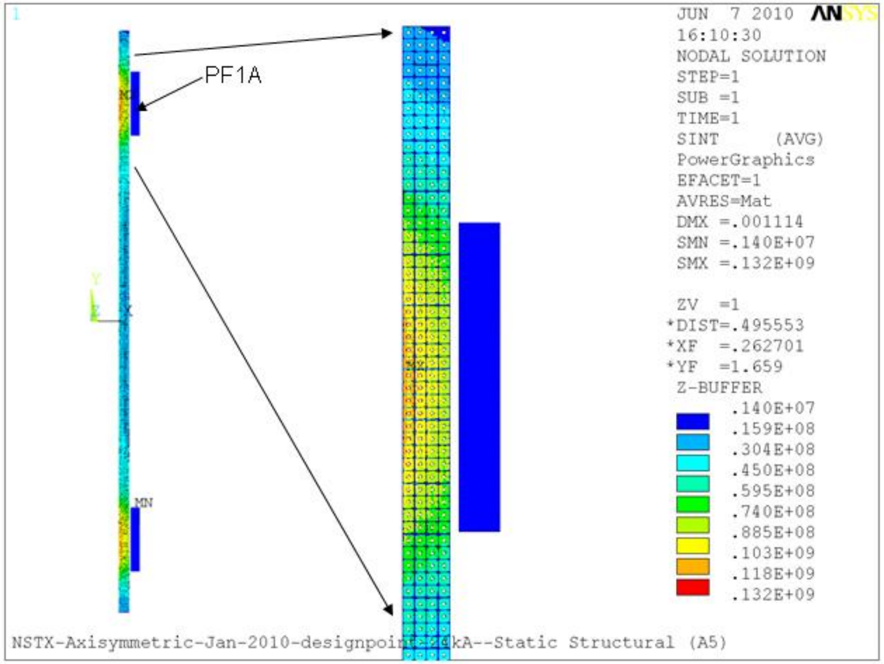


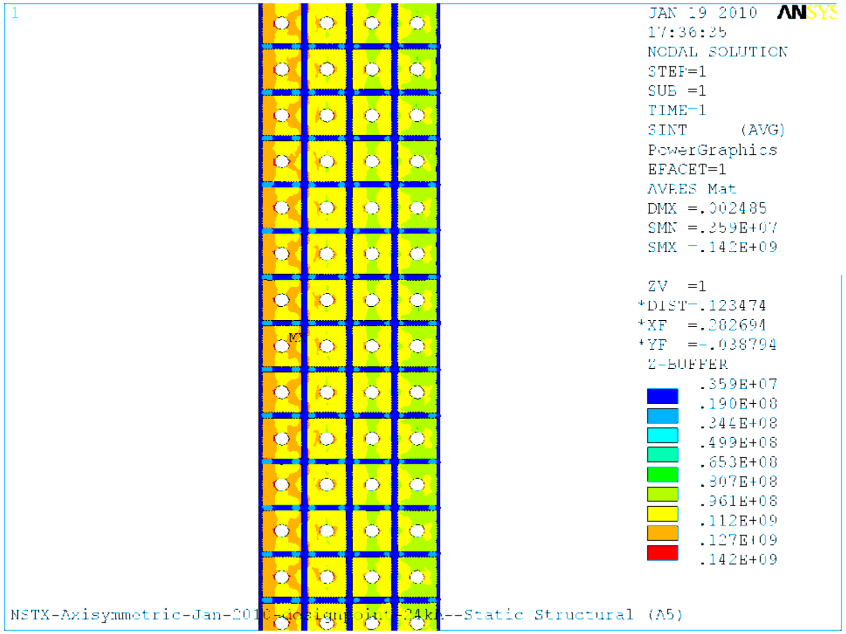
WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1
NSTX-CALC-133-01-01
Prepared By: Leonard Myatt, Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski

All New Center Stack Requires New Analysis and Qualification Cooling and Stress are Critical Sizing Issues



OH Stress Calculation NSTXU-CALC-133-08-00, OH Stress Analyses
Prepared by: Ali Zolfaghari,
Reviewed by: H.M. Fan
Cognizant Engineering: Jim Chrzanowski



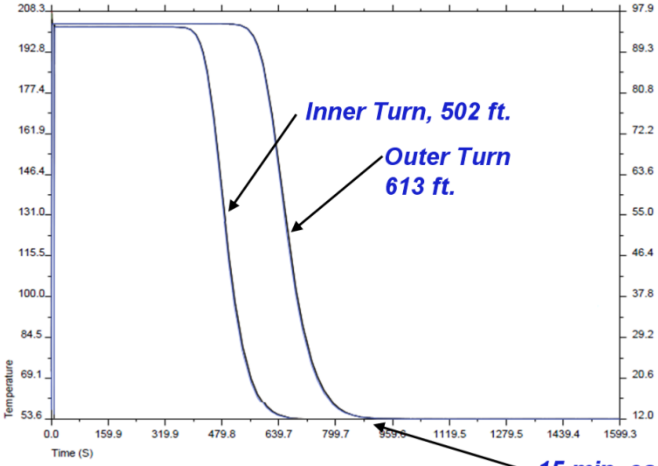


Stress Intensity in the OH Coil Due to Self Currents and Interaction with Current in Adjacent PF1A Poloidal Field Coil

This Stress is not Accessible by Influence Calcs

OH Cooling Requires Metered Flow to Avoid Excessive Cooldown Stress

OH Stress Calculation NSTXU-CALC-133-08-00, OH Stress Analyses
Prepared by: Ali Zolfaghari, Reviewed by: H.M. Fan
Cognizant Engineering: Jim Chrzanowski

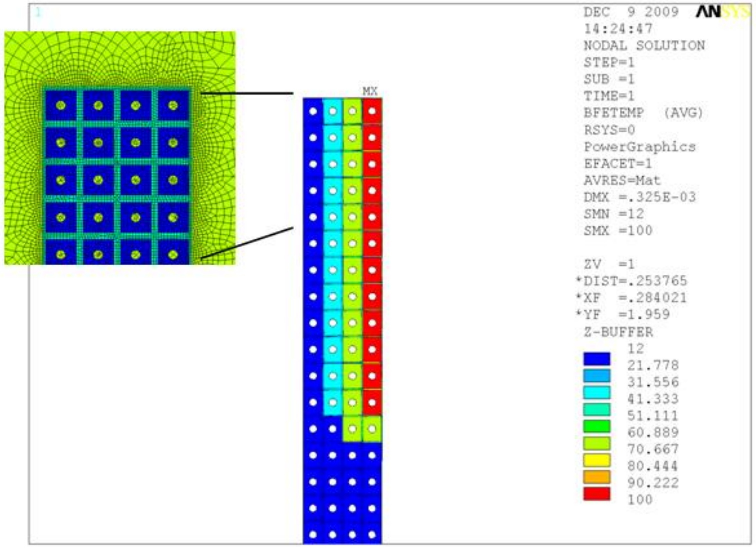


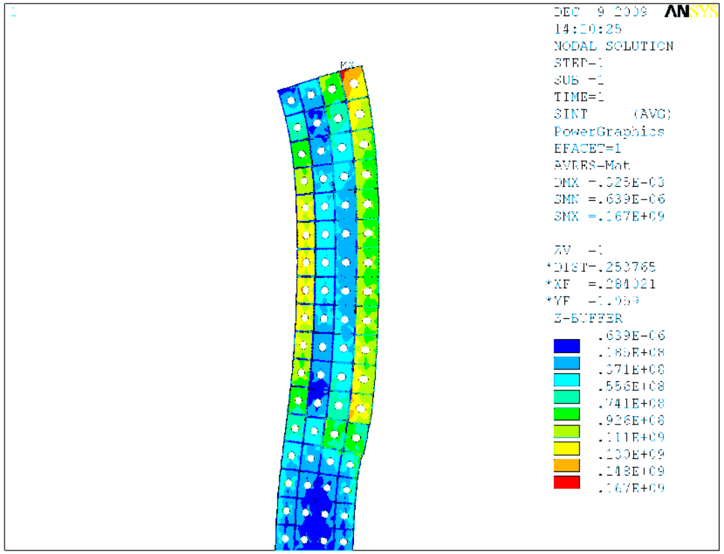
Inner Turn, 502 ft.

Outer Turn 613 ft.

15 min. cooling time

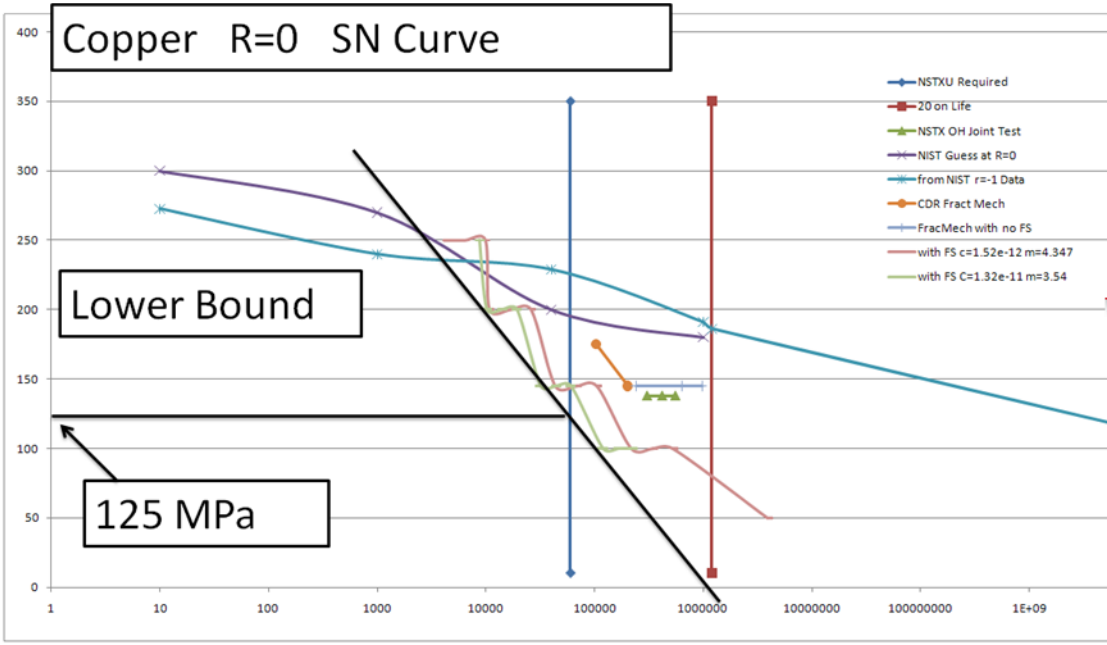
Coolant "Wave" Arrives at the End of the Coil in Different Times Depending on Path Length in the Layer

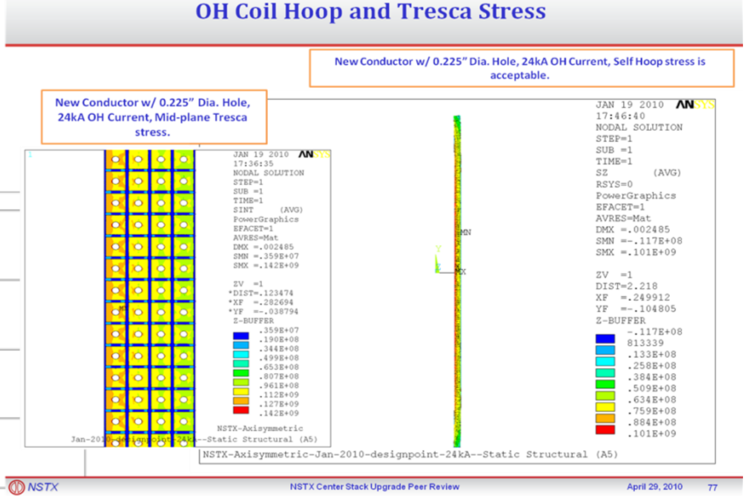




OH Coolant Hole Optimization, NSTXU-CALC-133-06-00
Prepared by: Ali Zolfaghari, Cognizant Engineering: Jim Chrzanowski

Sizing of the Machine is Driven by the OH Cyclic Stress Limit





OH Coil Hoop and Tresca Stress

New Conductor w/ 0.225" Dia. Hole, 24kA OH Current, Self Hoop stress is acceptable.

New Conductor w/ 0.225" Dia. Hole, 24kA OH Current, Mid-plane Tresca stress.

```
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SMX =.142E+09

ZV  =1
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*XF  =.282694
*YF  =-.038794
Z-BUFFER
 .359E+07
 .190E+08
 .344E+08
 .499E+08
 .653E+08
 .807E+08
 .961E+08
 .112E+09
 .127E+09
 .142E+09
NSTX-Axisymmetric
Jan-2010-designpoint-24kA--Static Structural (A5)
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PowerGraphics
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DMX =.002485
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SMX =.101E+09

ZV  =1
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YF  =-.104805
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 813339
 .133E+08
 .258E+08
 .384E+08
 .509E+08
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 .759E+08
 .884E+08
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NSTX-Axisymmetric-Jan-2010-designpoint-24kA--Static Structural (A5)
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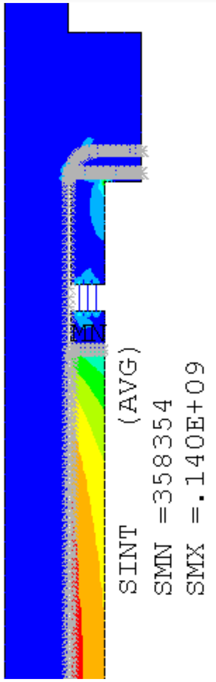
NSTX NSTX Center Stack Upgrade Peer Review April 29, 2010 77



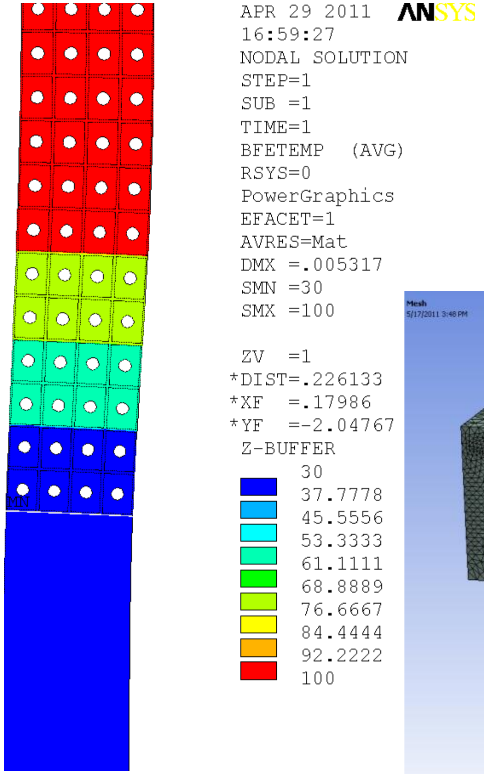
The OH Conductor Must have Manufacturing In-Process NDE to Meet Allowables Gary Voss has Provided Luvata Eddy Current Information – We are Evaluating whether Volumetric Inspection is Needed.

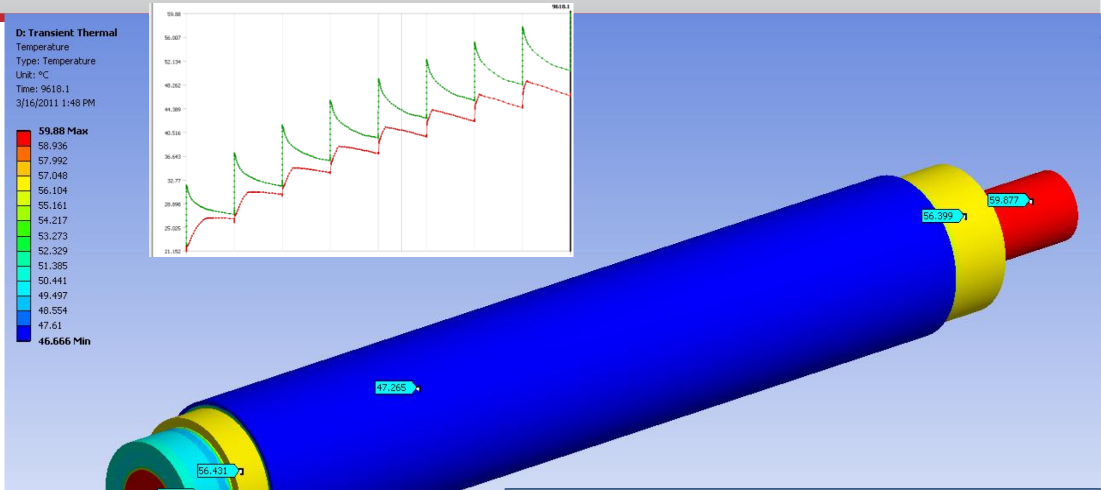
(No Braze Joint has been Qualified)

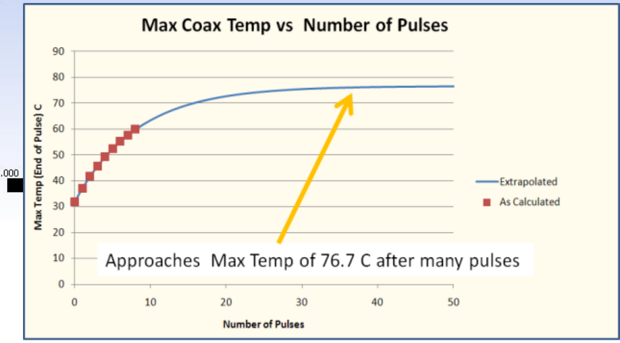
WBS 1.1.3 OH Conductor Fatigue Analysis Calculation Number NSTXU-CALC-133-09, Prepared By: Peter Titus, Reviewed by Irv Zatz Cognizant Engineer: Jim Chrzanowski

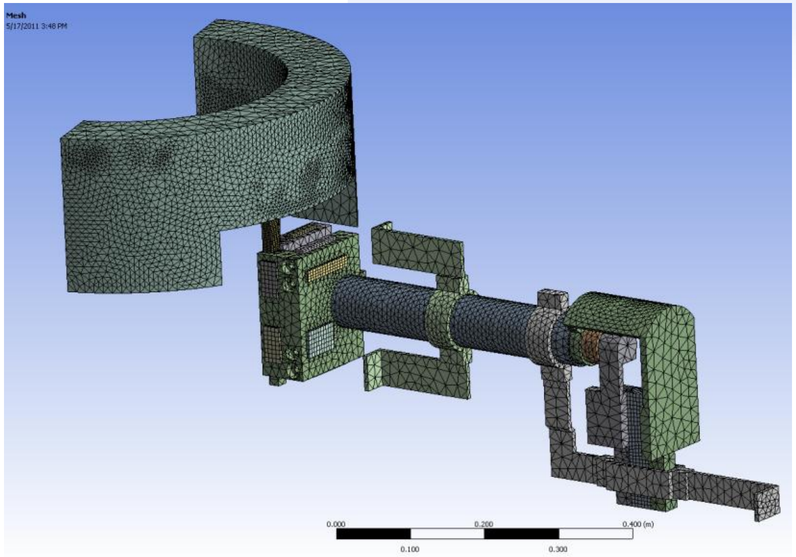
The OH Coax is at Bottom of the OH Coil. It is not Effected by the Vertical Expansion of the OH , But it is Effected by the Radial Expansion of the OH

WBS 1.1.3   OH Coax and Lead Conductor Analysis
Calculation Number NSTXU-CALC-133-07
Prepared By: Michael Mardenfeld , Reviewed By: Unassigned, Cognizant Engineer: Jim Chrzanowski



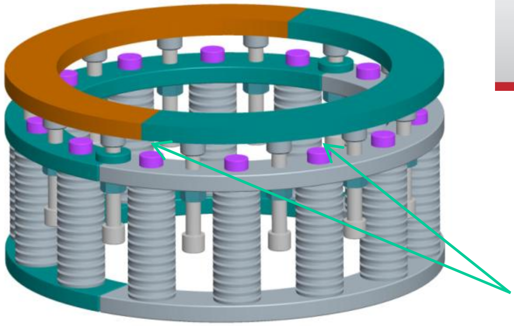






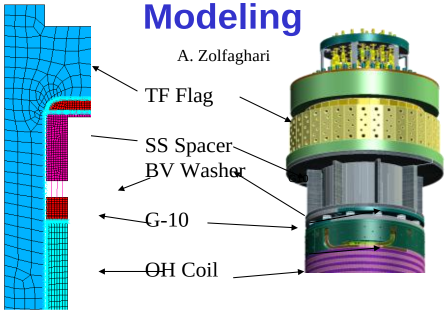
The OH Must be Held in Contact with the Lower G-10 Support Skirt to Disallow the Possibility of separation and loading the terminations and Coolant Connections. This must be done for all Launching Loads, and Thermal Conditions

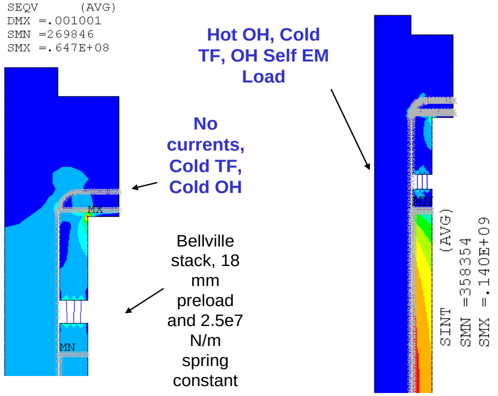
OH Coil Pre Load System



CS Structural/Emag Modeling

A. Zolfaghari





Hot OH, Cold TF, OH Self EM Load

No currents, Cold TF, Cold OH

Bellville stack, 18 mm preload and 2.5e7 N/m spring constant

TF Temp.	OH Temp.	TF Current	OH Current	Launch Force	Peak OH Stress	Peak TF Stress	Peak Displacement	OH Lifted?	Case #	Notes
COLD	COLD	OFF	OFF	OFF	7-14 MPA	7-14 MPA	0.6 mm TF	NO	00000	Bellville staff force only
HOT	COLD	ON	OFF	OFF	102-115 MPA	38-51 MPA	8.8 mm TF	NO	10100	TF grows pushing OH laterally
COLD	HOT	OFF	OFF	OFF	10-19 MPA	19-29 MPA	4.6 mm OH	NO	01000	
COLD	HOT	OFF	ON	OFF	125-140 MPA	16-31 MPA	1.6 mm OH	NO	01010	TF was off and OH current was turned on with hoop stress only
COLD	HOT	OFF	ON	ON	123-138 MPA	16-31 MPA	1.9 mm OH	NO	01011	TF was off and OH current was turned on with hoop stress and launch force.
HOT	COLD	ON	ON	ON	117-132 MPA	15-29 MPA	8.2 mm TF	NO	10111	Just in case, OH getting current before heating up
HOT	HOT	ON	ON	ON	110-134 MPA	15-19 MPA	8.3 mm	NO	11111	

Spring dimensions:
26 disk springs/stack
Di = 30.5 mm
De =60.0 mm
t = 3.5 mm
Lo =5.0 mm
E = 206,000. Mpa
mu = 0.3

Required gap = 23.87 mm (maximum permitted compression on the stack. Protects overloading of permitted spring stresses.)

Supporting calculations:

"TFhot OHcold26_14.ppt"
"TFcoldOHhot26_14.ppt"
"TFhotOHhot26_14.ppt"
"Spring Calculations in mm.x

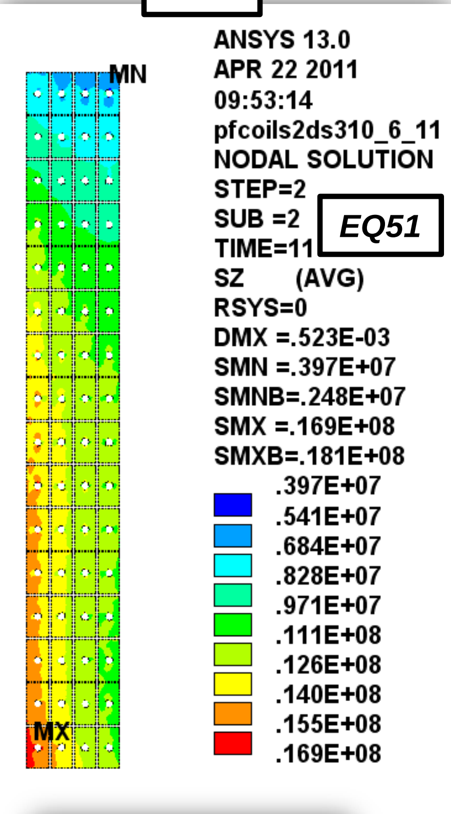
Required 14 stack to maintain a minimum of 20,000. lbs. total load on the OH coil

WBS 1.1.3 OH Preload System & Belleville Spring Design NSTXU-CALC-133-04-00, Prepared By: Peter Rogoff, Tested by T. Kozub, Cognizant Engineer: Jim Chrzanowski

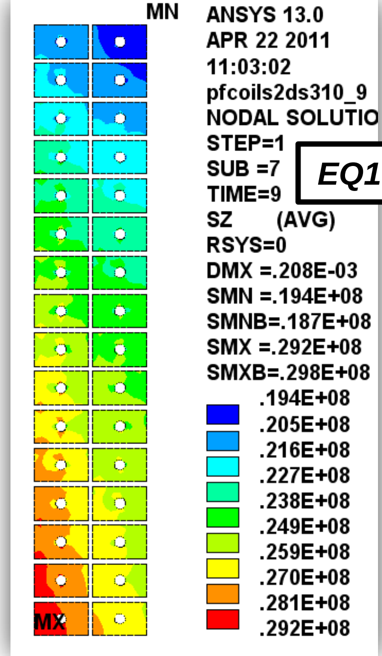
Note: Spring should be made from SS 301 mate
Depending on Stainless Steel conditions
modulus of elasticity may be slightly diff
In this case, minimum load on the OH co
decrease by a small percentage (say 3 to
while everything else will stay the same.

New Inner PF's Require Qualification

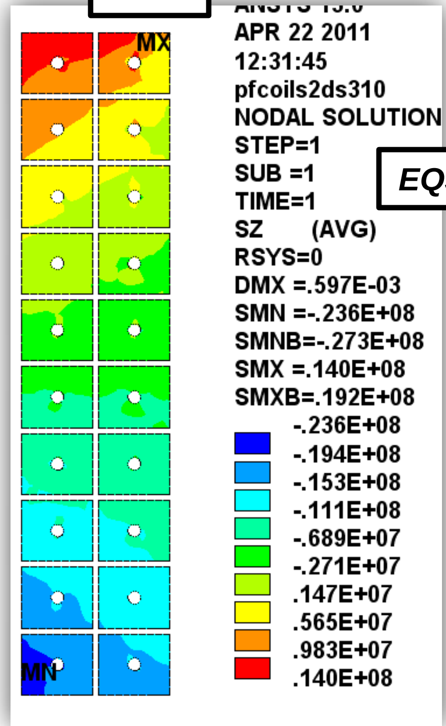
PF1a

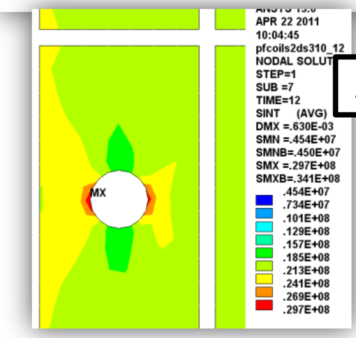

EQ51

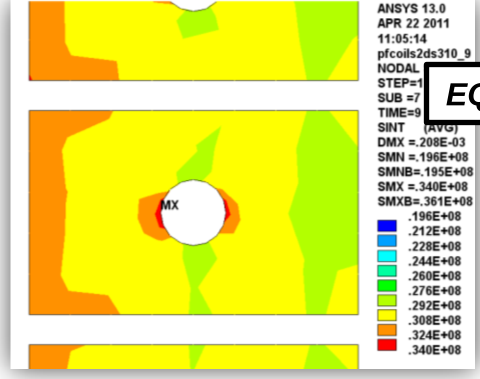
PF1b


EQ18

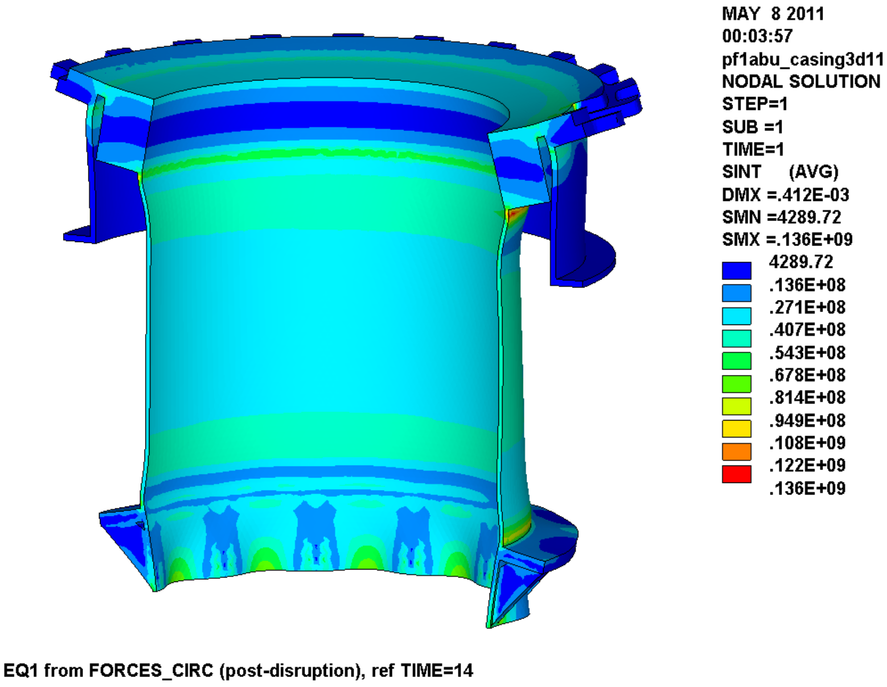
PF1c


EQ33

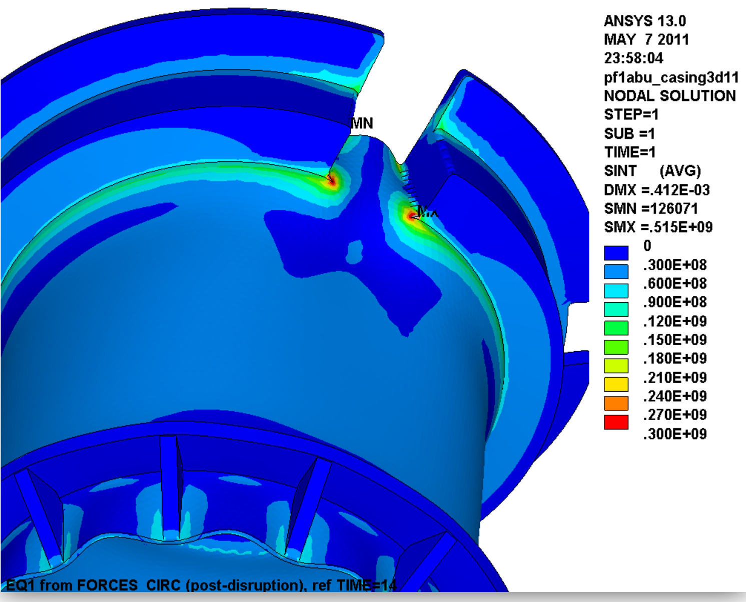

EQ54


EQ18

WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1
NSTX-CALC-133-01-01
Prepared By: Leonard Myatt, Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski



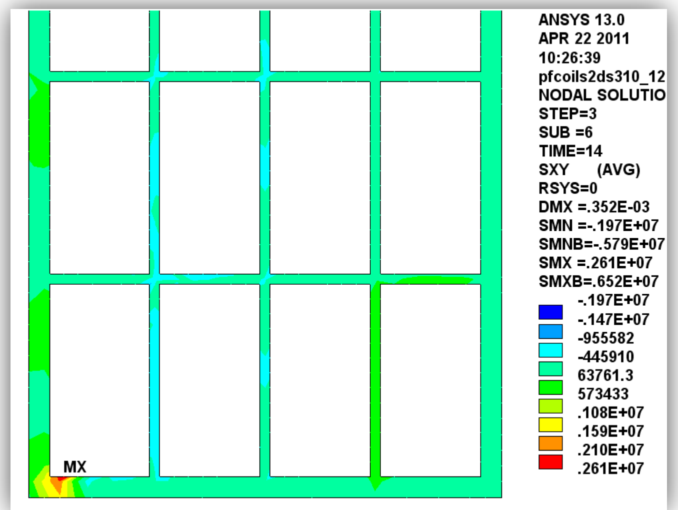
The 3D PF1a/b model reproduces the max axisymmetric mandrel stress of away 140 MPa from the most significant 3D structural features

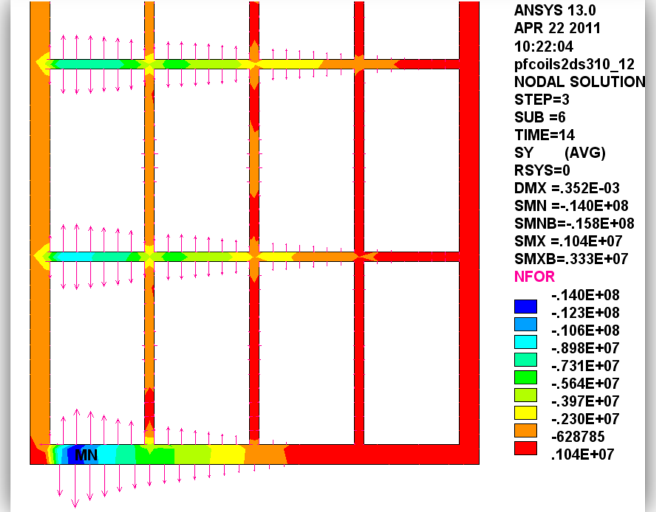


The winding shell flexure at the lead opening produces some significant local stresses:
Mem: 156 MPa (<300 MPa 👌)
M+B: 340 MPa (<450 MPa 👌)
Peak: 515 MPa (fatigue TBD)

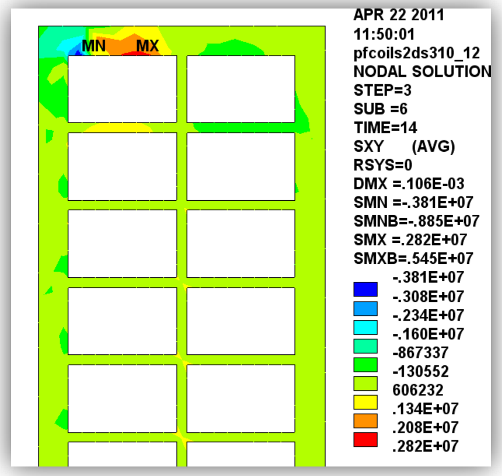
Shear Stresses are < 2 Mpa – Only CTD 101 K without Primer is Required

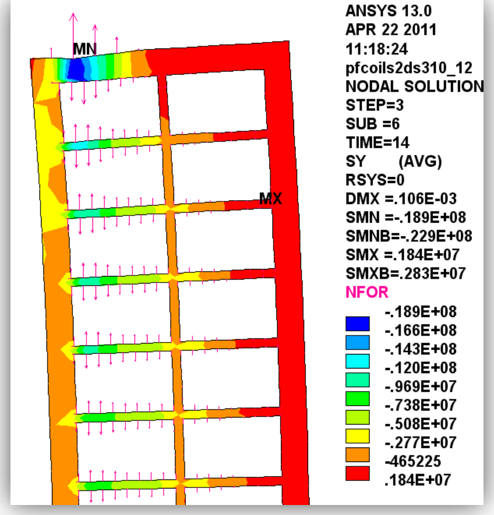
PF1a



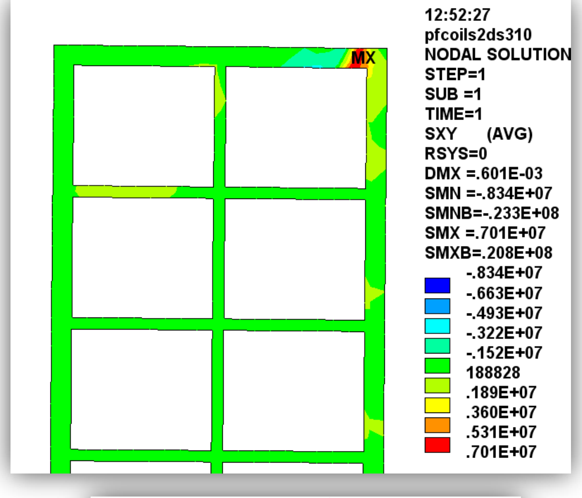


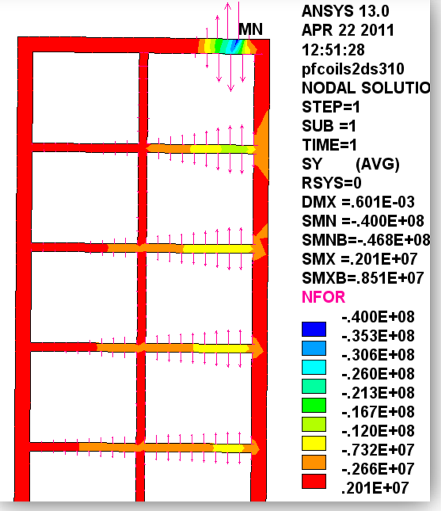
PF1b



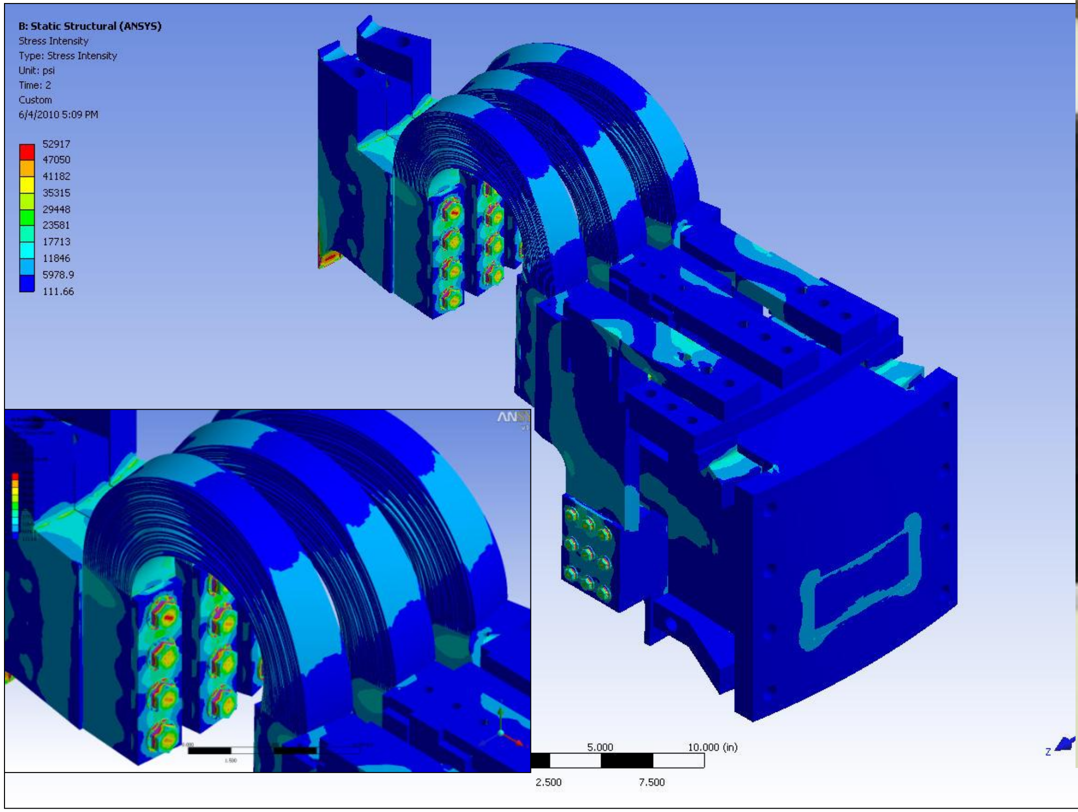


PF1c

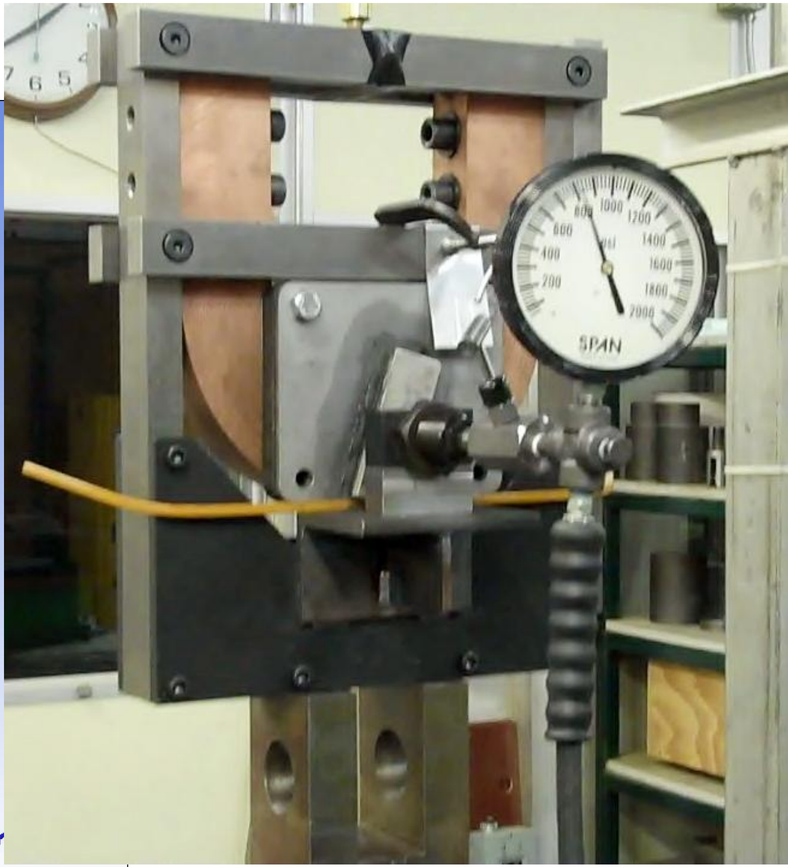




Past Difficulties with the TF Joint Demand a New Robust Joint Design

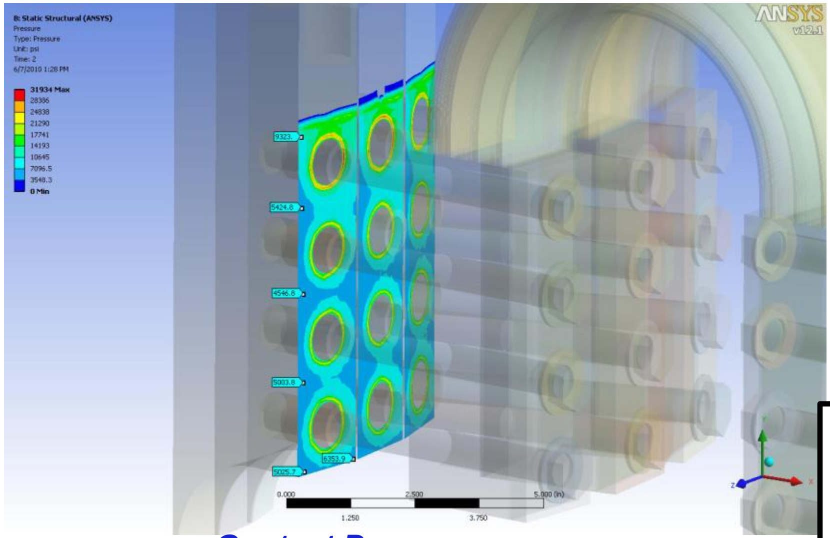


B: Static Structural (ANSYS)
Stress Intensity
Type: Stress Intensity
Unit: psi
Time: 2
Custom
6/4/2010 5:09 PM



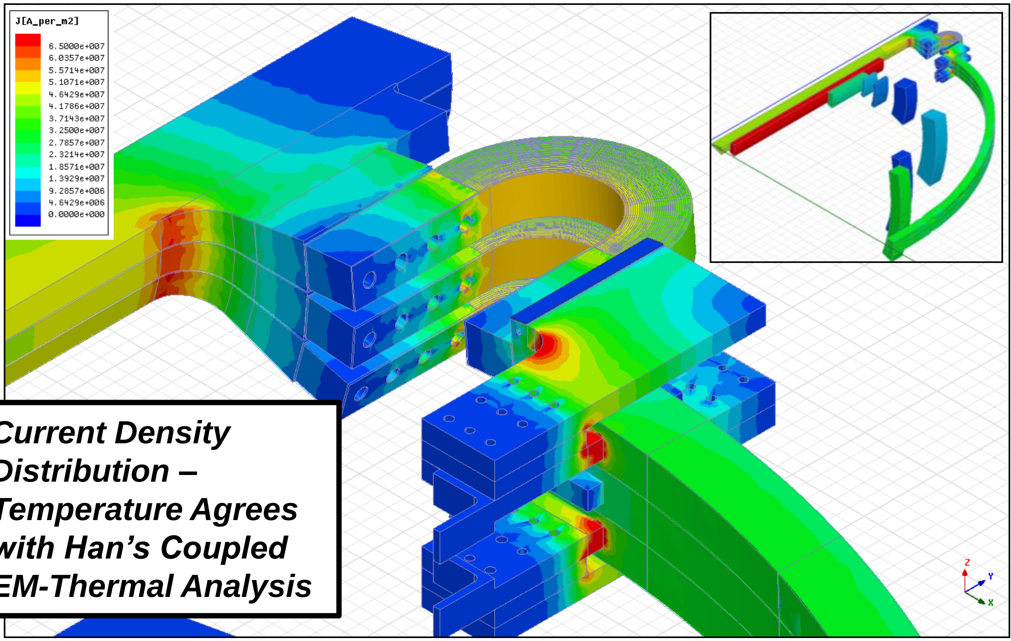
TF Flex Joint and TF Bundle Stub NSTXU-CALC-132-06-00
Prepared By: Tom Willard, Reviewed by: Ali Zolfaghari
Cognizant Engineer: Jim Chrzanowski

Contact Pressures are Maintained with a Large Margin - Based on Lessons Learned form Original NSTX Flag

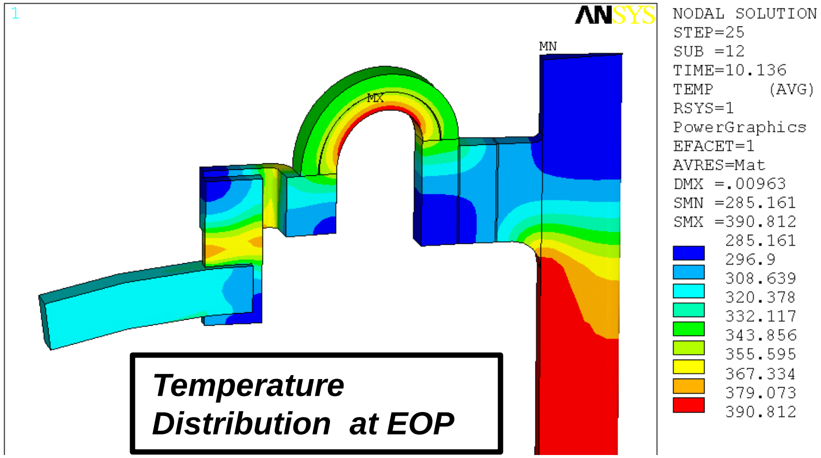


Contact Pressure

TF Flex Joint and TF Bundle Stub NSTXU-CALC-132-06-00
Prepared By: Tom Willard, Reviewed by: Ali Zolfaghari
Cognizant Engineer: Jim Chrzanowski



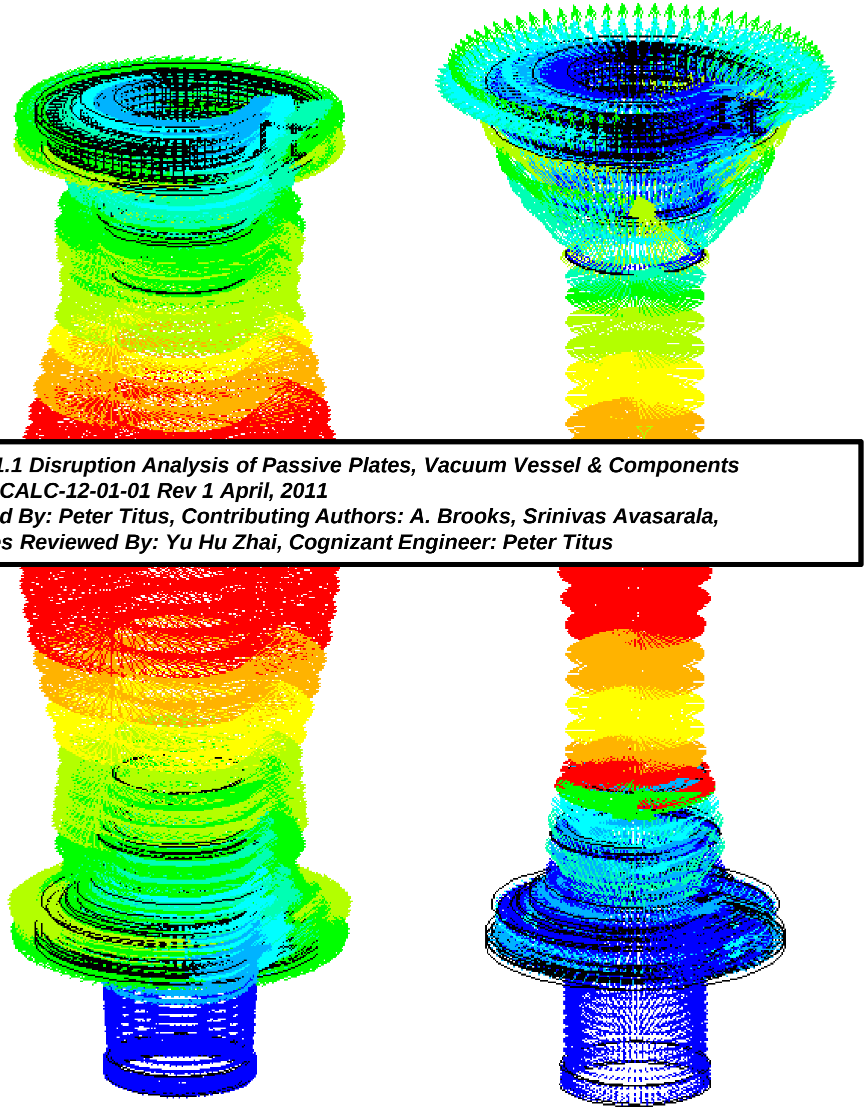
Current Density Distribution – Temperature Agrees with Han's Coupled EM-Thermal Analysis



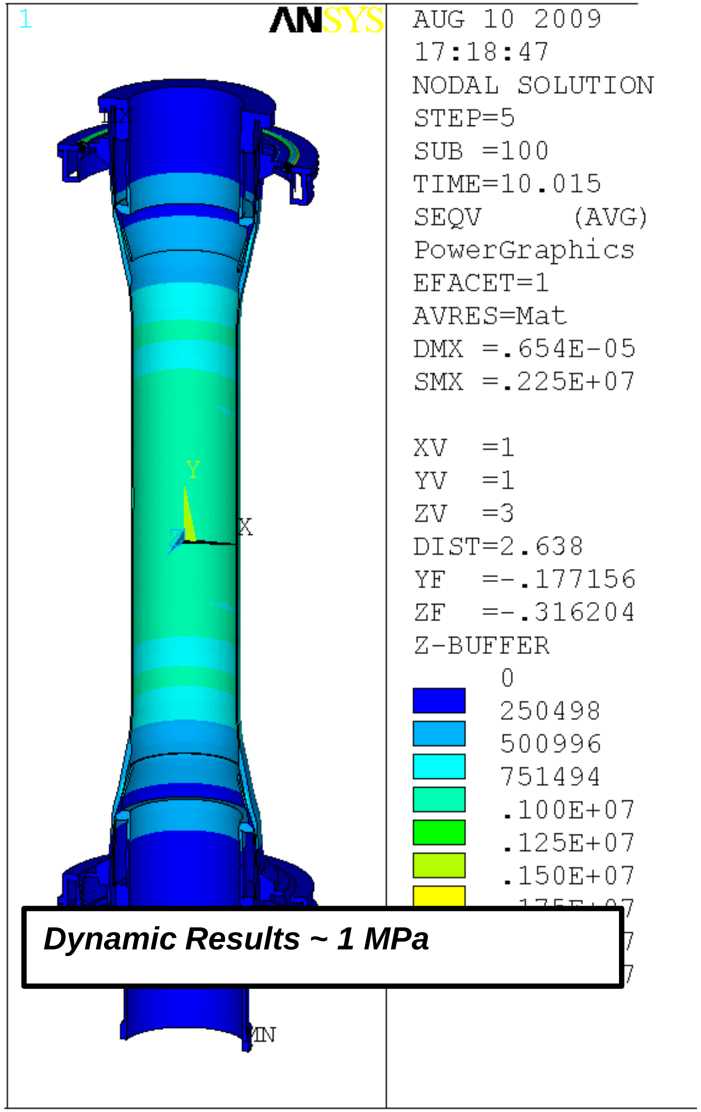
Temperature Distribution at EOP

TF Coupled Thermal Electromagnetic Diffusion Analysis,
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

Up to 40% of the Plasma Current is Inductively Driven in The Centerstack During a Disruption

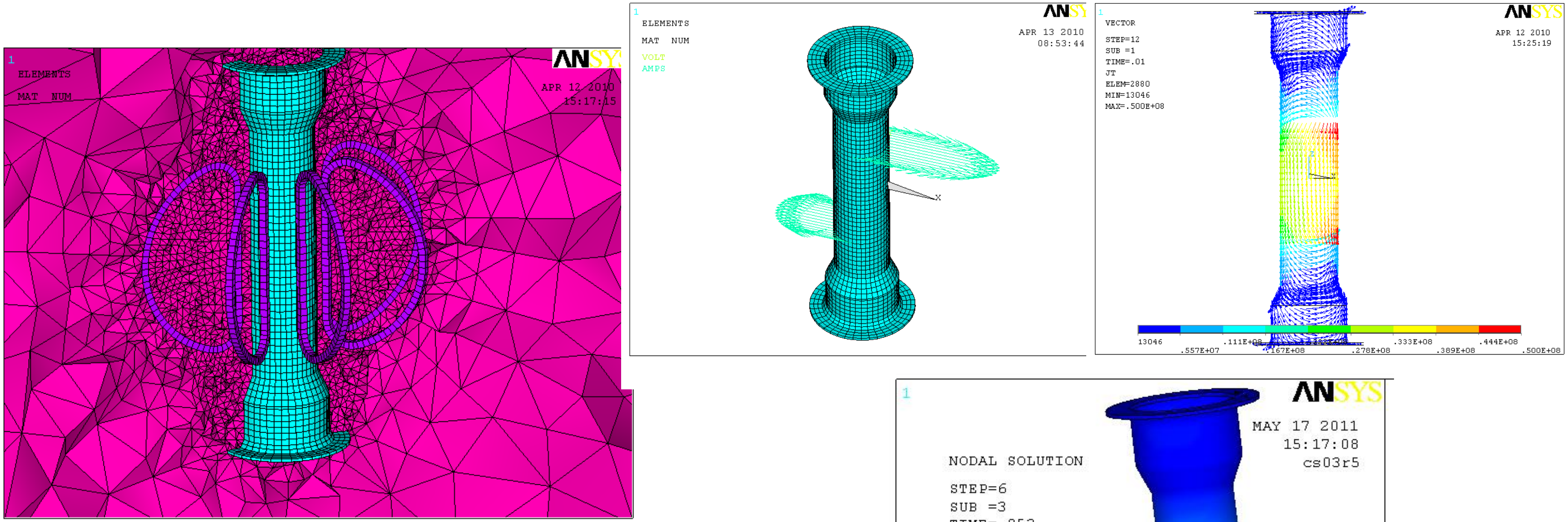


WBS 1.1.1 Disruption Analysis of Passive Plates, Vacuum Vessel & Components
NSTXU-CALC-12-01-01 Rev 1 April, 2011
Prepared By: Peter Titus, Contributing Authors: A. Brooks, Srinivas Avasarala, J. Boales Reviewed By: Yu Hu Zhai, Cognizant Engineer: Peter Titus



Dynamic Results ~ 1 MPa

The Tall Narrow Centerstack Could Experience Excessive Lateral Loads If Peaking Factors are Sustained.

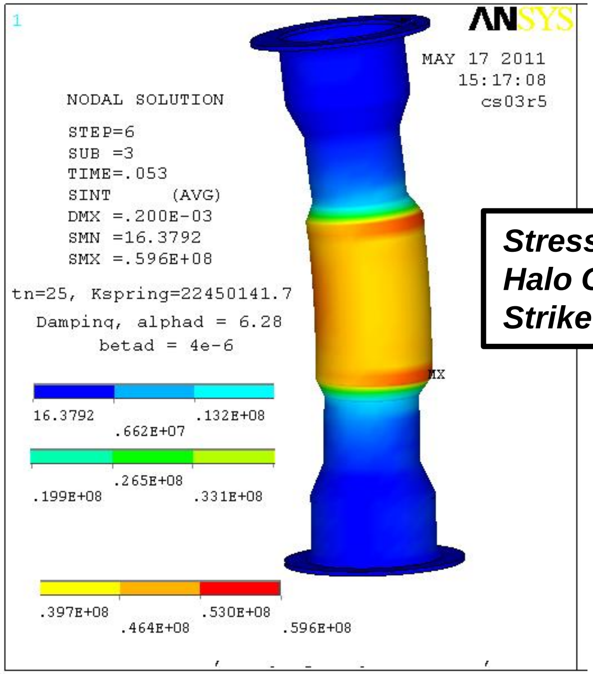


WBS 1.1.3 Magnet Systems, Halo Current Analysis of Center Stack

NSTXU-CALC-133-05-00

Prepared By: Art Brooks, Reviewed by: Peter Titus,

Cognizant Engineer: Jim Chrzanowski


1

NODAL SOLUTION

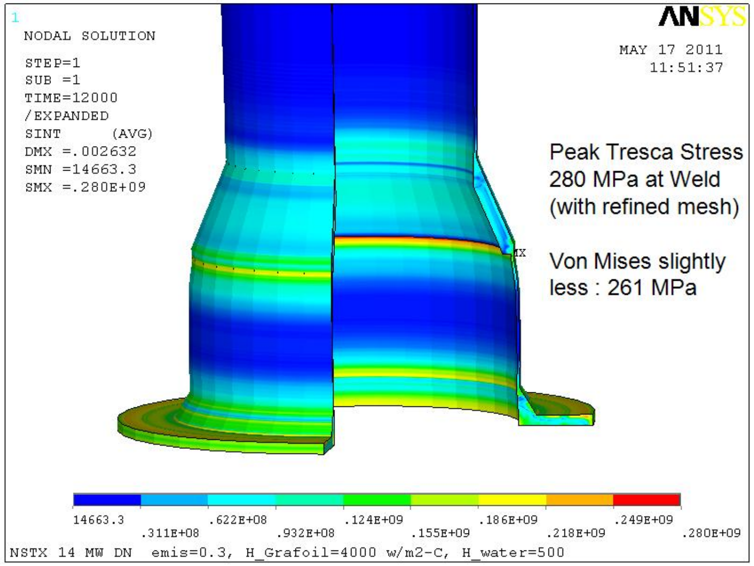
STEP=6
SUB =3
TIME=.053
SINT (AVG)
DMX =.200E-03
SMN =16.3792
SMX =.596E+08

tn=25, Kspring=22450141.7
Damping, alphad = 6.28
betad = 4e-6

MAY 17 2011
15:17:08
cs03r5

Stress Due Halo Current Strike

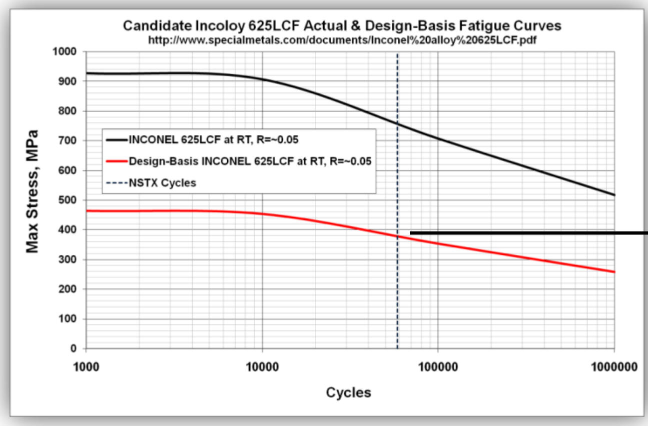
Stress Due Thermal Distribution



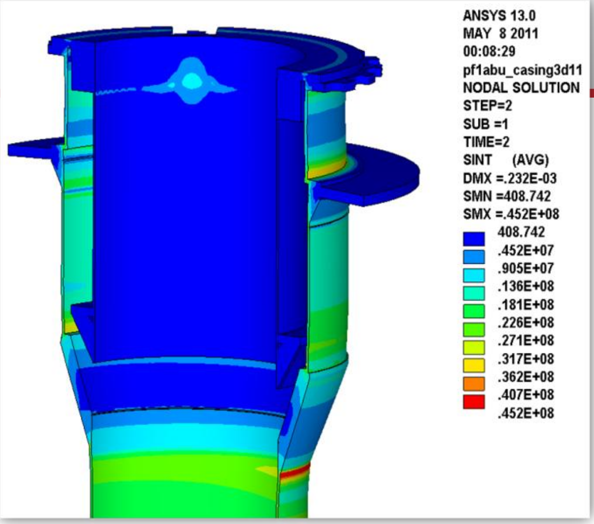
Peak Tresca Stress 280 MPa at Weld (with refined mesh)

Von Mises slightly less : 261 MPa

WBS 1.1.1 Plasma Facing Components, Global Thermal Analysis of Center Stack – Heat Balance NSTX-CALC-11-01-00
Prepared By: Art Brooks, Reviewed by: Han Zhang, Cognizant Engineer: Jim Chrzanowski



Stress Due to PF Loads

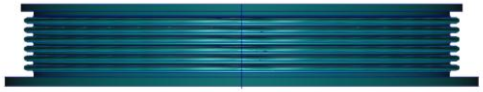


WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1 NSTX-CALC-133-01-01
Prepared By: Leonard Myatt, Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski

NSTX Upgrade Centerstack Casing Stress Summary NSTXU-CALC-133-03-00
Rev 0 May 2011 Prepared By: Peter Titus, PPPL Engineering Analysis Branch, Contributing Authors: A. Brooks, L.Myatt
Reviewed By: Unassigned
Jim Chrzanowski, NSTX Cognizant Engineer

Thermal +Lorentz +Inductive + Halo
261 + 42 + 1 + 60 = 364

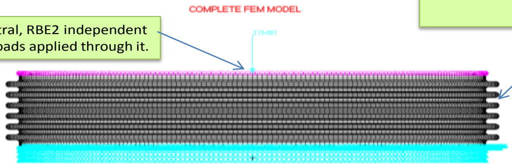
Bellows Allow Vertical Expansion of the Centerstack Casing – This is Axial Motion, but Lateral and Torsional Loads Exist



Modulus of Elasticity = 29,000,000.
stainless steel (FEA and EJMA)
t = variable (.02, .025, .03) in.

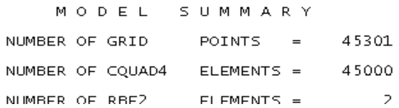
Di = 38.0 inches
Do =40.25 inches

w = 1.095 in. convolution height
q = 1.0 in. convolution pitch



Node #49436 – central, RBE2 independent Deformations and loads applied through it.

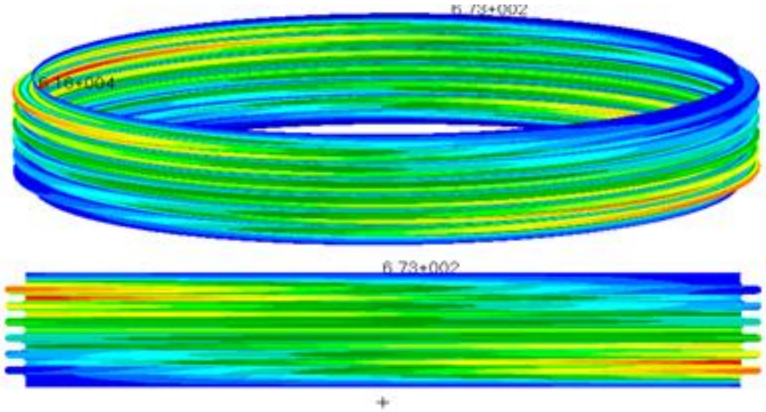
Fixed : x, y, z, Rx ,Ry, Rz



```
        M O D E L    S U M M A R Y

NUMBER OF GRID      POINTS   =    45301
NUMBER OF CQUAD4    ELEMENTS =    45000
NUMBER OF RBE2      ELEMENTS =        2
```

<u>Note</u>: All stresses reported are for cquad4 surface “Z2” . This is the bellows inside surface.



WBS 1.1.3 Center Stack Casing Bellows,
Calculation Number NSTXU-CALC-133-10-00
Prepared By: Peter Rogoff, Reviewed by Irv Zatz
Cognizant Engineer: Jim Chrzanowski

•Halo Current Loads (upper bellows only). Reference calculation #NSTX CALC 133-04-00.

•The upper bellows must allow thermal motion due to the bake-out and the normal operation where heat from the plasma is transferred to the CS casing through the insulating tiles. Reference calculation # NSTX CALC 11-01-00.

•The upper bellows must support the seismic loads, Reference calculation #NSTX CALC 10-01-02.

•The upper and lower bellows transmit some portion of the torsional moment from the upper vessel structure to the center stack casing. This moment comes through the umbrella structure, Reference calculation # NSTX CALC 10-01-02.

•Pressure due to vacuum conditions.

EJMA

These calculations were performed using:

- ***EJMA (Expansion Joint Manufacturers Association) Basic equations presented in section 4.13 of the manual.***

•NASTRAN Version MSC FEA x64 2010.1.2 finite element code.

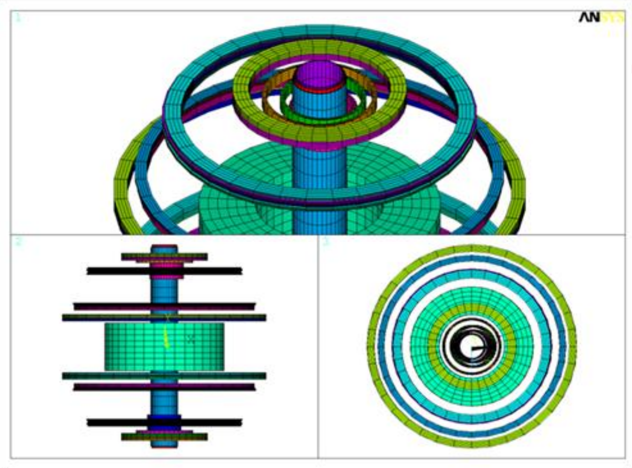
The Upper End of the Centerstack Casing is Only Coupled to the Rest of the Machine Through the Bellows

WBS 1.1.3 OH & PF1 & 2 Electromagnetic Stability Analyses
NSTXU-CALC-133-11-00 Rev 0 March 2 2010
Prepared By: Peter Titus, Ali Zolfaghari,
Reviewed By: H.M.Fan,
Cognizant Engineer: Jim Chrzanowski

The Centerstack Stability with Respect to the Rest of the Poloidal Coil System relies on the stiffness of the Upper and Lower Lid – and some centering system of the OH with Respect to the TF (Bumpers in the Gap? Lateral Stiffness of the Belleville Spring Stacks?)

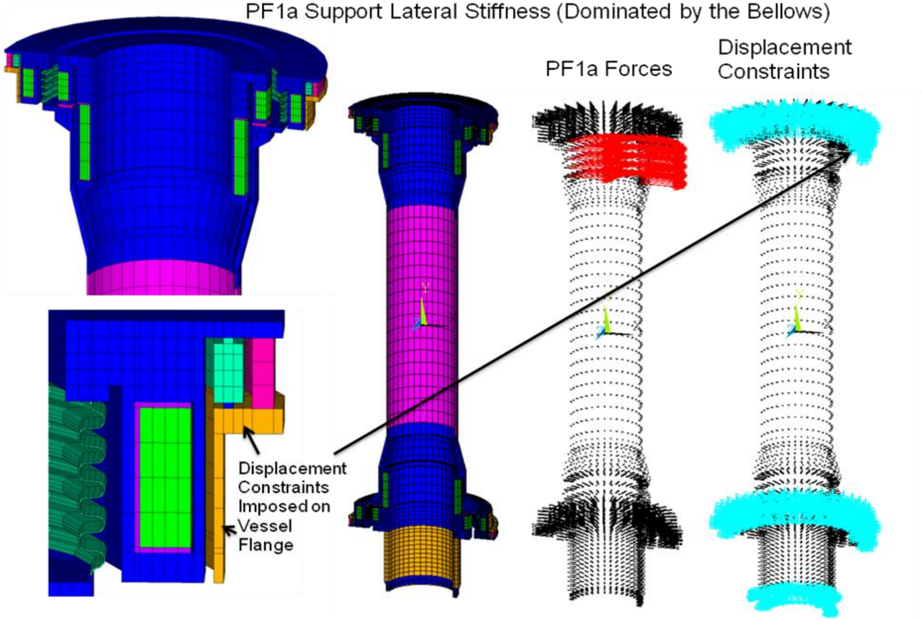
Other Stabilities Need to Be Addressed

Magnetic Stability of PF's and OH



Stability of PF1a,b with Respect to the OH

PF1a Support Lateral Stiffness (Dominated by the Bellows)



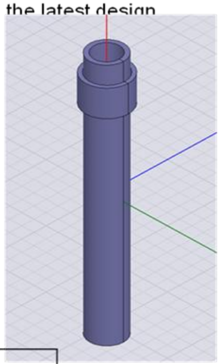
Magnetic Stability of PF1a With Respect to the OH
A Zolfaghari MAXWELL Results

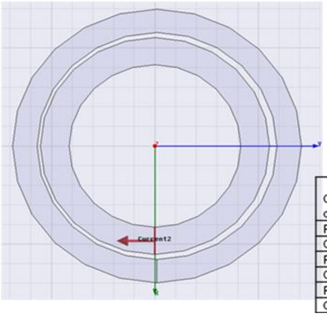
PF1a is supported off the centerstack casing which is stabilized laterally by the bellows/ceramic break assembly. The stiffness of the supports must be sufficient to overcome the magnetic stiffness. To quantify the magnetic stiffness the Lorentz force between the OH and PF1a coils was calculated for different lateral offsets.

Pf1a and Oh coils dimensions and arrangement were used from the latest design point.

Coil	Current (kA)	Turns
OH	24	884
PF1a	18.3	64

The PF1a is moved 2mm and 5mm in the positive Y direction.

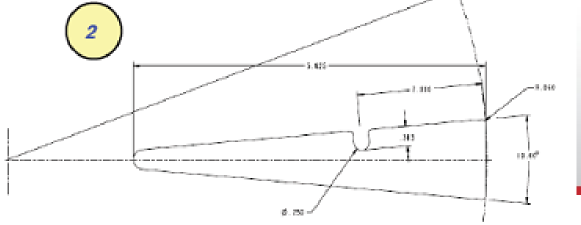


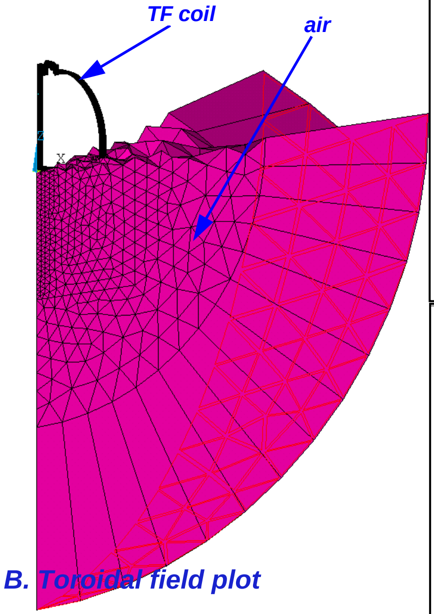


Magnetic Stiffness= 3189/.005 N/m = .637MN/m

Orientation of currents	PF1a Offset (mm) in +Y direction	Force on PF1a (N) in +Y Direction
Parallel	2	1191
Opposite	2	-1255
Parallel	5	3167
Opposite	5	-3189
Parallel	0	-141
Opposite	0	125

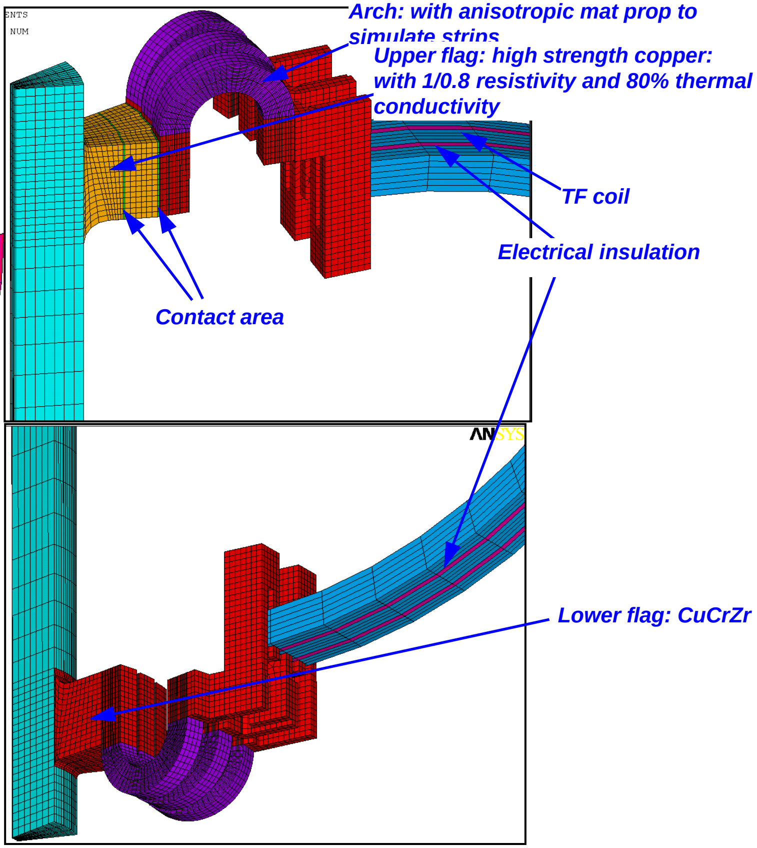
Single Width “Blade” Or Bitter Magnet Design Introduces Possibility of Transient Coupled Electromagnetic Thermal Diffusion




TF coil

air

B. Toroidal field plot


Arch: with anisotropic mat prop to simulate strips

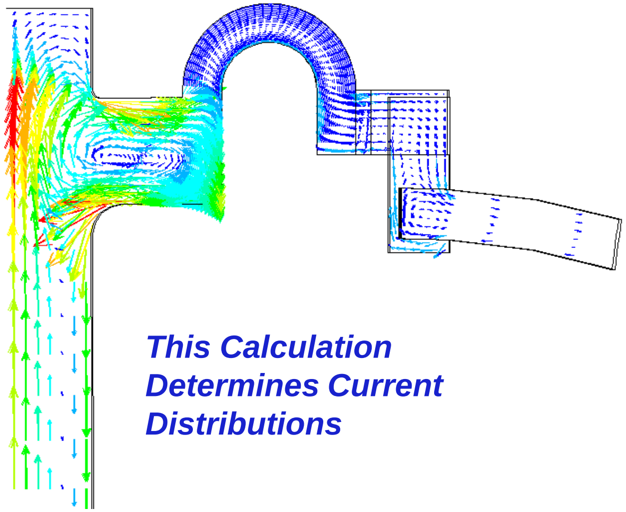
Upper flag: high strength copper: with 1/0.8 resistivity and 80% thermal conductivity

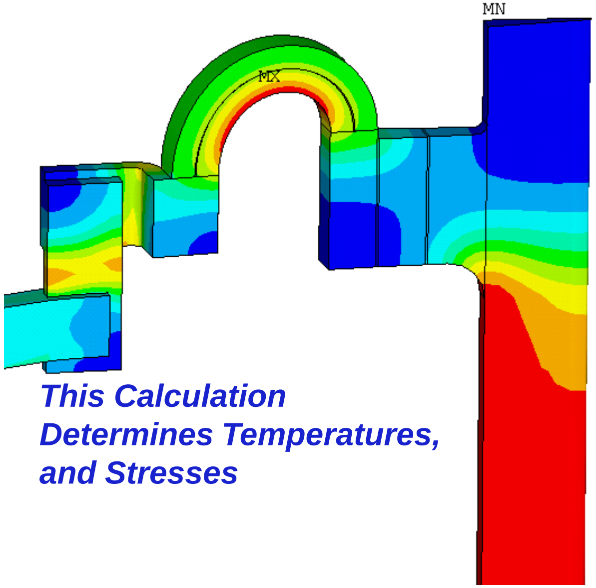
TF coil

Electrical insulation

Contact area

Lower flag: CuCrZr

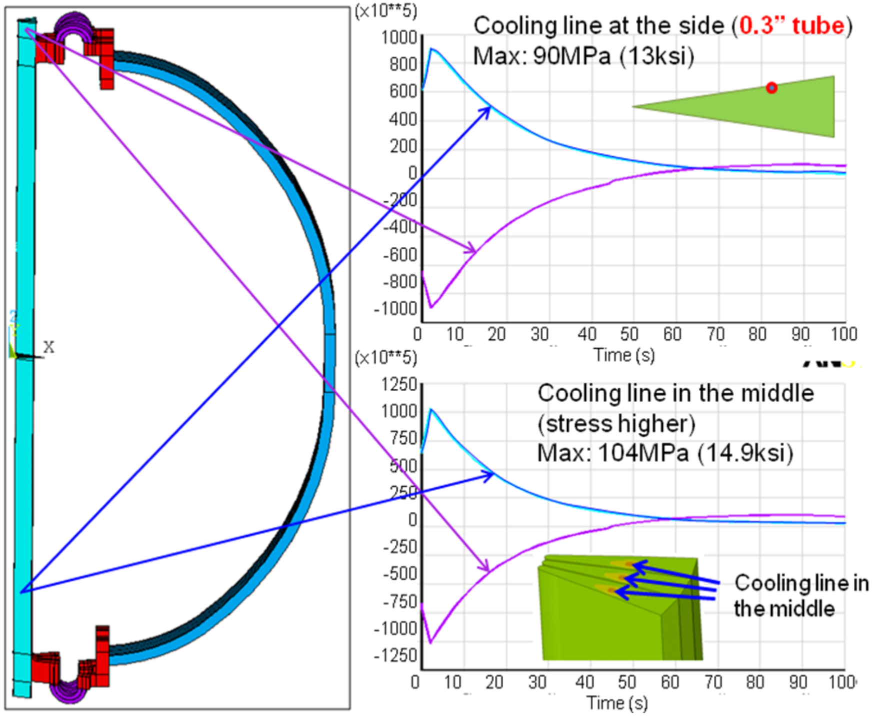

This Calculation Determines Current Distributions

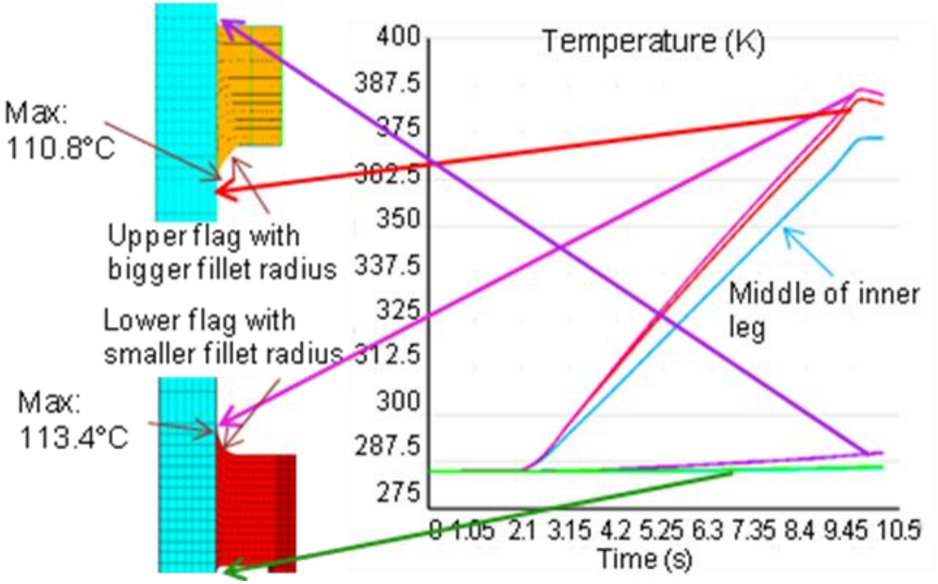


This Calculation Determines Temperatures, and Stresses

TF Coupled Thermal Electromagnetic Diffusion Analysis,
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

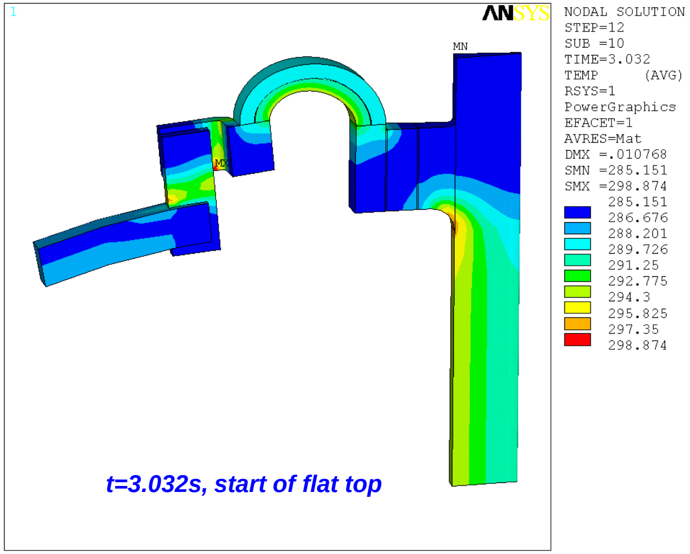
Single Width "Blade" Or Bitter Magnet Design Introduces Possibility of Transient Coupled Electromagnetic Thermal Diffusion



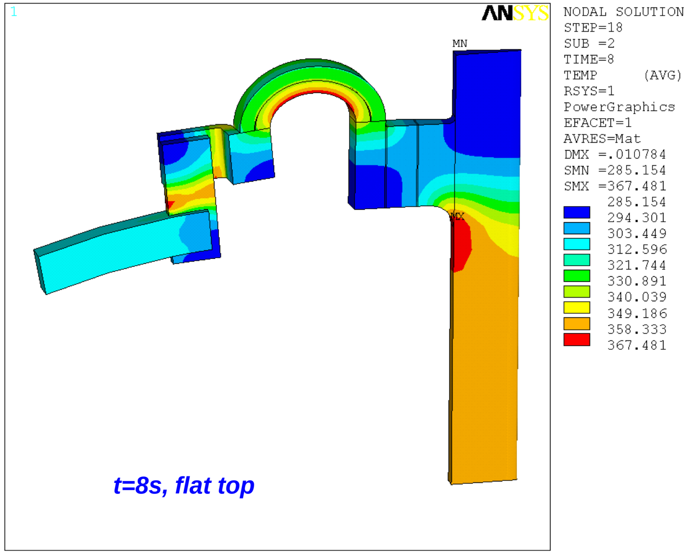


TF Coupled Thermal Electromagnetic Diffusion Analysis,
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

TF Coils are at the Thermal Limit for Epoxies

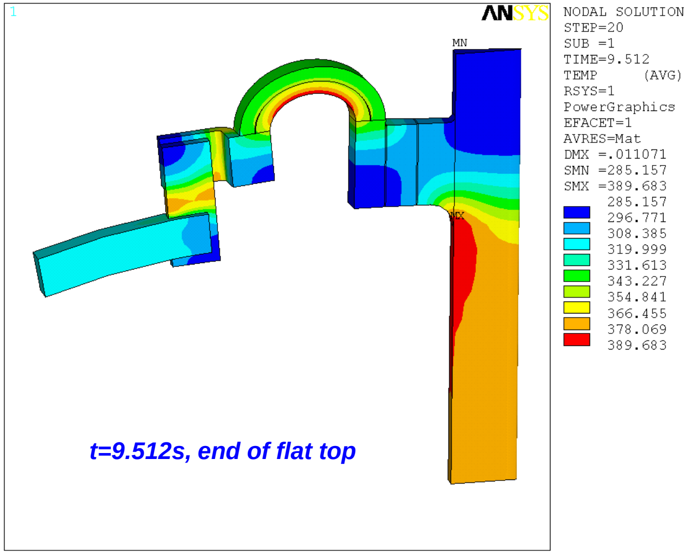


t=3.032s, start of flat top

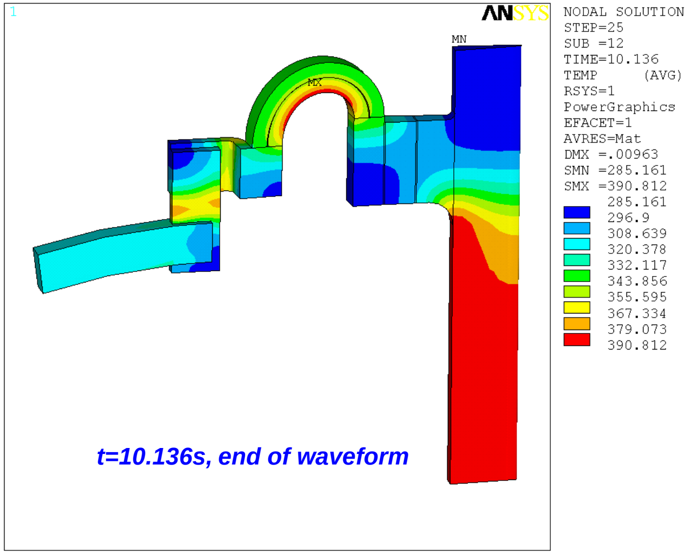


t=8s, flat top

TF Coupled Thermal Electromagnetic Diffusion Analysis, NSTXU-CALC-132-05-01, Prepared By: Han Zhang, Reviewed by Yuhu Zhai, Cognizant Engineer: Jim Chrzanowski

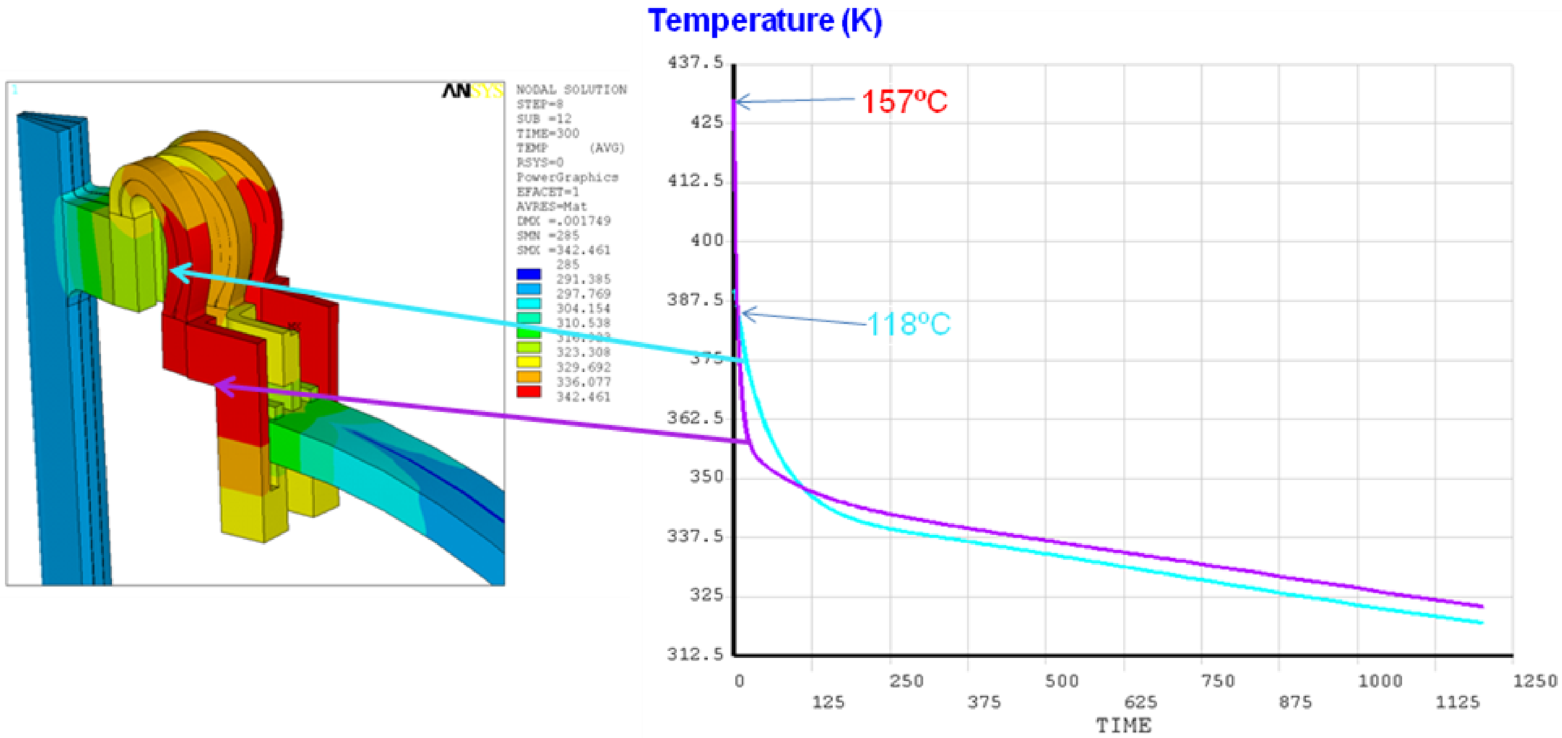


t=9.512s, end of flat top



t=10.136s, end of waveform

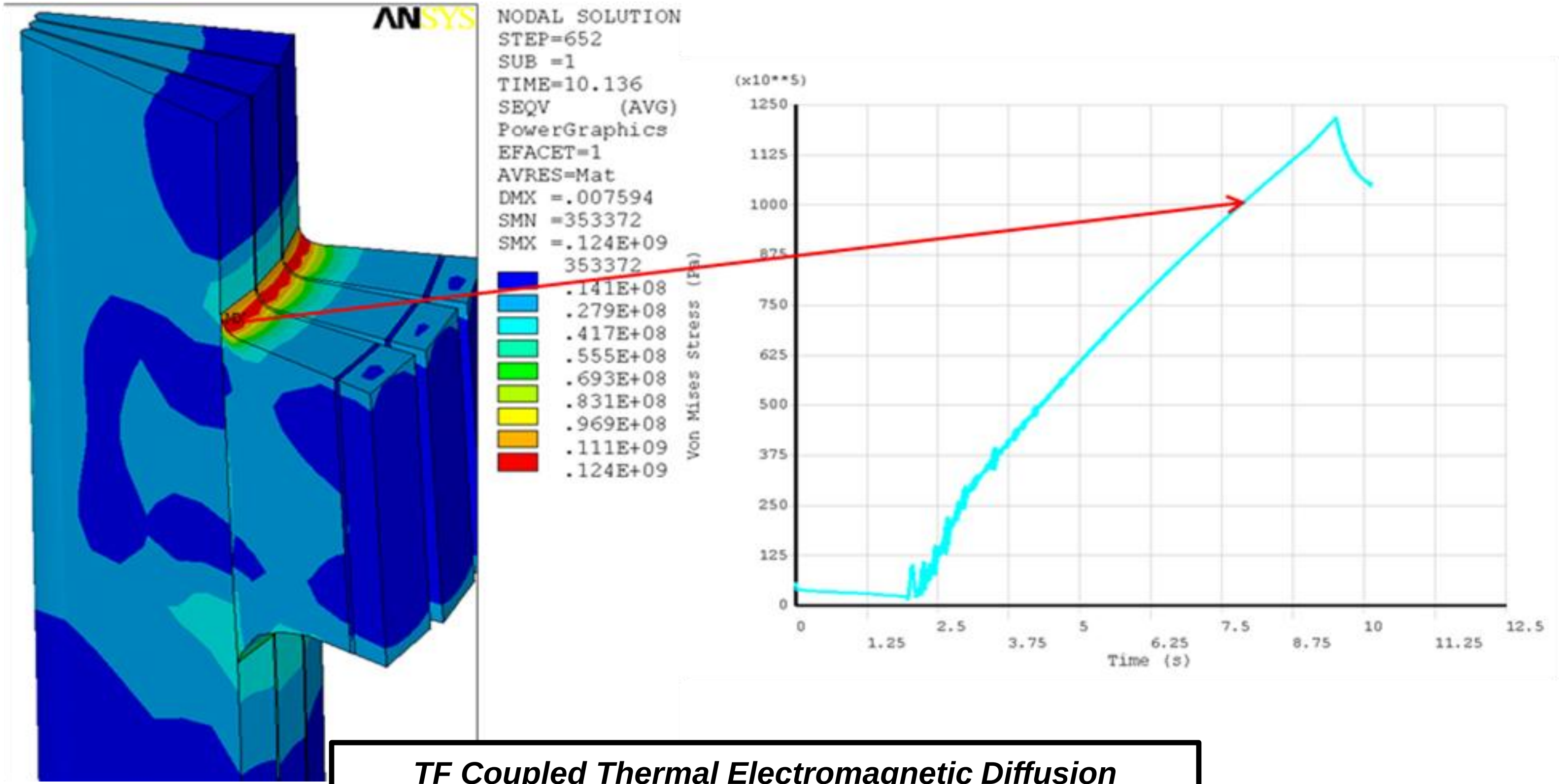
TF Flex Must be Conduction Cooled from Its Ends – Higher Resistivity High Strength Friction Stir Welded Flag Must Perform Adequately Thermally



TF Coupled Thermal Electromagnetic Diffusion Analysis, (Part 2)
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

TF Cool-down using FCOOL CALC-132-10-00
Prepared by: Ali Zolfaghari, Reviewed by: Mike Kalish
Cognizant Engineer: Jim Chrzanowski

Higher Resistivity High Strength Friction Stir Welded Flag Must Perform Adequately



TF Coupled Thermal Electromagnetic Diffusion Analysis, (Part 2)
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

Existing NSTX has been Cyclically Loaded.
Many Existing Weldments are not “Fatigue Friendly”

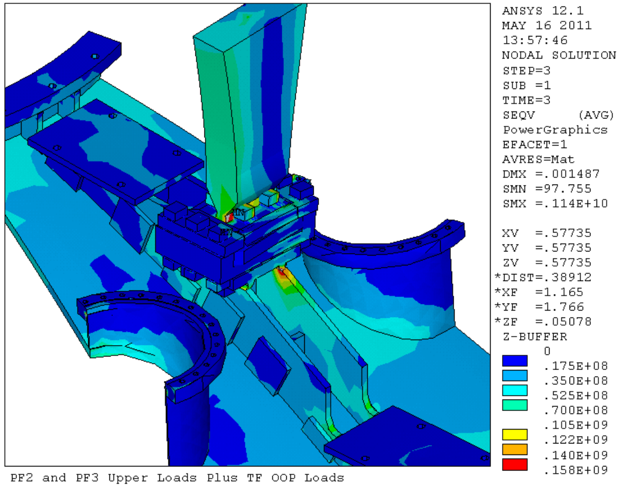
Qualify Analytically Where Possible

Add Reinforcements/Radii

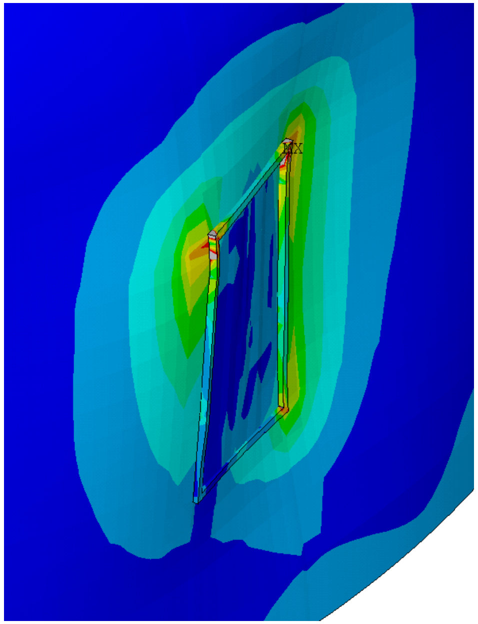
Inspect

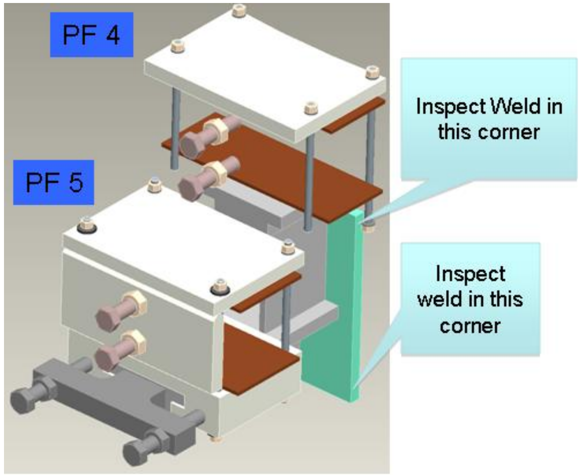
Avoid Fatigue Sensitive Welds
  - ***Small Fillets?***
  - ***Intermittent Welds?***
  - ***Partial Penetration***

Consider Peening



PF2 and PF3 Upper Loads Plus TF OOP Loads

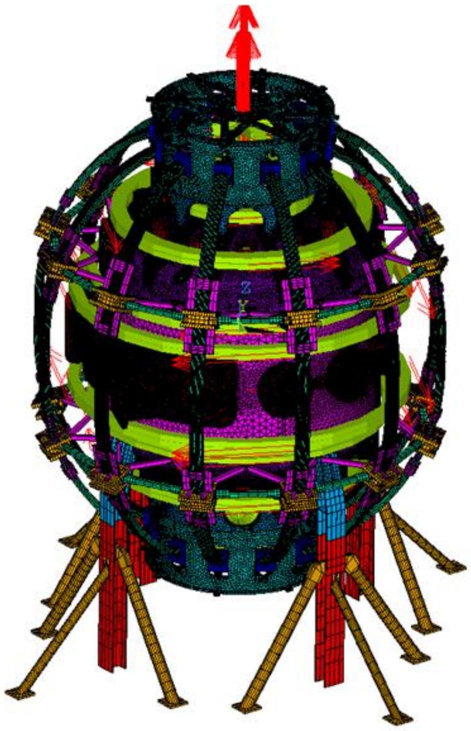




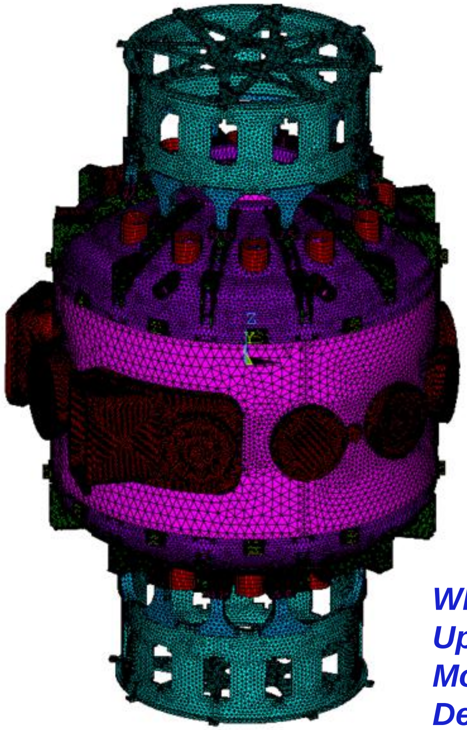
The Tokamak is Multiply Redundant, Global Model Model Simulations are Required

Global Model Is Used For:

Address Statically Indeterminate Structures
Selecting Worst Cases
Scoping Studies
Providing Boundary Conditions for Other Models
Cross-Checking other Models
Seismic Analysis

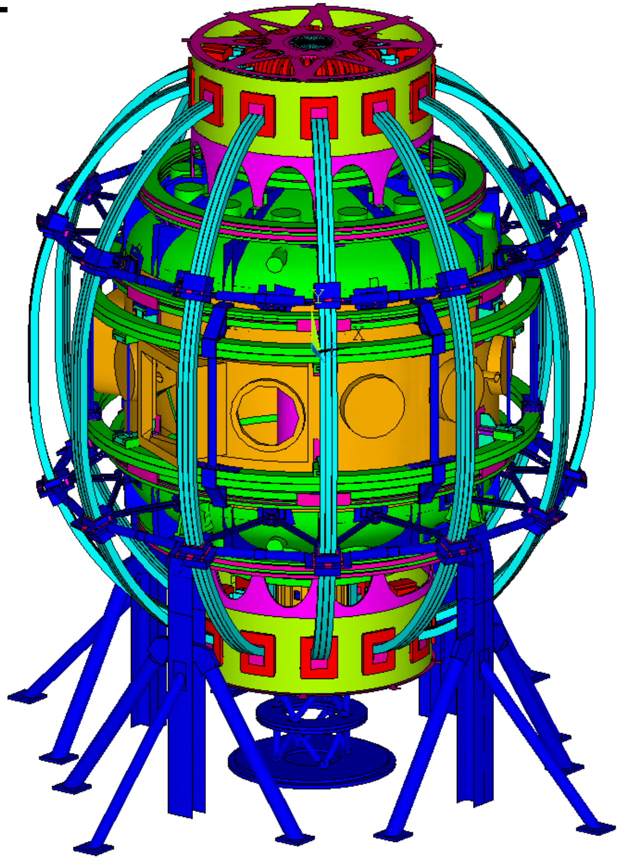


Analysis of TF Outer Leg, NSTXU-CALC-132-04-00, Prepared By: Han Zhang, Reviewed by Peter Titus Cognizant Engineer: Mark Smith

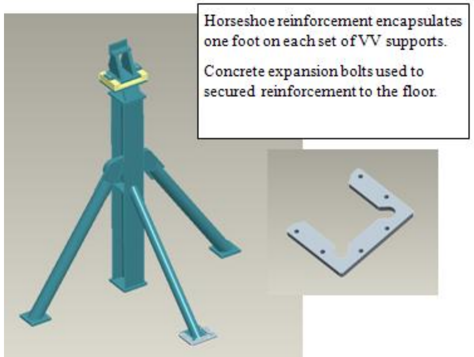


WP 1.1.1 Seismic Analysis NSTXU-CALC-10-02-00, Prepared by Peter Titus, Reviewed by F. Dahlgren, Cognizant Engineer: Peter Titus

WP 1.1.0 NSTX Upgrade Global Model – Model Description, Mesh Generation, and Results NSTXU-CALC-10-01-02 Prepared by Peter Titus, Reviewed by Unassigned, Cognizant Engineer: Peter Titus

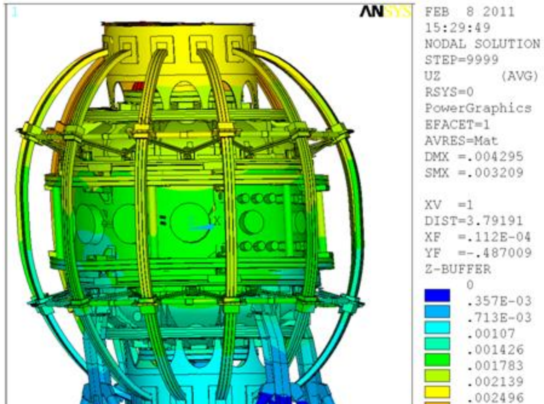


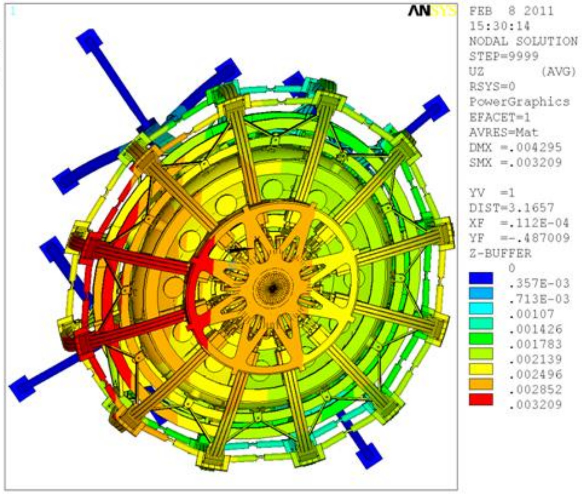
Global Model Model is Used for the Seismic Analysis

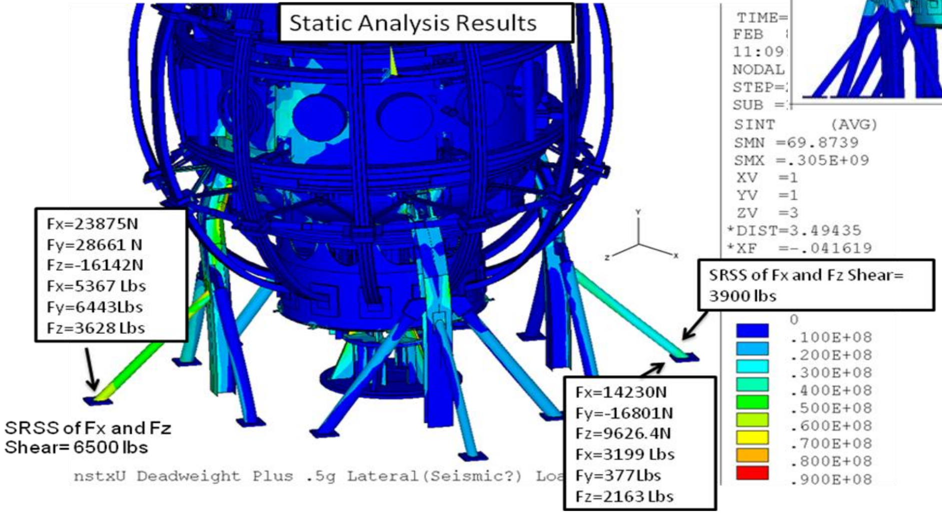


Horseshoe reinforcement encapsulates one foot on each set of VV supports.

Concrete expansion bolts used to secured reinforcement to the floor.







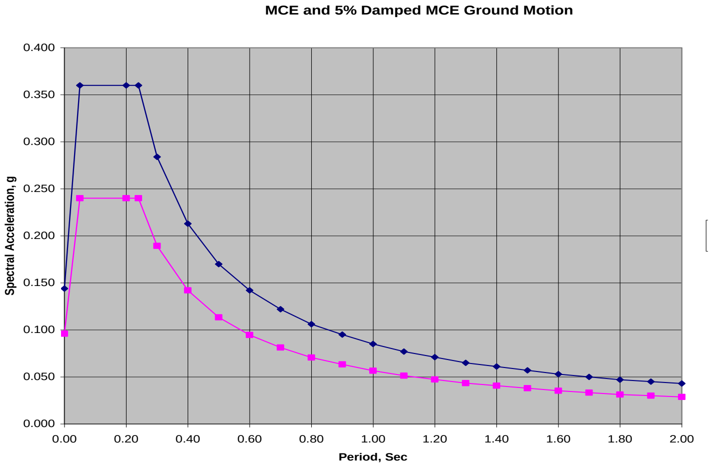
Static Analysis Results

Fx=23875N
Fy=28661 N
Fz=-16142N
Fx=5367 Lbs
Fy=6443Lbs
Fz=3628 Lbs

SRSS of Fx and Fz Shear= 6500 lbs

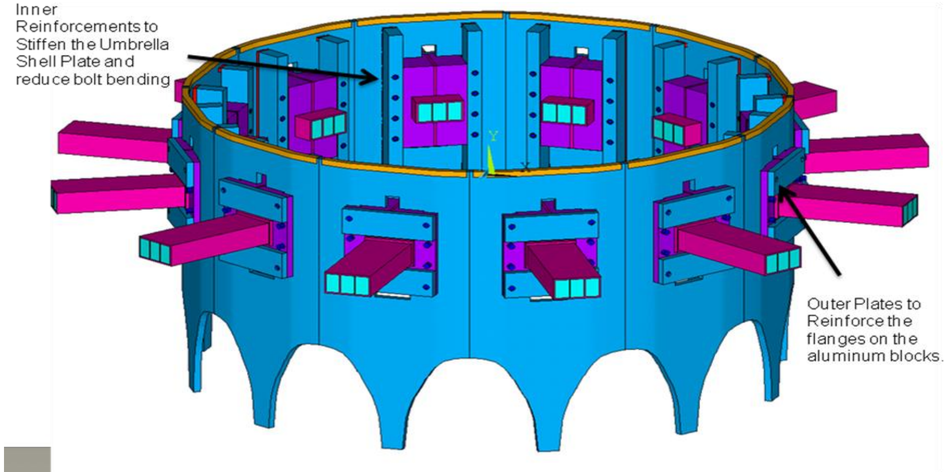
SRSS of Fx and Fz Shear= 3900 lbs

Fx=14230N
Fy=-16801N
Fz=9626.4N
Fx=3199 Lbs
Fy=377Lbs
Fz=2163 Lbs

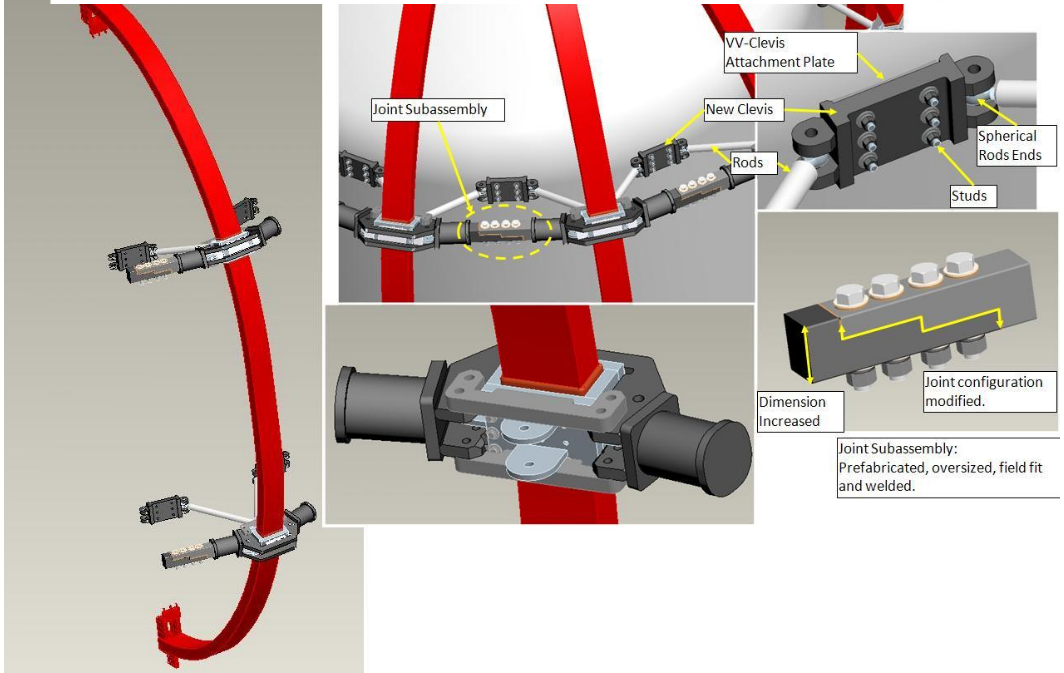


WP 1.1.1 Seismic Analysis NSTXU-CALC-10-02-00, Prepared by Peter Titus, Reviewed by F. Dahlgren, Cognizant Engineer: Peter Titus

TF In-Plane Load is Four Times Larger



WBS 1.1.2 Upgrade TF to Umbrella Structure Aluminum Block Connection NSTXU-CALC-12-06-00, Prepared By: Peter Titus, Reviewed By: Mark Smith, NSTX Cognizant Engineer Mark Smith



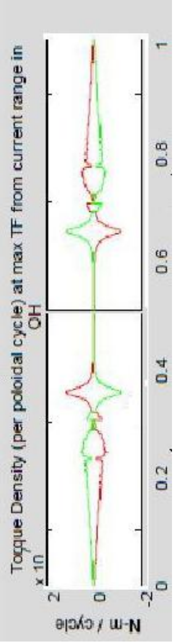
Analysis of TF Outer Leg, NSTXU-CALC-132-04-00, Prepared By: Han Zhang, Reviewed by Peter Titus Cognizant Engineer: Mark Smith

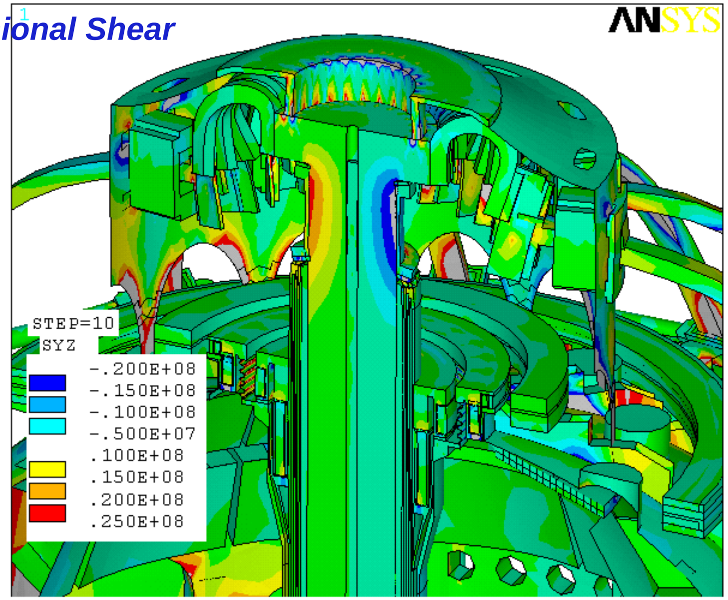
WBS 1.1.2 Ring Bolted Joint, NSTXU-CALC-132-11-00 Prepared By: Peter Rogoff, Reviewed By Irv Zatz, Cognizant Engineer: Mark Smith

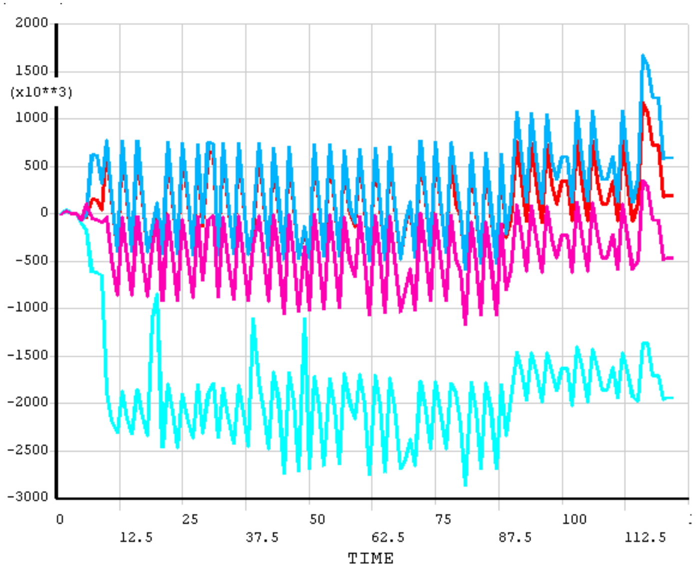
Out-of-Plane Torque is Much Larger Inner Leg Torsional Shear is Limiting

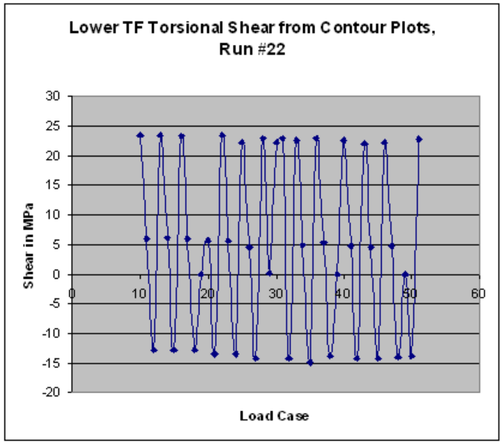
TF Inner Leg Torsional Shear

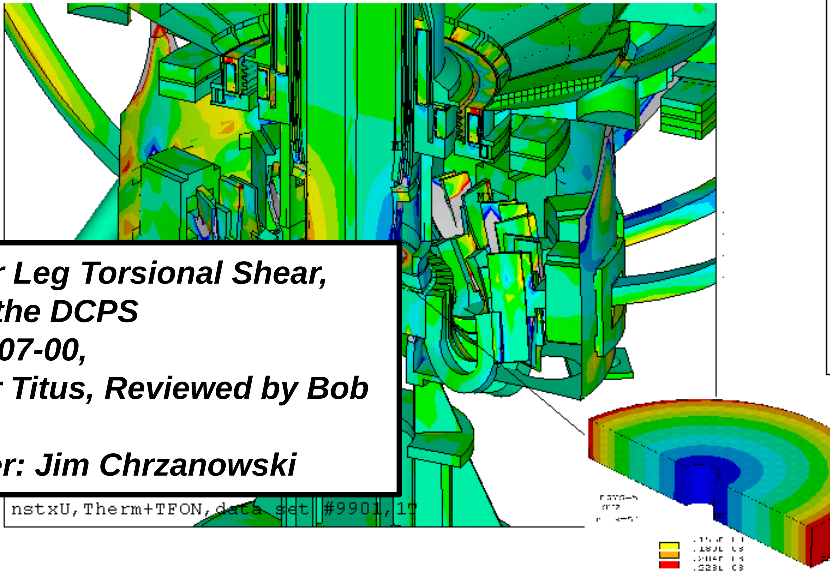
Bob Woolley's Moment Sum





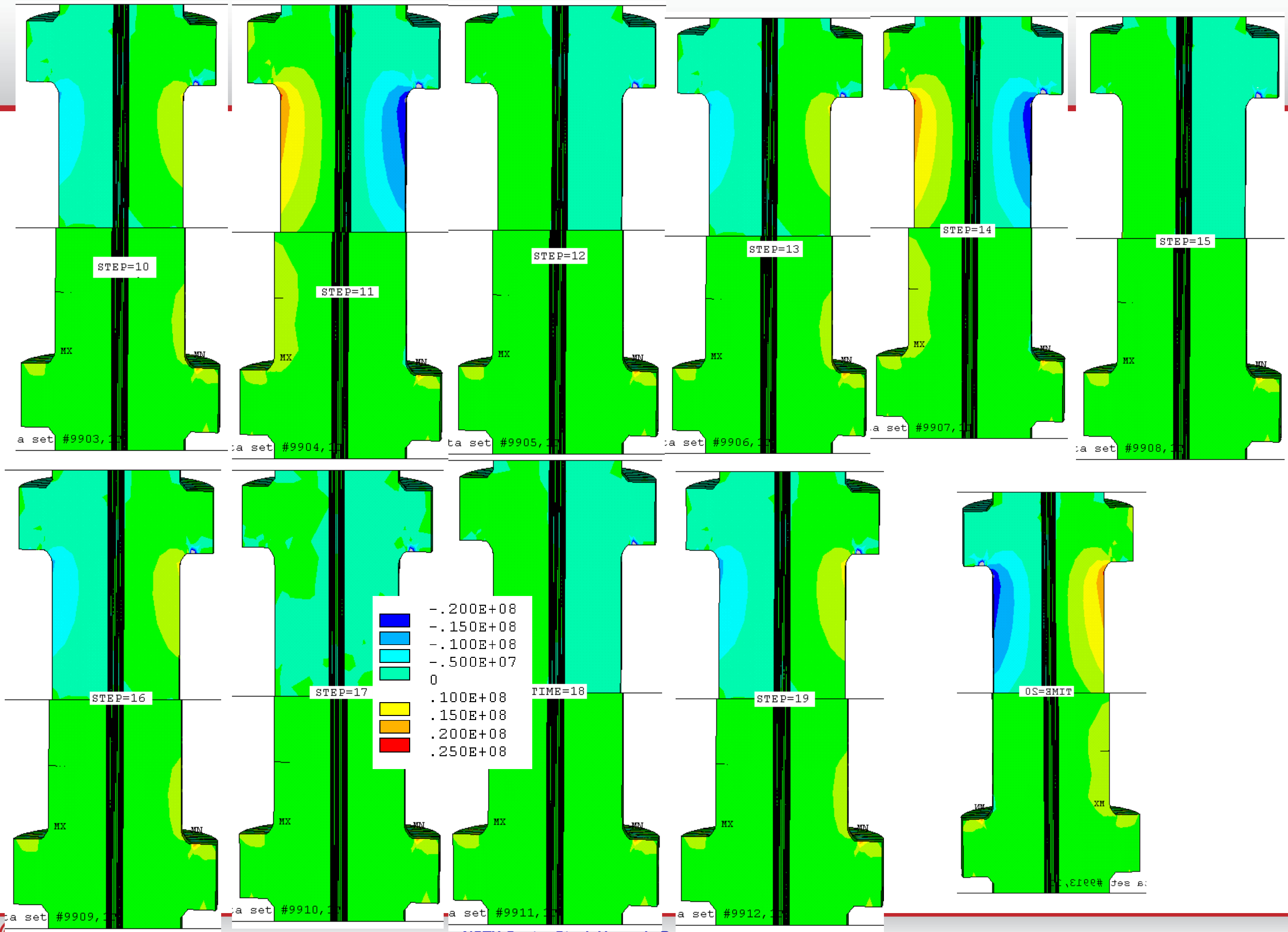






WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS NSTXU-CALC-132-07-00,
Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski

The Max torsional shear is 24 MPa with an allowable of 21.7 MPa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MX
MN
STEP=11
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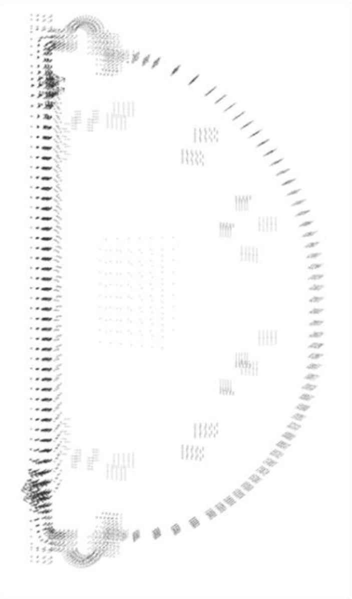
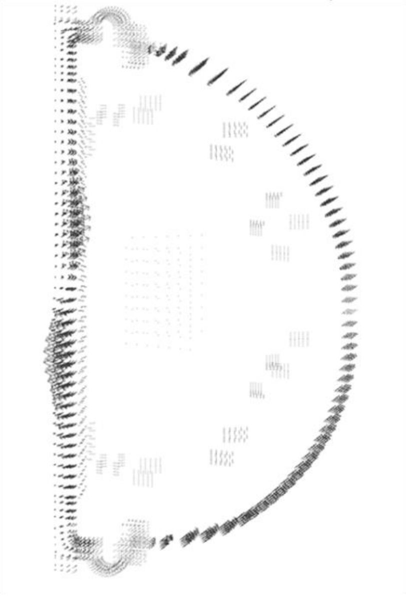
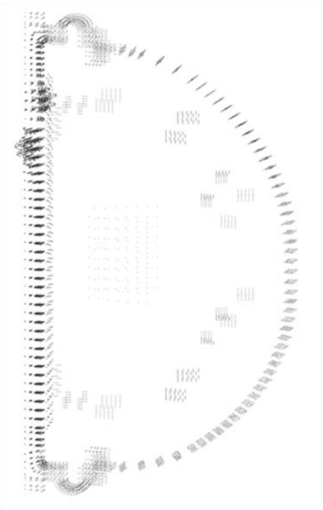
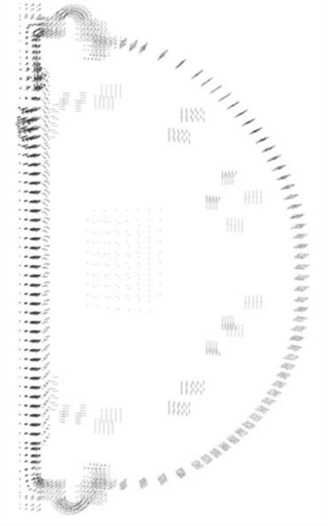
STEP=17
a set #9910,
TIME=18
a set #9911,
STEP=19
a set #9912,
TIME=20
a set #9913,
-.200E+08
-.150E+08
-.100E+08
-.500E+07
0
.100E+08
.150E+08
.200E+08
.250E+08

Calculation of Inner Leg Torsional Shear Using the Global Model Derived Influence Coefficients

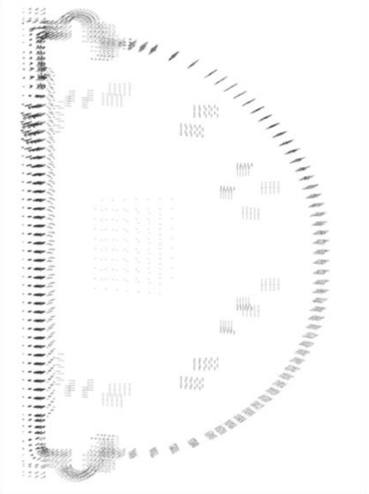

Due to Unit Current in OH si01

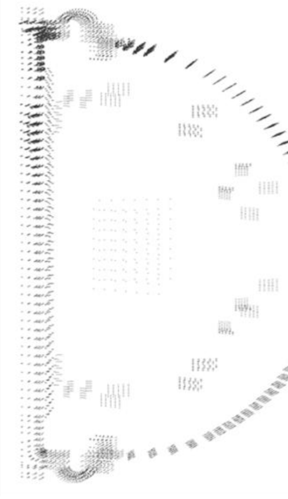

Due to Unit Current in Ip


Due to Unit Current in PF1aU


Due to Unit Current in PF1bU, si03

WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS
NSTXU-CALC-132-07-00, Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski

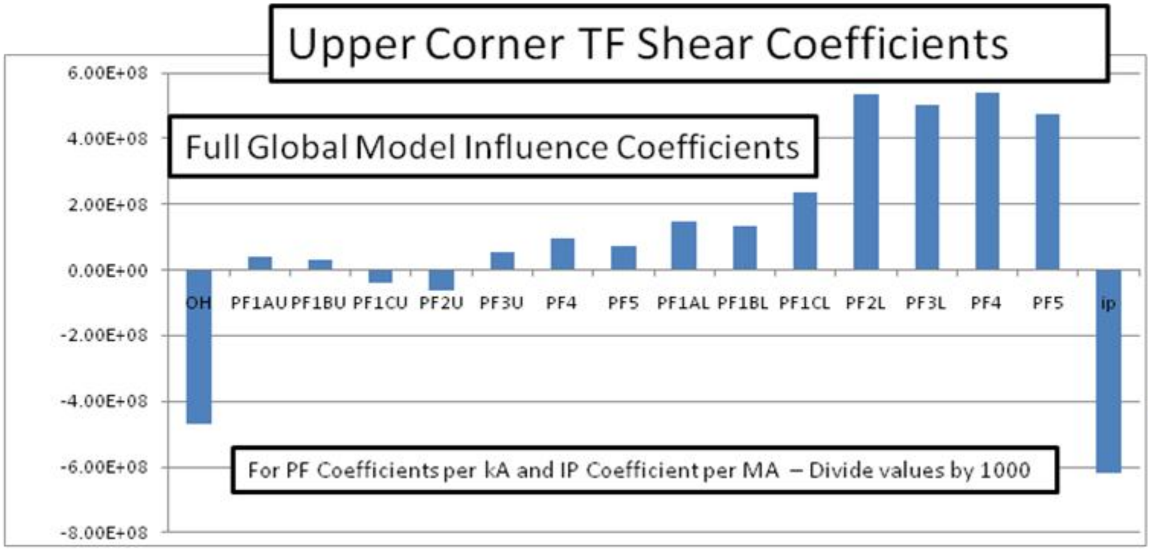

Due to Unit Current in PF1cU, si04


Due to Unit Current in PF2U, si05

Note: Scale has been adjusted, and TFON Subtracted

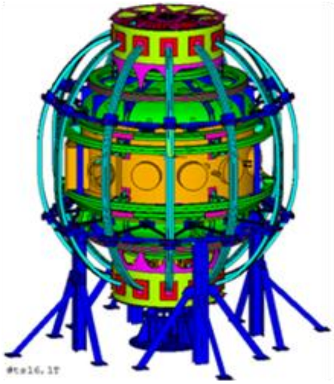
Calculation of Inner Leg Torsional Shear Using the Global Model Derived Influence Coefficients

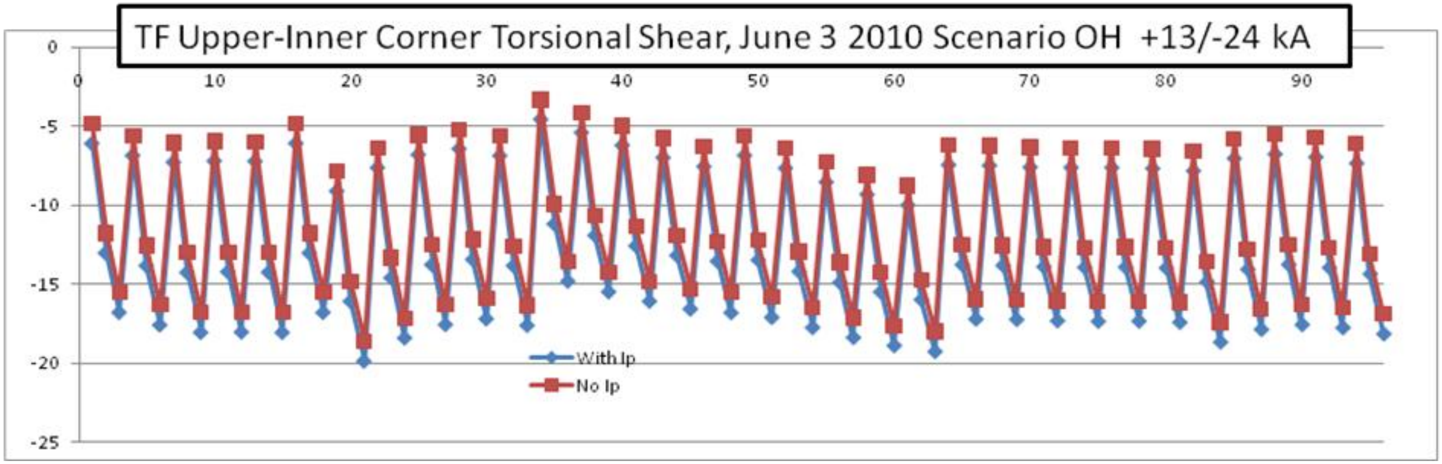
WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS
NSTXU-CALC-132-07-00, Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski


Upper Corner TF Shear Coefficients

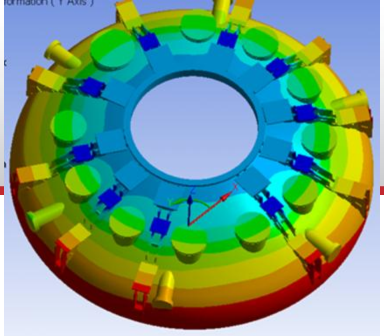
Full Global Model Influence Coefficients

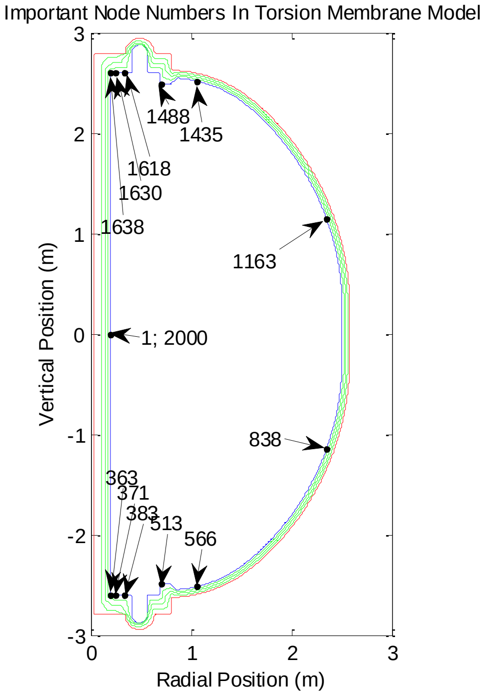
For PF Coefficients per kA and IP Coefficient per MA – Divide values by 1000

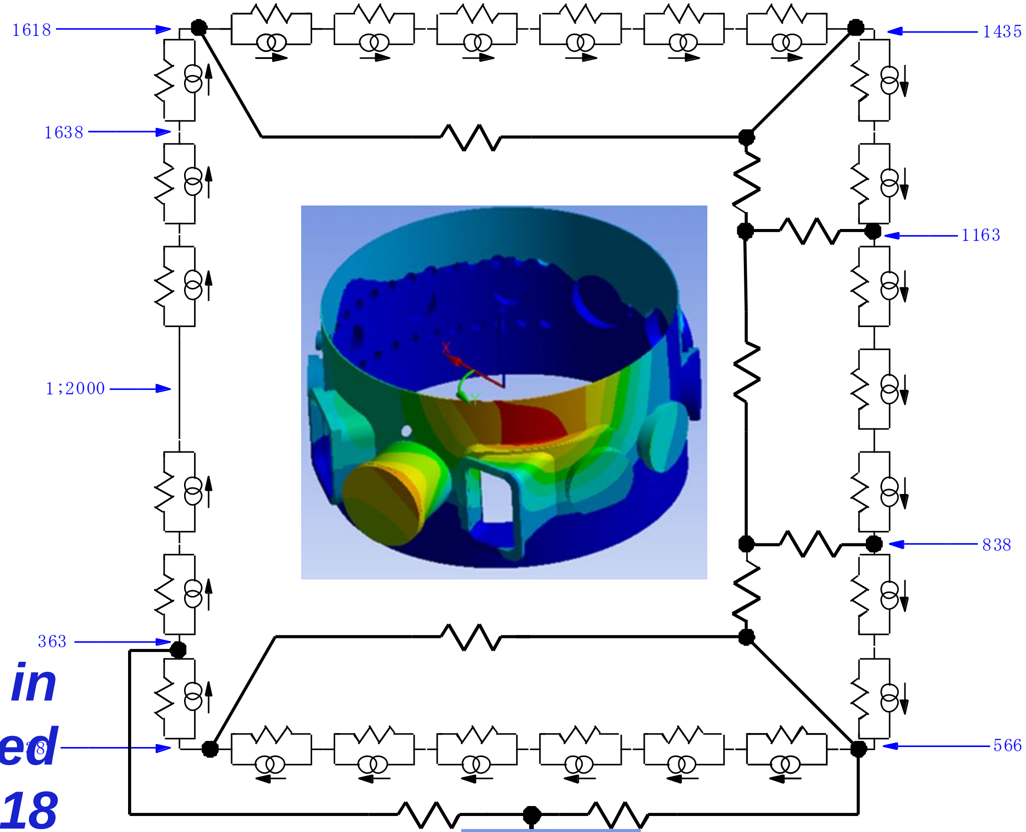



TF Upper-Inner Corner Torsional Shear, June 3 2010 Scenario OH +13/-24 kA

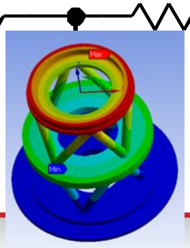
Bob Wooley's Calculation of Inner Leg Torsional Shear Using Mark Smith's Global Model Stiffnesses







Peak torsional shear stress in the TF centerstack calculated by these methods is 25.18 MPa. Bob's Shears are Up-Down Symmetric

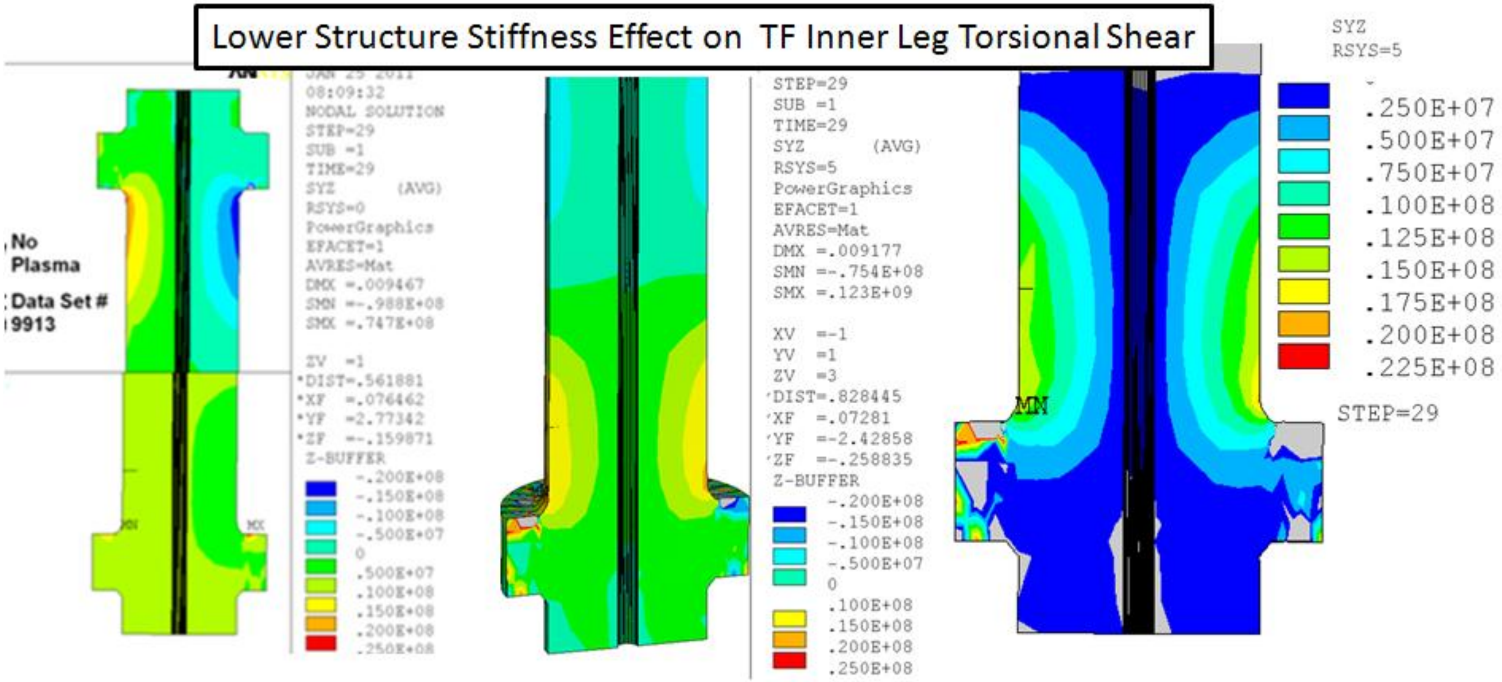


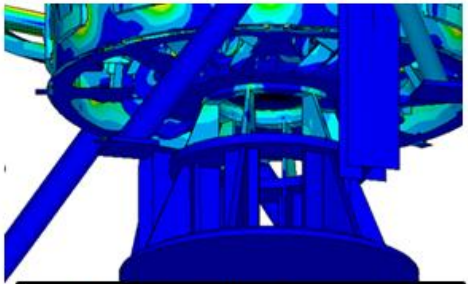
With Similar Stiffnesses to Bob Woolley/Mark Smith, Titus's Analysis Produces Up-Down Symmetry

WP 1.1.0 NSTX Upgrade Global Model – Model Description, Mesh Generation, and Results NSTXU-CALC-10-01-02 Prepared by Peter Titus, Reviewed by Unassigned, Cognizant Engineer: Peter Titus

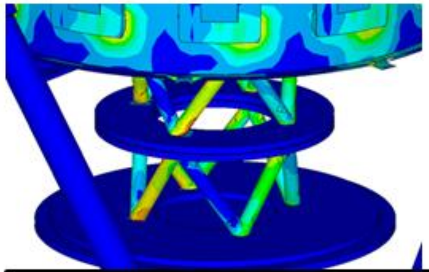
WBS 1.1.2 Lid/Spoke Assembly, Upper & Lower NSTX-CALC-12-08-00 Rev 0 May 2011 Prepared by: Peter Titus, Reviewed By: Unassigned, Cognizant Engineer: Mark Smith

Lower Structure Stiffness Effect on TF Inner Leg Torsional Shear

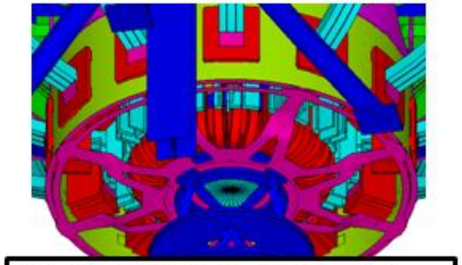




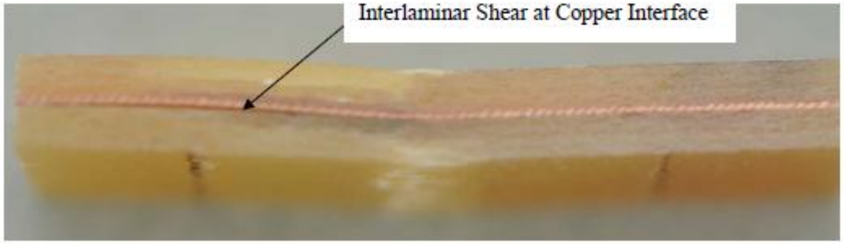
Rotationally Compliant Pedestal/Stiff Lower Lid



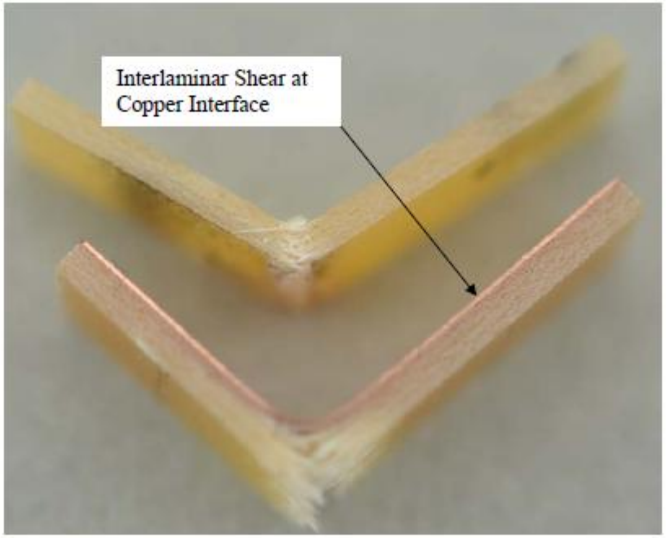
Rotationally Stiff Pedestal/Stiff Lower Lid



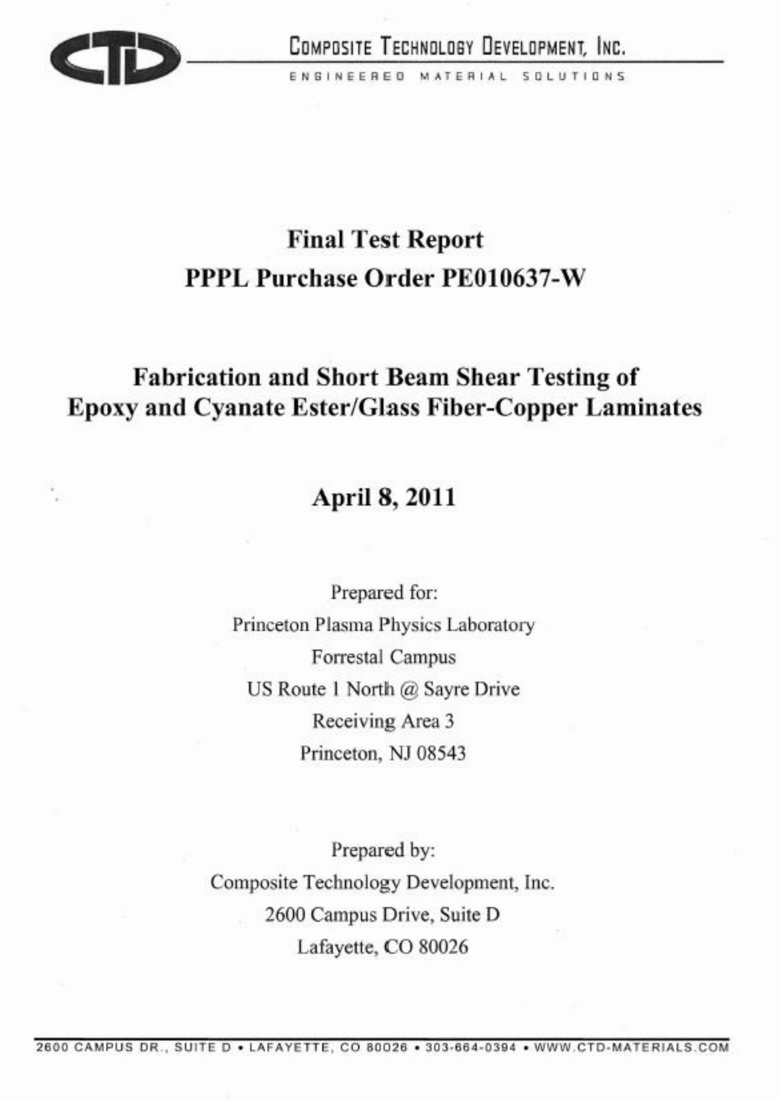
Rotationally Stiff Pedestal/Compliant Lower Lid



CTD-425 Specimen #15- Fatigue at 60% of Ultimate Stress (31 MPa, 21867 cycles)



CTD-425 Specimen #14- Fatigue at 60% of Ultimate Stress (31 MPa, 26851 cycles)



COMPOSITE TECHNOLOGY DEVELOPMENT, INC.
ENGINEERED MATERIAL SOLUTIONS

Final Test Report
PPPL Purchase Order PE010637-W

Fabrication and Short Beam Shear Testing of Epoxy and Cyanate Ester/Glass Fiber-Copper Laminates

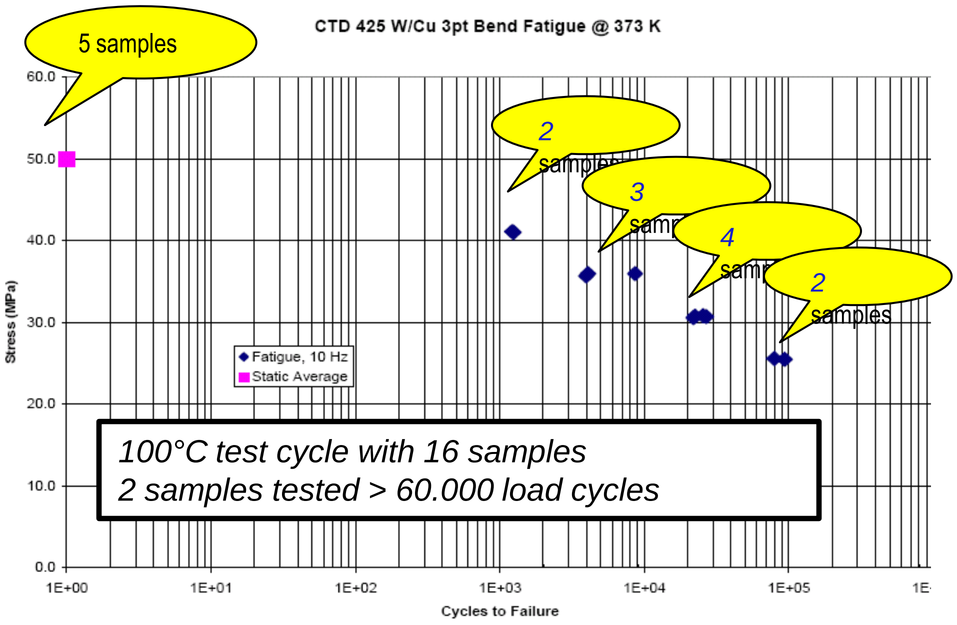
April 8, 2011

Prepared for:
Princeton Plasma Physics Laboratory
Forrestal Campus
US Route 1 North @ Sayre Drive
Receiving Area 3
Princeton, NJ 08543

Prepared by:
Composite Technology Development, Inc.
2600 Campus Drive, Suite D
Lafayette, CO 80026

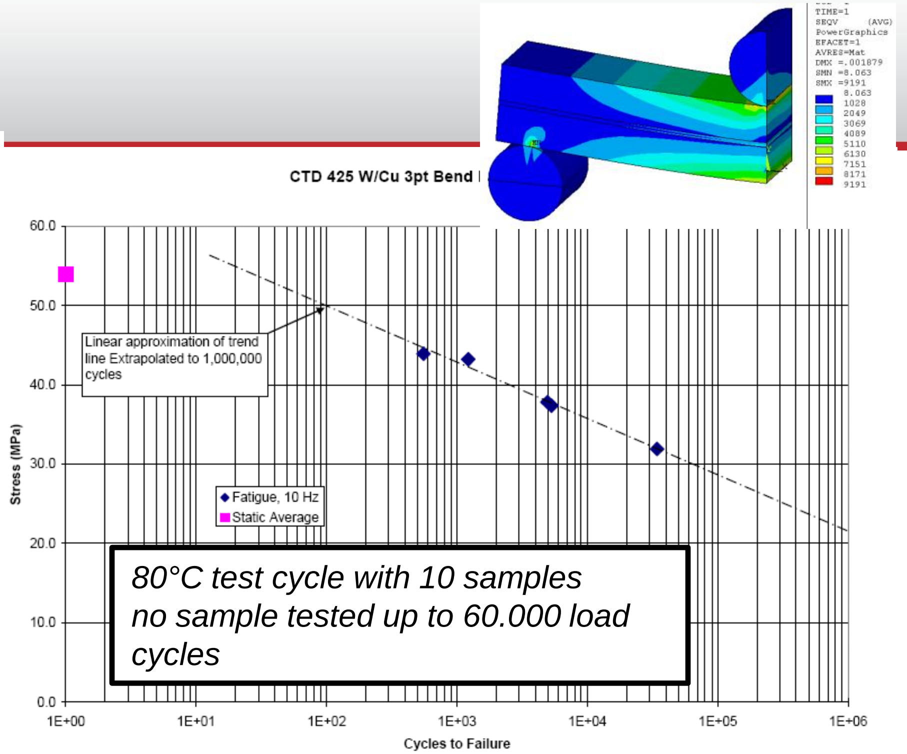
2600 CAMPUS DR., SUITE D • LAFAYETTE, CO 80026 • 303-664-0394 • WWW.CTD-MATERIALS.COM

CTD Fatigue Tests



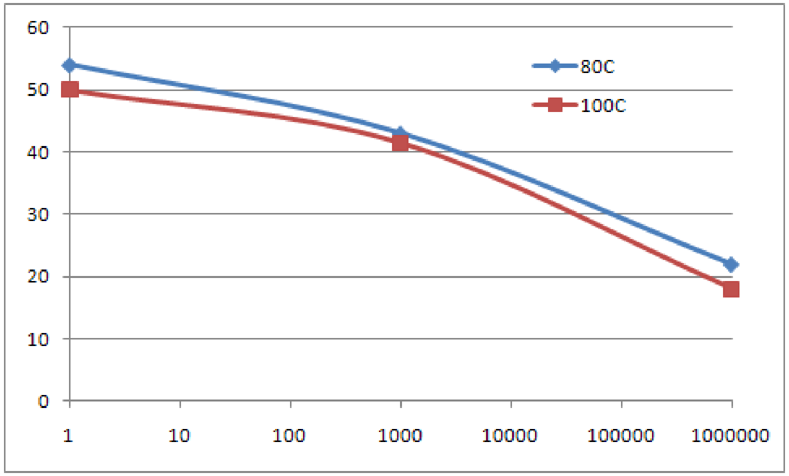
100°C test cycle with 16 samples
2 samples tested > 60.000 load cycles

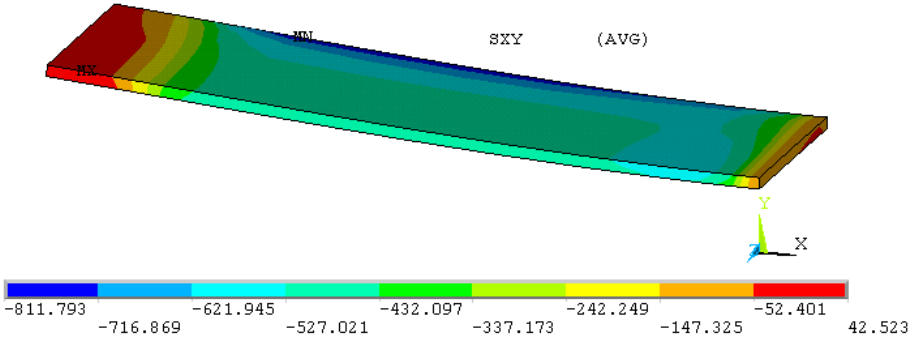
Figure 2: CTD-425 S-N chart



80°C test cycle with 10 samples
no sample tested up to 60.000 load cycles

Figure 3: CTD-425 80°C S-N Chart





With Two Independent Methods, Both Results for the Maximum TF Inner Leg Torsional Shear are Similar

Bob Woolley Gets 25.18 Mpa

P. Titus Gets:

Based on the DCPS influence coefficient TF inner leg upper corner torsional shear stresses, for all scenarios, are all below 20 MPa with and without plasma. Rigorously these should have the 10% headroom applied (the coefficients do not include this) - So the torsional shear stress to compare with the allowable is 22 MPa.

2. We have CTD -425 Qualification for 20 Mpa at 100C for ~ 300,000 cycles

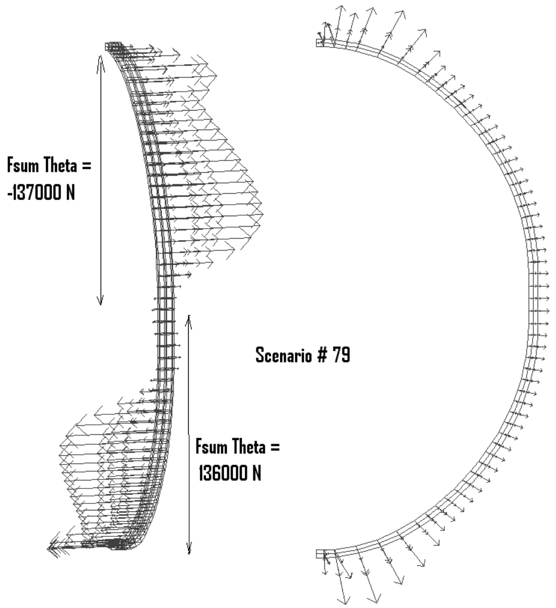
Out-of-Plane Torque Equations in the Design Point Spreadsheet

WBS 1.1.0 NSTXU 132-03-00, Torques On TF Conductors & Resulting Torsion & Shear Stress in NSTX CSU, 04 May2010 Design Point, Prepared by R. Woolley Reviewed by Peter Titus, Cognizant Engineer: Peter Titus

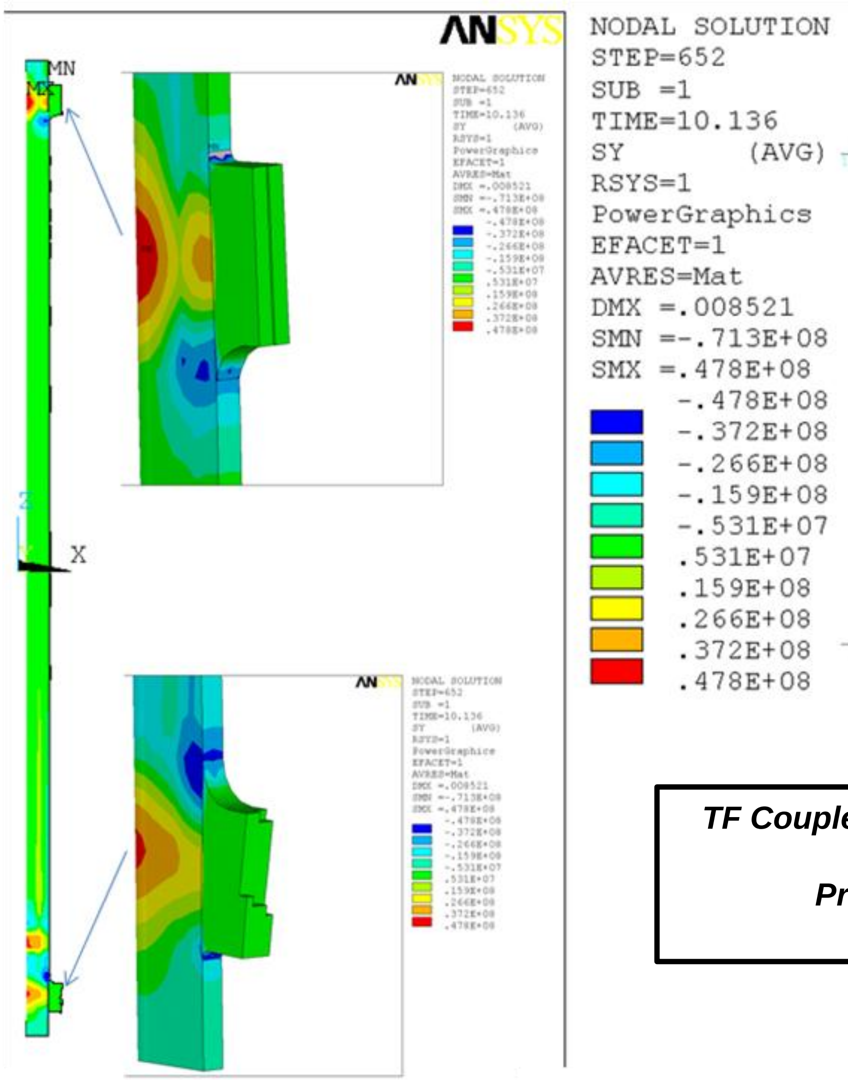
$$\left[\frac{\text{Net TF System OuterLeg Torque}}{1\ \text{N - m}}\right] = 3519.9\left[\frac{I_{\text{PF1AU}} - I_{\text{PF1AL}}}{1\ \text{kA}}\right] + 3692.0\left[\frac{I_{\text{PF1BU}} - I_{\text{PF1BL}}}{1\ \text{kA}}\right] + 4293.8\left[\frac{I_{\text{PF1CU}} - I_{\text{PF1CL}}}{1\ \text{kA}}\right] + 13191\left[\frac{I_{\text{PF2U}} - I_{\text{PF2L}}}{1\ \text{kA}}\right] + 16497\left[\frac{I_{\text{PF3U}} - I_{\text{PF3L}}}{1\ \text{kA}}\right]$$

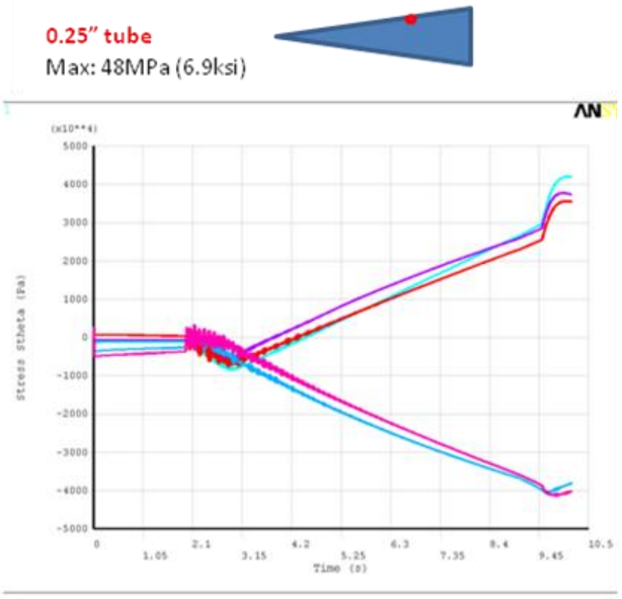
$$\left[\frac{\text{Net Upper Half TF System Torque}}{1\ \text{N - m}}\right] = 13563.1\left[\frac{I_{\text{OH}}}{1\ \text{kA}}\right] + 2260.9\left[\frac{I_{\text{PF1AU}} + I_{\text{PF1AL}}}{1\ \text{kA}}\right] + 1580.6\left[\frac{I_{\text{PF1BU}} + I_{\text{PF1BL}}}{1\ \text{kA}}\right] + 1851.5\left[\frac{I_{\text{PF1CU}} + I_{\text{PF1CL}}}{1\ \text{kA}}\right] + 5197.5\left[\frac{I_{\text{PF2U}} + I_{\text{PF2L}}}{1\ \text{kA}}\right] + 21915.7\left[\frac{I_{\text{PF3U}} + I_{\text{PF3L}}}{1\ \text{kA}}\right] + 56813.9\left[\frac{I_{\text{PF4}}}{1\ \text{kA}}\right] + 118636.5\left[\frac{I_{\text{PF5U}}}{1\ \text{kA}}\right] + 713308.9\left[\frac{I_{\text{plasma}}}{1\ \text{MA}}\right]$$

Global Torque Sums Agree with FEA Calculations by Willard and Titus



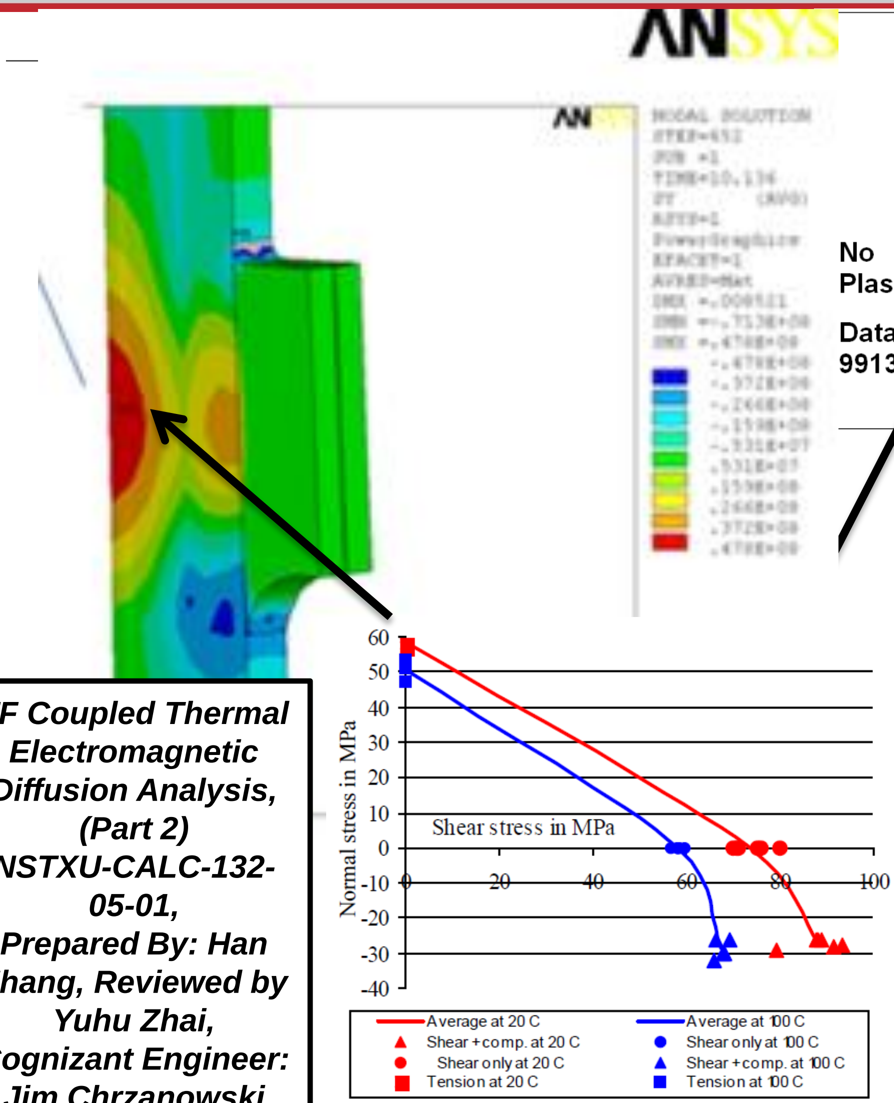
Hoop Tension Develops from Thermal Distribution





TF Coupled Thermal Electromagnetic Diffusion Analysis, (Part 2)
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

Hoop Tension Develops from Thermal Distribution. But Not Where Torsional Shear is Greatest.



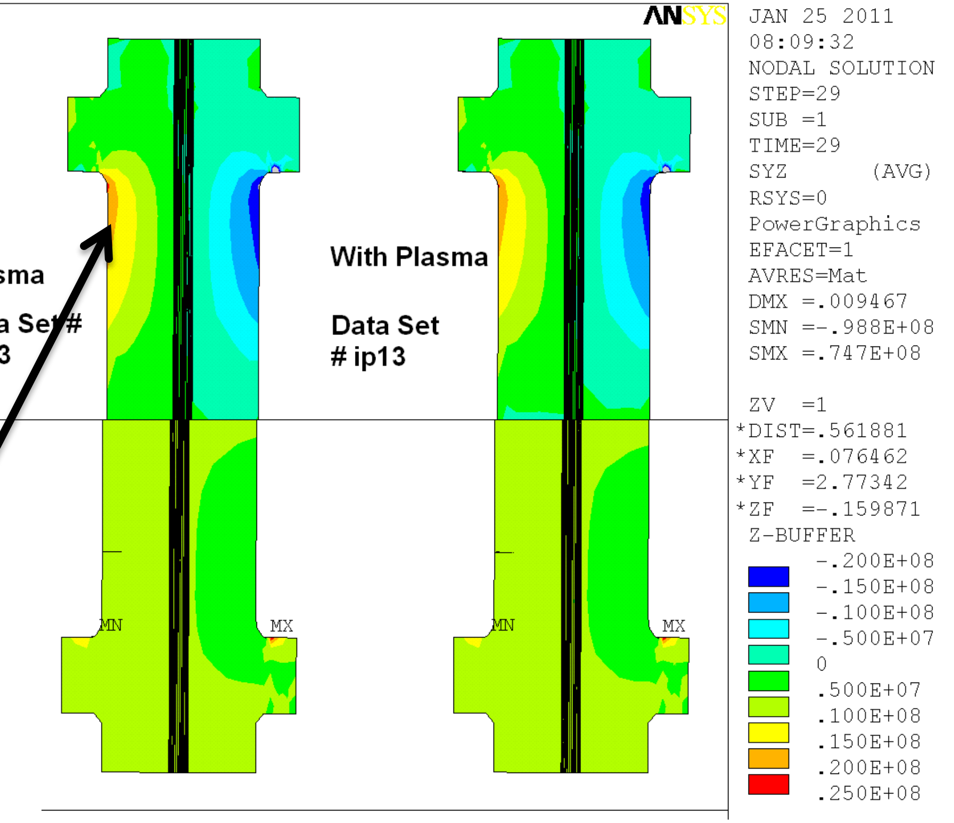
TF Coupled Thermal Electromagnetic Diffusion Analysis, (Part 2)
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

No Plasma

Data Set # 9913

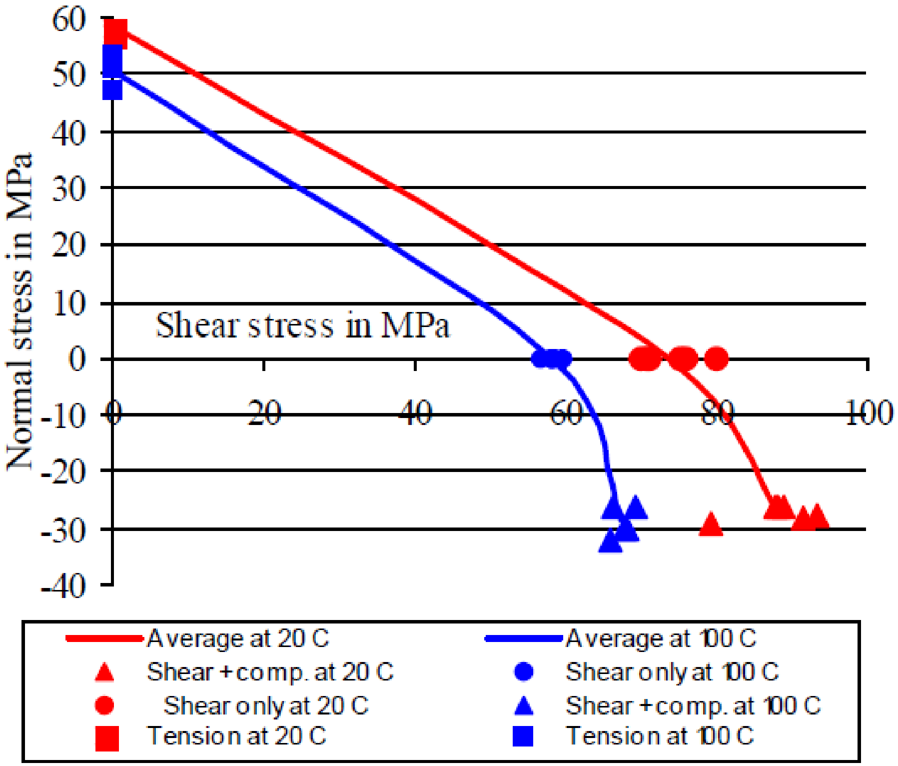
With Plasma

Data Set # ip13



WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS
NSTXU-CALC-132-07-00,
Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski

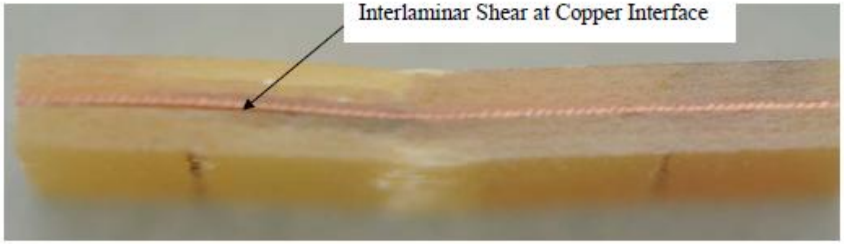
CTD 425 is a Blend which Uses the CTD 450 Cyanate Ester Primer . Adhesion of the insulation is expected to be governed by Cyanate Ester Properties. Zero Shear Tension Capacity at 80C is 60 Mpa.



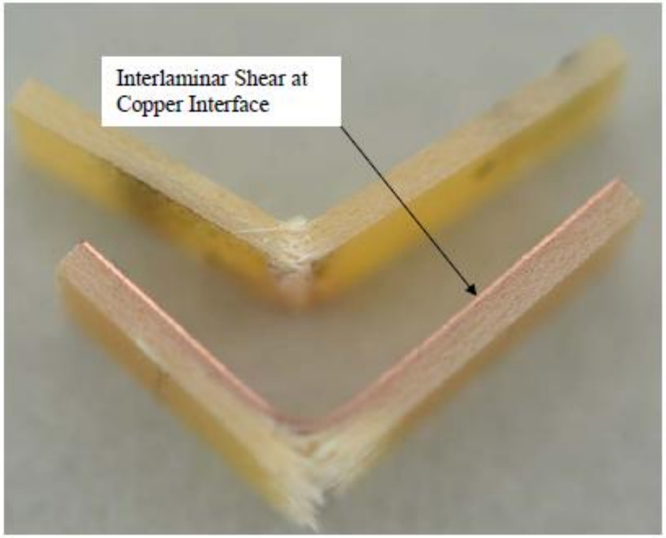
From Gary Voss Paper on Cyanate Ester

If there is Tensile or Shear Failure, It is desirable to have debonding at the Copper /Insulator Interface.

From the CTD 425 Fatigue Qualification:

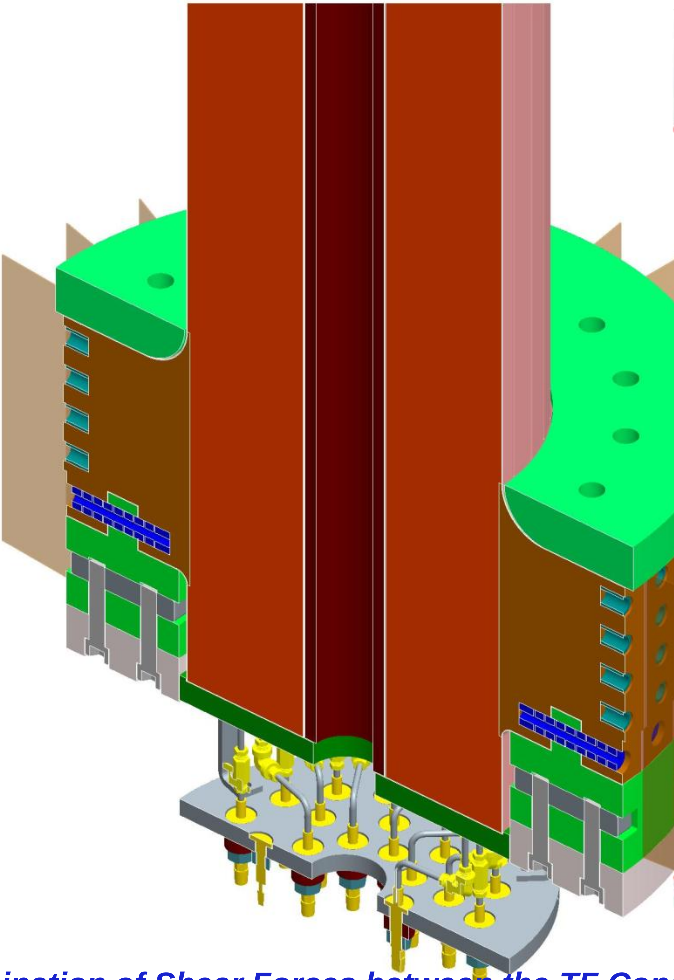


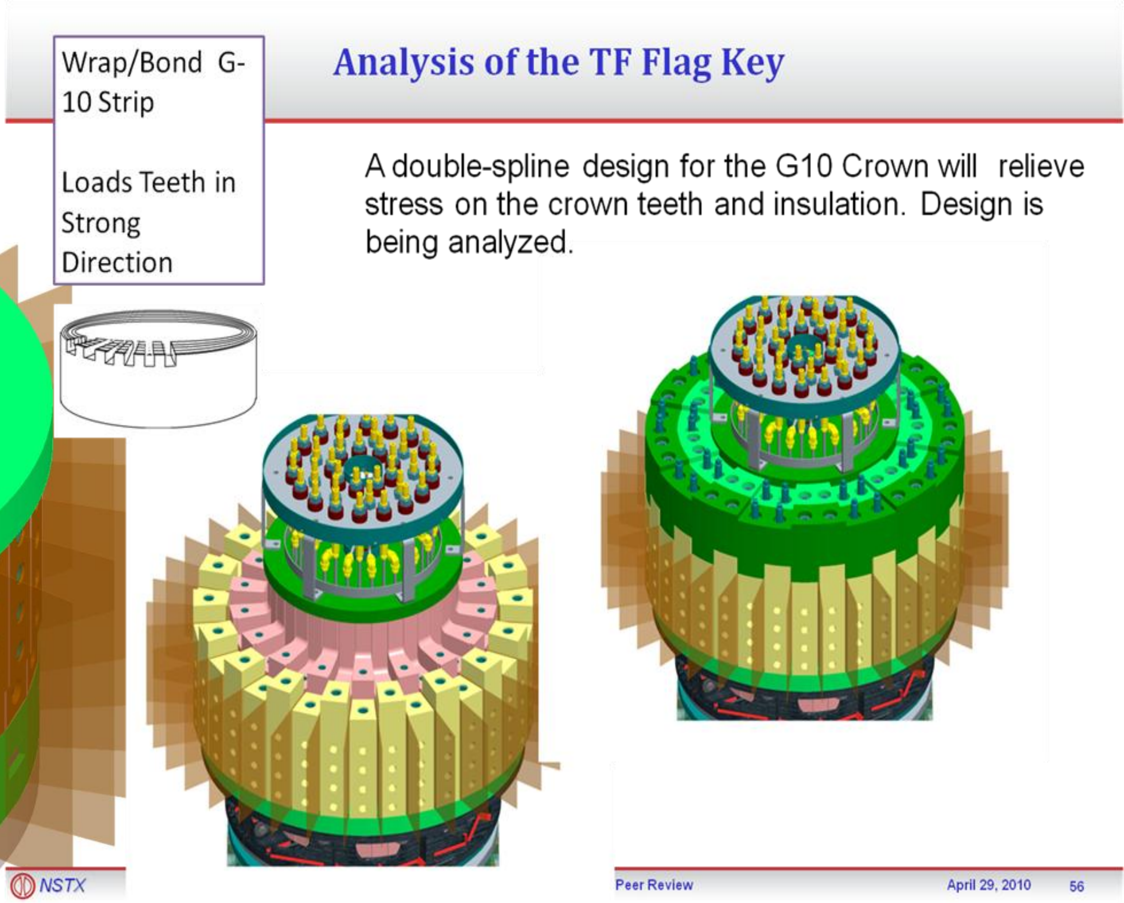
CTD-425 Specimen #15- Fatigue at 60% of Ultimate Stress (31 MPa, 21867 cycles)



CTD-425 Specimen #14- Fatigue at 60% of Ultimate Stress (31 MPa, 26851 cycles)

Inner leg Torques are Partially Reacted by Connections to the Spoked Lids





Wrap/Bond G-10 Strip

Loads Teeth in Strong Direction

Analysis of the TF Flag Key

A double-spline design for the G10 Crown will relieve stress on the crown teeth and insulation. Design is being analyzed.

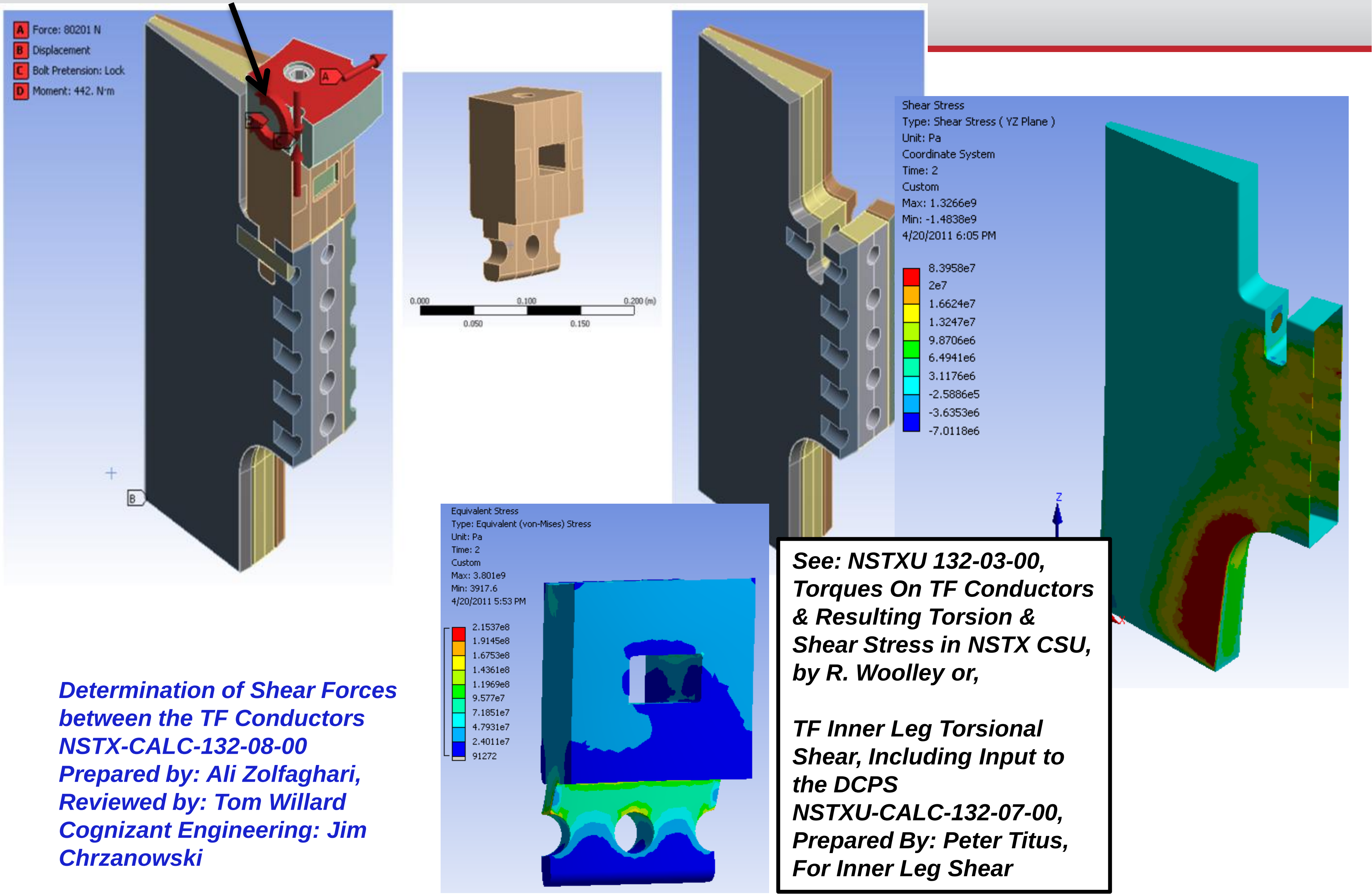
NSTX

Peer Review April 29, 2010 56

Determination of Shear Forces between the TF Conductors
NSTX-CALC-132-08-00
Prepared by: Ali Zolfaghari, Reviewed by: Tom Willard
Cognizant Engineering: Jim Chrzanowski

Pinned Connections are Used on Top and Bottom

Moment From Spoked Lid Analysis

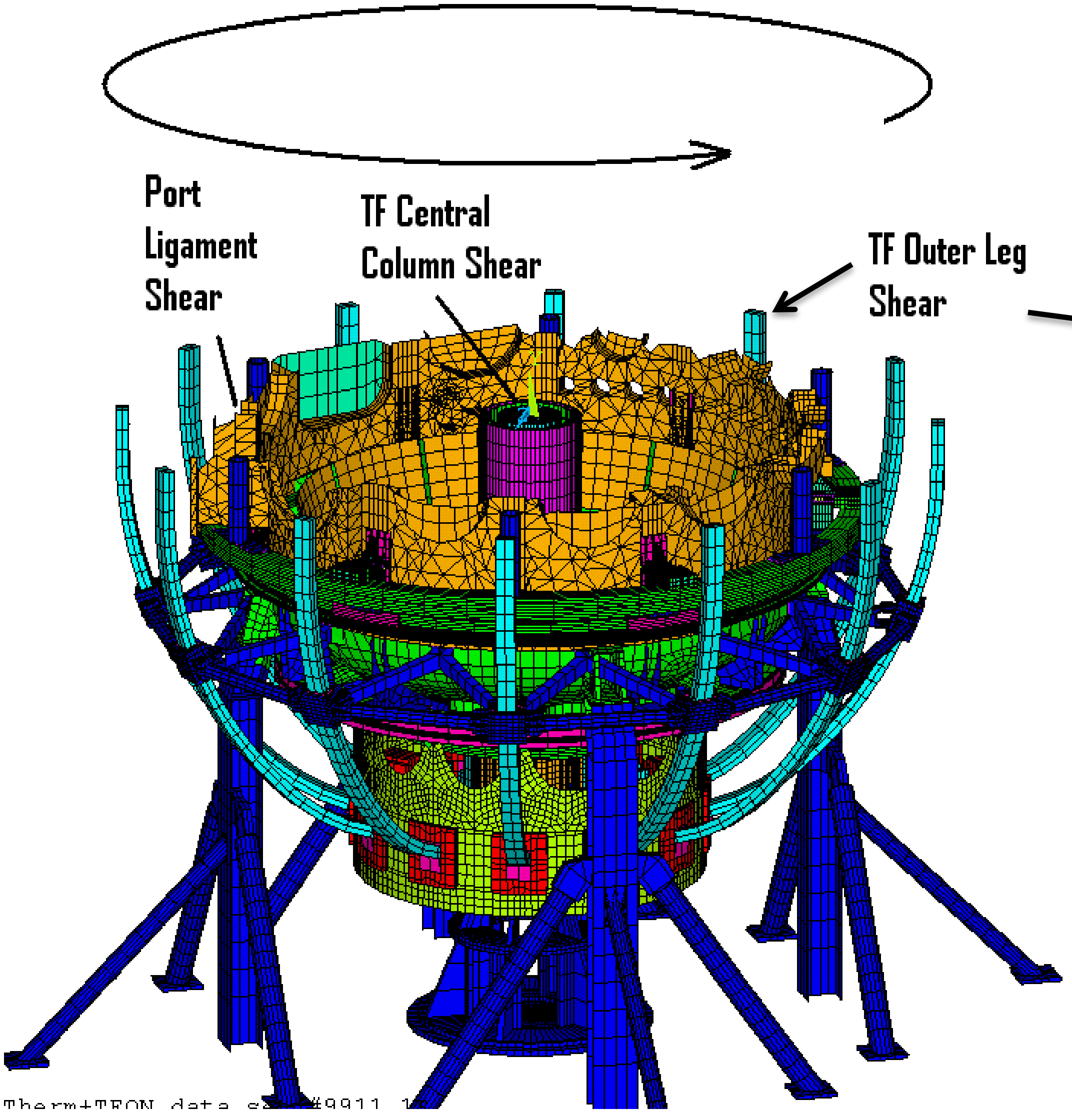


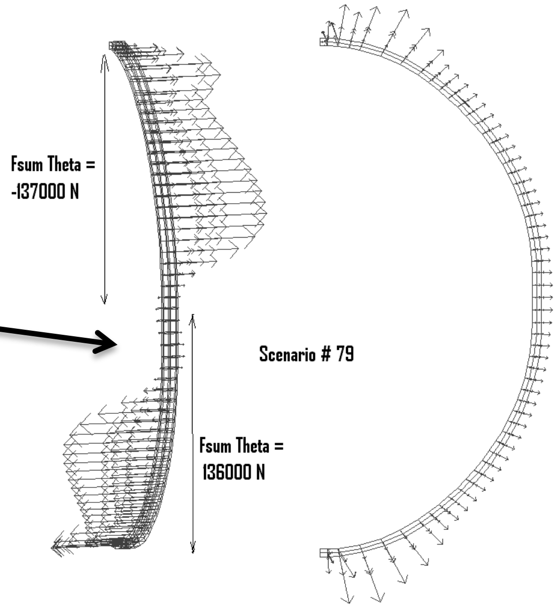
Determination of Shear Forces between the TF Conductors NSTX-CALC-132-08-00 Prepared by: Ali Zolfaghari, Reviewed by: Tom Willard Cognizant Engineering: Jim Chrzanowski

See: NSTXU 132-03-00, Torques On TF Conductors & Resulting Torsion & Shear Stress in NSTX CSU, by R. Woolley or,

TF Inner Leg Torsional Shear, Including Input to the DCPS NSTXU-CALC-132-07-00, Prepared By: Peter Titus, For Inner Leg Shear

Out-of-Plane Torque is Much Larger. Most is taken by the Vessel, Some by the TF Outboard Legs, A little by the CS Casing and Central Column





OOP Forces for Scenario #79 Summed from the joint flags out. From the aluminum blocks out the sum is 127000 N for the upper half.

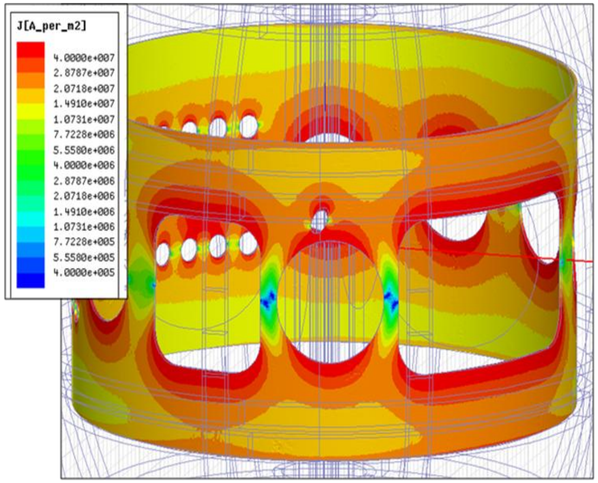
Out-of-Plane Torque Must be Taken by Existing Structural Load Paths – Can the Vessel Take It?

Basic Elements of the OOP Load Carrying "Logic" Remain: i.e.
Global Twist is Carried Predominantly by the Vacuum Vessel Equatorial Region With Some Help from TF

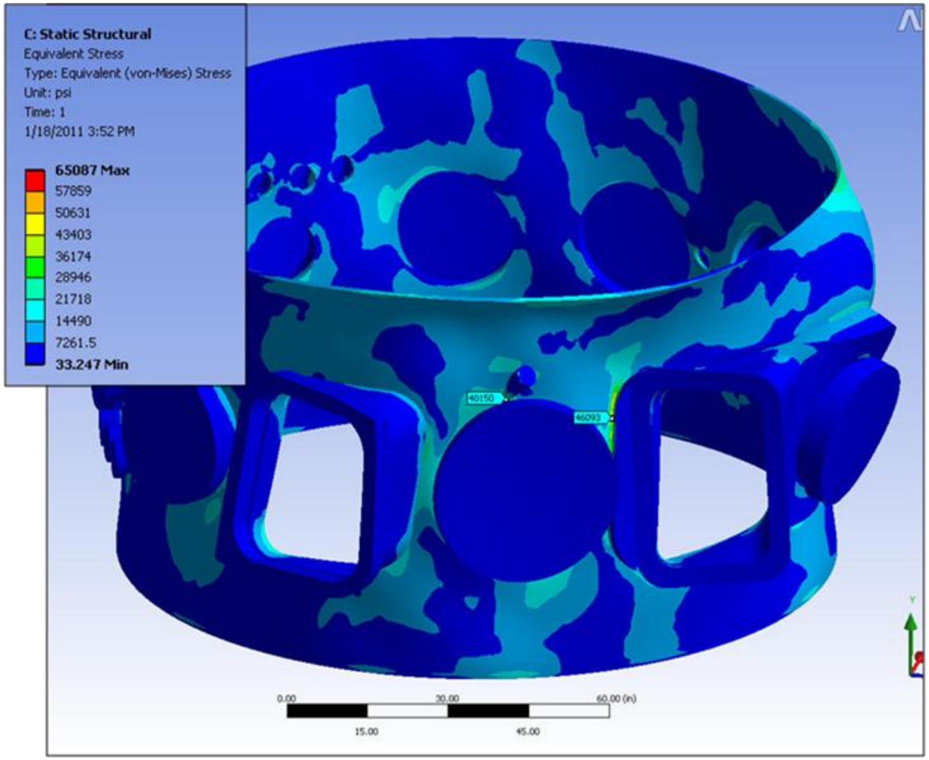
TF OOP Loads are Still transferred to Umbrella Structure and Knuckle Clevis

We tried other things – "Diamond Truss" , "Top Hat" and Truss to the Cell Walls

WBS 1.1.2 Vessel Rework for the Neutral Beam and Thomson Scattering Port
NSTXU-CALC-24-01-00
Prepared By: T. Willard Reviewed by: A. Zolfaghari
Cognizant Engineers: M. Smith, G. Labik, C. Priniski

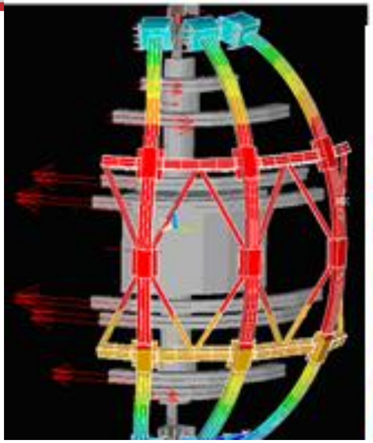


Eddy Current Density on Vacuum Vessel w/o Ports: End of Quench
1ms Centered-Plasma Disruption: Current Scenario #79 w/ Headroom Background Field

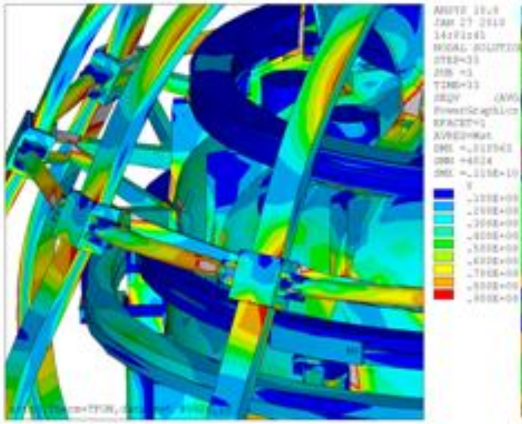


Static Structural Results, Ports Excluded from EM Solution: von Mises Stress
1ms Centered-Plasma Disruption: Current Scenario #79 w/ Headroom Background Field

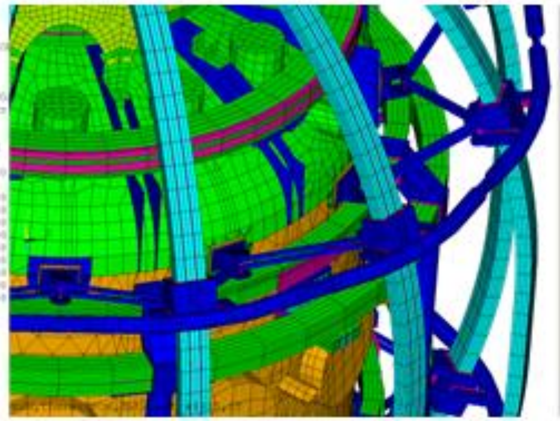
Outer Leg In-Plane and Out-of-Plane Support Many Concepts Were Tried – Many had Interference Problems



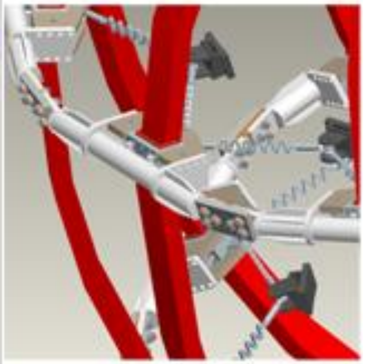
Diamond Truss



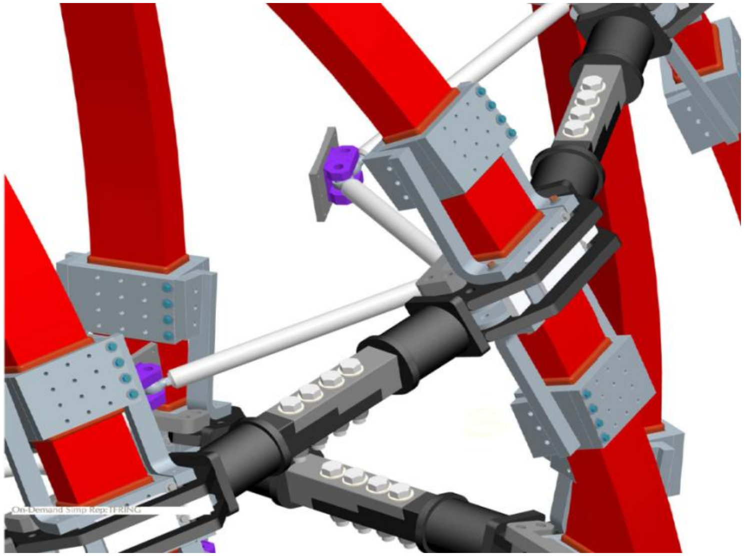
Pinned Ring Rigid Truss



Rigid Ring to Existing Clevis



Soft Springs to Existing Clevis



Outer Leg Support Must Control:

Copper Stress

Bending Related Bond Shear

Loads at Attachment Points

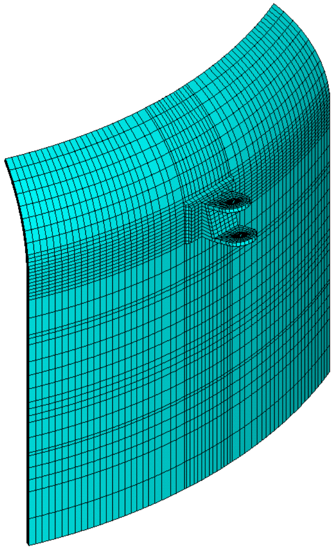
Displacements

Analysis of TF Outer Leg, NSTXU-CALC-132-04-00, Prepared By: Han Zhang, Reviewed by Peter Titus Cognizant Engineer: Mark Smith

WBS 1.1.2 TF Strut to Vessel Knuckle Clevis Connection NSTXU-CALC-132-09-00 Rev 0 March 2011, Prepared By: Peter Titus, Reviewed by Han Zhang, Mark Smith, NSTX Cognizant Engineer

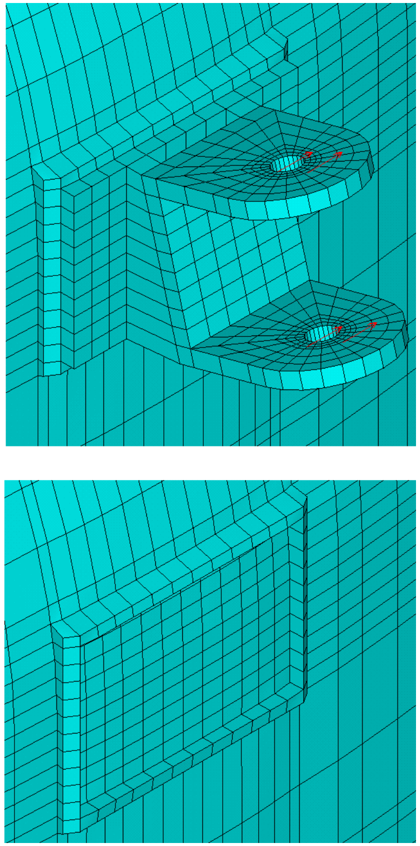
Existing Clevis Was Offset From the Surface of the Vessel and Was Held On by 5/16 Screws – It Had Little Load Capacity

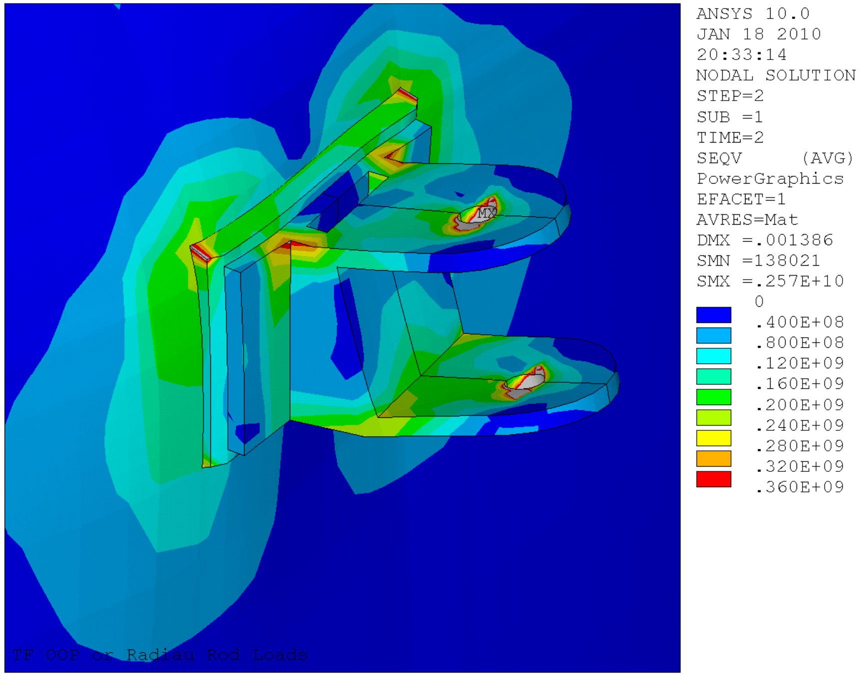
TF Truss or Radius Rod Lug

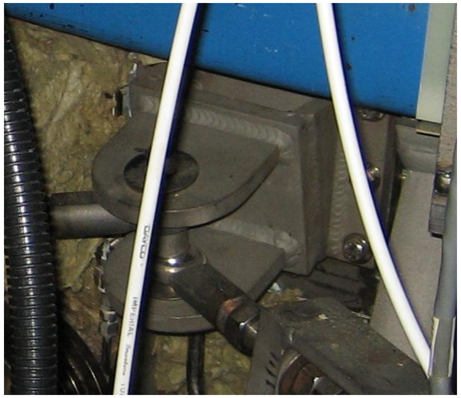


Actual (2009) Weld Size is 3/16

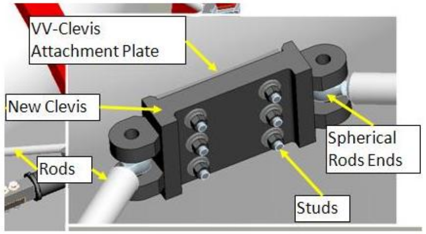
Model Weld is 8.6mm



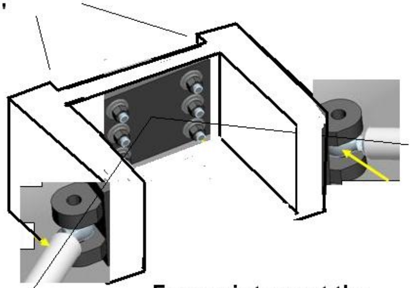




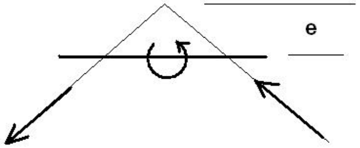
Welded Clevis Replacement



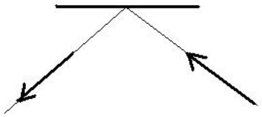
Shear load is taken by "lips"



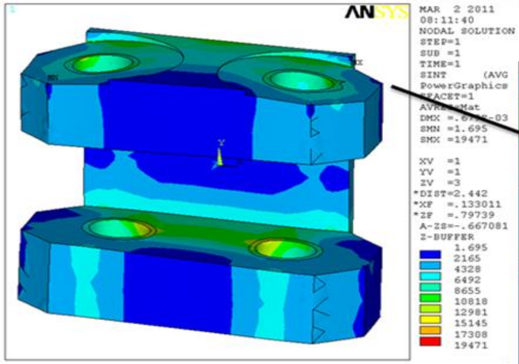
eccentricity produces a moment and tension at the stud pattern

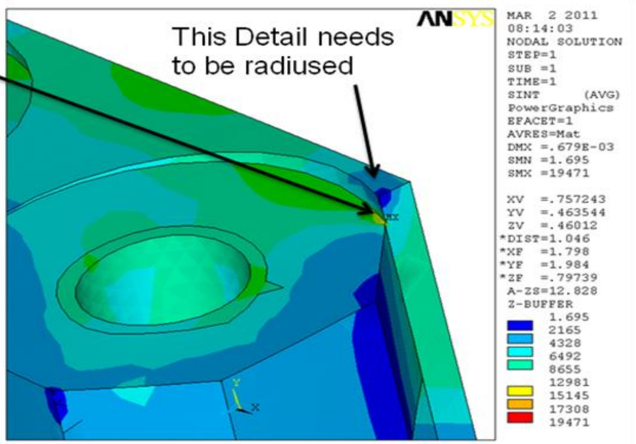


Forces intersect the centroid of the stud pattern - no moment is produced.

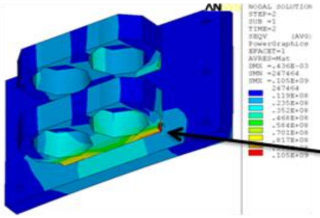


WBS 1.1.2 TF Strut to Vessel Knuckle Clevis Connection NSTXU-CALC-132-09-00 Rev 0 March 2011, Prepared By: Peter Titus, Reviewed by Han Zhang, Mark Smith, NSTX Cognizant Engineer

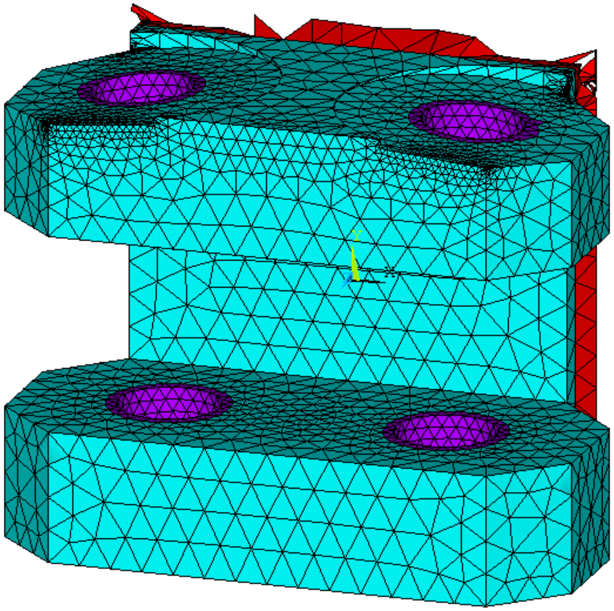




This Detail needs to be radiused

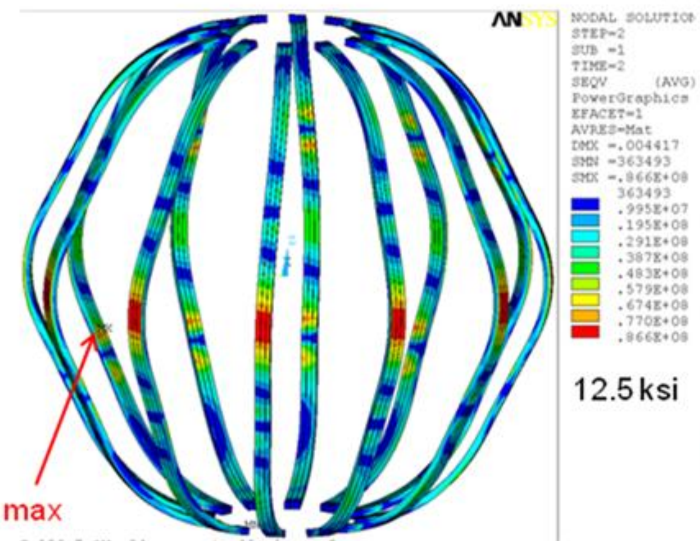


Ref [1] Preliminary Result from Wednesday Meeting. This Detail needs to be radiused

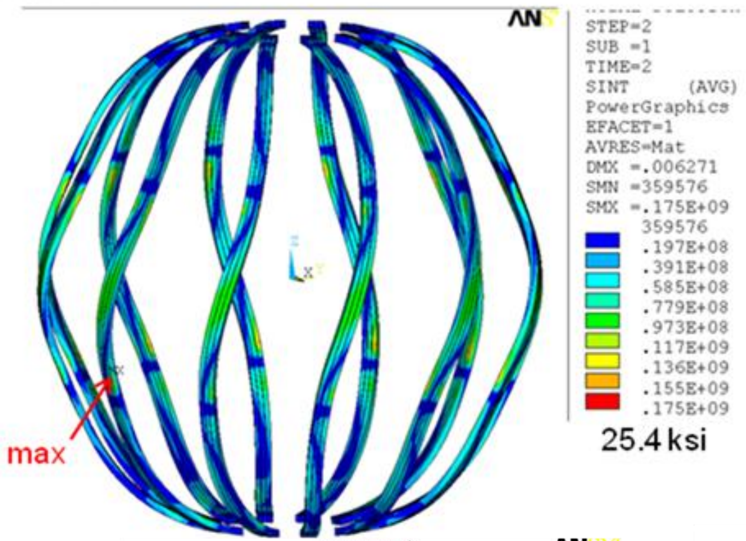


Clamps Produce Local Stress Concentrations – Leg Braces Help – Do we Need Them?

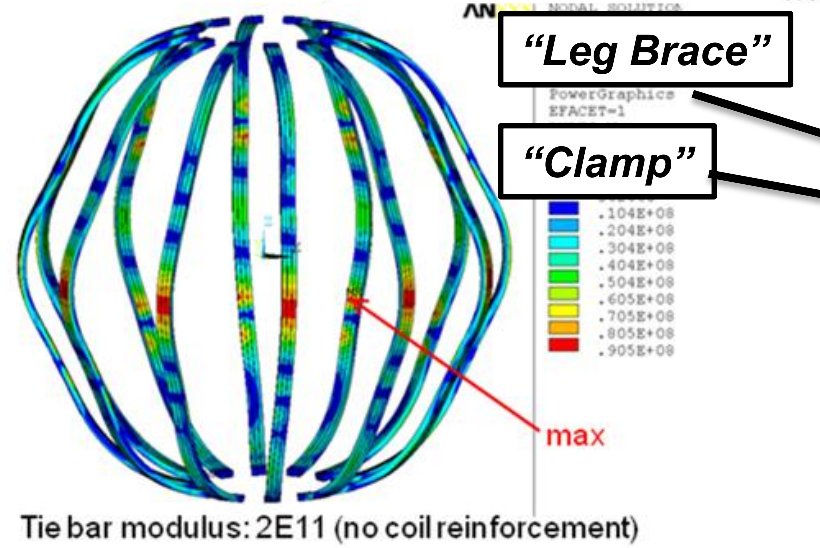
Scenario 49



Tie bar modulus: 2E11 (with coil reinforcement)



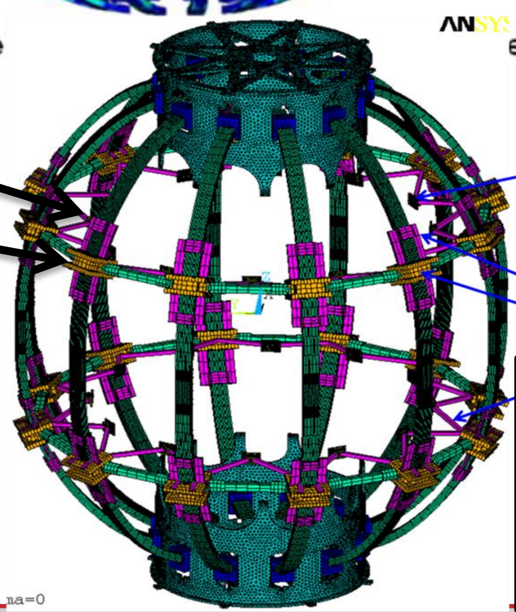
This is the result with/without coil reinforcement. Without reinforcement, max stress is 90MPa. With reinforcement, it reduces to 86MPa. Comparing with previous spring design, 175MPa, it seems the tie bar stiffness is the main factor for coil stress..

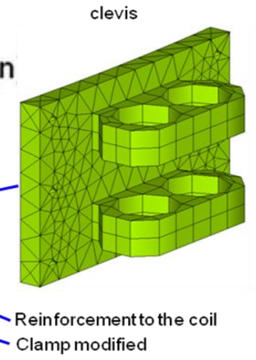


Tie bar modulus: 2E11 (no coil reinforcement)

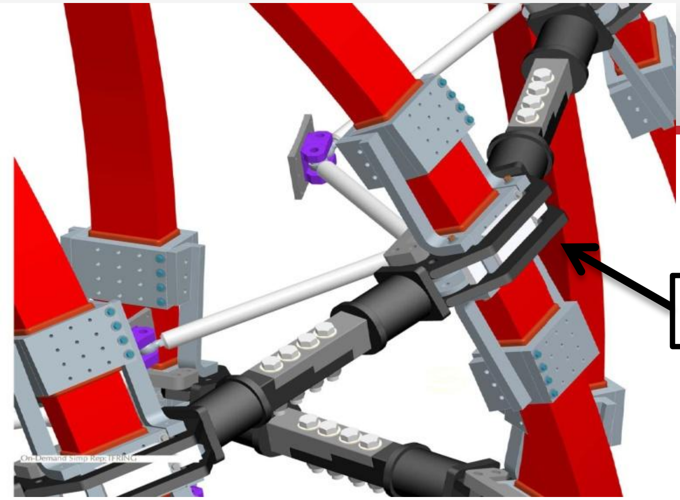
"Leg Brace"

"Clamp"



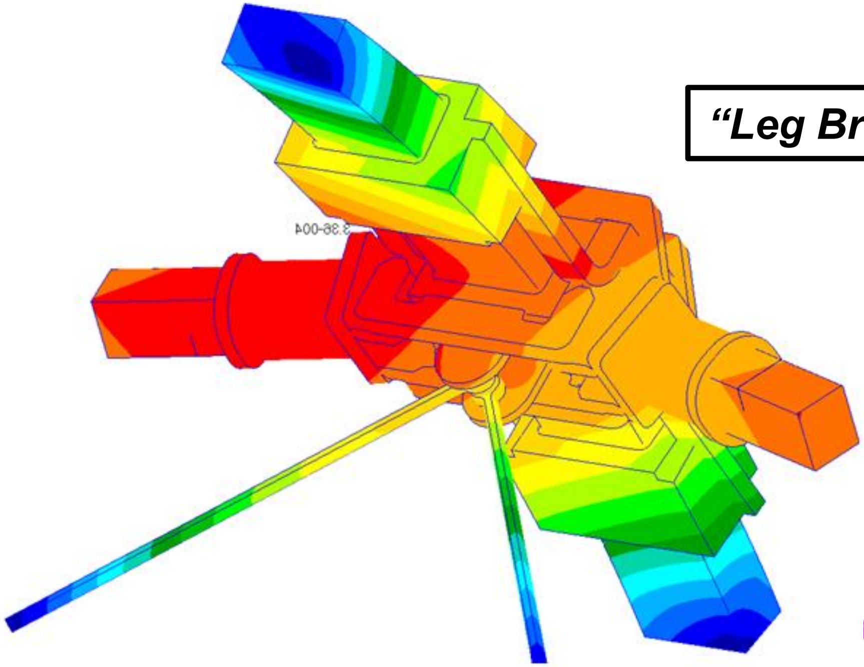


Analysis of TF Outer Leg, NSTXU-CALC-132-04-00, Prepared By: Han Zhang, Reviewed by Peter Titus Cognizant Engineer: Mark Smith



“Clamp”

WBS 1.1.2 TF Clamp Assembly NSTXU-CALC-132-10-00 Rev 0 March 2011, Prepared By: Peter Rogfff Reviewed by Unassigned, Mark Smith, NSTX Cognizant Engineer



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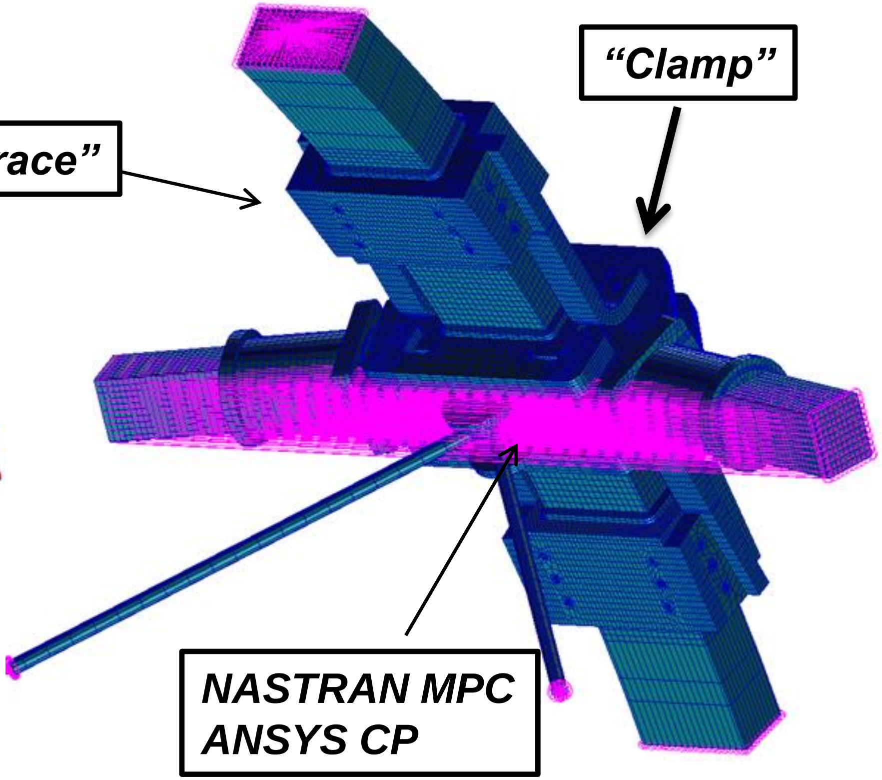
Fringe: Default, A1:Static Subcase, Displacements, Translational, Magnitude, (NON-LAYERED)

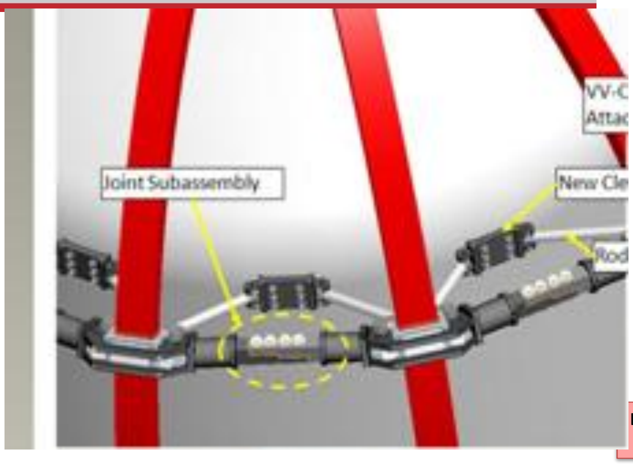


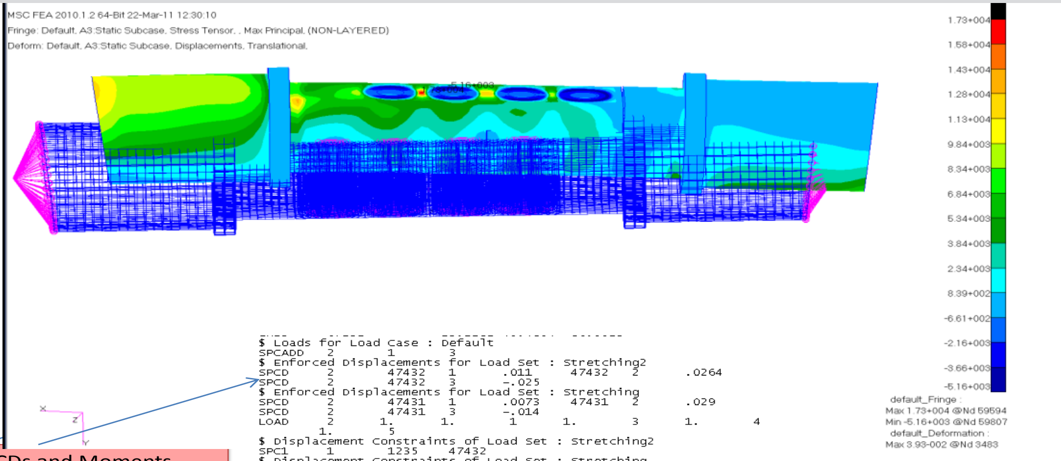
“Leg Brace”

“Clamp”

NASTRAN MPC
ANSYS CP

The Ring Supports the Bursting Loads and OOP rotations. The Bolted Joint is Designed for Tension and Moments





Loads with SPCDs and Moments
Total Loads

```
$ Loads for Load Case : Default
SPCADD   2       1       3
$ Enforced Displacements for Load Set : Stretching2
SPCD     2       47432   1       .011     47432   2       .0264
SPCD     2       47432   3       -.025
$ Enforced Displacements for Load Set : Stretching
SPCD     2       47431   1       .0073    47431   2       .029
SPCD     2       47431   3       -.014
LOAD     2      1.      1.       1       1.       3      1.       4
        1.       5
$ Displacement Constraints of Load Set : Stretching2
SPC1     1       1235    47432
$ Displacement Constraints of Load Set : Stretching
SPC1     3       1235    47431
$ Nodal Forces of Load Set : UPPreLOAD
FORCE    3       47294   5       44000.  1.      0.      0.
FORCE    3       47307   5       44000.  1.      0.      0.
FORCE    3       47320   5       44000.  1.      0.      0.
FORCE    3       47333   5       44000.  1.      0.      0.
$ Nodal Forces of Load Set : DOWNPreLOAD
FORCE    1       47306   5       44000.  -1.     0.      0.
FORCE    1       47319   5       44000.  -1.     0.      0.
FORCE    1       47332   5       44000.  -1.     0.      0.
FORCE    1       47345   5       44000.  -1.     0.      0.
$ Nodal Forces of Load Set : Right Force
MOMENT   5       47431   21      25506.6 -.901061 0.     .433692
$ Nodal Forces of Load Set : Left Force
MOMENT   4       47432   21      38188.9 -.94551 0.      .325592
$ Referenced Coordinate Frames
CORD2R   5               29.8001 45.0852 -83.68784.01658 46.1807 12.5327
        29.5188 -54.5299-82.629
CORD2R   10              19.5362 44.76   -86.434419.8165 144.032 -87.4893
        -6.1586345.8515 9.4541
CORD2C   16              36.4143 45.0927 -81.916427.6557 145.057 -81.8895
        65.0164 47.6246 -178.068
CORD2C   17              9.42231 45.0925 -89.148116.9968 145.058 -84.7788
        32.724  47.5916 -186.72
CORD2R   21              22.9182 45.085  -85.531723.1987 144.445 -86.5875
        48.6339 43.9926 -181.506
ENDDATA 3359329b
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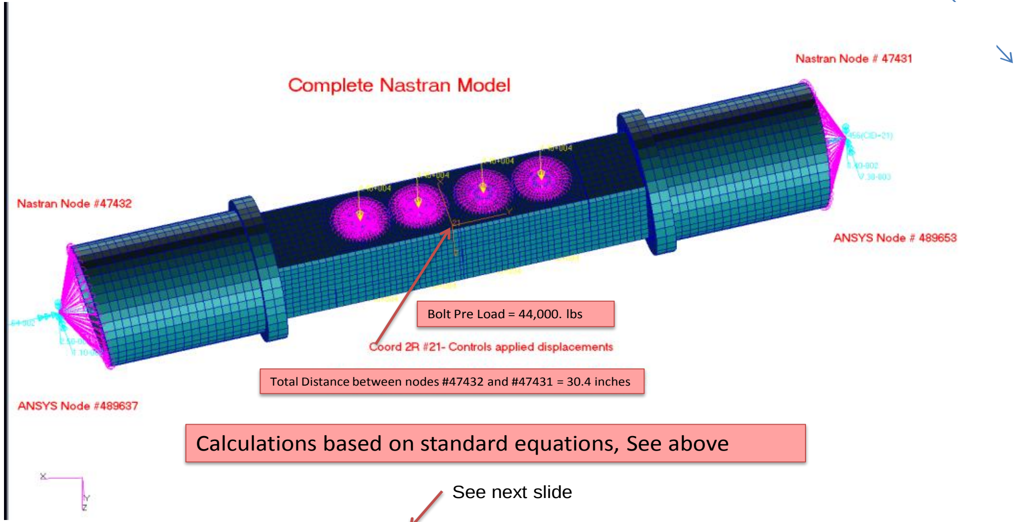


Bolt Pre Load = 44,000. lbs

Coord 2R #21- Controls applied displacements

Total Distance between nodes #47432 and #47431 = 30.4 inches

Calculations based on standard equations, See above

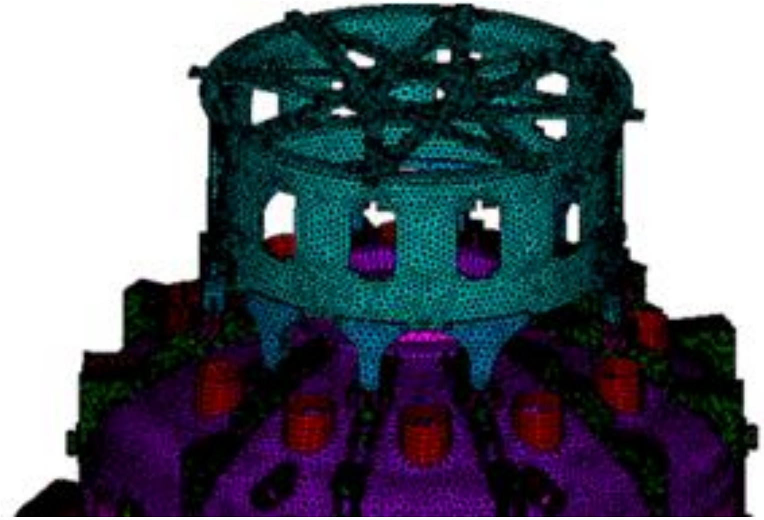
See next slide

Problem: 1.0 in. dia. Bolt , As= .663 in^2, Yield = 100.ksi, Based on 2/3 yield = 66.7 ksi.

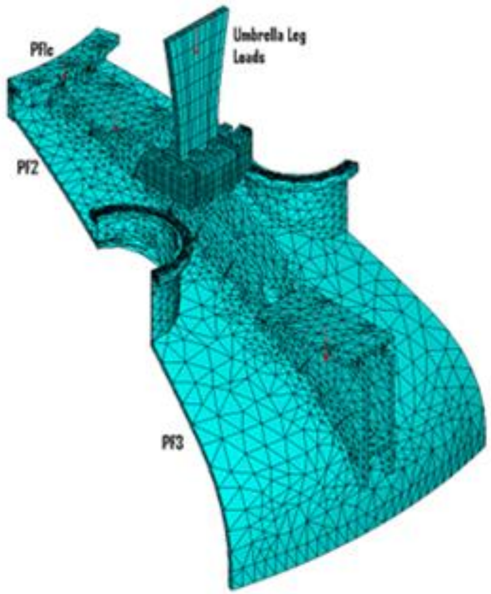
Fp = 66.7ksi x .663in^2 = 44.22 Kips per bolt, If mu = .3, Fs = 44.22 Kips X .3 = 13,266 lbs/bolt
Typical "nut factor" see the torque equation
For two bolts Fs= 26532. lbs And required torque = 44,220 lbs. x .2 x 1.0 in.= 8,844 lb-in

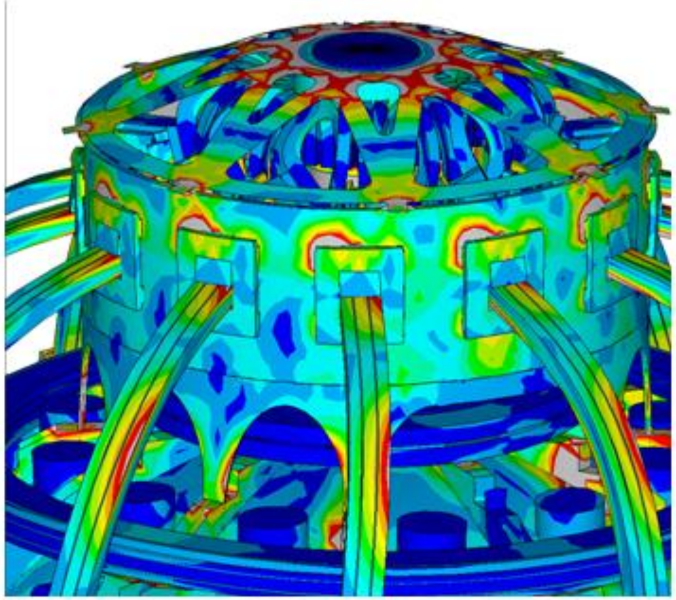
WBS 1.1.2 Ring Bolted Joint,
NSTXU-CALC-132-11-00
Prepared By: Peter Rogoff,
Reviewed By Irv Zatz,
Cognizant Engineer: Mark Smith

Out-of-Plane Loads Are Transferred from the TF to the Vessel Via the Umbrella Structure as Well. Original Legs Were Too Weak



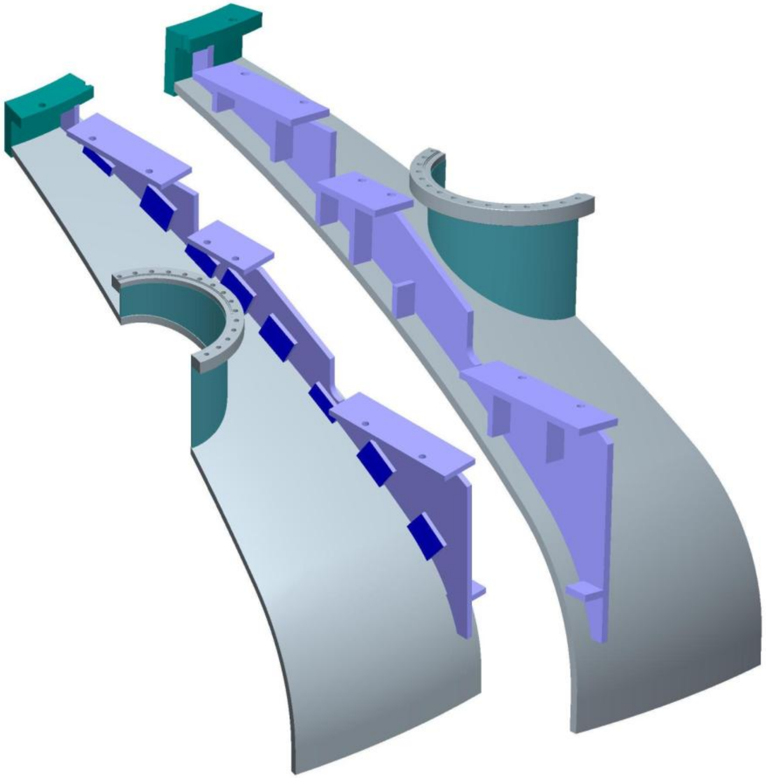
WBS 1.1.2 NSTX Upgrade Umbrella Arch and Foot Reinforcements, Local Dome Details, NSTXU-CALC-12-07-00 May 2011Prepared by: Peter Titus, Han Zhang, Reviewed By: Irv Zatz, Cognizant Engineer: Mark Smith

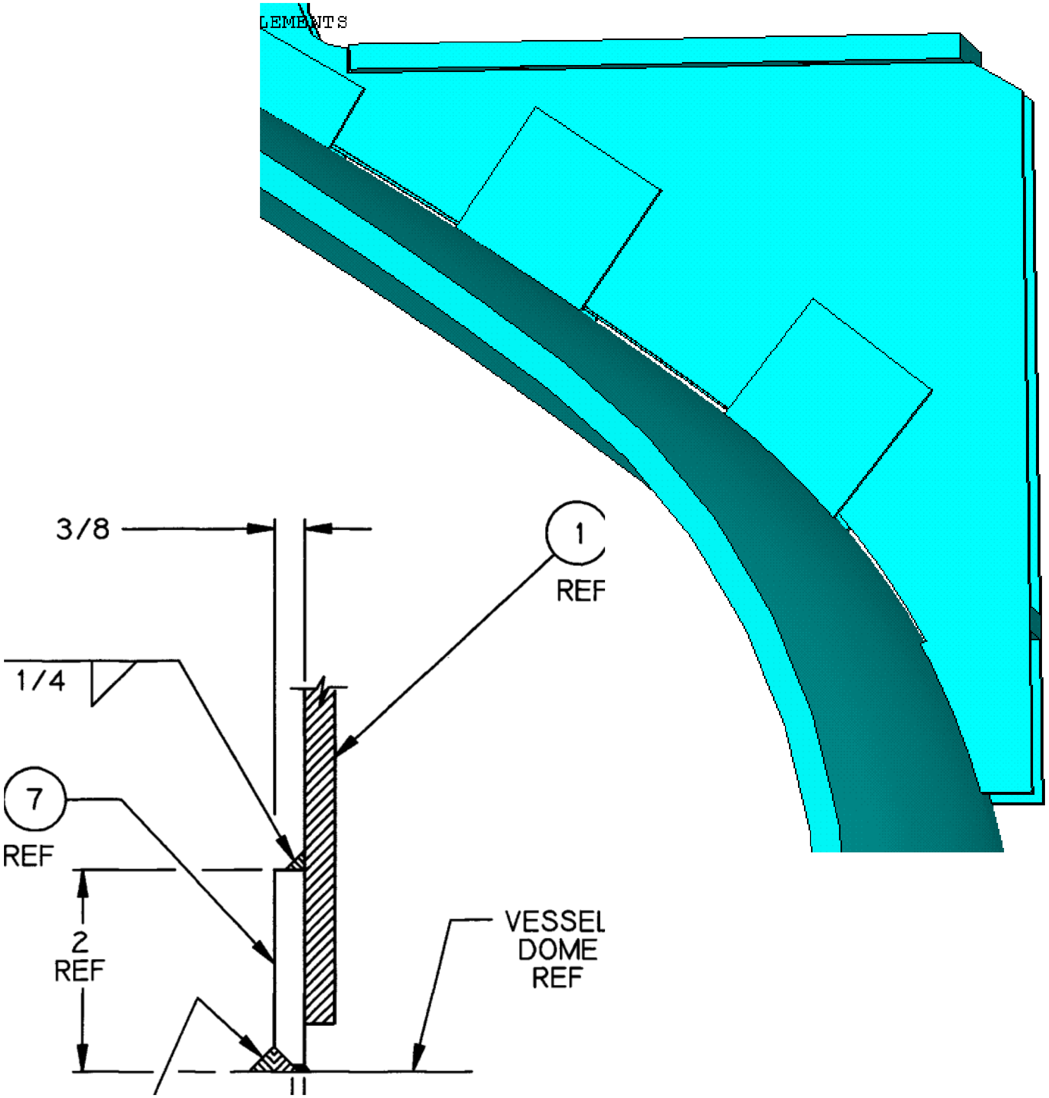




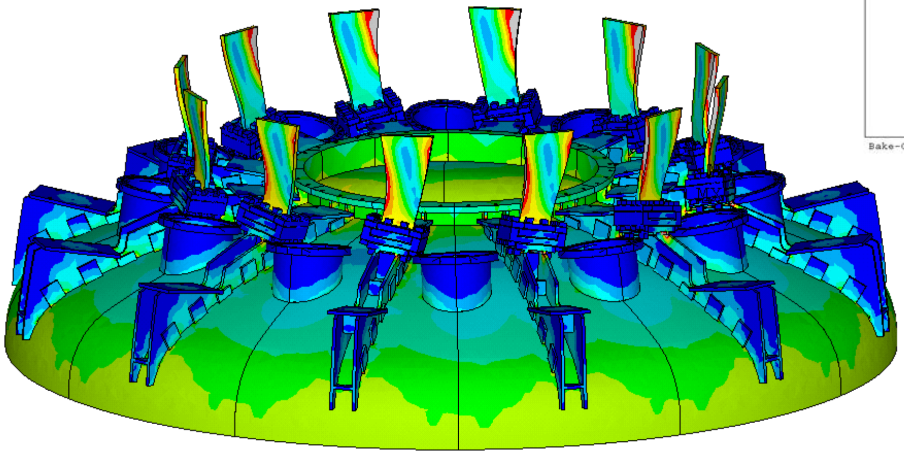
OOP and Vertical Load from Umbrella Legs, PF1c 2,and 3 Loads are Applied to the Ribs. Solid Models Needed Updating

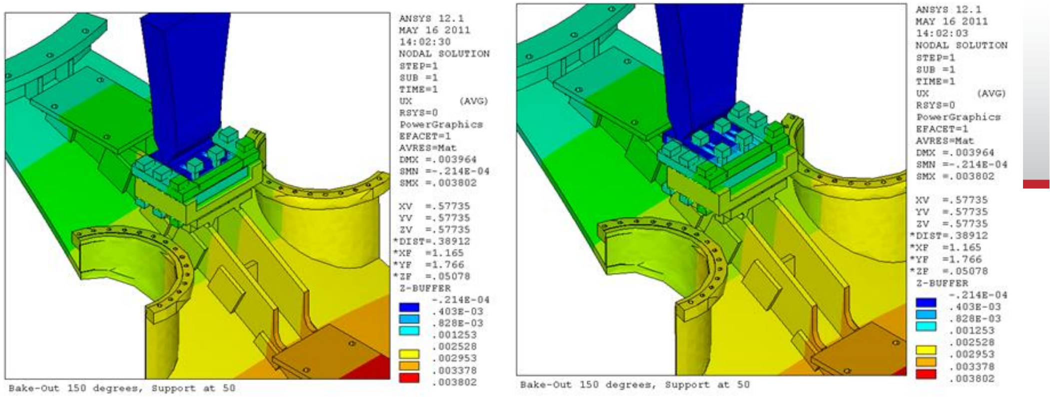
Bruce Paul Built the Solid Model of the Dome Rib Based on Non-Conformance Report





Dished Head Supports PF1c,2, and 3 Loads

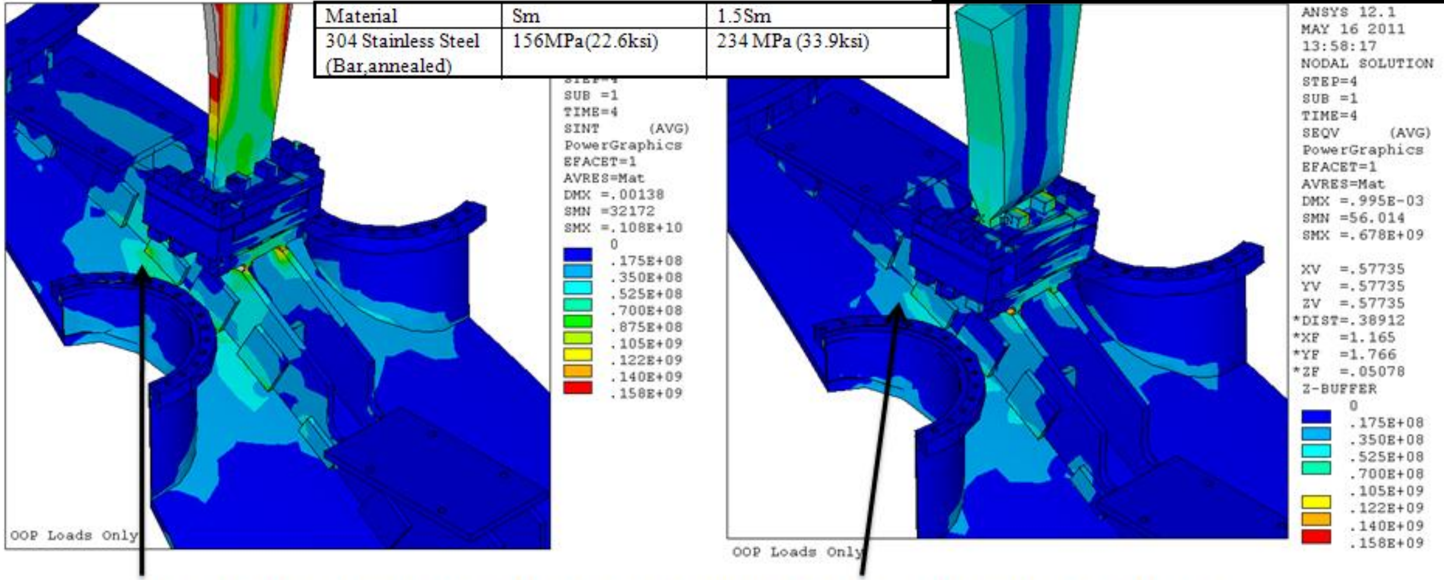




Sliding Block Allows Bake-Out Motion

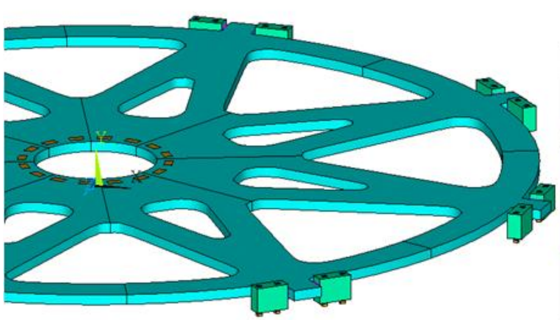
WBS 1.1.2 NSTX Upgrade Umbrella Arch and Foot Reinforcements, Local Dome Details, NSTXU-CALC-12-07-00 May 2011Prepared by: Peter Titus, Han Zhang, Reviewed By: Irv Zatz, Cognizant Engineer: Mark Smith

Material	Sm	1.5Sm
304 Stainless Steel (Bar,annealed)	156MPa(22.6ksi)	234 MPa (33.9ksi)

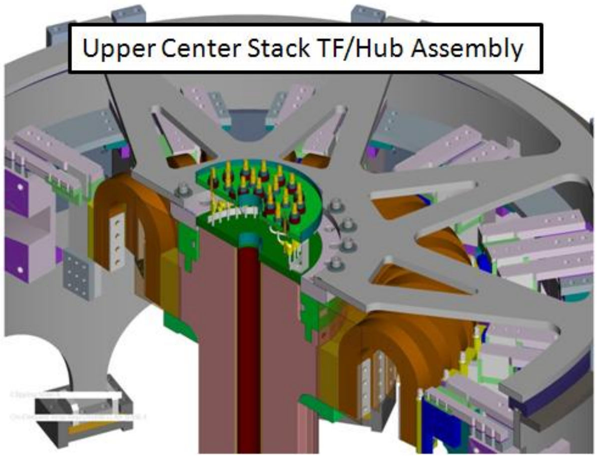


The Thicker Umbrella Structure Slightly Reduces the Dome Stress

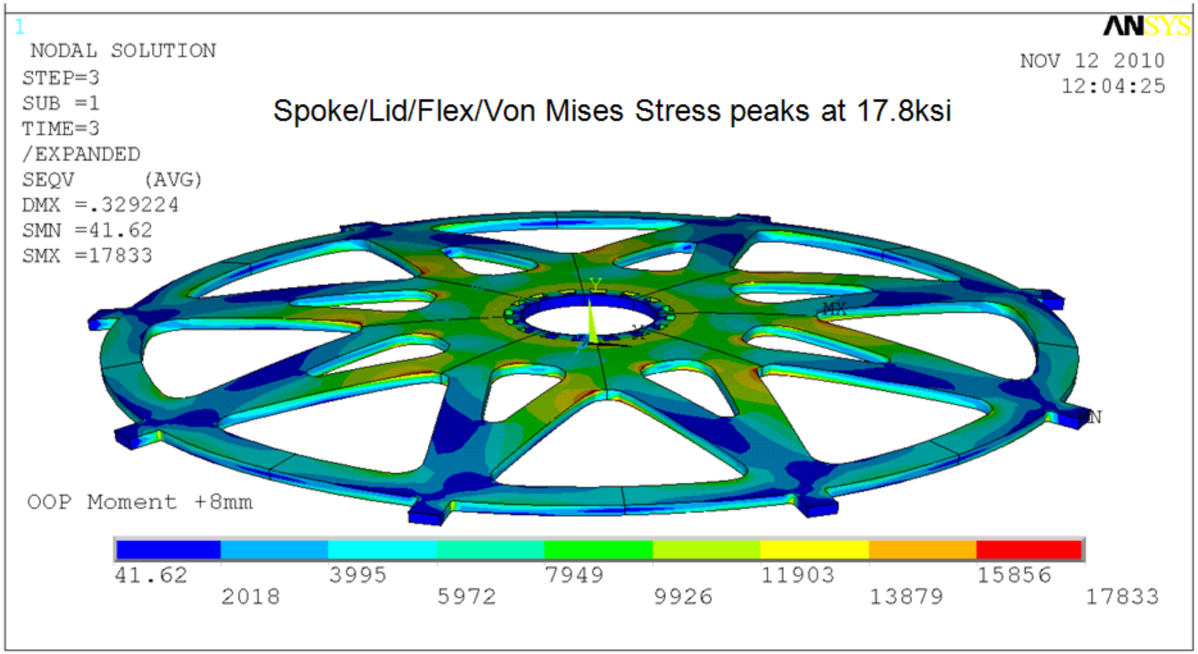
Out-of-Plane Torque Are Taken by Existing Structural Load Paths – Torque from Umbrella Structure Goes to Umbrella Legs – And to Upper Spoked Lid



Spoked Lid/Flex 45 degree FEA Model – With Symmetry Expansion



WBS 1.1.2 Lid/Spoke Assembly, Upper & Lower
NSTX-CALC-12-08-00 Rev 0 May 2011
Prepared by: Peter Titus, Reviewed By: Unassigned,
Cognizant Engineer: Mark Smith

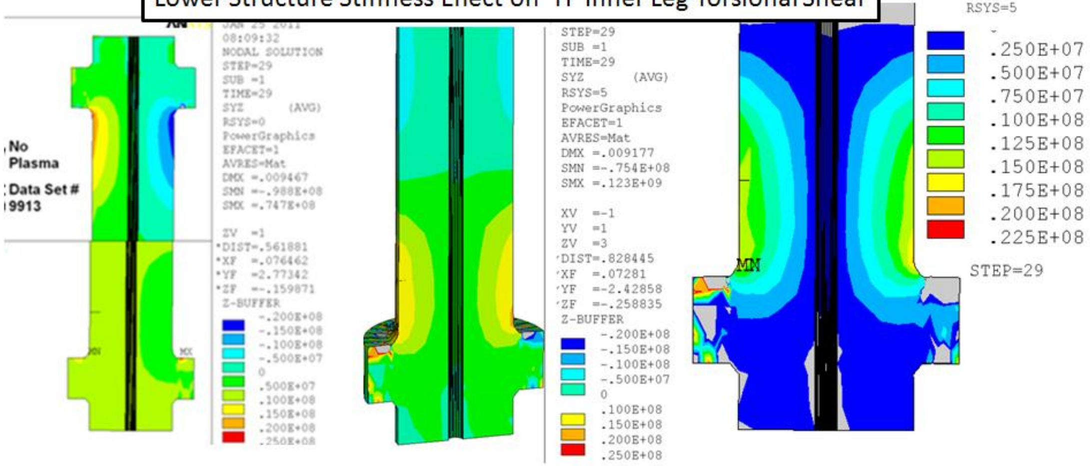


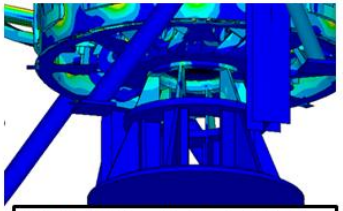
Spoke/Lid/Flex/Von Mises Stress peaks at 17.8ksi

Upper Spoked Lid Must Flex Upward to Allow Thermal Growth of the Centerstack

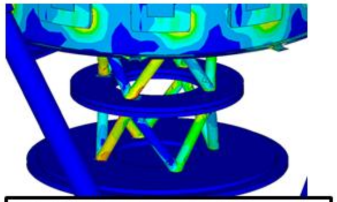
Lower Out-of-Plane Torque Load Path Was Changed to Ensure Adequate Access from Below

Lower Structure Stiffness Effect on TF Inner Leg Torsional Shear

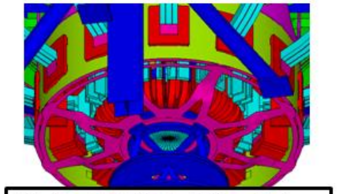




Rotationally Compliant Pedestal/Stiff Lower Lid

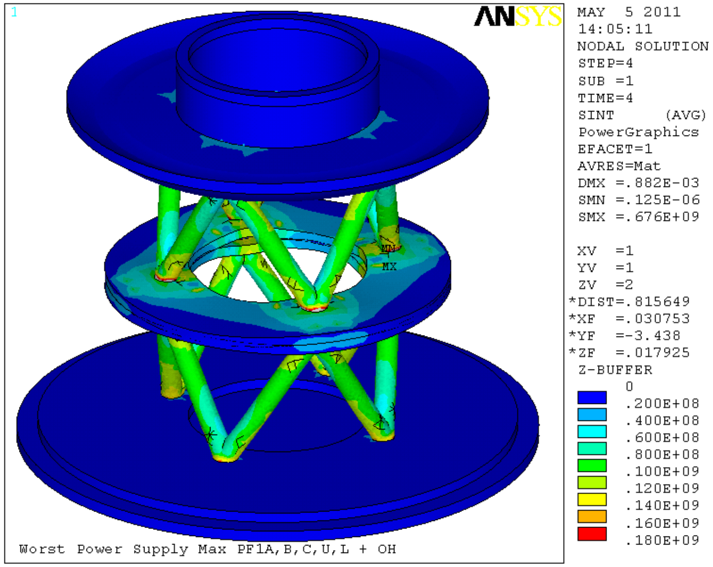


Rotationally Stiff Pedestal/Stiff Lower Lid



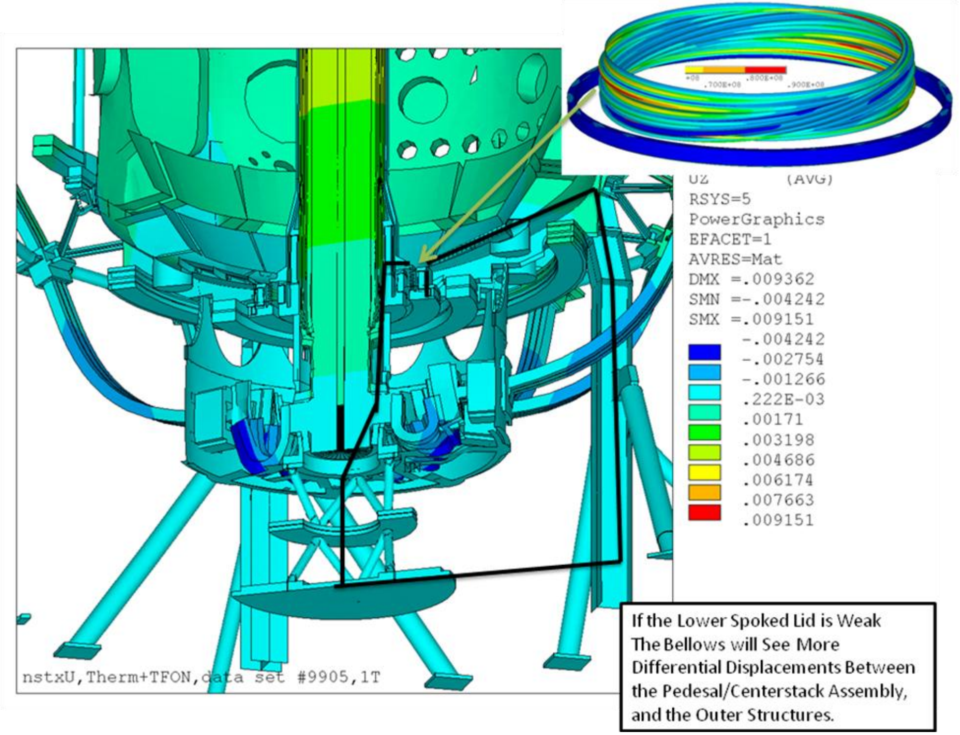
Rotationally Stiff Pedestal/Compliant Lower Lid

WBS 1.1.2 Analysis of the NSTX Upgrade Centerstack Support Pedestal NSTXU-CALC-12-09-00 May 2011 Prepared By: Peter Titus Reviewed By: Ali Zolfaghari, Cognizant Engineer: Mark Smith



WBS 1.1.2 Lid/Spoke Assembly, Upper & Lower
NSTX-CALC-12-08-00 Rev 0 May 2011
Prepared by: Peter Titus, Reviewed By: Unassigned,
Cognizant Engineer: Mark Smith

Stiff Pedestal and Soft Lower Spoked Lid Could Introduce Loads on the Bellows

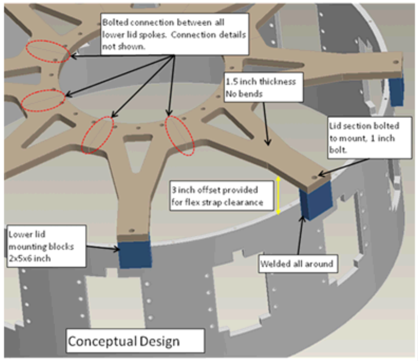


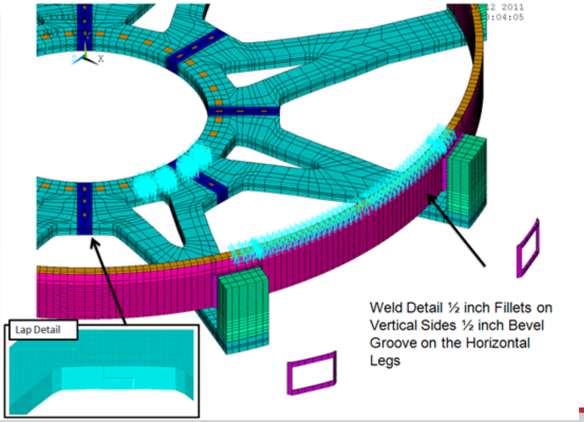
If the Lower Spoked Lid is Weak The Bellows will See More Differential Displacements Between the Pedesal/Centerstack Assembly, and the Outer Structures.

WBS 1.1.2 Lid/Spoke Assembly, Upper & Lower
NSTX-CALC-12-08-00 Rev 0 May 2011
Prepared by: Peter Titus, Reviewed By: Unassigned,
Cognizant Engineer: Mark Smith

Soft "Bent Spoke" Lower Lid was Considered.

It Potentially Caused Loading of the Bellows – From Halo Loads as Well as From OOP Torques

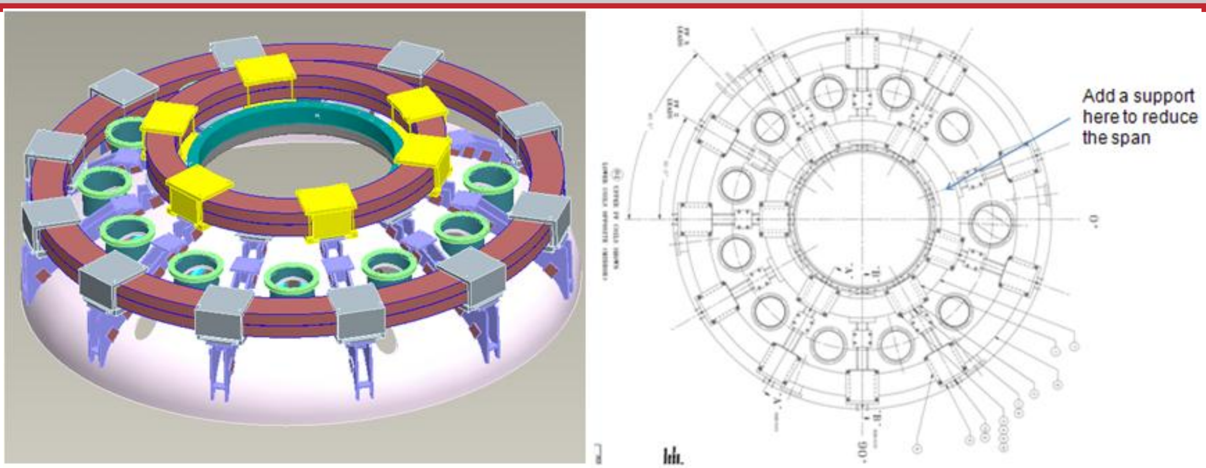




Weld Detail ½ inch Fillets on Vertical Sides ½ inch Bevel Groove on the Horizontal Legs

Stiffer Lower Spoked Lid Connects Umbrella and TF Central Column and Pedestal – Protecting the Bellows

PF Vertical or Axial Loads are Larger to Support 2 MA Operation

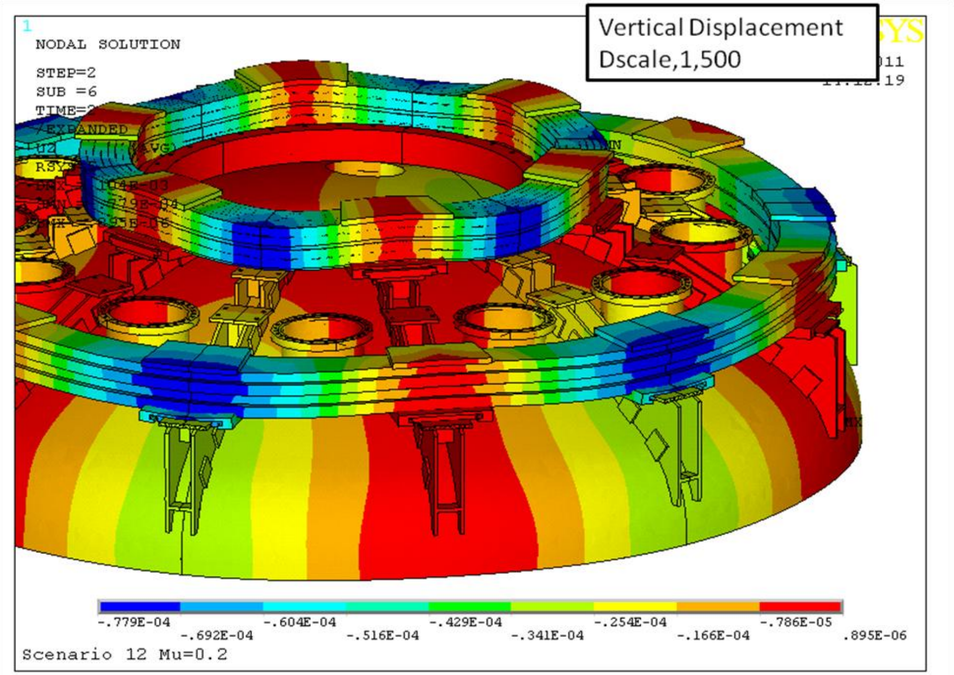


Add a support here to reduce the span

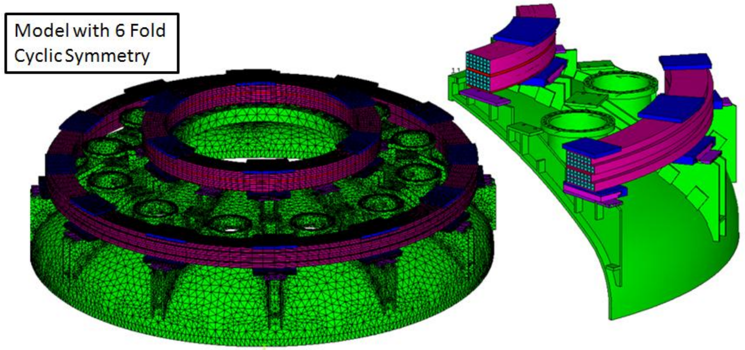
Current (2010) locations of the PF2 supports, and the proposed location of the seventh support

PF2,3 Analysis

WBS 1.1.2 PF2 and PF3 Coils and Support Analysis
NSTXU-CALC-12-04-00
Rev0, March 2011
Prepared By: Peter Titus
Reviewed By: Irv Zatz,
Cognizant Engineer: Mark Smith



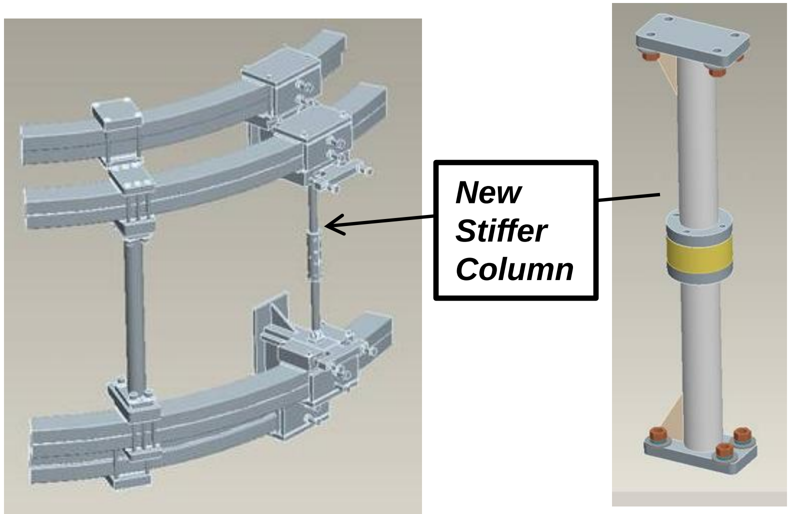
Vertical Displacement
Dscale,1,500



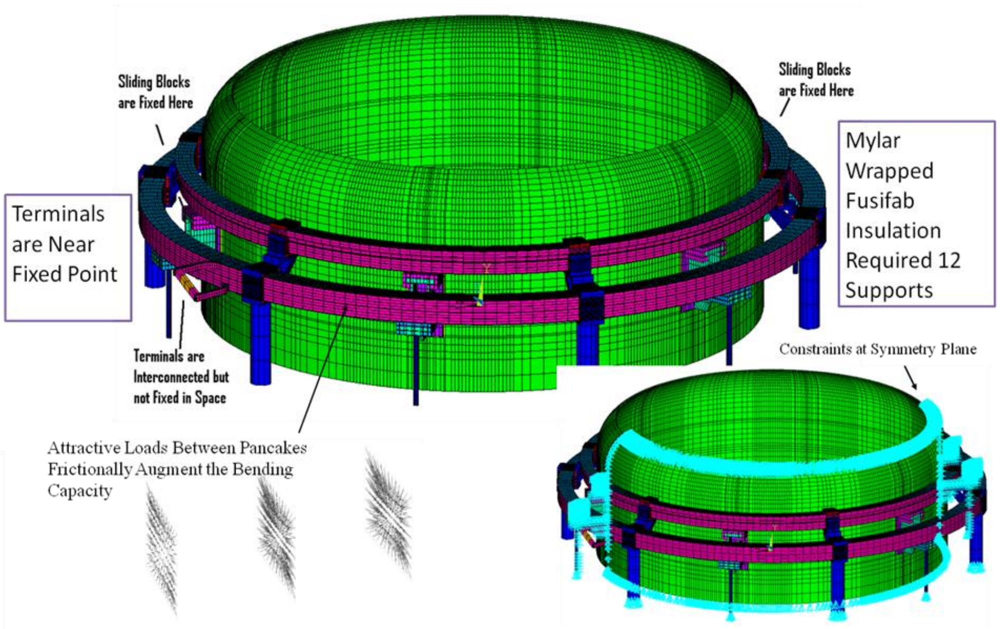
Model with 6 Fold Cyclic Symmetry

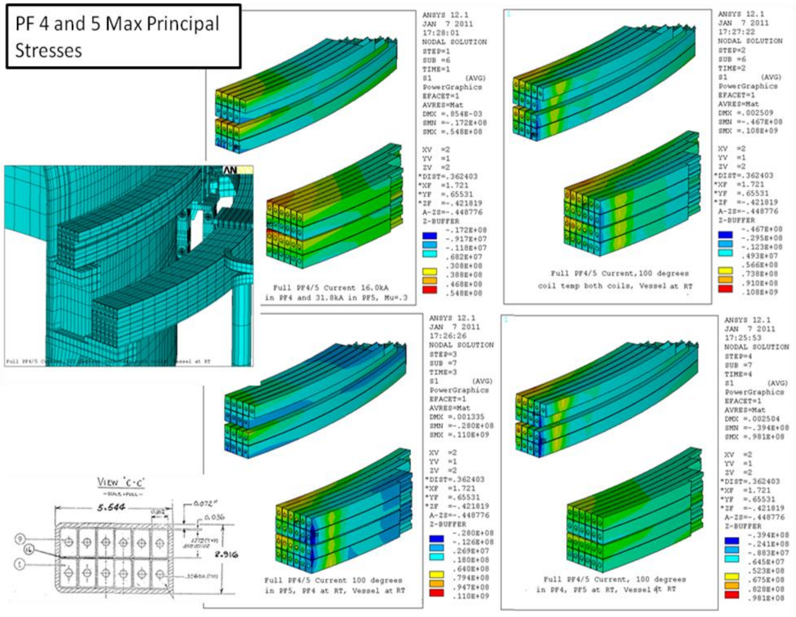
PF Vertical or Axial Loads are Larger to Support 2 MA Operation

PF4,5 Analysis



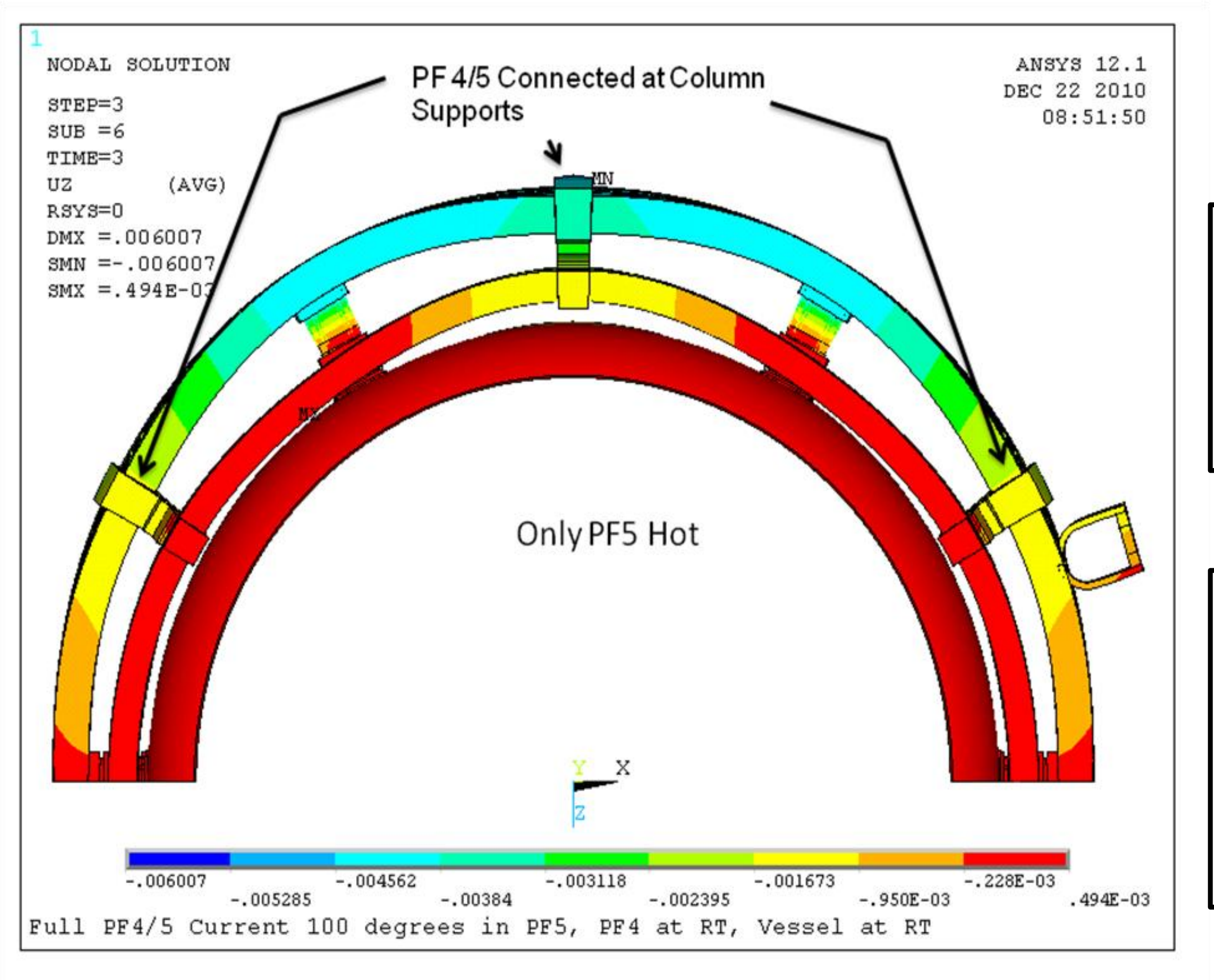
PF4 and 5 With 12 Support Points
Six Columns, 6 Existing PF Supports





WBS 1.1.2 Analysis of Existing & Upgrade PF4/5 Coils & Supports – With Alternating Columns, NSTXU-CALC-12-05-00,
Prepared By: Peter Titus, Reviewed by Irv Zatz,
Cognizant Engineer: Mark Smith

5 Second Pulse Adds More Joule Heat in the Coils



PF 4/5 Connected at Column Supports

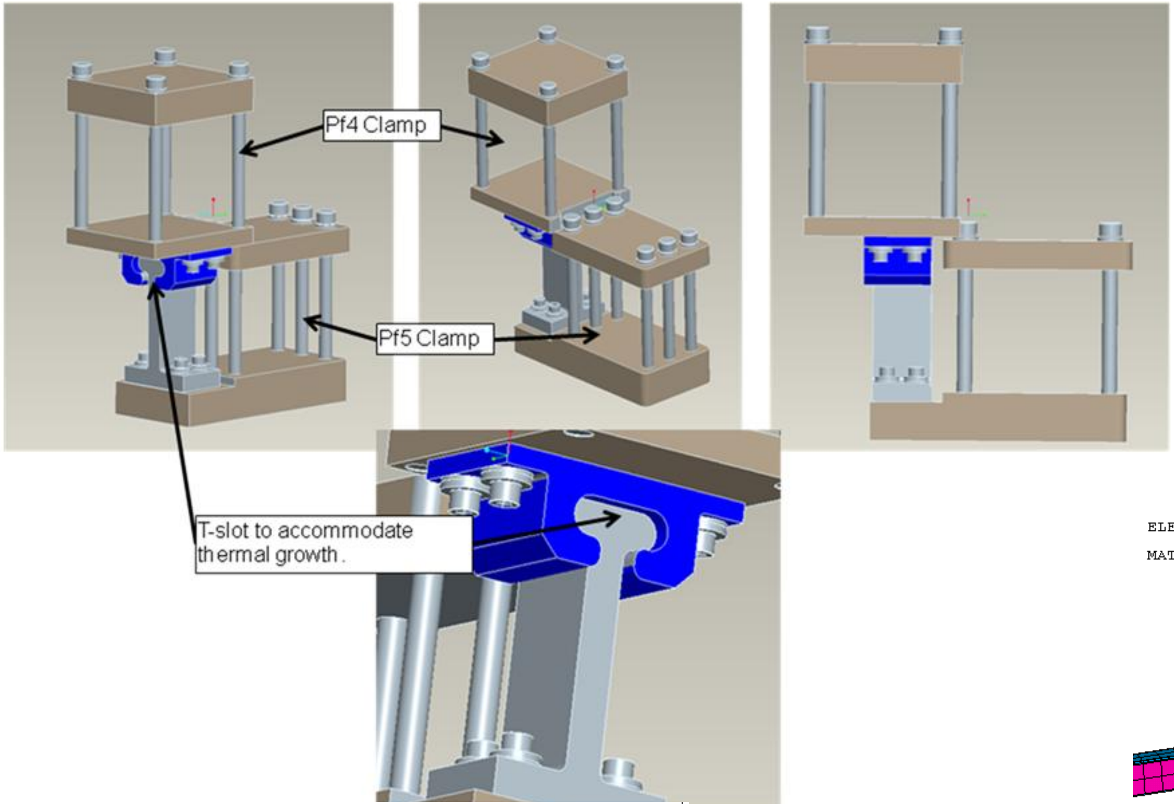
Only PF5 Hot

Significant Increases in Temperature Occur in PF 1 a,b
And PF4 and 5

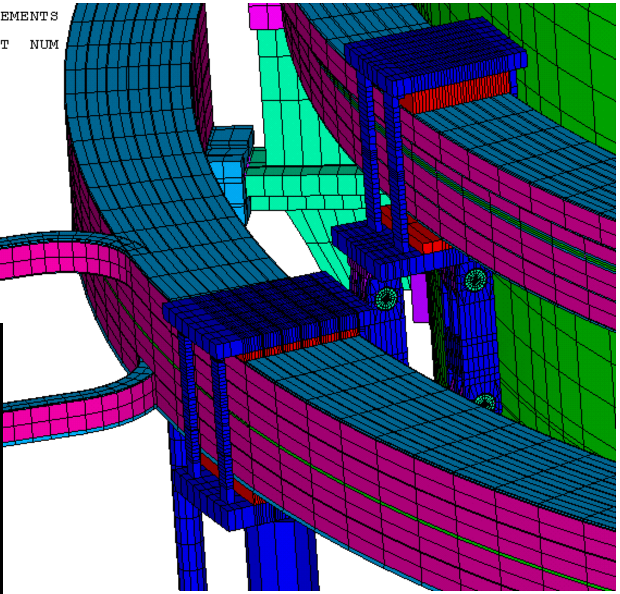
WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1
NSTX-CALC-133-01-01
Prepared By: Leonard Myatt, Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski

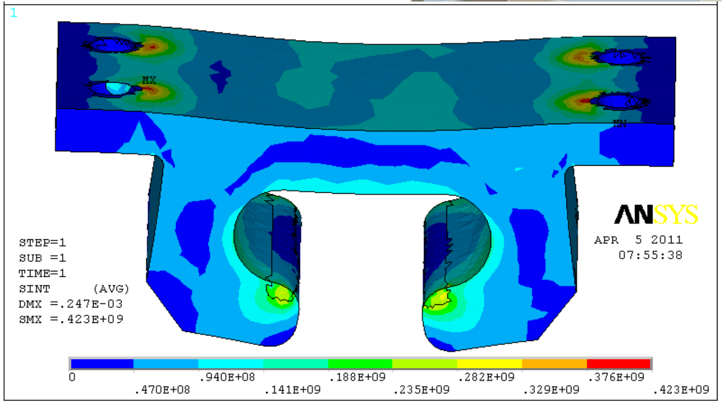
WBS 1.1.2 Analysis of Existing & Upgrade PF4/5 Coils & Supports – With Alternating Columns, NSTXU-CALC-12-05-00,
Prepared By: Peter Titus, Reviewed by Irv Zatz, Cognizant Engineer: Mark Smith

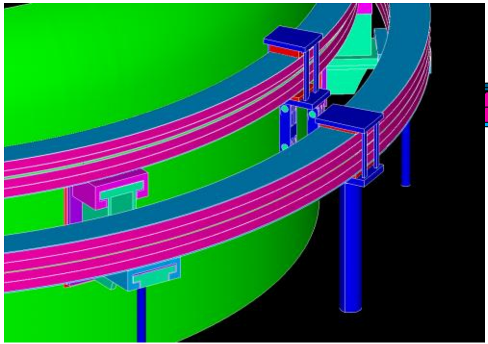
5 Second Pulse Adds More Joule Heat in the Coils



Link Model Used To Model Radial Motion at Added PF4/5 Columns

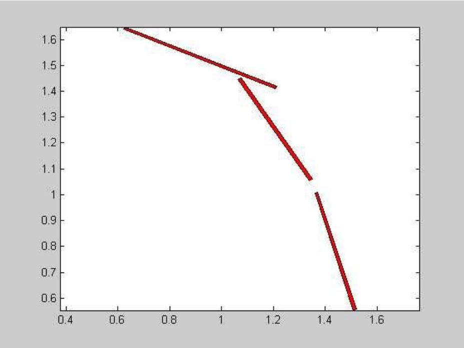


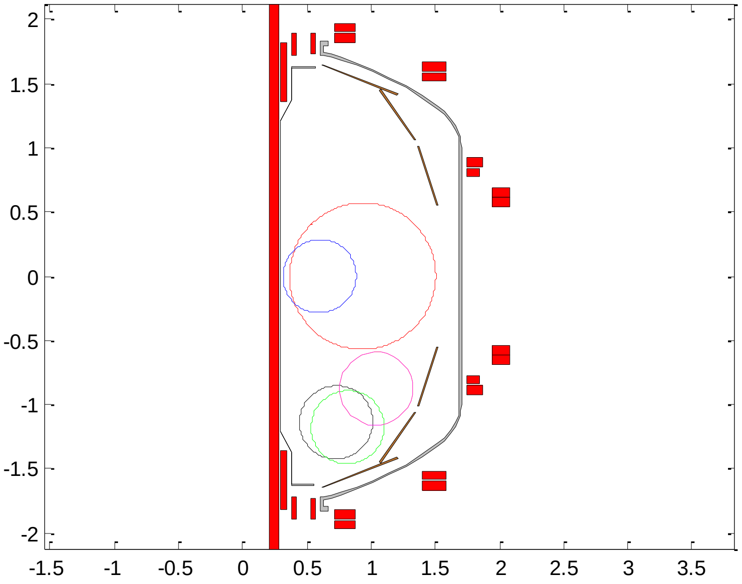


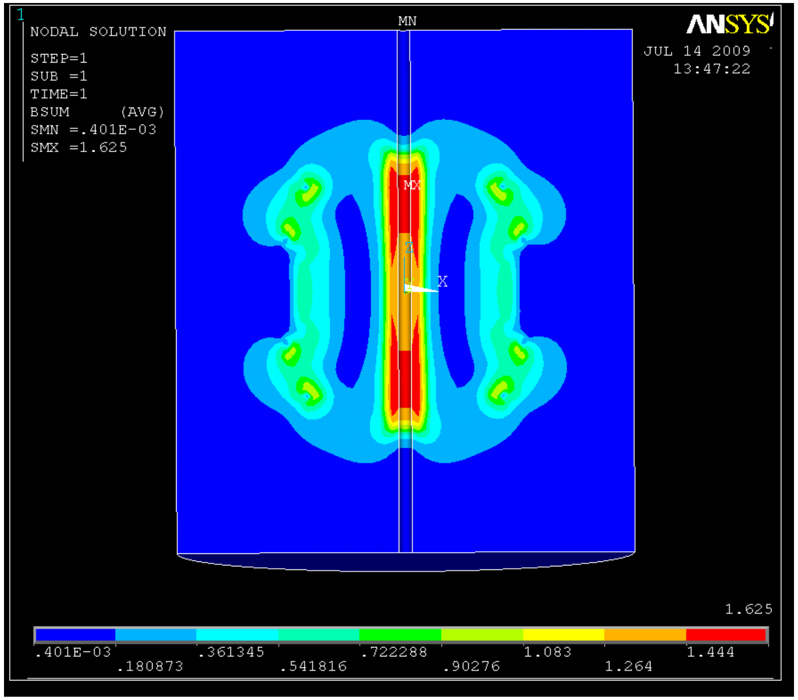


More Plasma Current, Higher TF Field, Higher PF Field, Increase Disruption Electromagnetic Loads in In-Vessel and Ex Vessel Components

Opera 2D Electromagnetic Analysis NSTXU-CALC-12-03-00
Prepared by: Ron Hatcher, Reviewed by: Art Brooks,
Cognizant Engineer: Peter Titus





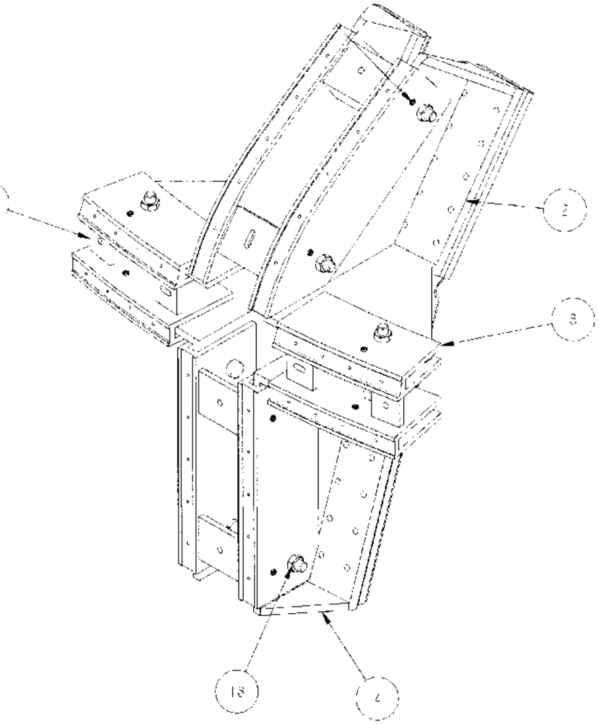


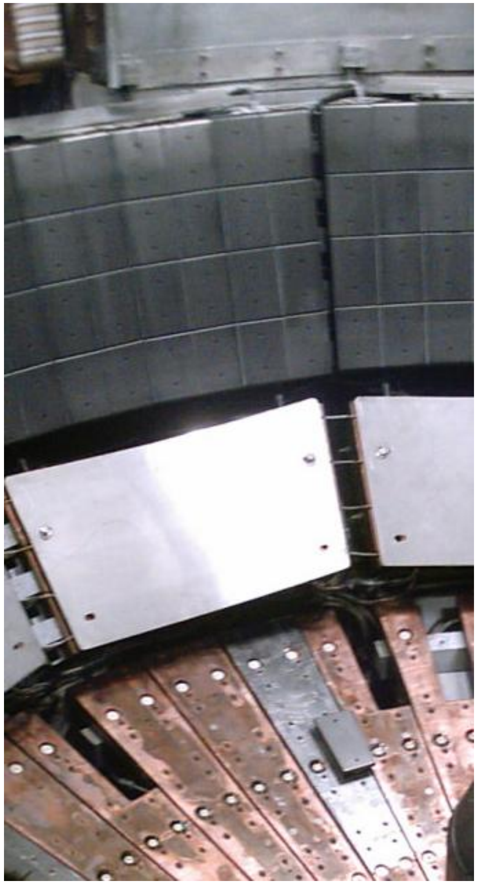
```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
BSUM      (AVG)
SMN =.401E-03
SMX =1.625
```

Opera Poloidal Fields Re-Constructed in ANSYS From OPERA Vector Potential Output

Complicated Components Needed to be Qualified. Large Models With Air Were Difficult to Mesh and Analyze Dynamically



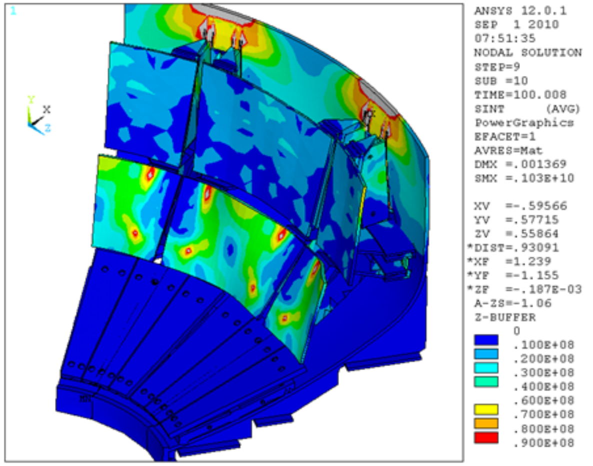


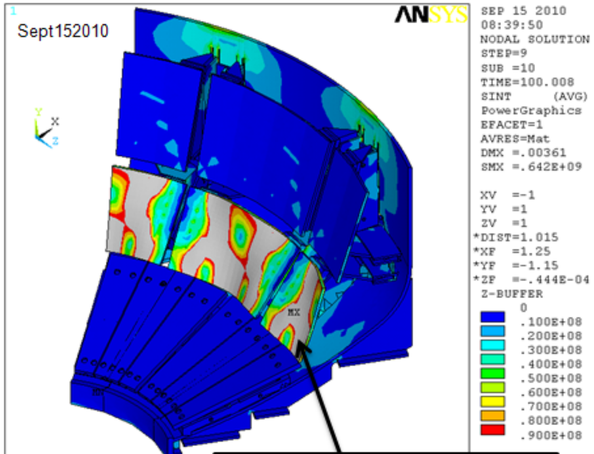
Complicated Components Needed to be Qualified. Large Models With Air Were Difficult to Mesh and Analyze Dynamically

Dynamic Analysis Results
Mid Plane Disruption
Fast Quench of Plasma 1

Same /Contour Scale as for the Mid Plane Disruption

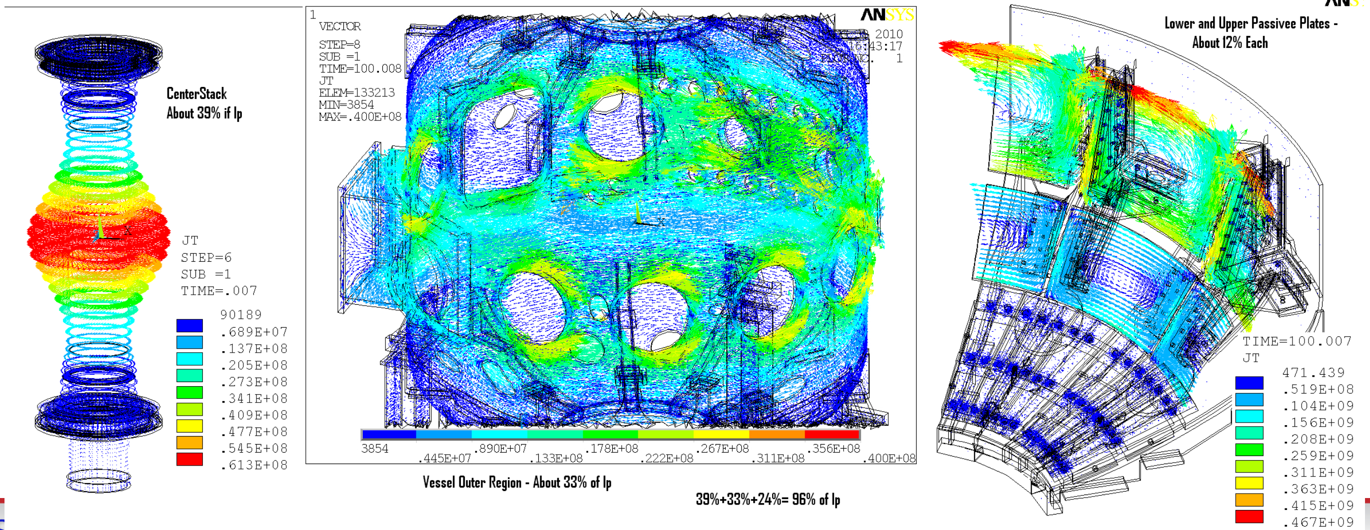
Dynamic Analysis Results
Disruption Near Secondary Passive Plate
Fast Quench of Plasma 4





Gray means > 90 MPa

2D Opera Results Were Imposed as Boundary Conditionns on 3D ANSYS Electromagnetic Models, Then Passsed to Dynamic Structural Analyses



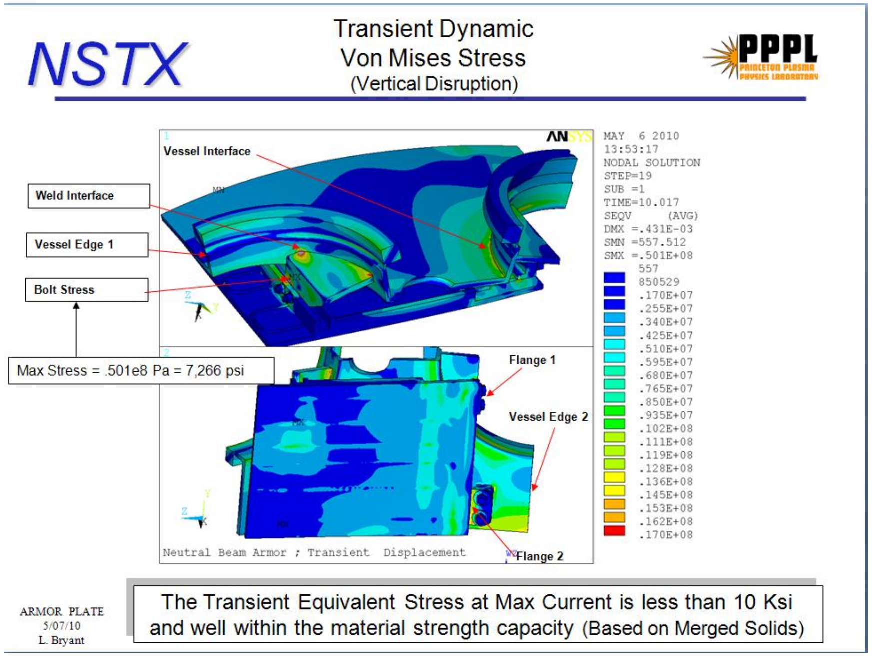
39%+33%+24%= 96% of Ip

WBS 1.1.1 Disruption Analysis of Passive Plates, Vacuum Vessel & Components NSTXU-CALC-12-01-01 Rev 1 April, 2011 Prepared By: Peter Titus, Contributing Authors: A. Brooks, Srinivas Avasarala, J. Boales Reviewed By: Yu Hu Zhai, Cognizant Engineer: Peter Titus

Other Disruption Analyses

NSTX HHFW (High Harmonic Fast Wave) Eddy Current Analysis for Antenna NSTX-CALC-24-03-00 Jan 10, 2011 Prepared By: Han Zhang, Robert Ellis Reviewed By: Ron Hatcher Cognizant Engineer: Peter Titus,

ARMOR BACKING PLATE, NSTX-CALC-24-02-00
Prepared by: Larry Bryant, Reviewed by Irv Zatz, Pete Titus,
Cognizant Engineer: Craig Prinski

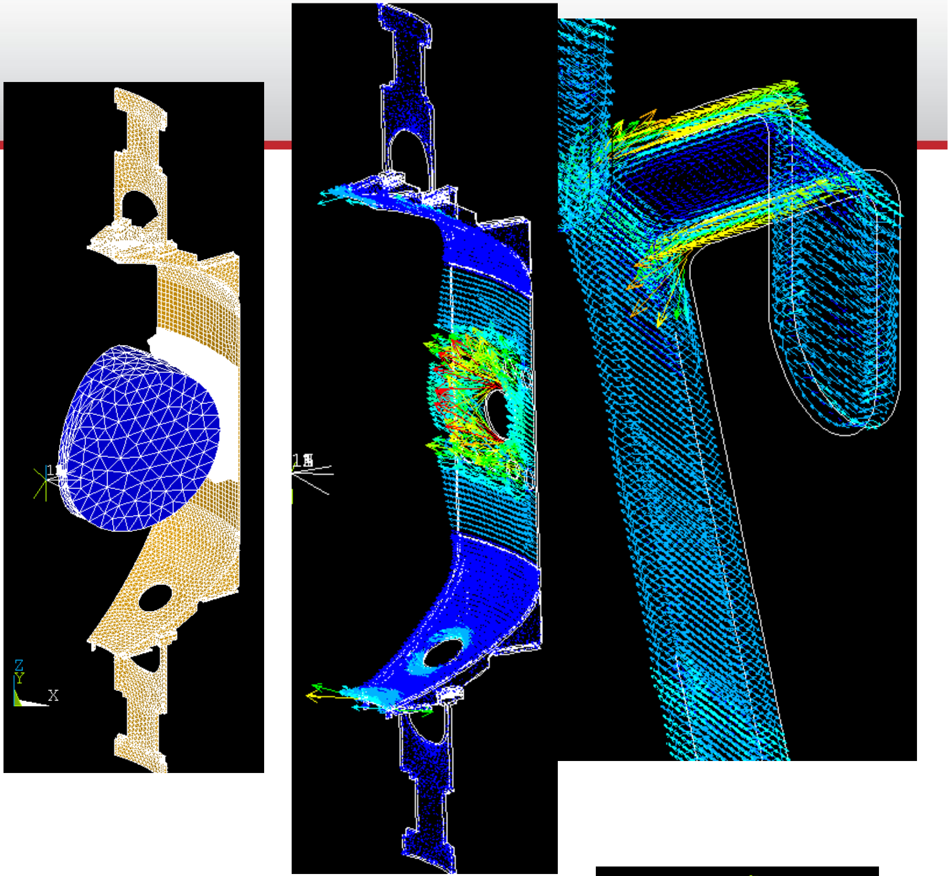

NSTX

Transient Dynamic
Von Mises Stress
(Vertical Disruption)

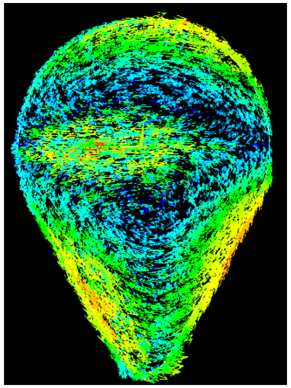
Max Stress = .501e8 Pa = 7,266 psi

The Transient Equivalent Stress at Max Current is less than 10 Ksi and well within the material strength capacity (Based on Merged Solids)

ARMOR PLATE
5/07/10
L. Bryant



WBS 1.2.3 NSTXU Diagnostics Review and Database NSTXU-CALC-40-01-00 September 2010 Prepared By: Joe Boales, Reviewed By: Yuhu Zhai, NSTX Cognizant Engineer Bob Kiata



Machine Protection System Algorithms

Addition of Moment Influence Coefficients to DCPS

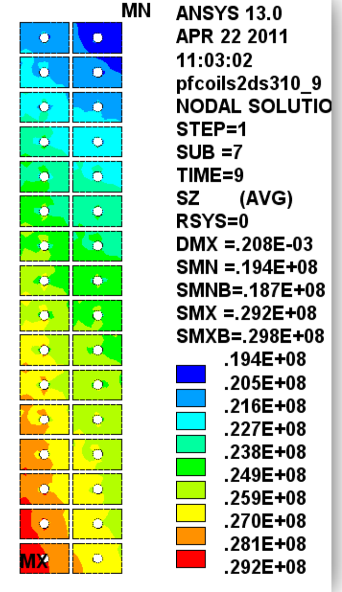
PF1,2,3 supports, welds bolts – At this stage, These are just calculated from influence coefficient matrix loads divided by weld or bolt area. Proposing to add Moment Influence Coefficients

PF 4/5 support weldment (see example)
PF4/5 Conductor (Titus)

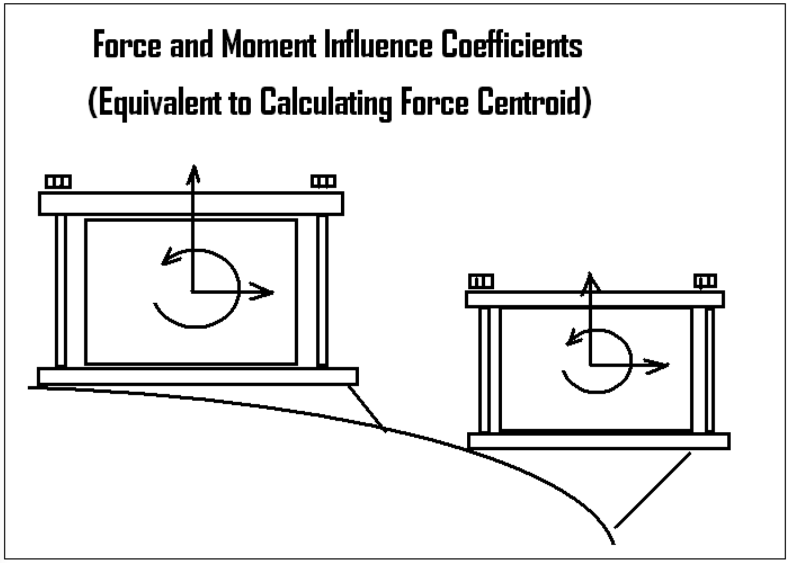
OH Preload-Launch-TF temperature dependence
PF1a-OH interaction Stress
Vertical Loads on pedestal load path (TF Flag Bolts, Pedestal hilti's), (Ali)

TF Strap (T. Willard)
– Mostly designed to TF max Current.
DCPS should trip if vertical field exceeds limit (.24T?)

-More – As a Guide on Scope: Use the number of calculations each with a few sensitive areas



Hoop Stress in PF1b

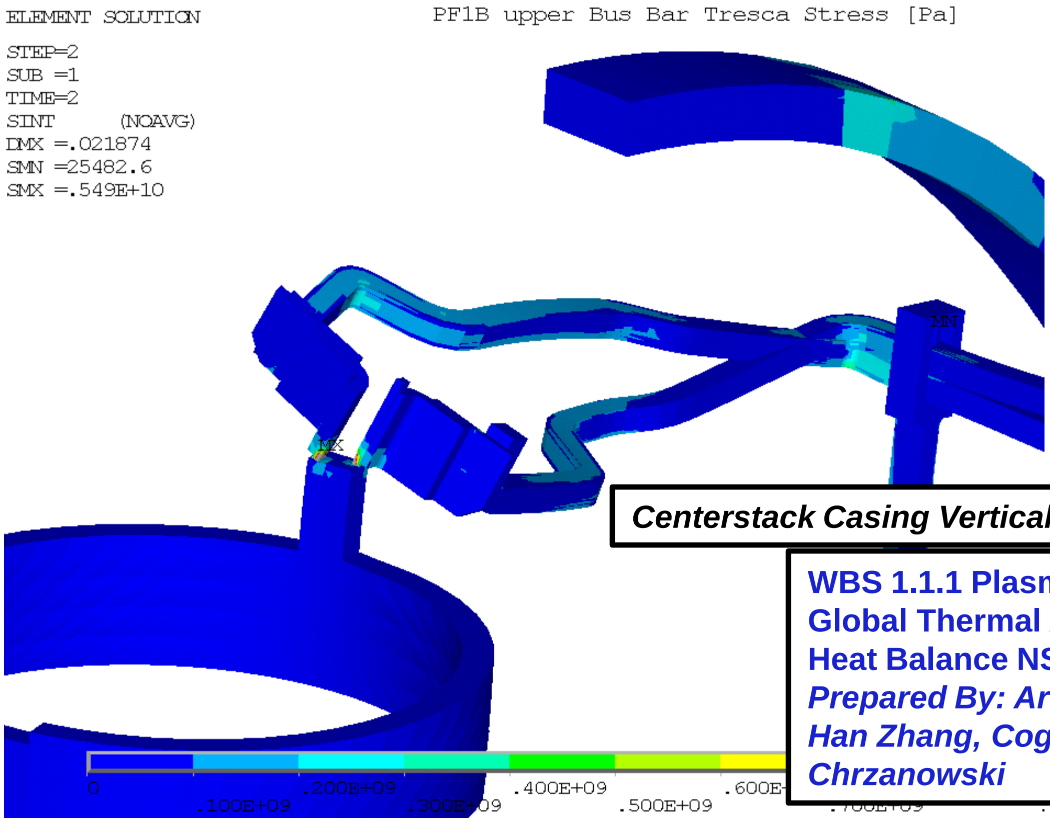


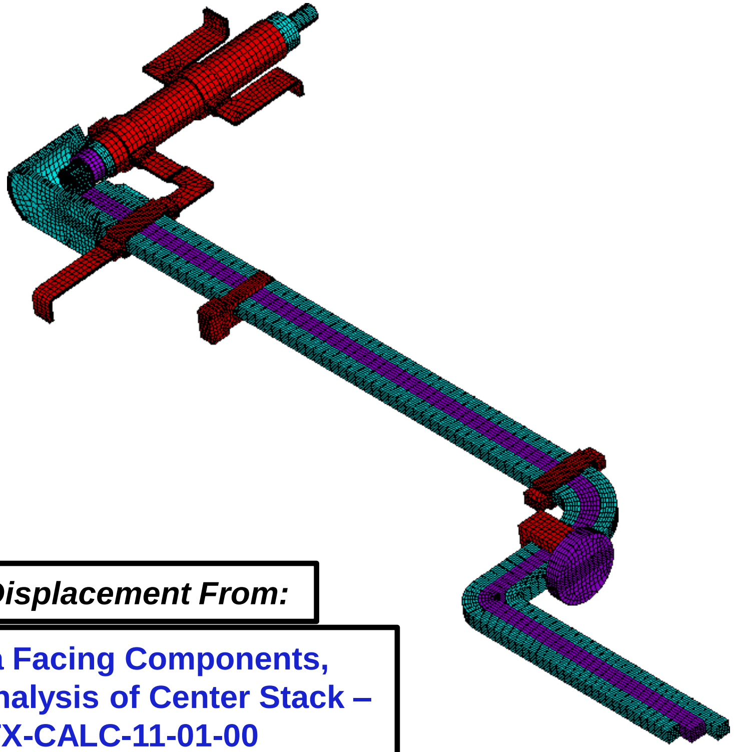
Bolt Loads are calculated from the vertical force and the moment divided by the width of the bolt pattern

WBS 1.5.2 Upgrade Moment Influence Coefficients
NSTXU-CALC-13-05-00 January 18 2011
Prepared By: Peter Titus,
Reviewed By: R. Woolley, Ron Hatcher, NSTX Cognizant Engineer

The Bus Bars See Complicated Lorentz Loads and Thermal Loads, PF1a,b Move Upward with the Expansion of the Centerstack

WBS 1.5.5 Structural Analysis of PF1, TF & OH Bus Bars
NSTXU-CALC-55-01 Prepared By: Andrei Khodak
Reviewed by Peter Titus Cognizant Engineer: Mark Smith


PF1B upper Bus Bar Tresca Stress [Pa]



Centerstack Casing Vertical Displacement From:

WBS 1.1.1 Plasma Facing Components, Global Thermal Analysis of Center Stack – Heat Balance NSTX-CALC-11-01-00
Prepared By: Art Brooks, Reviewed by: Han Zhang, Cognizant Engineer: Jim Chrzanowski

Needing Resolution:

PF4/5 coil/support calculation concluded a stiffer PF4/5 column needed. Updated column design needs to be incorporated into the calculation.

Slow VDE loading on passive plates needs design to accept large loads or analysis to show they are not needed

TF Clamp – No leg brace is needed. Calculations must confirm interim conclusion.

Fatigue Data for CTD 101K at 100C is needed.

Highly Localized Temperatures in the TF reach 113 degrees C – Test Result look good for 100C- Do we need another test? Or can we back-off slightly on i^2 T? – Or accept as-is with slight potential for creep.

Centerstack Casing Loads and Stresses for Halo Strikes other than Mid-Plane, Inductive Currents due to P1-P2

DCPS Input and Testing.

Upper Spoked Lid OD Fixed Connection vs. Pinned

PF1a,b Upper Leads to Allow Vertical Motion, Flex of the bus, AND Radial Thermal Growth of the PF's

The OH Conductor Must have Manufacturing In-Process NDE to Meet Allowables
Gary Voss has Provided Luvata Eddy Current Information – We are Evaluating whether Volumetric Inspection is Needed.

Back-Up

Weld Allowable

From the NSTX Criteria:

For welds in steel, ***the design Tresca stress shall be the lesser of:***

2/3 of the minimum specified yield if the weld at temperature, or

1/3 of the minimum specified tensile strength of the weld at temperature.

Minimum Weld Size

AISC Table 1.17.5 , AWS Table 5.8, page 194

Material thickness of thicker part joined (inches)	Minimum size of fillet weld (inches)	Material thickness of thicker part joined (inches)	Minimum size of fillet weld (inches)
To ¼ inch inclusive	1/8	over1.5 to 2.5	3/8
Over ¼ to ½ in.	3/16	Over 2.25 to 6	1/2
Over ½ to 3/4 in.	¼	Over 6	5/8
Over ¾ to 1.5 in.	5/16		

From the AISC Criteria:

Reference and Weld	Rod or weld wire	Parent Material	Allowable Stress (Exclusive of Weld Efficiency)
AISC Stress on cross section of full penetration Welds	*-Peter*	All	Same as Base material
AISC Shear Stress on Effective Throat of fillet weld	AWS A5.1 E60XX	A36 -	21 ksi

For shear on an effective throat of a fillet, For 304 Stainless, the weld metal is annealed, or the base metal in the heat effected zone is annealed. and Estimate 241*21/36 = 140 MPa = 20 ksi (without weld efficiency)

This is consistent with NSTX Criteria of 2/3 yield or 2/3 of 30ksi for annealed 304

With a weld efficiency of .7 the allowable is 14ksi, or 96 MPa

For fillets divide weld area by sqrt(2)

Criteria – Allowables for Coil Copper Stresses

The TF copper ultimate is 39,000 psi or 270 MPa . The yield is 38ksi (262 MPa). Sm is 2/3 yield or 25.3ksi or 173 MPa – for adequate ductility, which is the case with this copper which has a minimum of 24% elongation. Note that the ½ ultimate is not invoked for the conductor (It is for other structural materials) . These stresses should be further reduced to consider the effects of operation at 100C. This effect is estimated to be 10% so the Sm value is 156 MPa.

- From: I-4.1.1 Design Tresca Stress Values (Sm), NSTX_DesCrit_IZ_080103.doc
- • (a) For conventional (i.e., non-superconducting) conductor materials, the design Tresca stress values (Sm) shall be 2/3 of the specified minimum yield strength at temperature, for materials where sufficient ductility is demonstrated (see Section I-4.1.2). *
- It is expected that the CS would be a similar hardness to the TF so that it could be wound readily. For the stress gradient in a solenoid, the bending allowable is used. The bending allowable is 1.5*156 or 233MPa,

NSTX Fatigue Criteria Document:

A fatigue strength evaluation is required for those NSTX CSU components with undetectable flaws that are either cycled over 10,000 times or are exposed to cyclic peak stresses exceeding yield stress.

NSTX GRD:

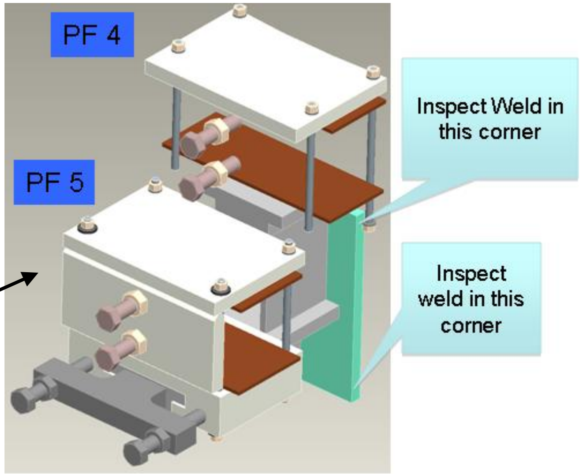
For engineering purposes, number of NSTX pulses, after implementing the Center Stack Upgrade, shall be assumed to consist of a total of ~ 60,000 pulses based on the GRD specified pulse spectrum.

Aged Components:

NSTXBo x NSTXIp
NSTX-UBo x NSTX-UIp

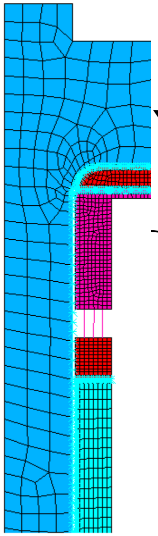
NSTX Components Have Been Aged (Maybe the cause of the present OH terminal failure)

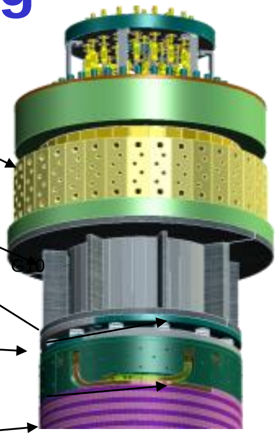
- ***Because of the increase in loads, Minors Rule and Non-Linearity of Fatigue, Previous Stress Cycles Will Add Little. The Criteria document includes guidance on how to treat this, but:***
- ***The primary means of qualification for fatigue will be in-service inspection.***
- ***The Upgrade will have what is essentially a pre-service inspection.***
- ***Develop an Inspection regimen based on visual screening and penetrant tests of suspect areas.***
- ***Use the DCPS for cycle counting and Minors rule usage factor tracking?***



CS Structural/Emag Modeling

A. Zolfaghari





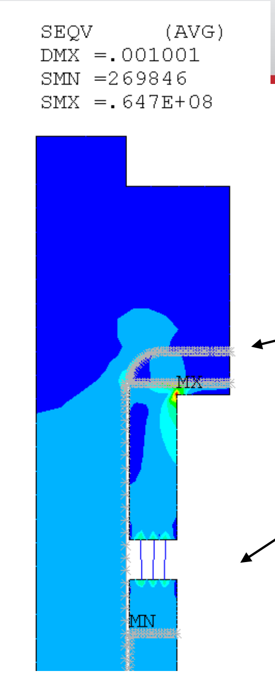
TF Flag

SS Spacer

BV Washer

G-10

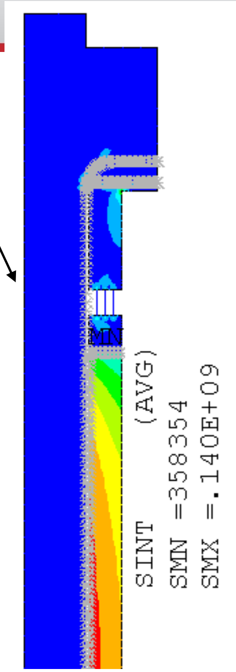
OH Coil



No currents, Cold TF, Cold OH

Bellville stack, 18 mm preload and 2.5e7 N/m spring constant

Hot OH, Cold TF, OH Self EM Load



TF Temp.	OH Temp.	TF Current	OH Current	Launch Force	Peak OH Stress	Peak TF Stress	Peak Displacement	OH Lifted?	Case #	Notes
COLD	COLD	OFF	OFF	OFF	7-14 MPA	7-14 MPA	0.6 mm TF	NO	00000	Bellville staff force only
HOT	COLD	ON	OFF	OFF	102-115 MPA	38-51 MPA	8.8 mm TF	NO	10100	TF grows pushing OH laterally
COLD	HOT	OFF	OFF	OFF	10-19 MPA	19-29 MPA	4.6 mm OH	NO	01000	
COLD	HOT	OFF	ON	OFF	125-140 MPA	16-31 MPA	1.6 mm OH	NO	01010	TF was off and OH current was turned on with hoop stress only
COLD	HOT	OFF	ON	ON	123-138 MPA	16-31 MPA	1.9 mm OH	NO	01011	TF was off and OH current was turned on with hoop stress and launch force.
HOT	COLD	ON	ON	ON	117-132 MPA	15-29 MPA	8.2 mm TF	NO	10111	Just in case, OH getting current before heating up
HOT	HOT	ON	ON	ON	110-134 MPA	15-19 MPA	8.3 mm	NO	11111	

Insulation Shear Stress Allowable

From NSTX TF Test Report:

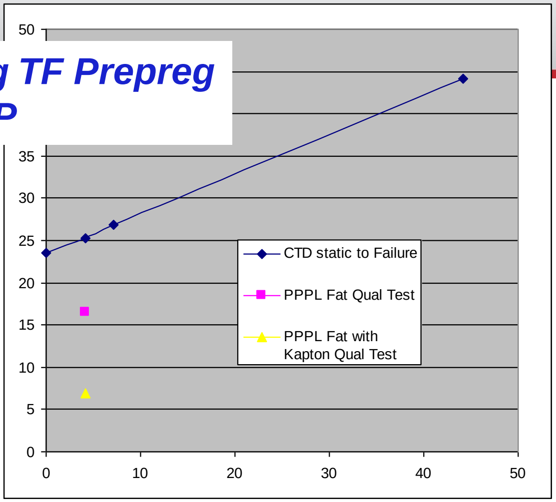
Planned VPI CTD 101K

- ***From Dick Reed Reports/Conversations:***
- Shear strength, short-beam-shear, interlaminar
- **Without Kapton 65 MPa (TF, PF1 a,b,c)**
- **With Kapton 40 MPa (CS)**
- **Estimated Strength at Copper Bond 65 MPa/2 =32.5 MPa (All Coils)**

- ***From Criteria Document:***
- ***I-5.2.1.3 Shear Stress Allowable***
- The shear-stress allowable, Ss, for an insulating material is most strongly a function of the particular material and processing method chosen, the loading conditions, the temperature, and the radiation exposure level. The shear strength of insulating materials depends strongly on the applied compressive stress. Therefore, the following conditions must be met for either static or fatigue conditions:
- Ss = [2/3 to]+ [c2 x Sc(n)]

2/3 of 32.5 MPa = 21.7 MPa

Existing TF Prepreg CTD 12P

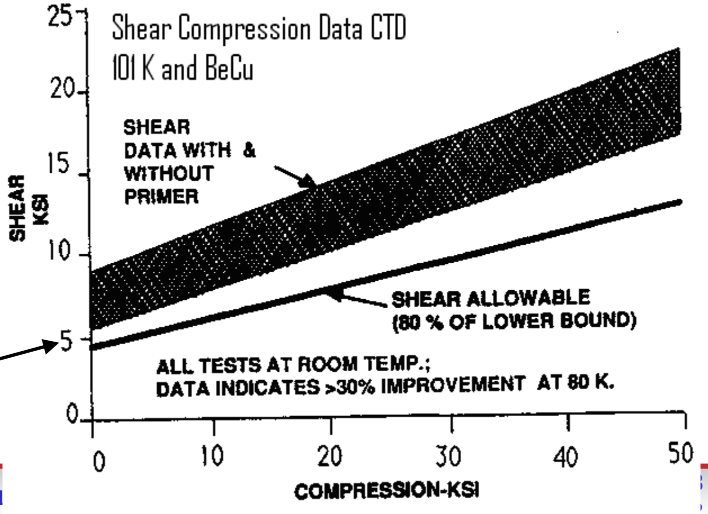


2/3 of 24 = 16 MPa (Static)

C2~.44

Should be Further De-rated for Fatigue

From an October 27 2009 email from Dick Reed



5ksi=34 MPa

2/3 of this is 23 MPa

C2~=.1 (not .3)

AWS Criteria

- AWS states that it does not apply to pressure vessels. Our drawings of the vessel call out ASME B31.3 category D This is a non-hazardous piping code. Given that most of the weldments that we are evaluating are non-standard arrangements that neither fit the vessel code, or piping code, AWS would be an OK call-out
- AWS prefaces the Design section by stating that the sizing should be as specified in the contract – or the "Engineer" regarding requirements.
- Inspection is one area where the requirements are to be outlined in contract documents or in design specifications or drawings. Although the design guidance is clearly recommending inspection for fatigue applications.
- Table 2.3 (page24) gives allowable stresses in welds. The tension and compression stress limit for full penetration welds is the base metal strength. NSTX is using annealed properties of base metal.
- The stress limit for fillets is based on shear in the net section (consistent with ASME, and AISC)
- The allowable is based on 0.3* tensile strength of the filler metal or .4* the yield strength of the base metal. There are some notes that will require some interpretation, but it is consistent with AISC, and ASME.
- Guidance regarding weld efficiencies for specific inspection procedures is not included, but the code would not override guidance from the "Engineer" that chose to apply them.

•AWS has a lot of useful fatigue design guidance for welds.

It has of calculation guidance and local weld design, and surface contour guidance to mitigate the effects of fatigue. Inspection of welds subject to fatigue is required (paragraph 2.18 which requires RT or UT). Mag Particle (MT) is also mentioned in the fatigue sections. Inspection methods are described in section 6 which includes a note allowing penetrant (PT) inspection, but the code appears to prefer radiographic or ultrasonic inspection.

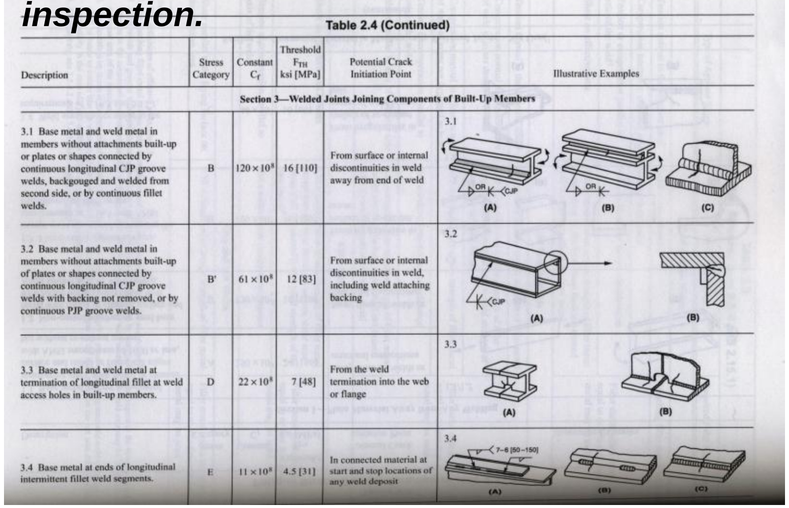


Table 2.4 (Continued)

Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members					
3.1 Base metal and weld metal in members without attachments built-up or plates or shapes connected by continuous longitudinal CJP groove welds, backgouged and welded from second side, or by continuous fillet welds.	B	120×10^8	16 [110]	From surface or internal discontinuities in weld away from end of weld	3.1
3.2 Base metal and weld metal in members without attachments built-up of plates or shapes connected by continuous longitudinal CJP groove welds with backing not removed, or by continuous PJP groove welds.	B'	61×10^8	12 [83]	From surface or internal discontinuities in weld, including weld attaching backing	3.2
3.3 Base metal and weld metal at termination of longitudinal fillet at weld access holes in built-up members.	D	22×10^8	7 [48]	From the weld termination into the web or flange	3.3
3.4 Base metal at ends of longitudinal intermittent fillet weld segments.	E	11×10^8	4.5 [31]	In connected material at start and stop locations of any weld deposit	3.4