NSTX

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U.S. DEPARTMENT OF ENERGY

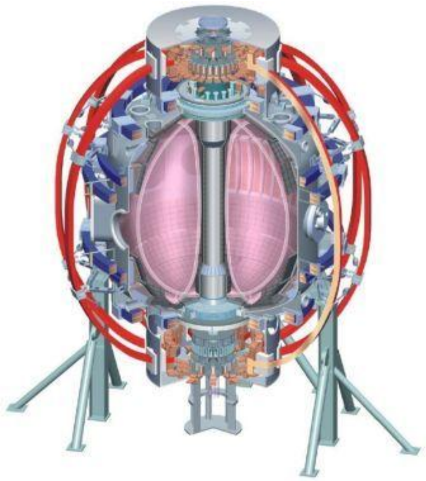
Office of Science

Analysis and Qualification Documentation

The NSTX Upgrade Team

Presented By Peter H. Titus

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



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ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Overview

- This presentation is an overview of the analyses and documentation that provides the basis of the final design for the NSTX Upgrade:
  - Since the PDR, over 10,000 person-hours of analyses were performed.
  - A total of 47 state-of-the art analyses (electromagnetic, thermal, and stress) have been documented -most have been checked. (Available at: http:/nstxupgrade.pppl.gov/Engineering/Calculations/index_Calcs.htm)
  - The Centerstack is the heart of the upgrade.
    - This has been carefully analyzed and redundant calculations were made for key components.
    - In addition to component analyses, systems analyses were performed on center stack, upgraded VV design, upgraded PF support design, and upgraded TF support design.
  - A Digital Coil Protection System, similar to the one used on TFTR, is also planned to assure that programmed conditions do not exceed operational limits.
      - Algorithm development is an integral part of the analysis effort.
  - **The analyses show that the NSTX-U design can handle all 96 planned operational scenarios.**
- **A sound design, supported by this robust analysis effort and R&D, has been developed and we are ready to proceed with construction.**

Our work is governed by:

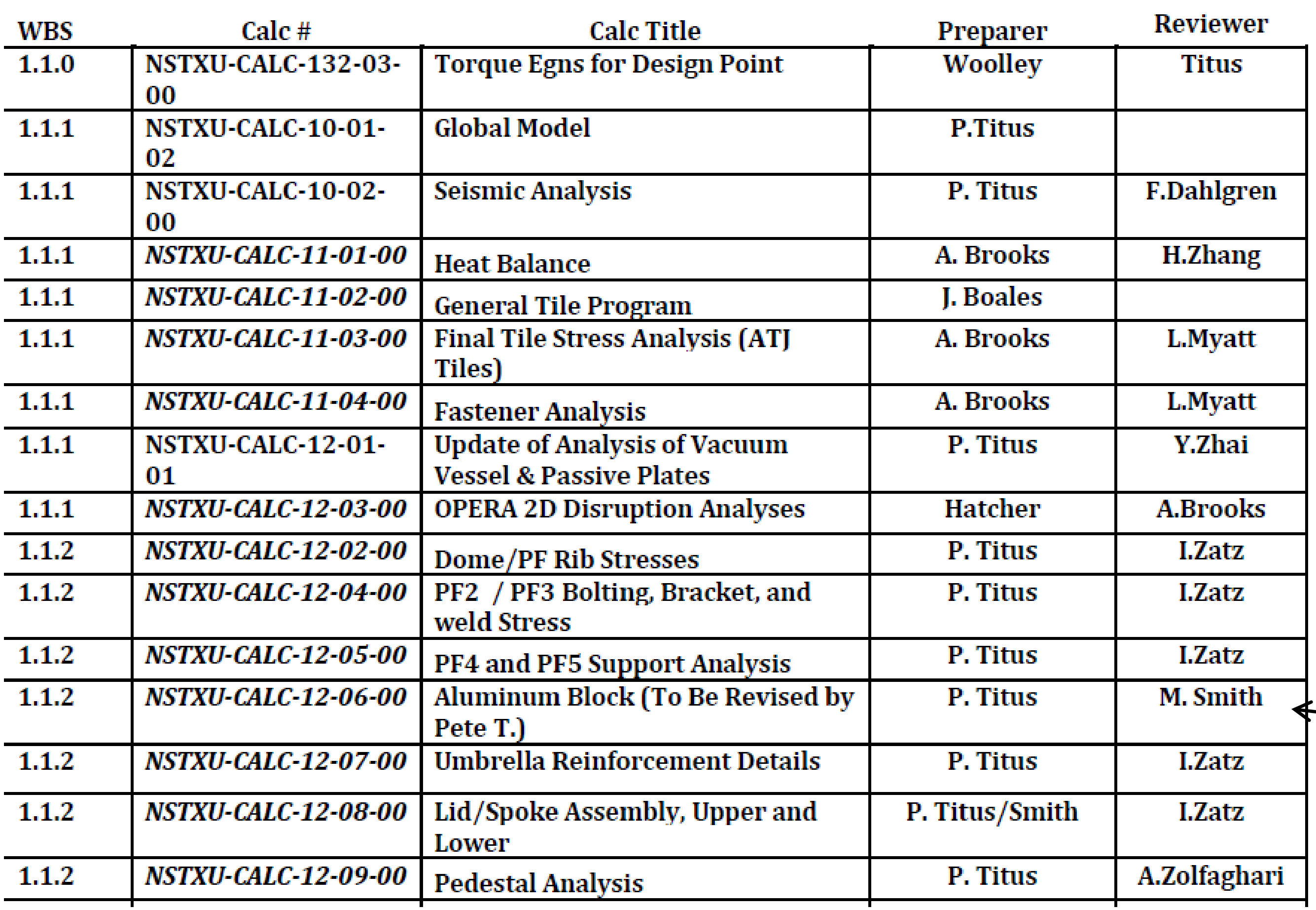
- *The GRD*
- *NSTX Criteria Document*
- *ENG33*
- *http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html*

When a Document is Reviewed and Signed in Accordance with ENG 33 it:

Satisfies the GRD
Satisfies the NSTX Criteria Document
Has Used or Considered the Latest Design Point Data

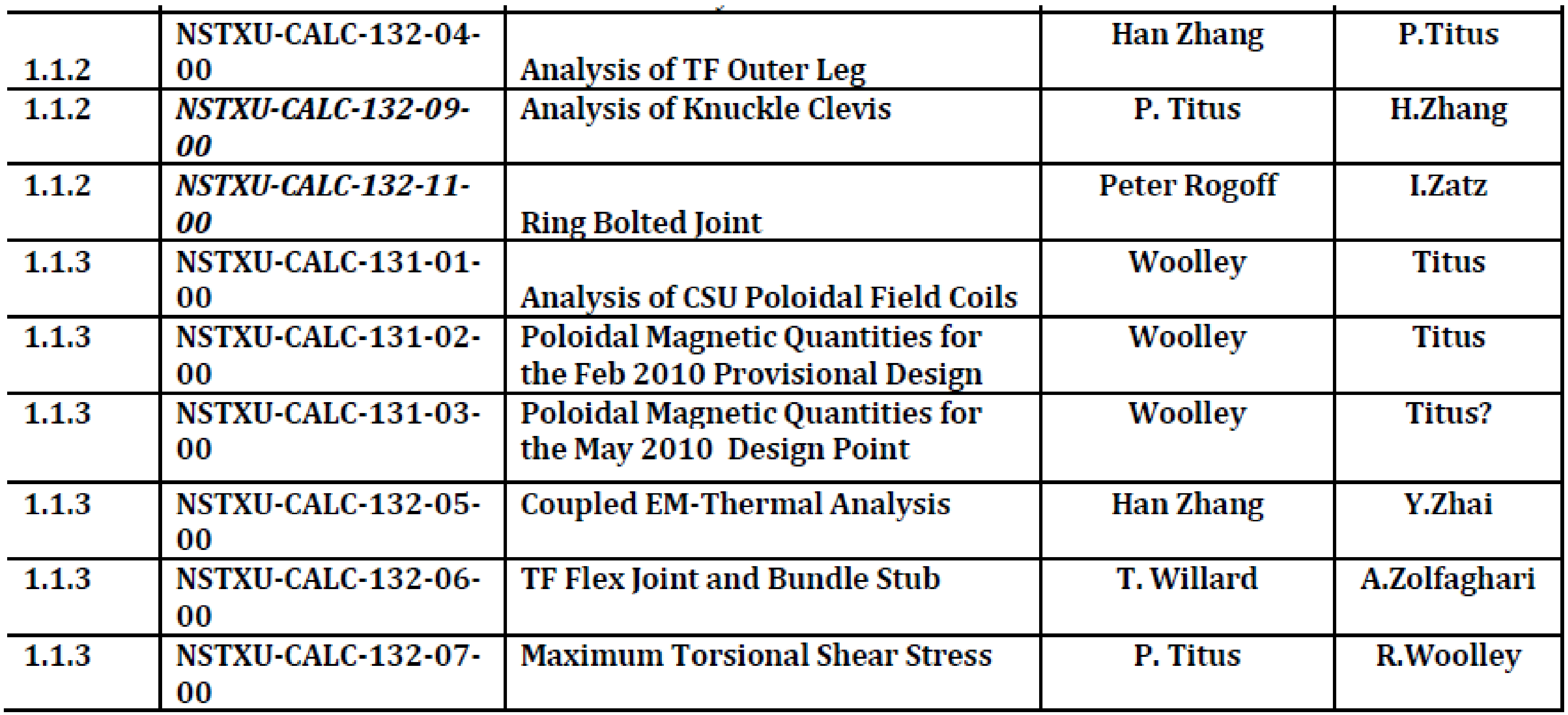
Provides Design, Fabrication, Assembly Guidance, Material Selection in Accordance with Good Engineering Practice

NSTX CSU Calculation Index



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

Based on Soft Truss Springs – Loads go Down



1.1.2	NSTXU-CALC-132-04-00	Analysis of TF Outer Leg	Han Zhang	P.Titus	✓
1.1.2	*NSTXU-CALC-132-09-00*	Analysis of Knuckle Clevis	P. Titus	H.Zhang	
1.1.2	*NSTXU-CALC-132-11-00*	Ring Bolted Joint	Peter Rogoff	I.Zatz	✓
1.1.3	NSTXU-CALC-131-01-00	Analysis of CSU Poloidal Field Coils	Woolley	Titus	
1.1.3	NSTXU-CALC-131-02-00	Poloidal Magnetic Quantities for the Feb 2010 Provisional Design	Woolley	Titus	
1.1.3	NSTXU-CALC-131-03-00	Poloidal Magnetic Quantities for the May 2010 Design Point	Woolley	Titus?	
1.1.3	NSTXU-CALC-132-05-00	Coupled EM-Thermal Analysis	Han Zhang	Y.Zhai	✓
1.1.3	NSTXU-CALC-132-06-00	TF Flex Joint and Bundle Stub	T. Willard	A.Zolfaghari	
1.1.3	NSTXU-CALC-132-07-00	Maximum Torsional Shear Stress	P. Titus	R.Woolley	✓

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	T.Willard	✓
1.1.3	*NSTXU-CALC-132-10-00*	TF Cool-down using FCOOL	A. Zolfaghari	*M.Kalish*	✓
1.1.3	NSTXU-CALC-133-01-01	Structural Analysis of the PF1 Coils, leads and Supports, Rev 1	L. Myatt	A Brooks	
1.1.3	NSTXU-CALC-133-02-00	Thermal Stresses on OH-TF Coils	S. Avasarala		
1.1.3	NSTXU-CALC-133-03-00	Center Stack Casing Disruption Inductive and Halo Current Loads	P. Titus	Myatt,Brooks	
1.1.3	NSTXU-CALC-133-04-00	OH Preload System and Belleville Spring Design	Peter Rogoff	I.Zatz	✓
1.1.3	*NSTXU-CALC-133-05-00*	CS Casing Halo Ind and Res Cur	A. Brooks	P Titus	
1.1.3	*NSTXU-CALC-133-06-00*	OH Coolant Hole Optimization	A. Zolfaghari	*M.Kalish*	
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	I.Zatz	✓
1.1.3	*NSTXU-CALC-133-10-00*	Center Stack Casing Bellows	Peter Rogoff	I.Zatz	✓
1.1.3	*NSTXU-CALC-133-11-00*	OH & PF1 Electromagnectic Stability Analysis	P. Titus/Zolfaghari	H.M.Fan	

1.1.4	*NSTXU-CALC-133-12-00*	Centerstack Manufacturing Fixtures	TBD	TBD	
1.2.3	*NSTXU-CALC-40-01-00*	Diagnostics Review and Database	J. Boales	Y.Zhai	
1.2.4	*NSTXU-CALC-24-01-00*	Vessel Port Re-Work for NB and Thomson Scattering Port	T. Willard	A.Zolfaghari	✓
1.2.4	*NSTXU-CALC-24-02-00*	Armor Plate Backing Plate	L. Bryant	I. Zatz	✓
1.2.4	*NSTXU-CALC-24-03-00*	HHFW Antenna (needs to be modified for upgrade loads)	Han Zhang/Ellis	R. Hatcher	✓
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	P. Titus	✓
1.5.2	*NSTXU-CALC-13-05-00*	DCPS Moment Influence Coefficients	Woolley/Titus	Titus/Wooley	✓
1.5.5	*NSTXU-CALC-55-01-00*	Bus Bar Analysis	A. Khodak	H Zhang	

http://nstx-upgrade.pppl.gov/Engineering/Calculations/index_Calcs.htm >)

Available Documentation:

47 Calculations Total

NSTXU Calculation Web page

http:/nstx-upgrade.pppl.gov/Engineering/Calculations/index_Calcs.htm

NSTX

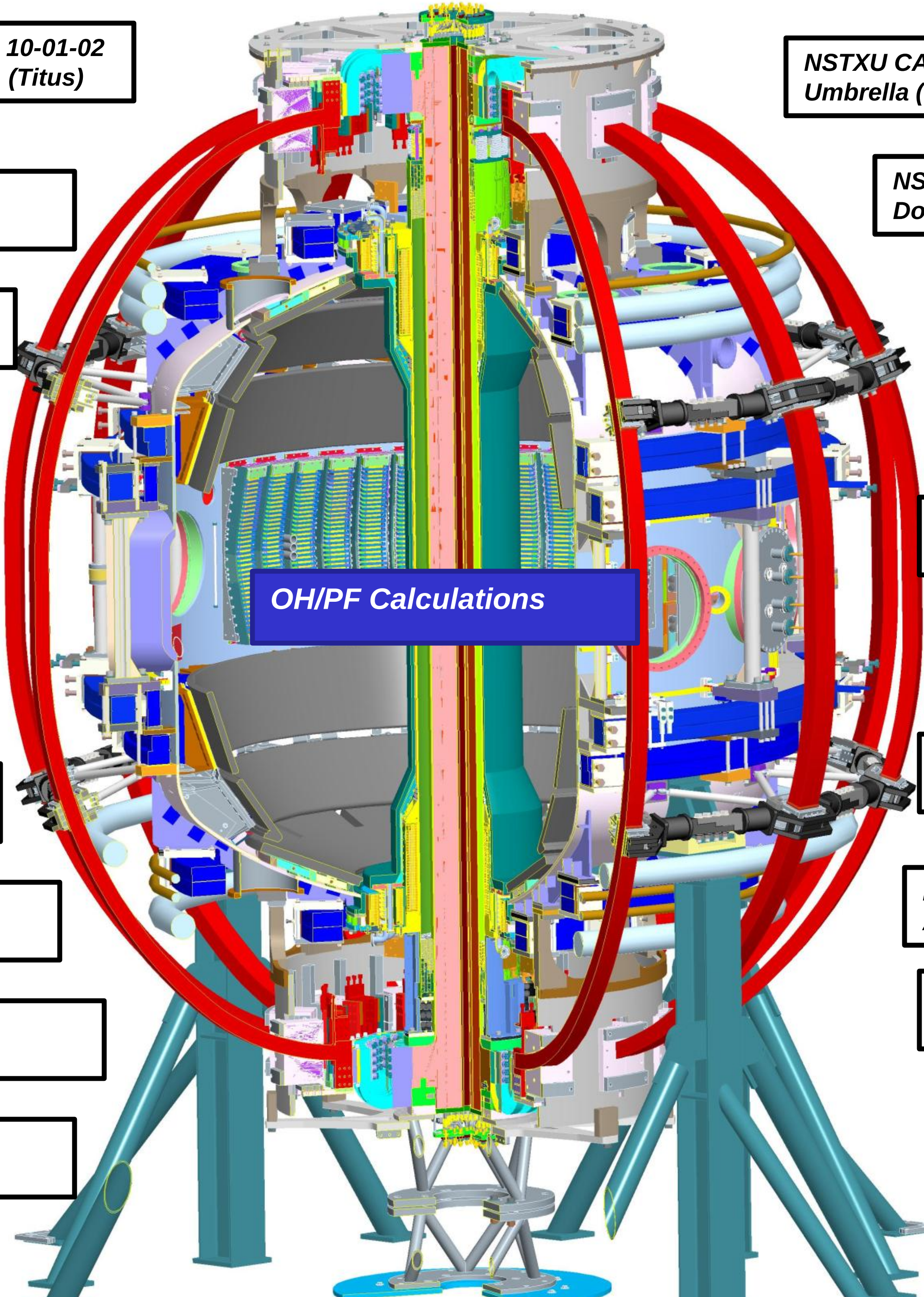
NSTX Upgrade

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

Machine Protection System Algorithms

Every Calculation Must Address the DCPS

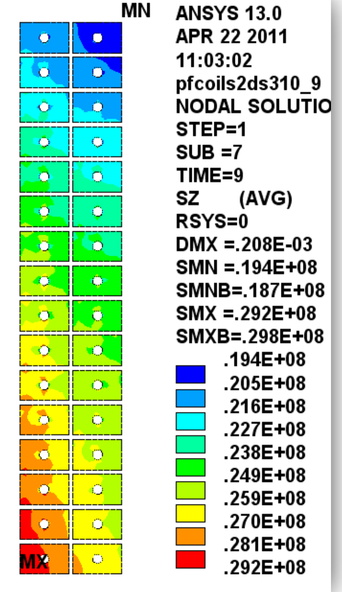
PF1,2,3 supports, welds bolts – At this stage, These are just calculated from influence coefficient matrix loads divided by weld or bolt area. Proposing to add Moment Influence Coefficients

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

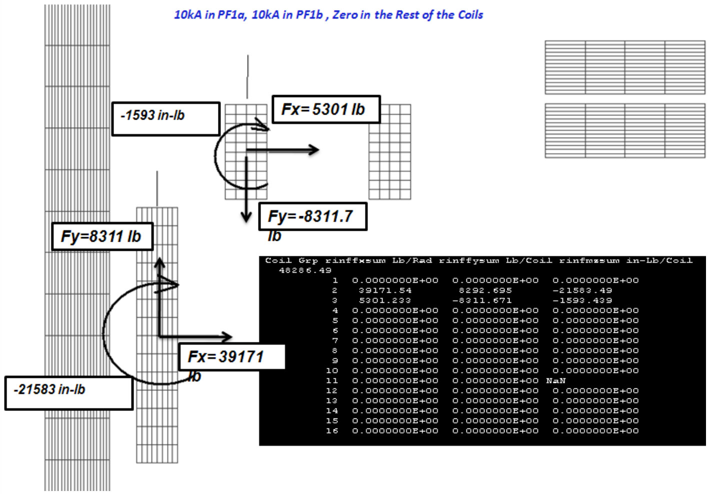
OH Preload-Launch-TF temperature dependence
PF1a-OH interaction Stress
Vertical Loads on pedestal load path (TF Flag Bolts, Pedestal Hilti's), (Ali)

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



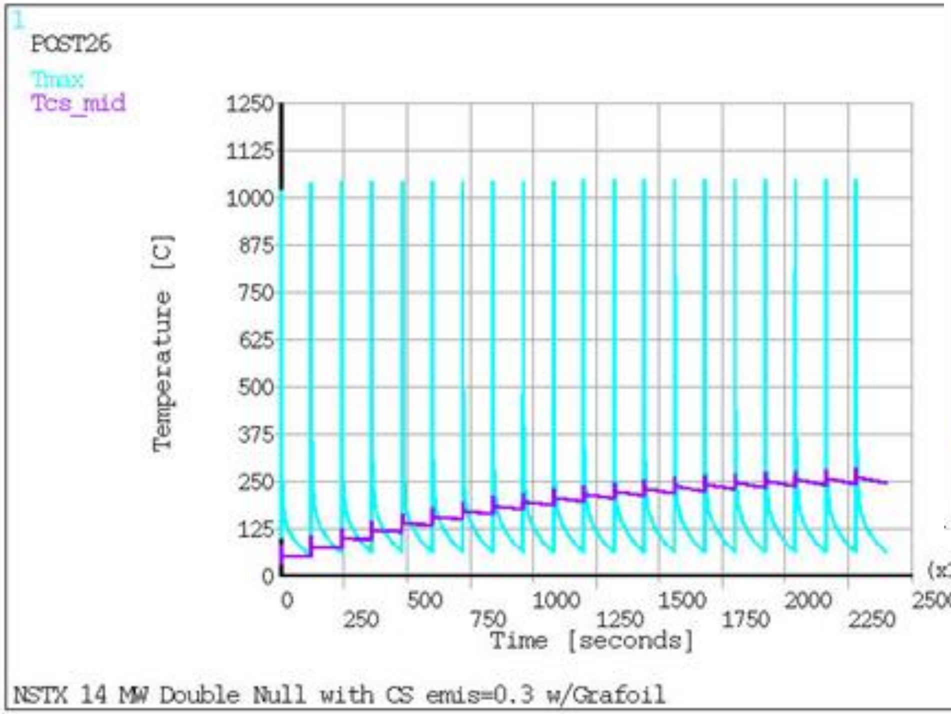
```
Coil Grp rinffxsum Lb/Rad rinffysum Lb/Coil rinfmzsum in-Lb/Coil
  48286.49
           1  0.0000000E+00  0.0000000E+00  0.0000000E+00
           2   39171.54       8292.695      -21583.49
           3   5301.233      -8311.671      -1593.439
           4  0.0000000E+00  0.0000000E+00  0.0000000E+00
           5  0.0000000E+00  0.0000000E+00  0.0000000E+00
           6  0.0000000E+00  0.0000000E+00  0.0000000E+00
           7  0.0000000E+00  0.0000000E+00  0.0000000E+00
           8  0.0000000E+00  0.0000000E+00  0.0000000E+00
           9  0.0000000E+00  0.0000000E+00  0.0000000E+00
          10  0.0000000E+00  0.0000000E+00  0.0000000E+00
          11  0.0000000E+00  0.0000000E+00 NaN
          12  0.0000000E+00  0.0000000E+00  0.0000000E+00
          13  0.0000000E+00  0.0000000E+00  0.0000000E+00
          14  0.0000000E+00  0.0000000E+00  0.0000000E+00
          15  0.0000000E+00  0.0000000E+00  0.0000000E+00
          16  0.0000000E+00  0.0000000E+00  0.0000000E+00
```

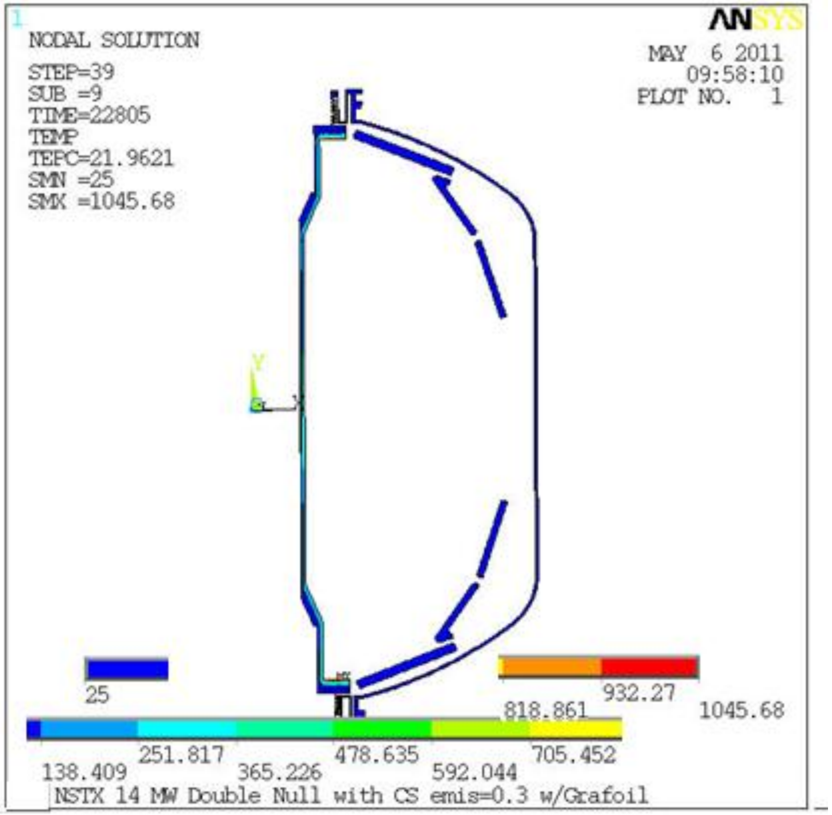
Bolt Loads are calculated from the vertical force and the moment divided by the width of the bolt pattern

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

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

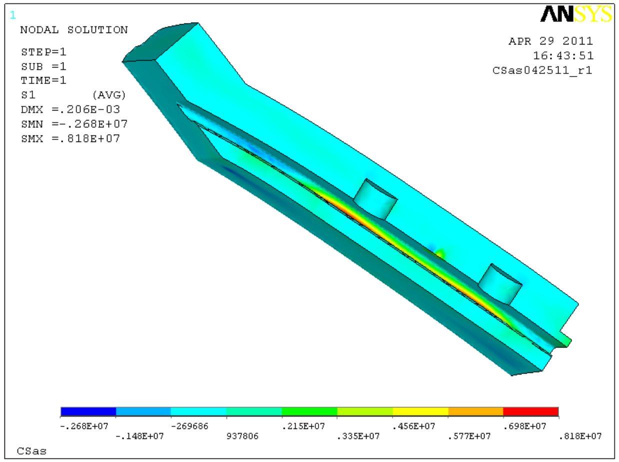




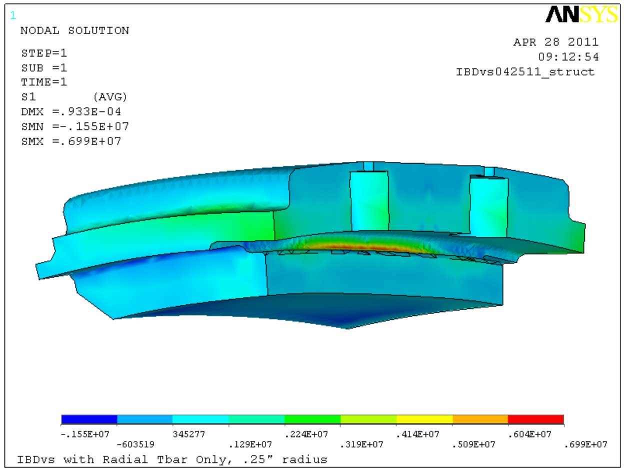
Active Cooling and Thermal Protection is Provided for

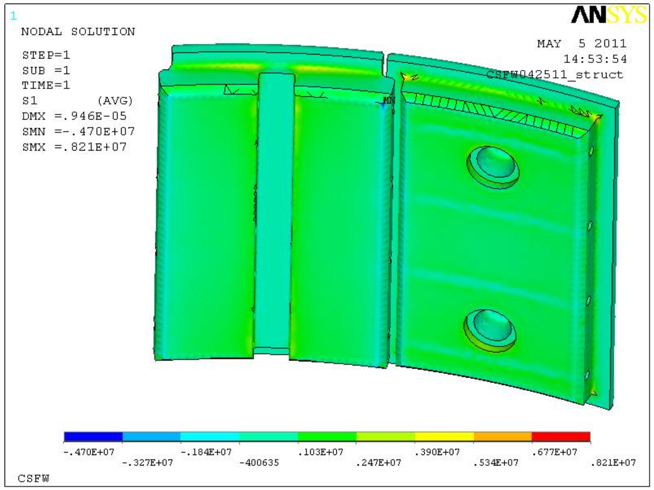
- ***The 8 Viton O-Rings (2 at each Ceramic Break, U&L)***
- ***PF1b Centerstack Casing Flange***

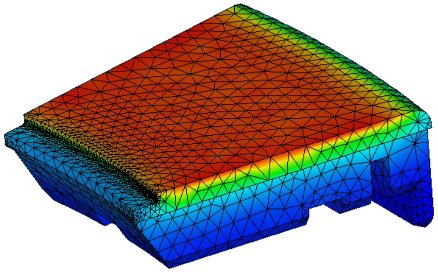
Longer Pulse, More Neutral Beam Power, More Plasma Current, Increases Heat Loads on Tiles, Increased Disruption and Halo Specs Increase Mechanical Loads on Tiles



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

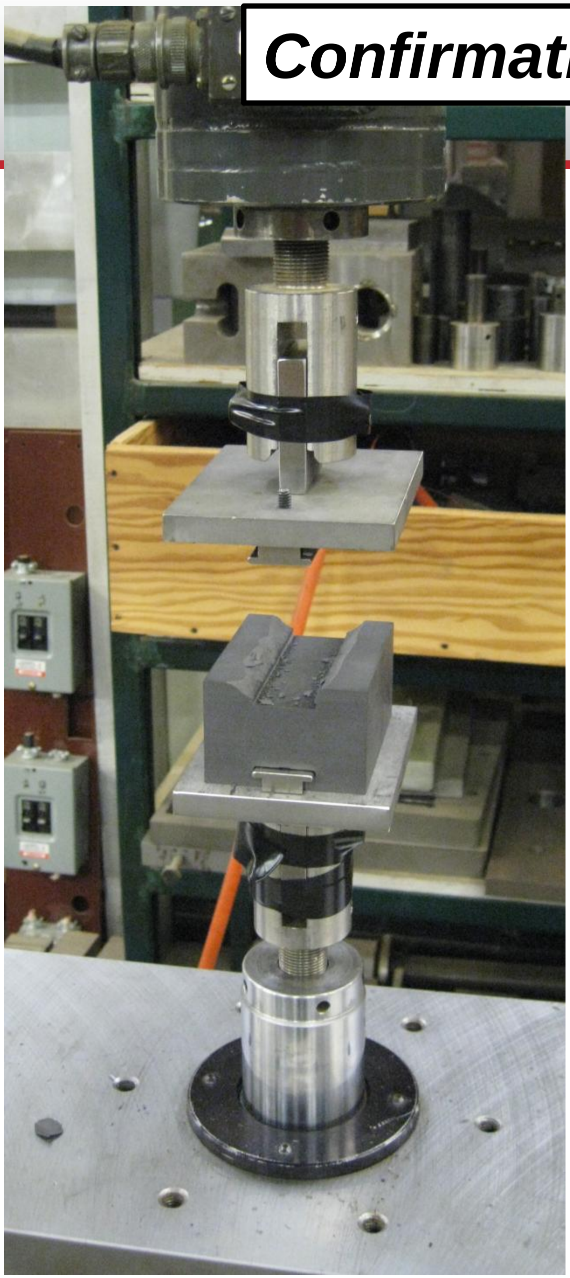


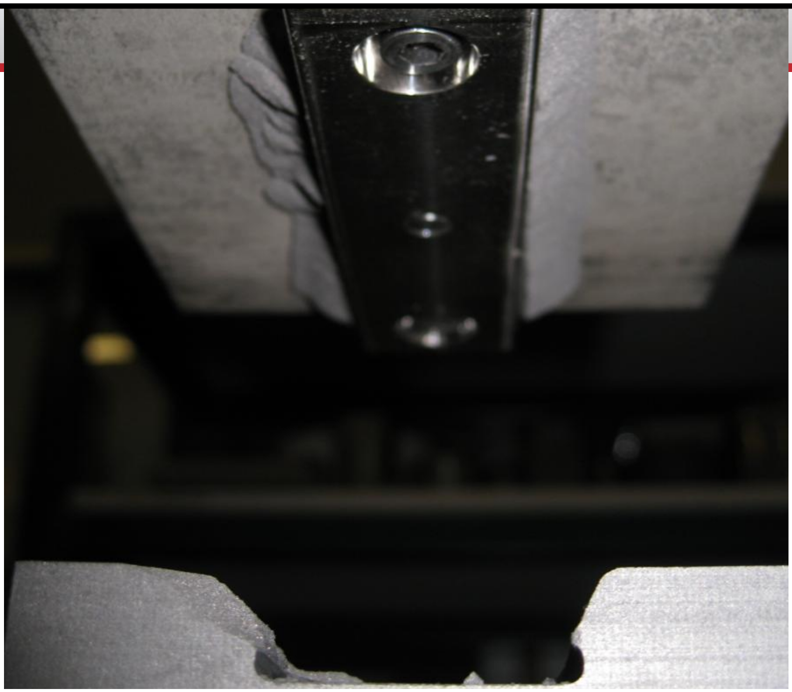


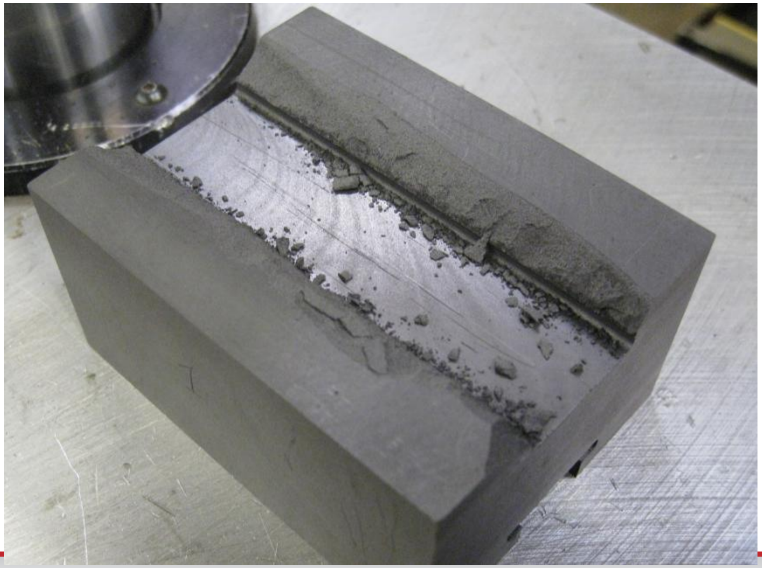


WBS 1.1.1 Basic Tile Analysis Qualification December 2010 NSTX-CALC-11-02-00 Prepared By: Joe Boales, Reviewed By: Art Brooks
Cognizant Engineer: Kelsey Tresemer

Confirmation of ATJ Tensile Stress Allowable

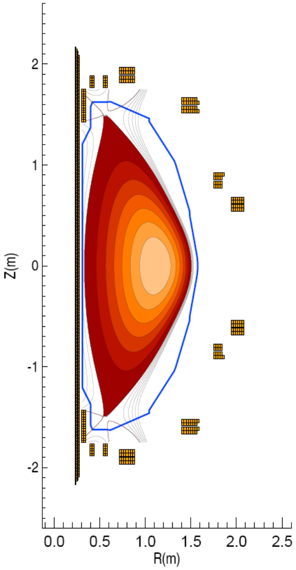






Sources of Lorentz Loading – The Design Point Spreadsheet

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



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

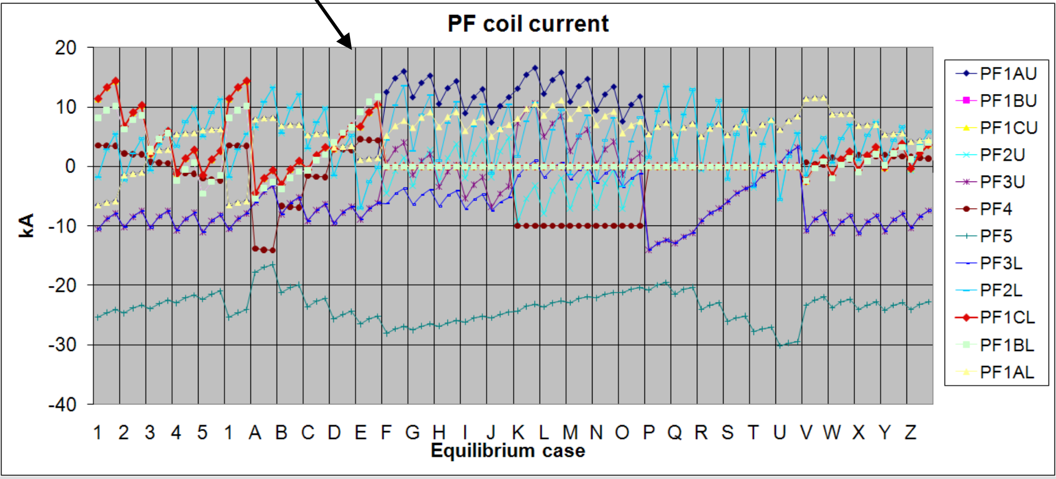
With Inductively Driven Currents from the Disruption

Max and Min Loads for the Scenarios are Tabulated

Worst Case Power Supply Loads are Tabulated

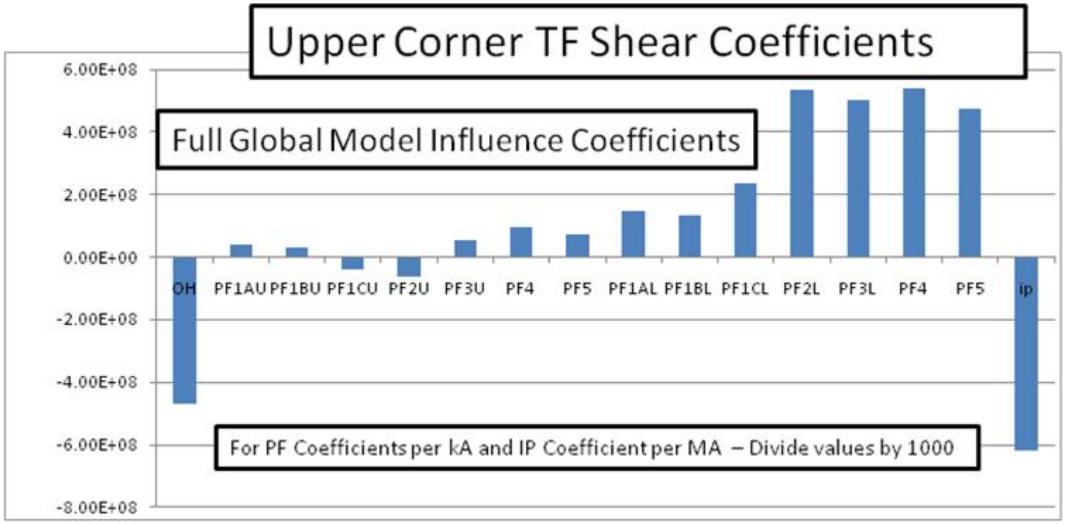
Very few areas are being qualified using maximum power supply loads from the design point. They were “Onerous”

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



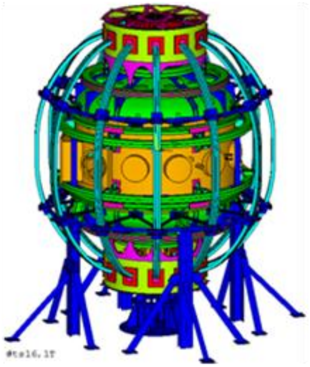
What do We Do If We Compute the Loads In the Analysis Models?

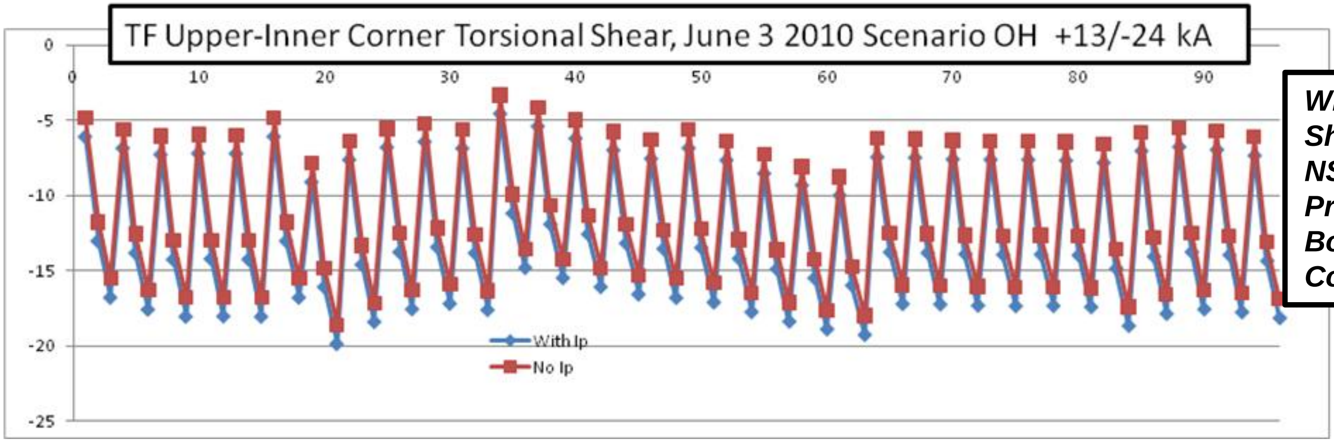
One Way is to Compute the Influence Coefficients as you Would For the DCPS and Calculate the Stress in a Spreadsheet. The Plasma can be Turned On and Off in the Spreadsheet – Remember to add 10% Headroom


Upper Corner TF Shear Coefficients

Full Global Model Influence Coefficients

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



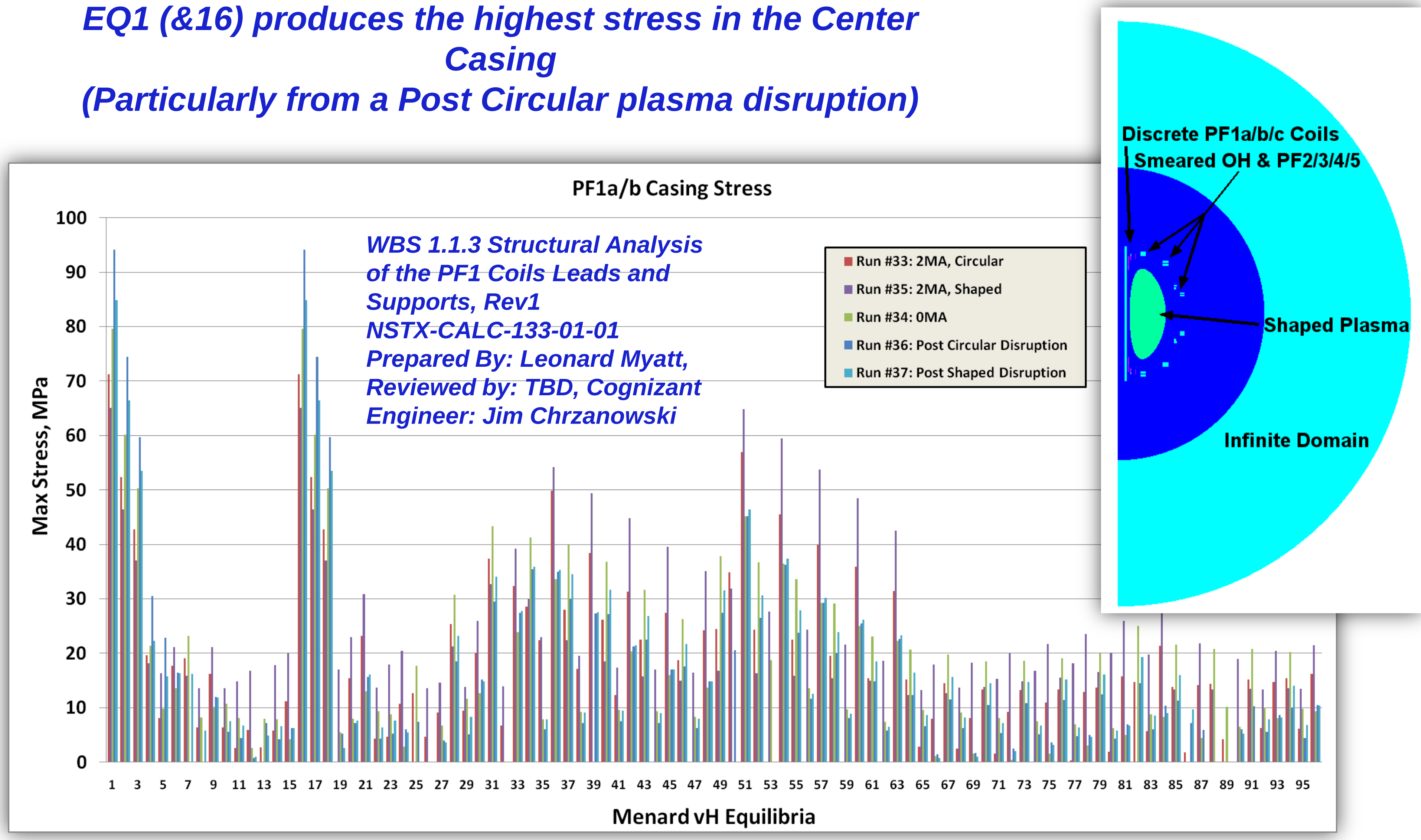

TF Upper-Inner Corner Torsional Shear, June 3 2010 Scenario OH +13/-24 kA

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

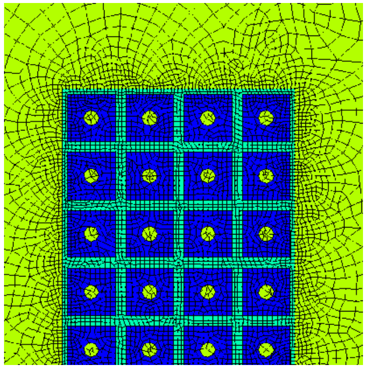
EQ1 (&16) produces the highest stress in the Center Casing

(Particularly from a Post Circular plasma disruption)

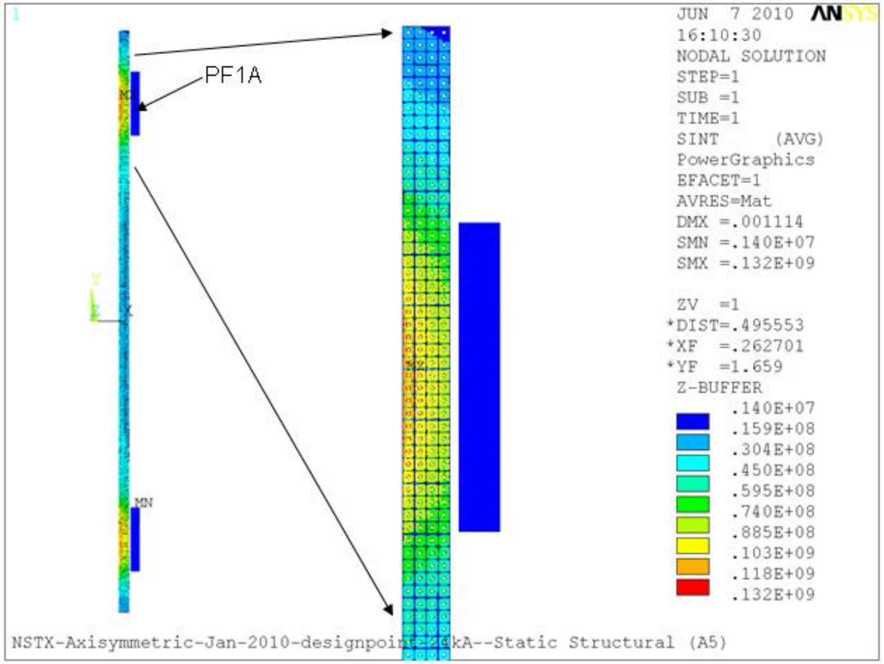


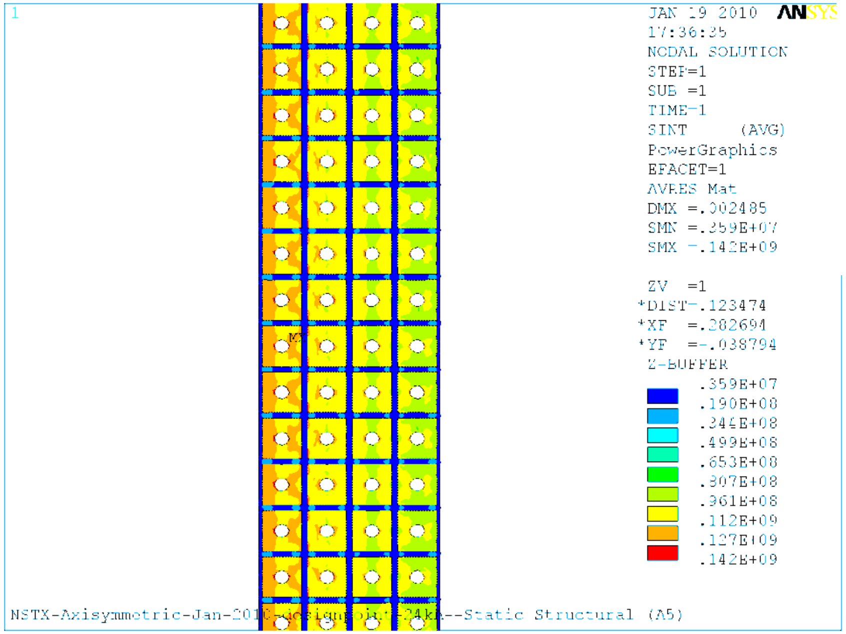
WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1
NSTX-CALC-133-01-01
Prepared By: Leonard Myatt, Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski

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



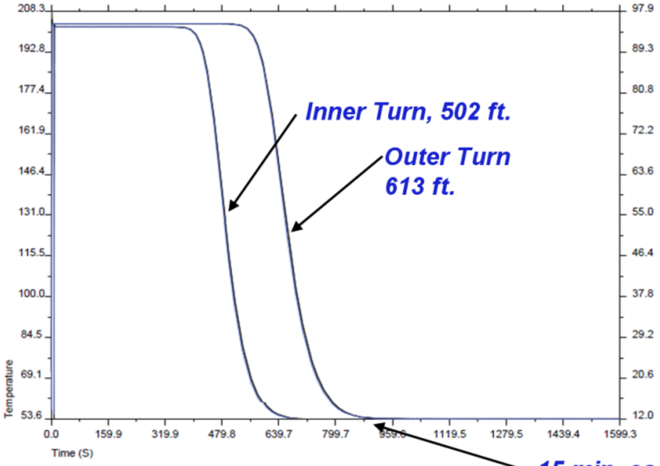


Stress Intensity in the OH Coil Due to Self Currents and Interaction with Current in Adjacent PF1A Poloidal Field Coil

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

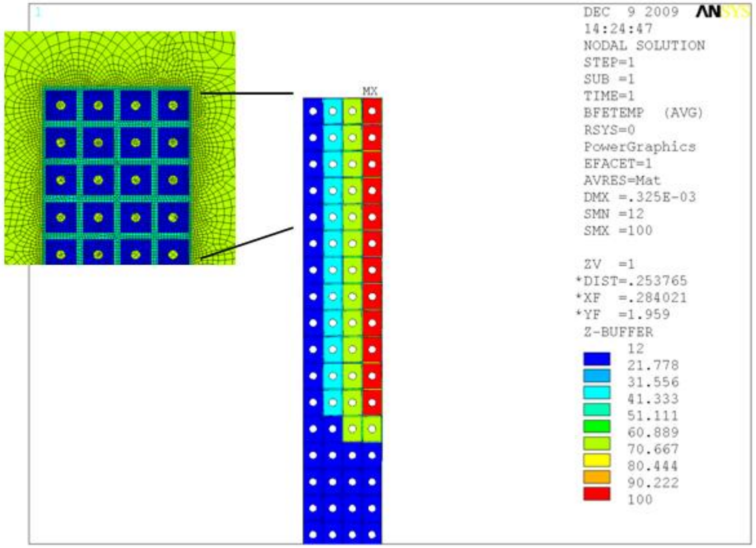


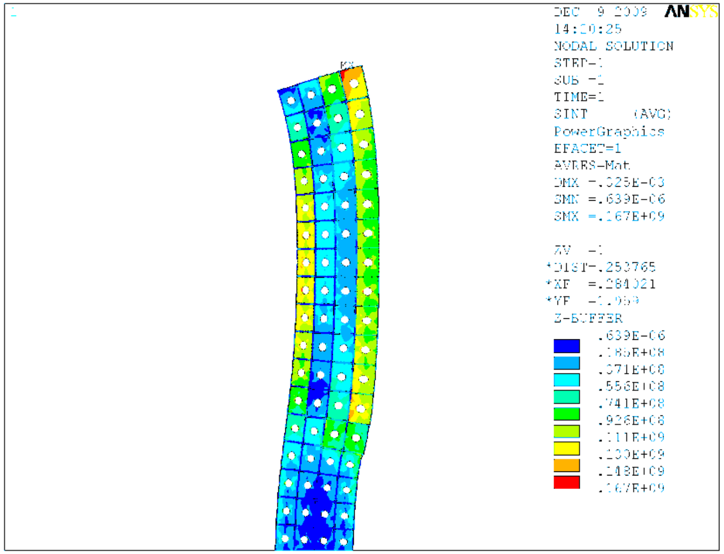
Inner Turn, 502 ft.

Outer Turn 613 ft.

15 min. cooling time

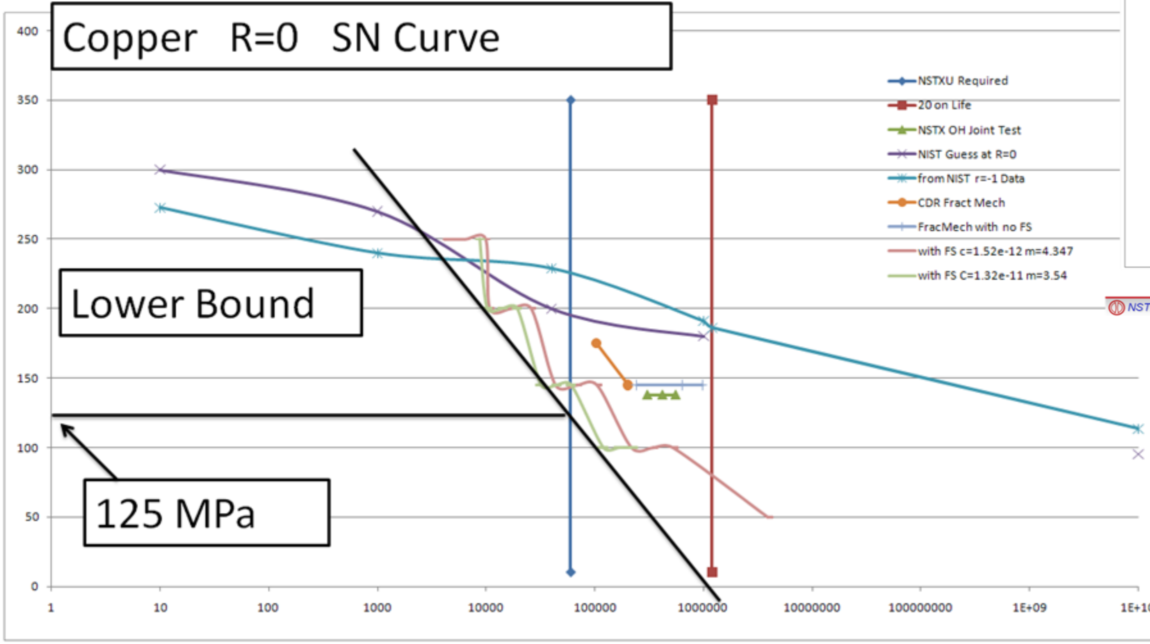
Coolant "Wave" Arrives at the End of the Coil in Different Times Depending on Path Length in the Layer

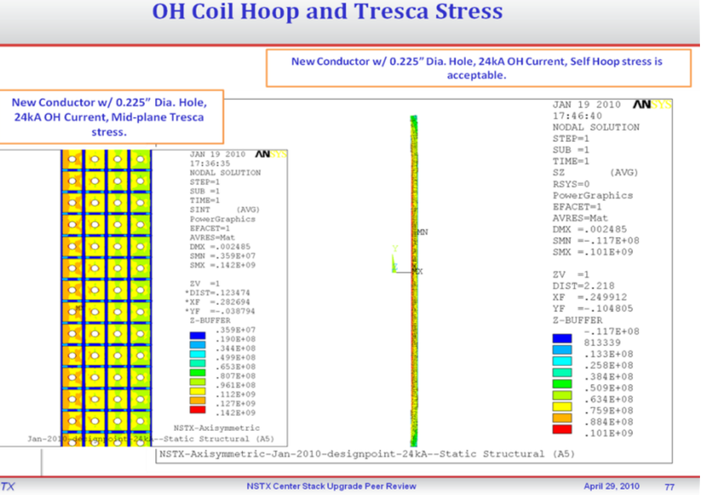




OH Coolant Hole Optimization, NSTXU-CALC-133-06-00
Prepared by: Ali Zolfaghari, Cognizant Engineering: Jim Chrzanowski

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.

```
JAN 19 2010
17:36:35
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SINT      (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.002485
SMN =.359E+07
SMX =.142E+09

ZV  =1
*DIST=.123474
*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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17:46:40
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SUB =1
TIME=1
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RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.002485
SMN =-.117E+08
SMX =.101E+09

ZV  =1
DIST=2.218
XF  =.249912
YF  =-.104805
Z-BUFFER
-.117E+08
813339
.133E+08
.258E+08
.384E+08
.509E+08
.634E+08
.759E+08
.884E+08
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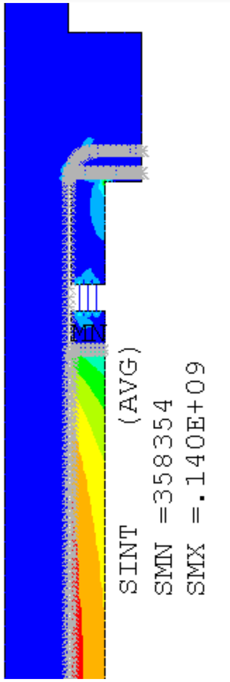
NSTX-Axisymmetric-Jan-2010-designpoint-24kA--Static Structural (A5)
```

NSTX NSTX Center Stack Upgrade Peer Review April 29, 2010 77



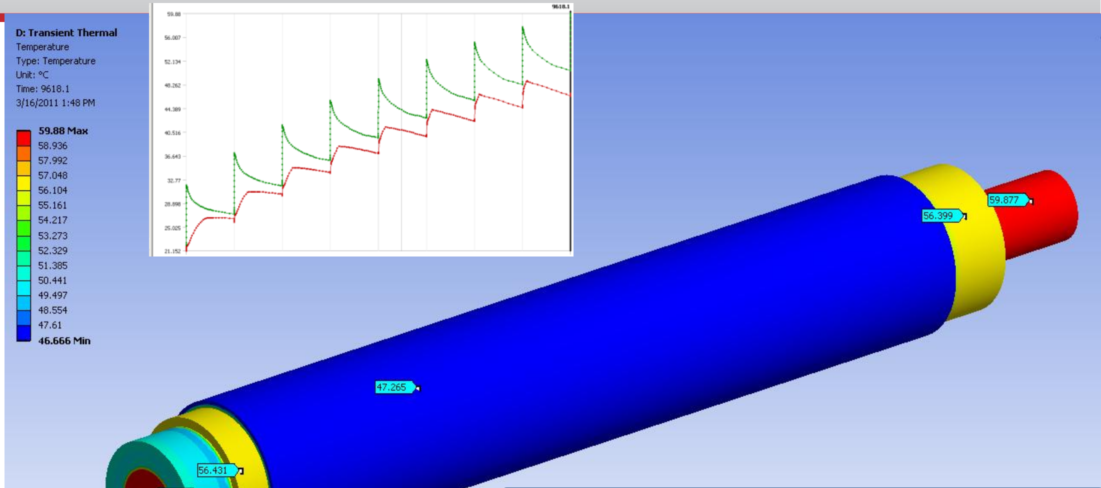
The OH Conductor Must have Manufacturing In-Process NDE to Meet Allowables Gary Voss has Provided Luvata Eddy Current Information – We are Evaluating whether Volumetric Inspection is Needed.

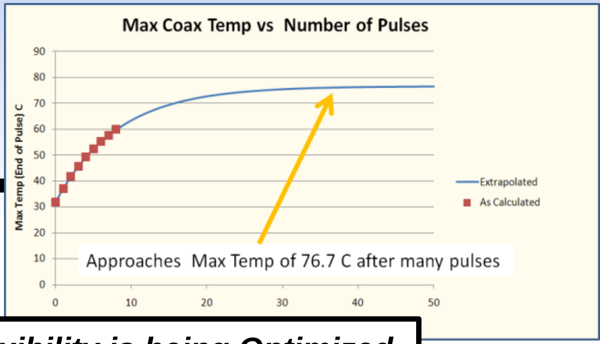
(No Braze Joint has been Qualified)

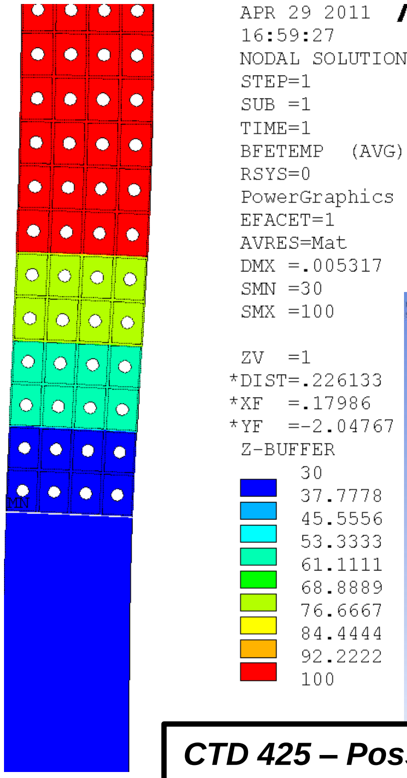
WBS 1.1.3 OH Conductor Fatigue Analysis Calculation Number NSTXU-CALC-133-09, Prepared By: Peter Titus, Reviewed by Irv Zatz Cognizant Engineer: Jim Chrzanowski ✓

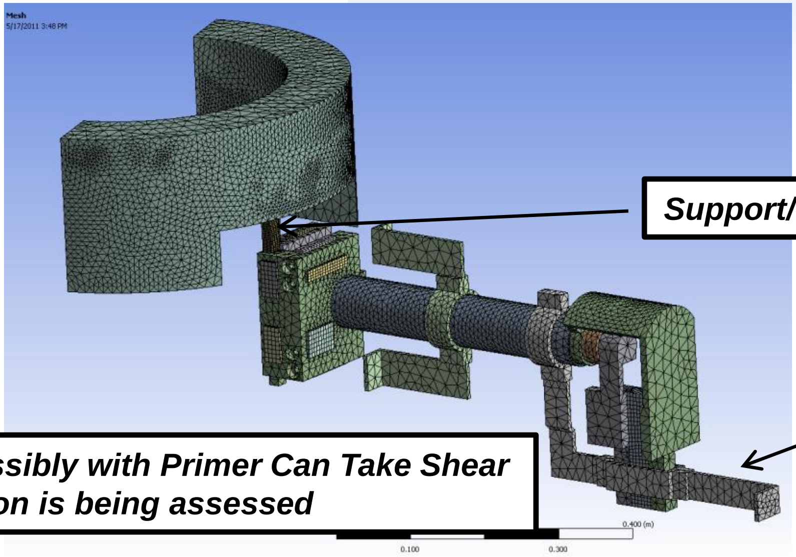
The OH Coax is at Bottom of the OH Coil. It is not Effected by the Vertical Expansion of the OH , But it is Effected by the Radial Expansion of the OH

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









Support/Flexibility is being Optimized

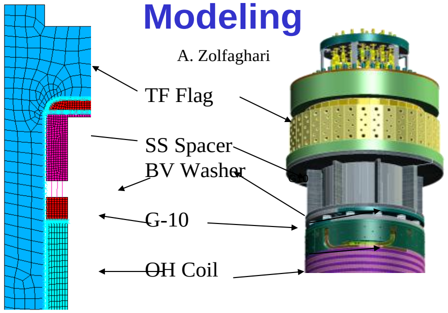
This needs to be Strengthened

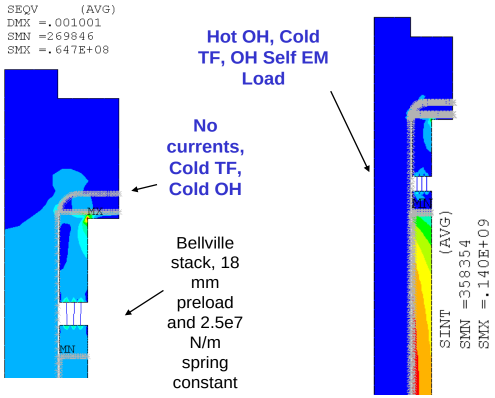
CTD 425 – Possibly with Primer Can Take Shear Effect of Kapton is being assessed

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

CS Structural/Emag Modeling

A. Zolfaghari





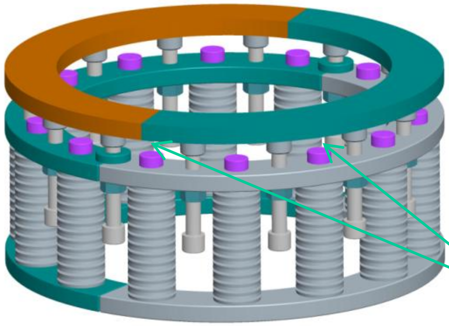
Hot OH, Cold TF, OH Self EM Load

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	

OH Coil Pre Load System



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

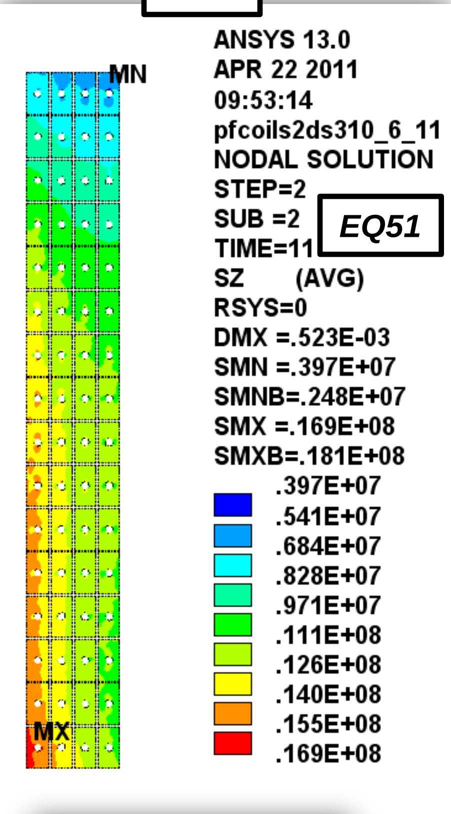
Required 14 stack to maintain a minimum of 20,000. lbs. total load on the OH coil

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 coi
decrease by a small percentage (say 3 to
while everything else will stay the same.

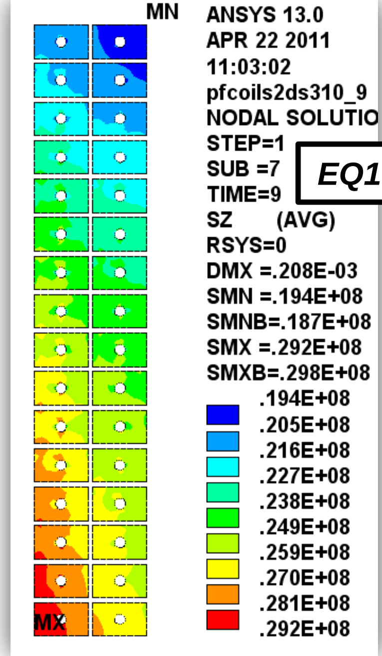
New Inner PF's Require Qualification

PF1a



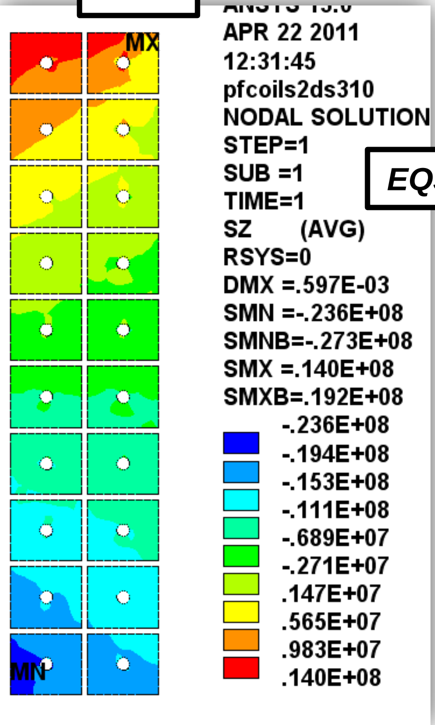
EQ51

PF1b

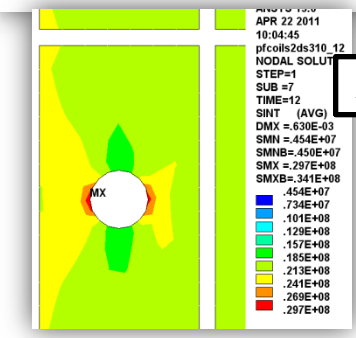


EQ18

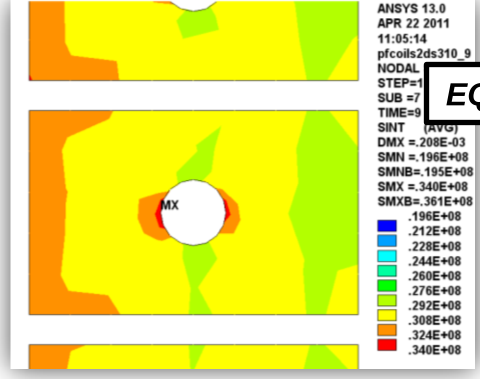
PF1c



EQ33

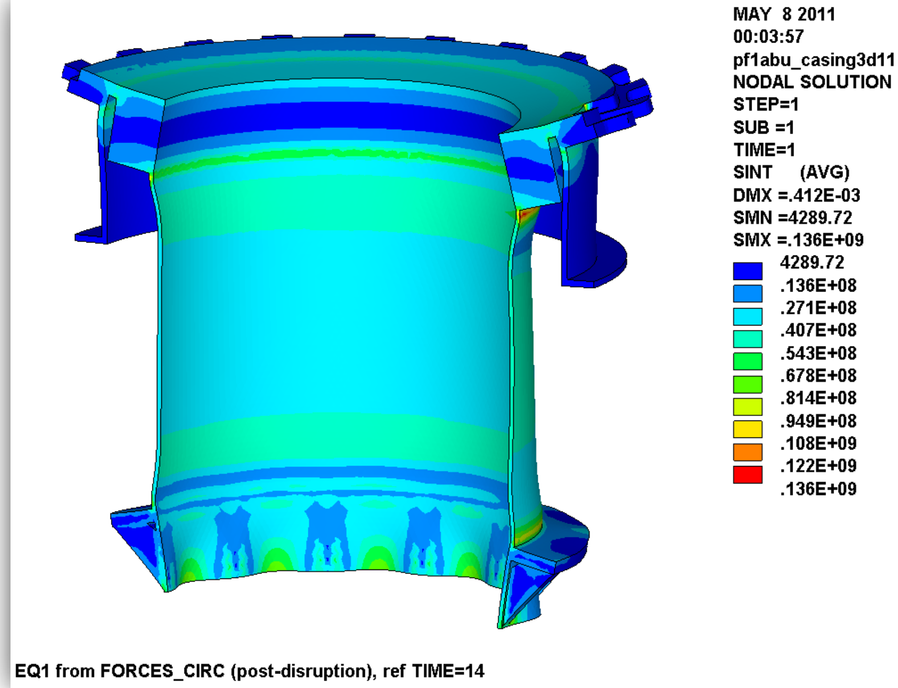


EQ54

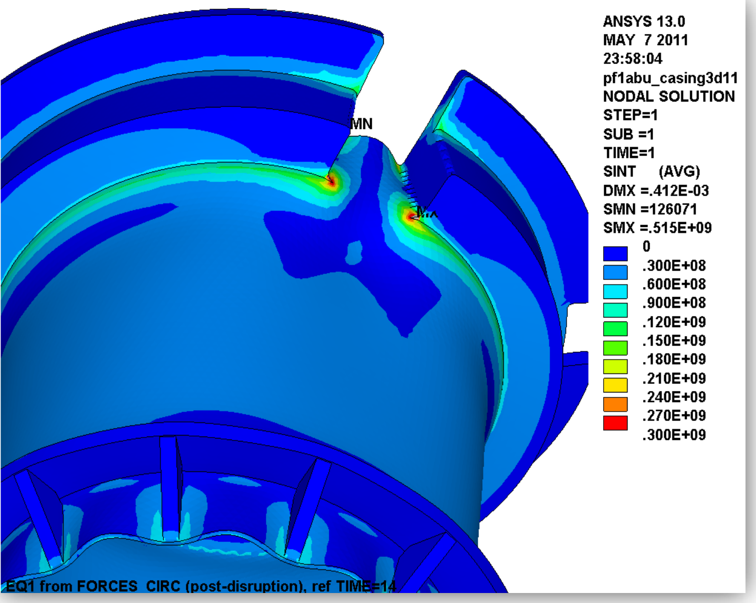


EQ18

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



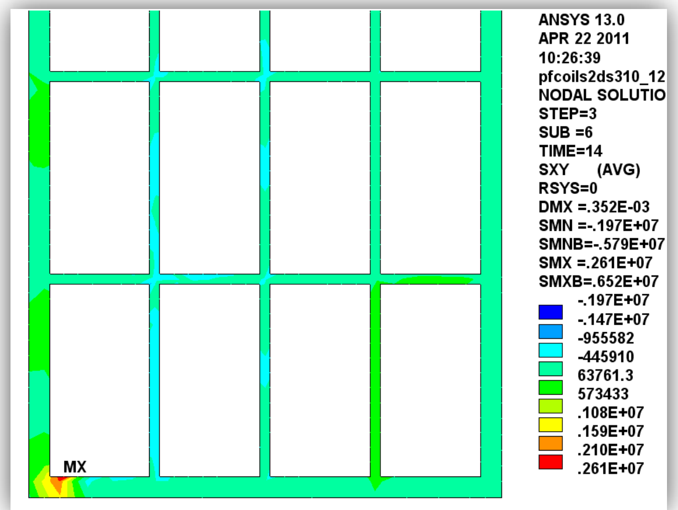
The winding shell flexure at the lead opening produces some significant local stresses:
Mem: 156 MPa (<300 MPa 👌)
M+B: 340 MPa (<450 MPa 👌)
Peak: 515 MPa (fatigue TBD)

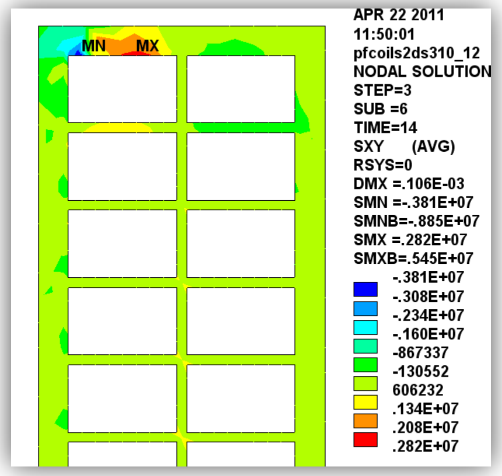
Shear Stresses are < 7 Mpa – Only CTD 101 K without Primer is Required – But to Have Fatigue Documentation, We are testing CTD 425 Without Primer .

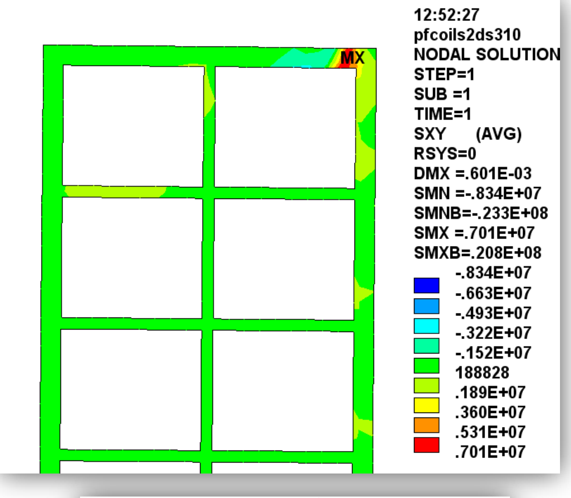
PF1a

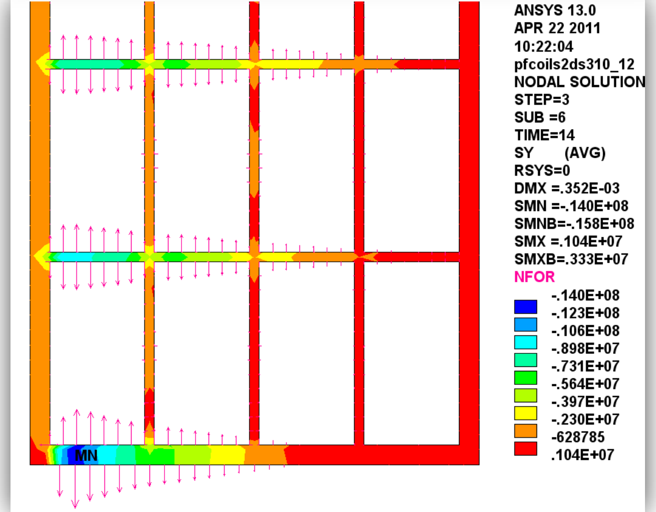
PF1b

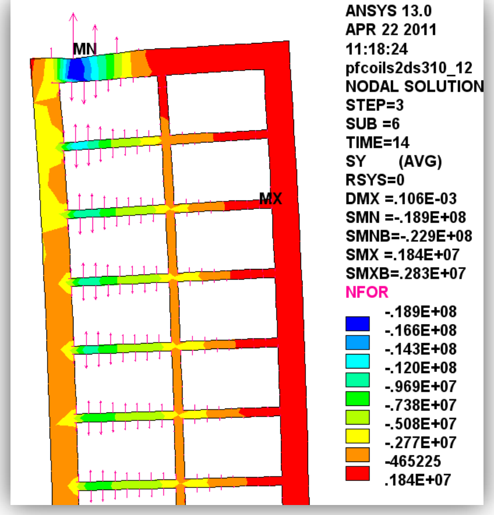
PF1c

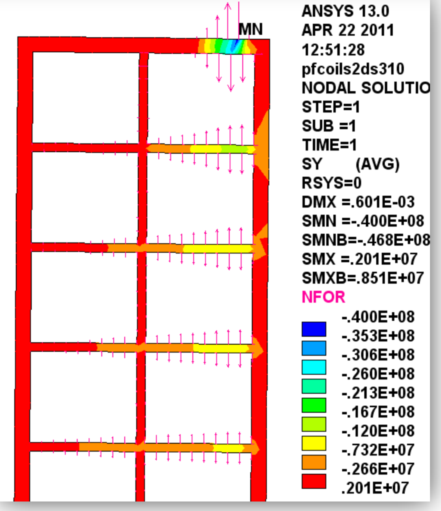




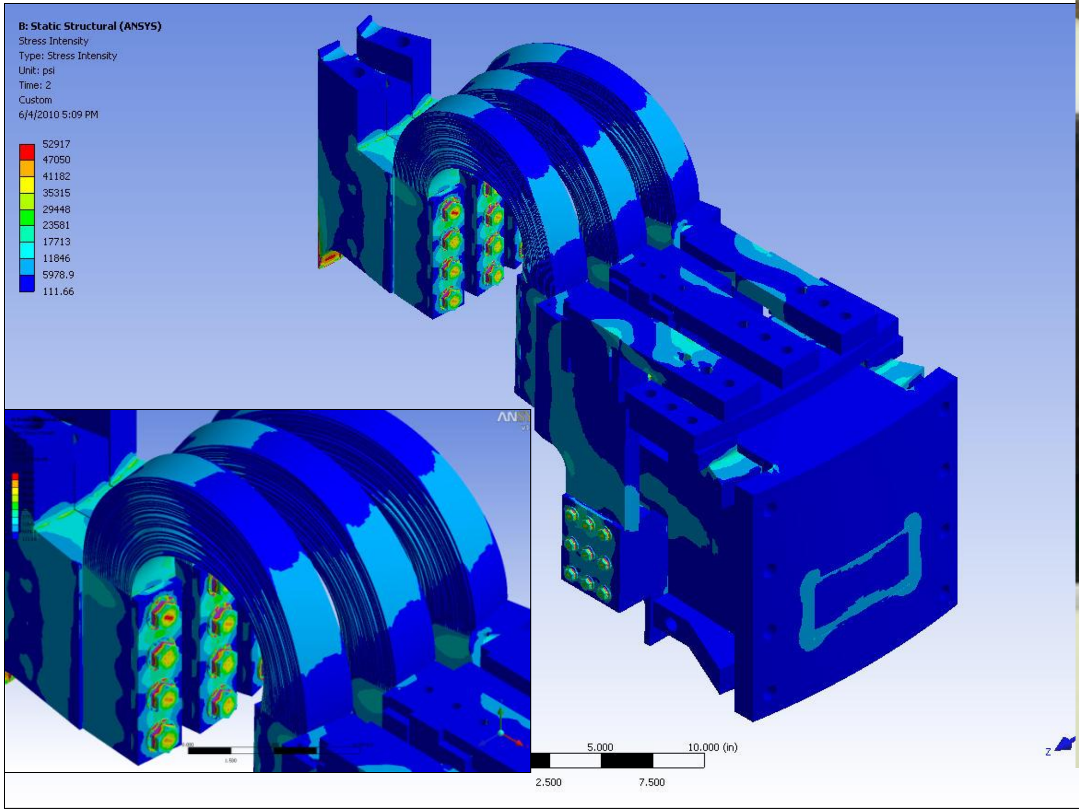


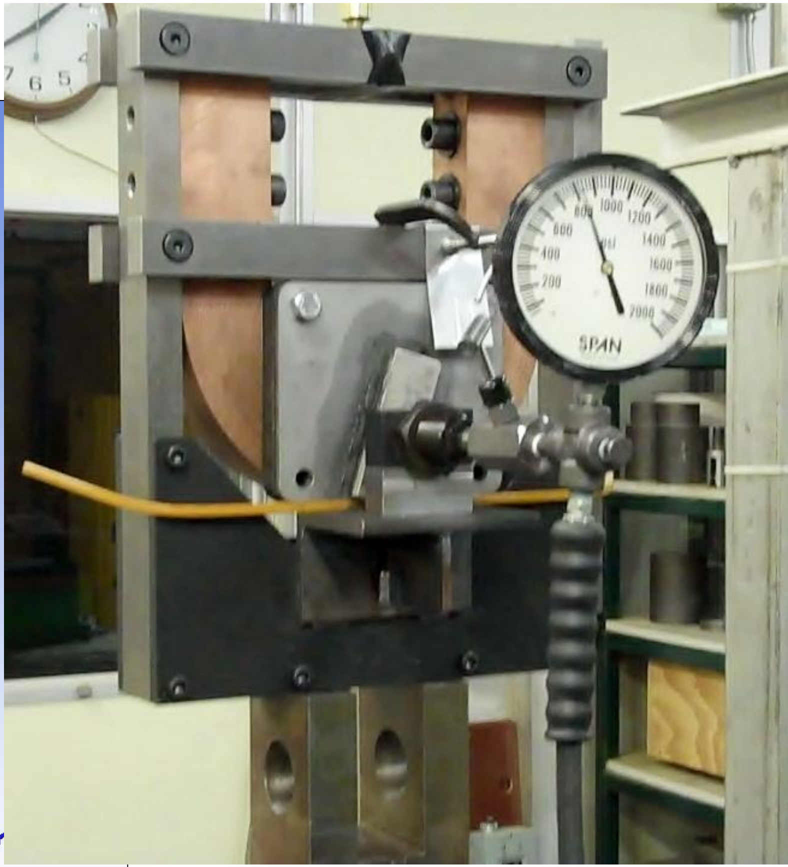






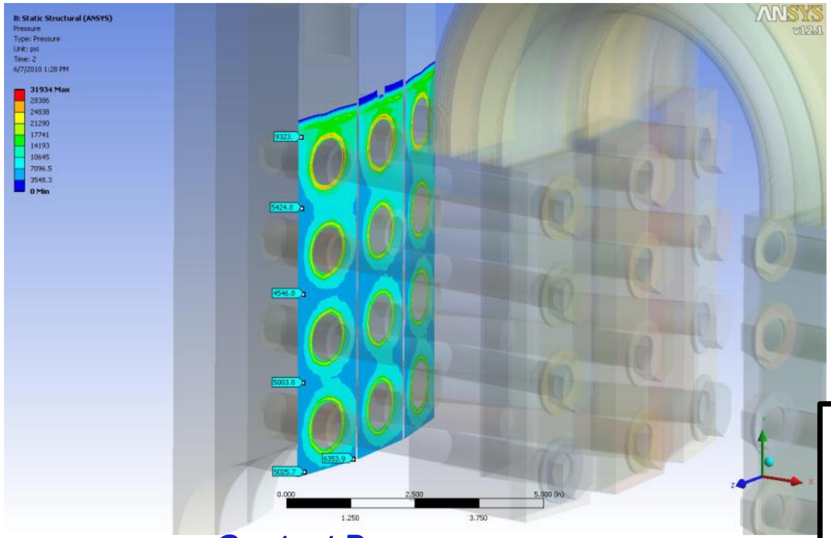
Past Difficulties with the TF Joint Demand a New Robust Joint Design





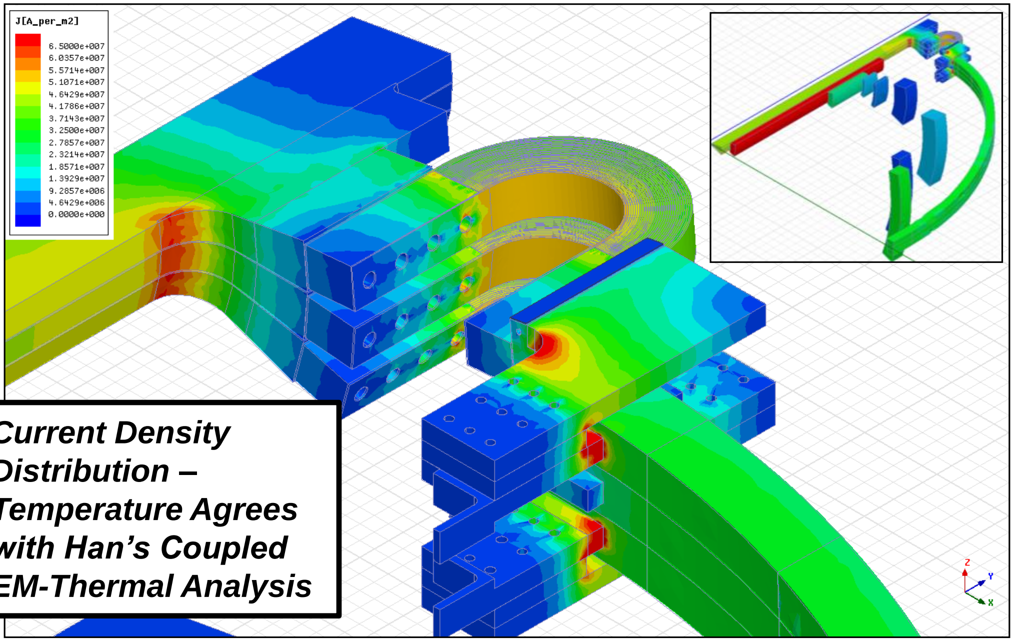
TF Flex Joint and TF Bundle Stub NSTXU-CALC-132-06-00
Prepared By: Tom Willard, Reviewed by: Ali Zolfaghari
Cognizant Engineer: Jim Chrzanowski

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

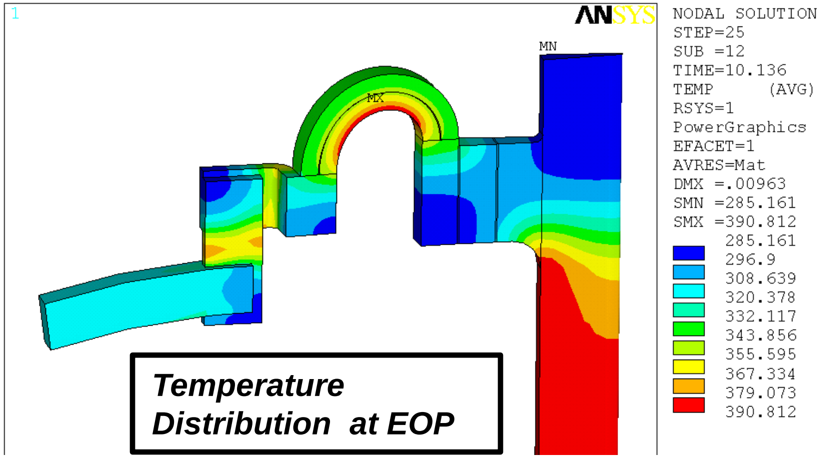


Contact Pressure

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



```
NODAL SOLUTION
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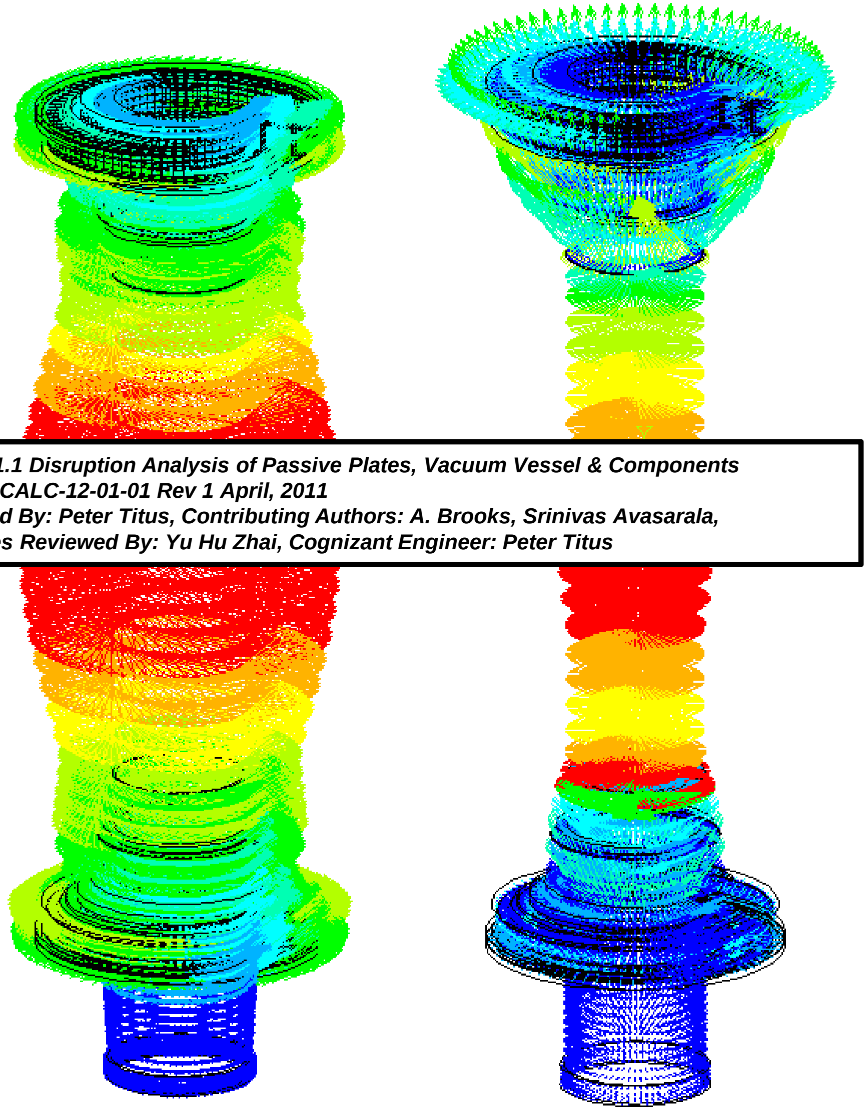
SUB =12
TIME=10.136
TEMP        (AVG)
RSYS=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.00963
SMN =285.161
SMX =390.812
       285.161
       296.9
       308.639
       320.378
       332.117
       343.856
       355.595
       367.334
       379.073
       390.812
```

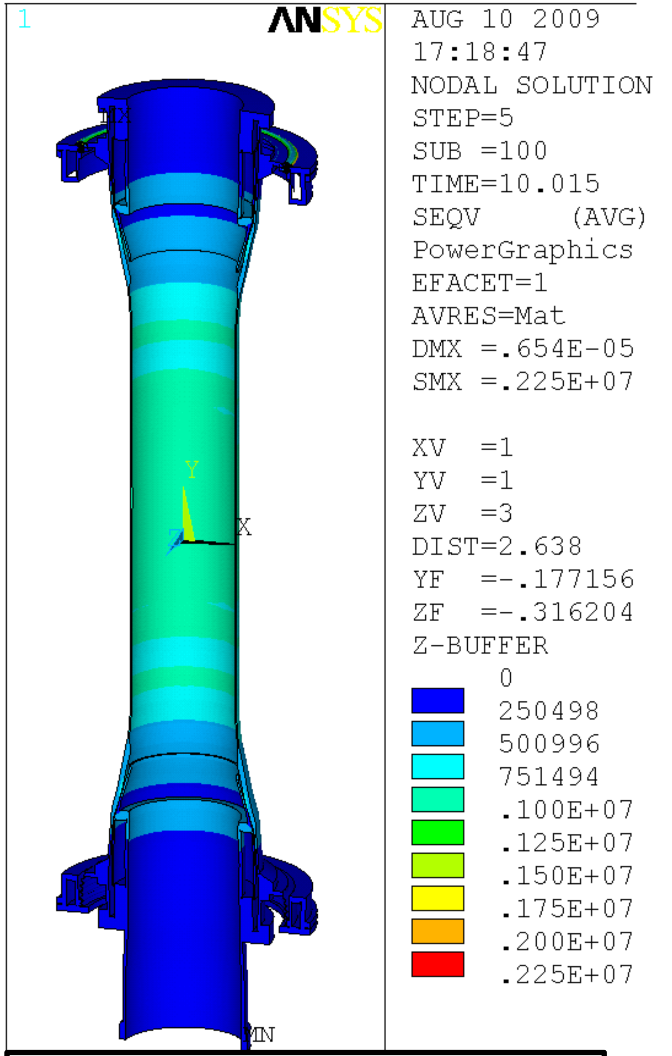
Temperature Distribution at EOP

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

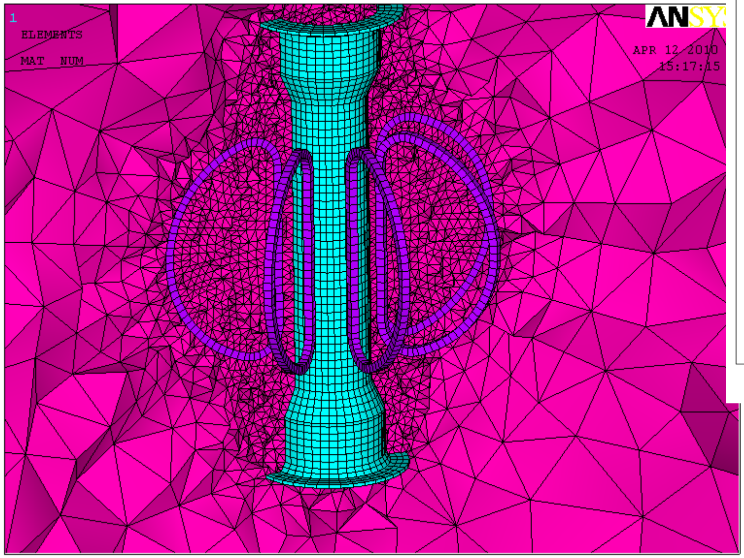


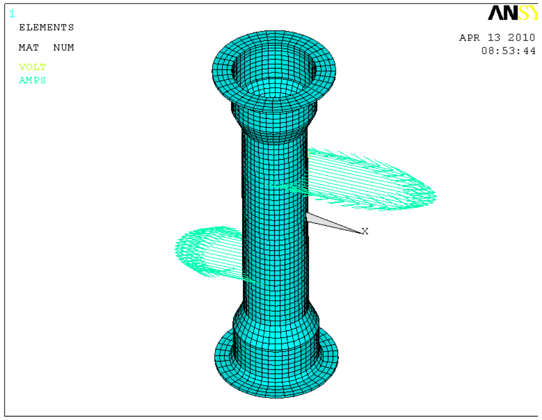
WBS 1.1.1 Disruption Analysis of Passive Plates, Vacuum Vessel & Components
NSTXU-CALC-12-01-01 Rev 1 April, 2011
Prepared By: Peter Titus, Contributing Authors: A. Brooks, Srinivas Avasarala, J. Boales Reviewed By: Yu Hu Zhai, Cognizant Engineer: Peter Titus

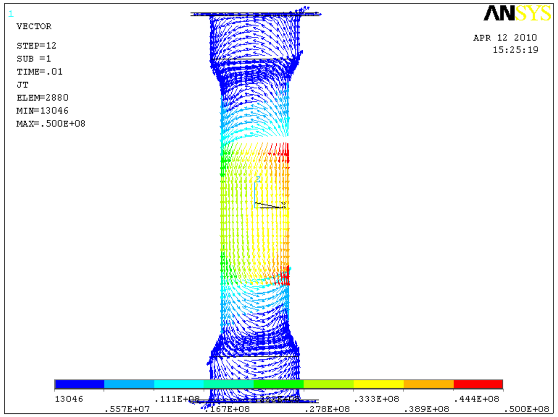


Dynamic Results ~ 1 MPa

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



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SUB =1
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JT
ELEM=2880
MIN=13046
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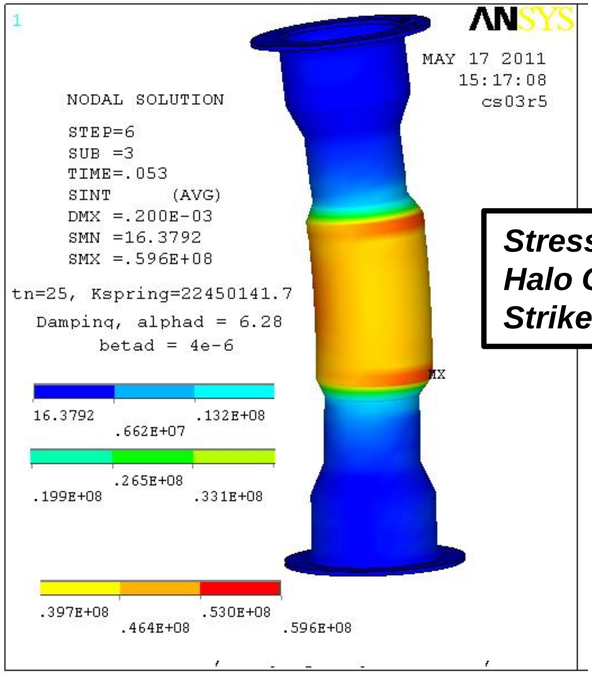
WBS 1.1.3 Magnet Systems, Halo Current Analysis of Center Stack

NSTXU-CALC-133-05-00

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

Cognizant Engineer: Jim Chrzanowski


```
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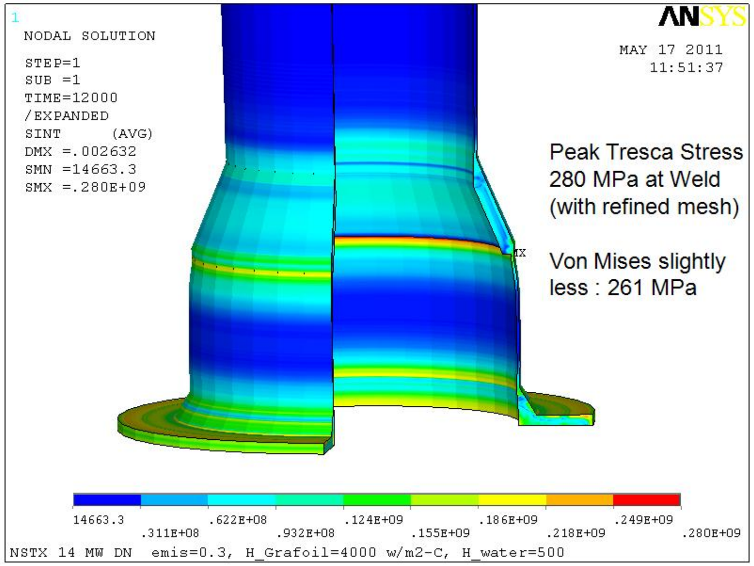
SUB =3
TIME=.053
SINT       (AVG)
DMX =.200E-03
SMN =16.3792
SMX =.596E+08
tn=25, Kspring=22450141.7
Damping, alphad = 6.28
betad = 4e-6
```

Stress Due Halo Current Strike

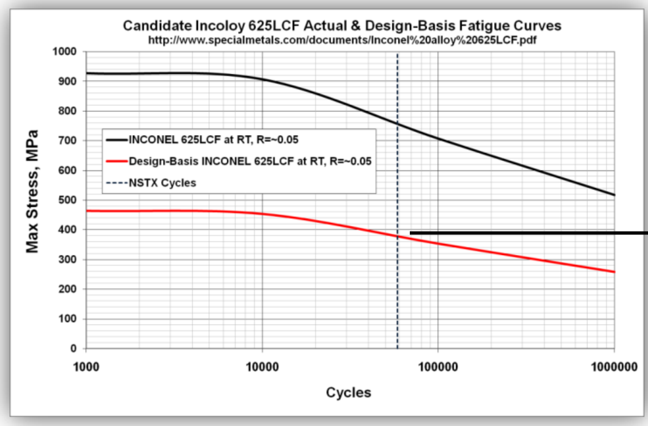
Stress Due Thermal Distribution



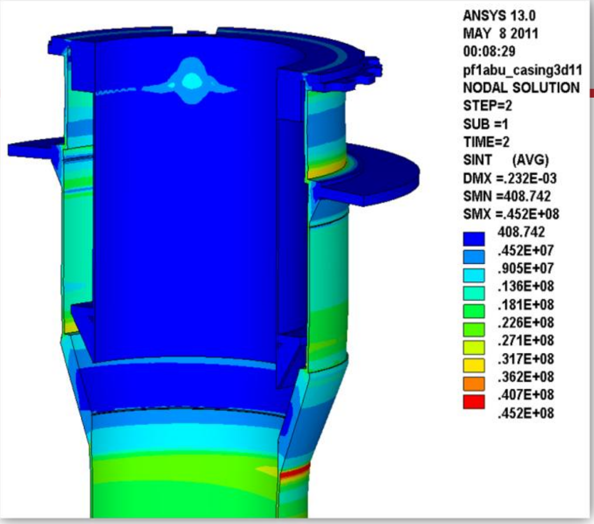
Peak Tresca Stress 280 MPa at Weld (with refined mesh)

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

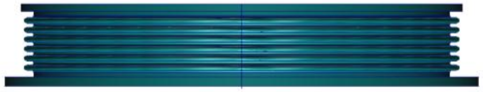


WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1
NSTX-CALC-133-01-01
Prepared By: Leonard Myatt, Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski

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

Torsions + Thermal +Lorentz +Inductive + Halo
50 + 261 + 42 + 1 + 60 = 414

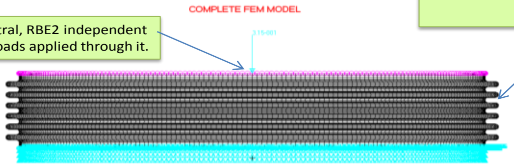
Bellows Allow Vertical Expansion of the Centerstack Casing – This is Axial Motion, but Lateral and Torsional Loads Exist



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

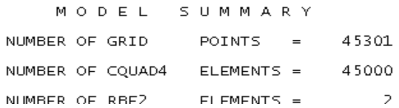
Di = 38.0 inches
Do =40.25 inches

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



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

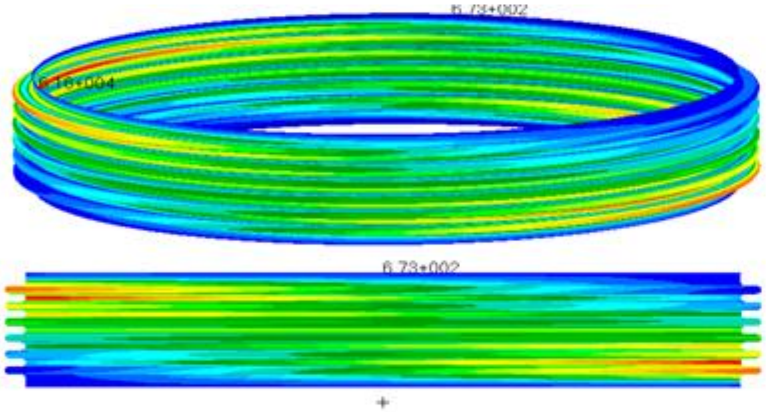
Fixed : x, y, z, Rx ,Ry, Rz



```
          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.***

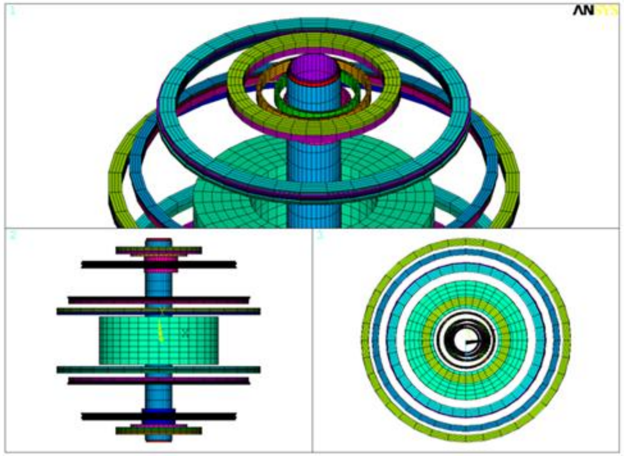
•NASTRAN Version MSC FEA x64 2010.1.2 finite element code.

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

Magnetic Stability of PF's and OH

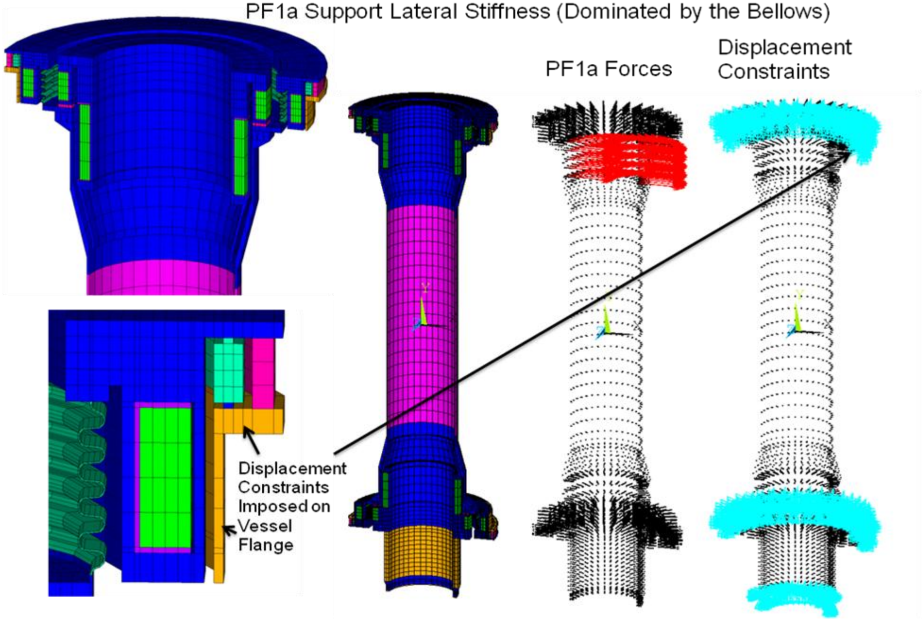
The Centerstack Stability with Respect to the Rest of the Poloidal Coil System relies on the stiffness of the Upper and Lower Lid – and some centering system of the OH with Respect to the TF (Bumpers in the Gap? Lateral Stiffness of the Belleville Spring Stacks?)

Other Stabilities Need to Be Addressed



Stability of PF1a,b with Respect to the OH

PF1a Support Lateral Stiffness (Dominated by 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,

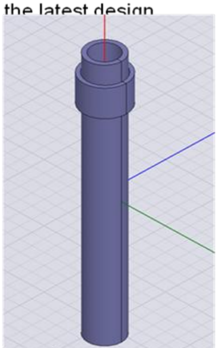
Cognizant Engineer: Jim Chrzanowski

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

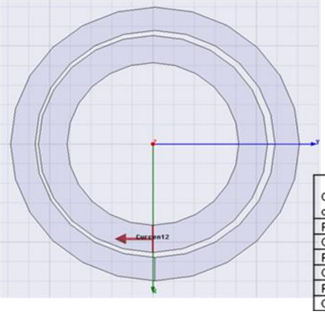
PF1a is supported off the centerstack casing which is stabilized laterally by the bellows/ceramic break assembly. The stiffness of the supports must be sufficient to overcome the magnetic stiffness. To quantify the magnetic stiffness the Lorentz force between the OH and PF1a coils was calculated for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

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

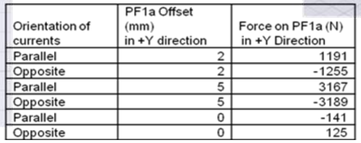
Coil	Current (kA)	Turns
OH	24	884
PF1a	18.3	64



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

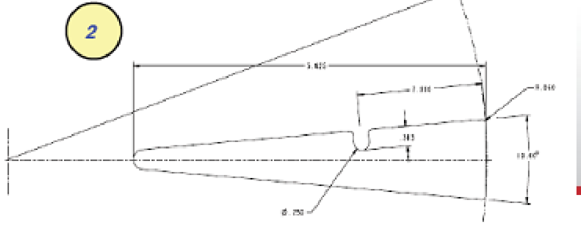


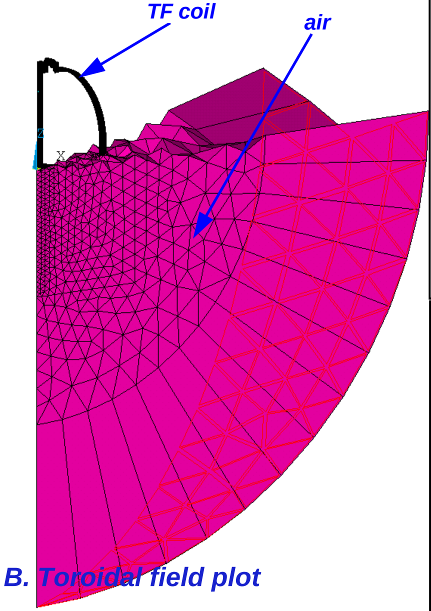
Magnetic Stiffness= 3189/.005 N/m = .637MN/m

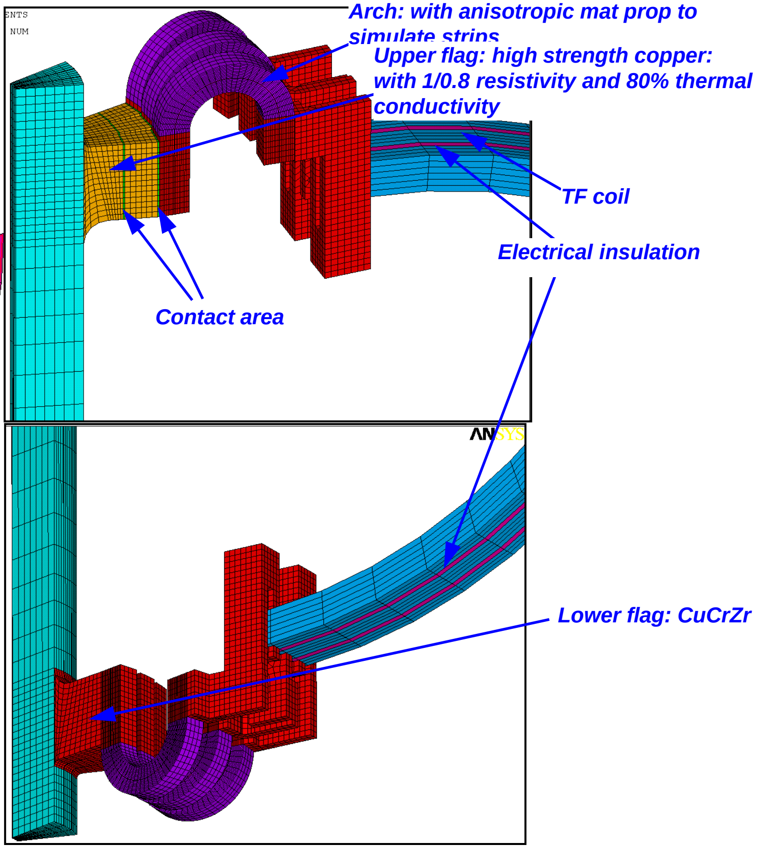


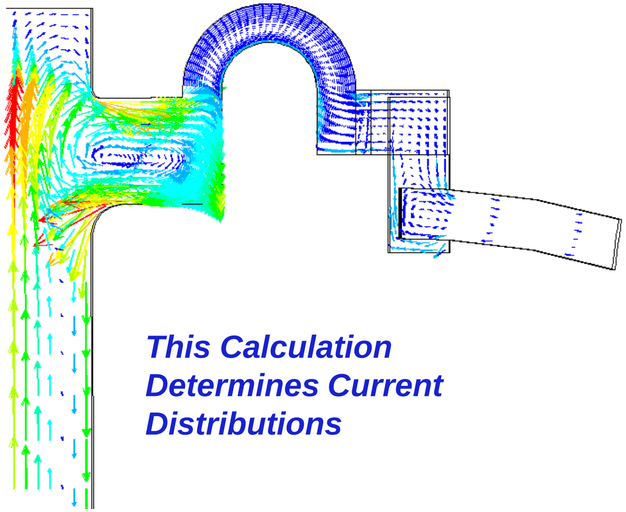
Orientation of currents	PF1a Offset (mm) in +Y direction	Force on PF1a (N) in +Y Direction
Parallel	2	1191
Opposite	2	-1255
Parallel	5	3167
Opposite	5	-3189
Parallel	0	-141
Opposite	0	125

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

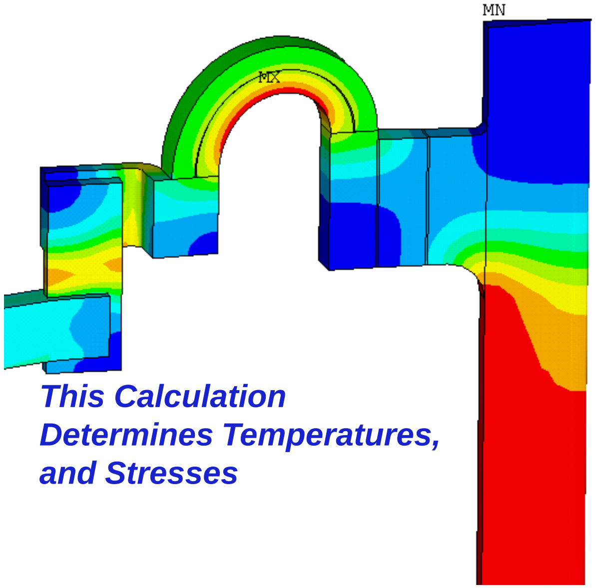








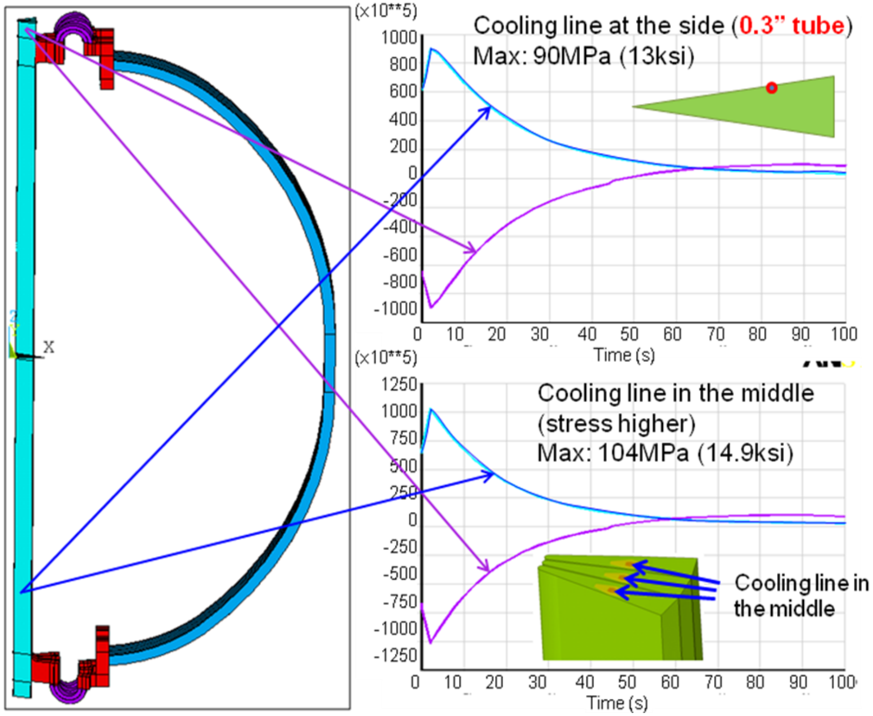
This Calculation Determines Current Distributions

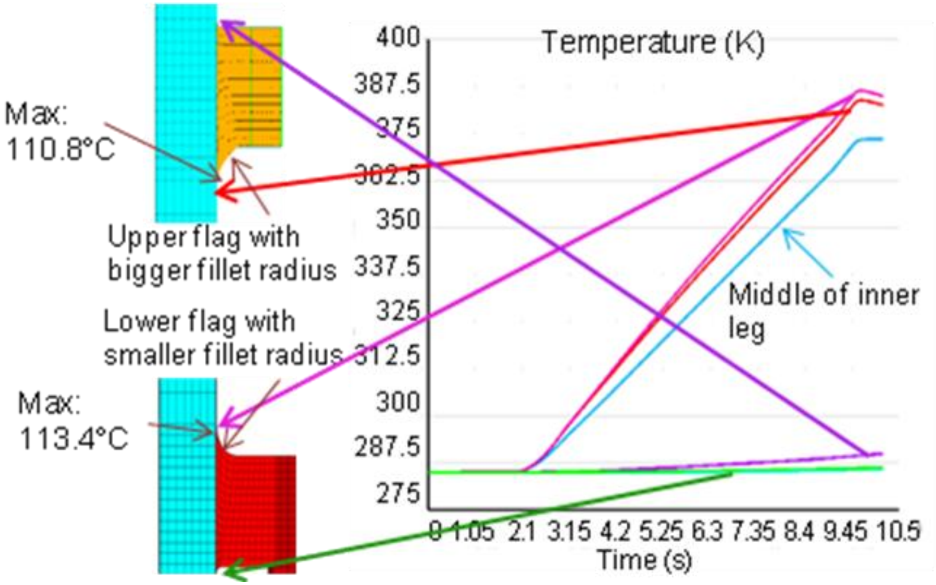


This Calculation Determines Temperatures, and Stresses

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

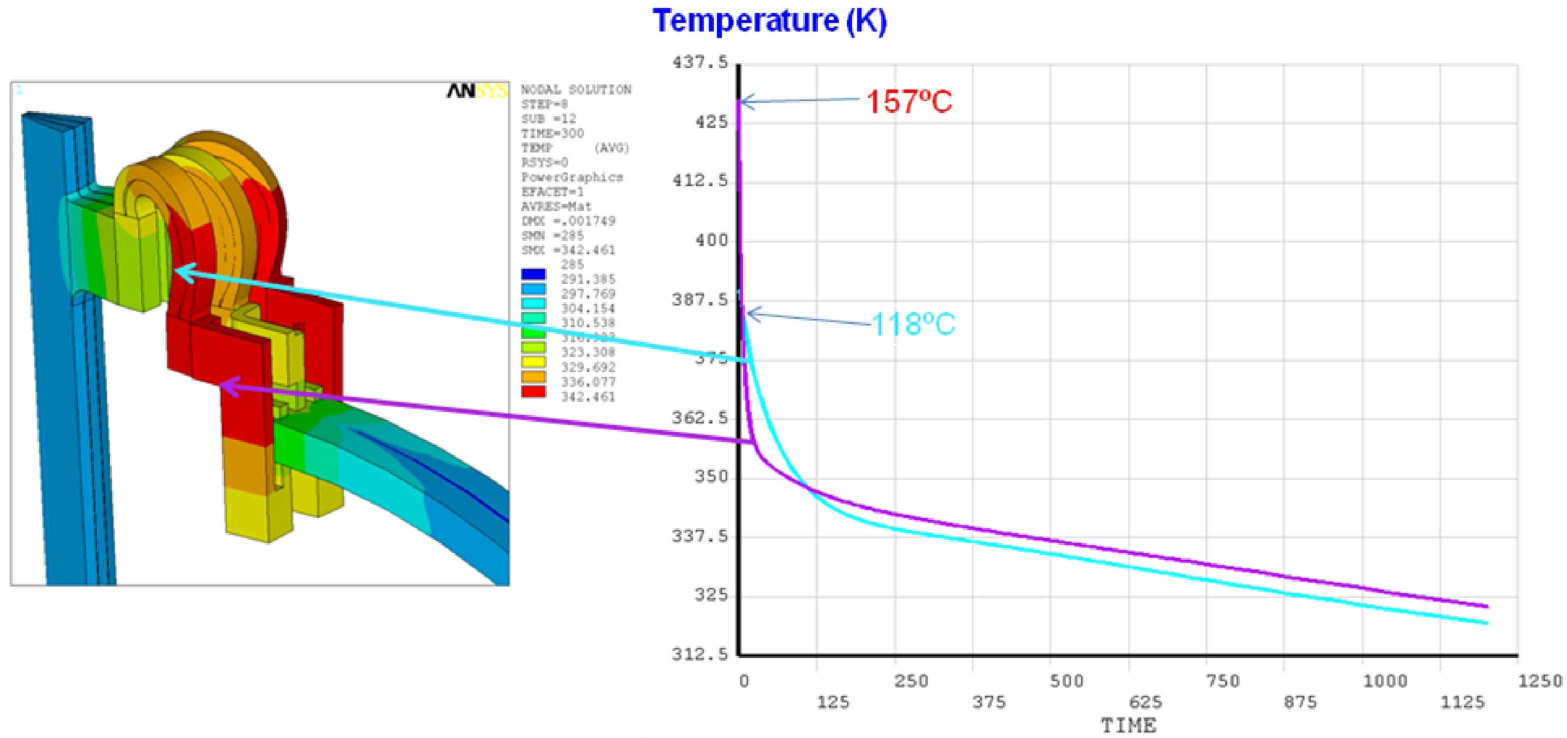




Highly Localized Temperatures in the TF reach 113 degrees C – Testing is being extended to 115C. If tests are not favorable, TF Profile adjustment or control of ramp-down OOP loading will be used.

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

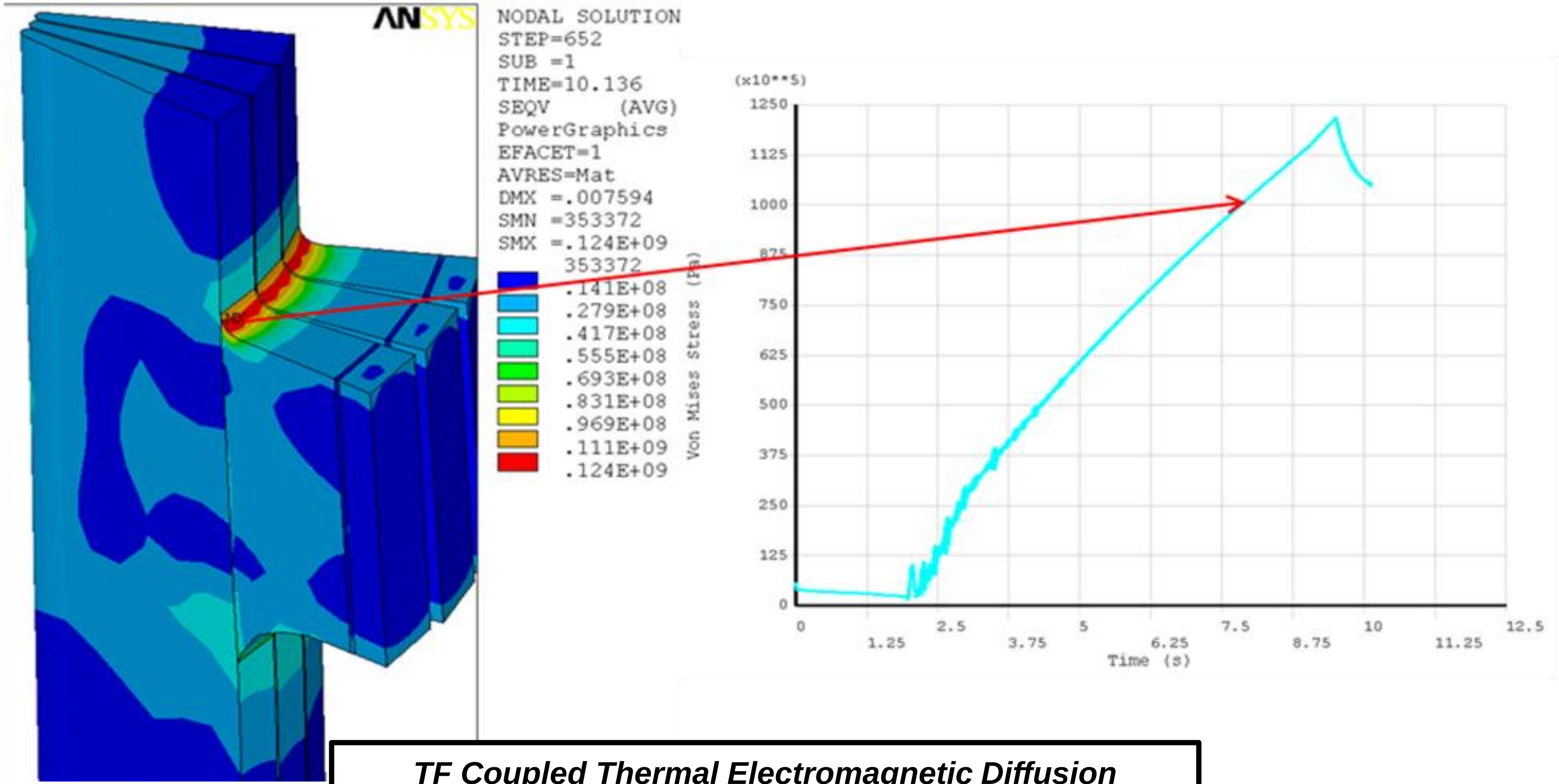
TF Flex Must be Conduction Cooled from Its Ends – Higher Resistivity High Strength Friction Stir Welded Flag Must Perform Adequately Thermally



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

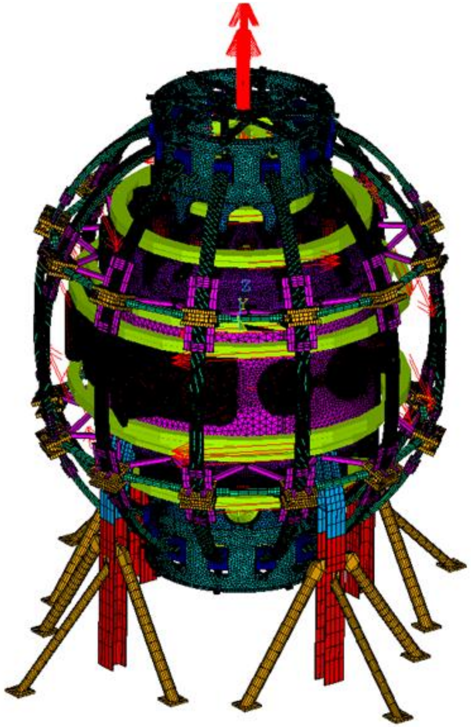


TF Coupled Thermal Electromagnetic Diffusion Analysis, (Part 2)
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

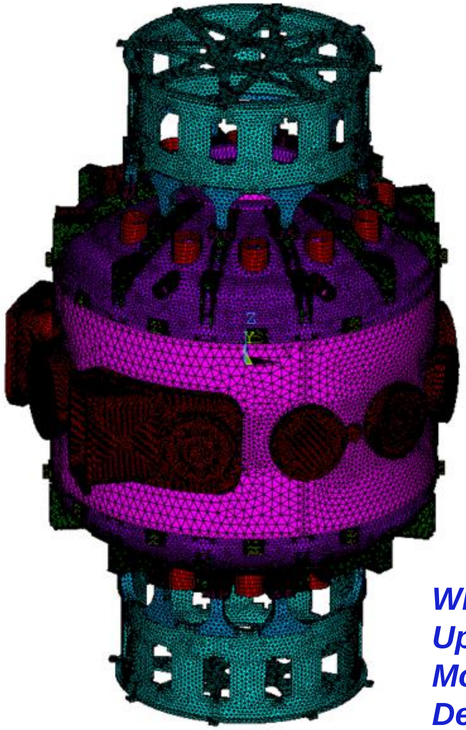
The Tokamak is Multiply Redundant, Global Model Model Simulations are Required

Global Model Is Used For:

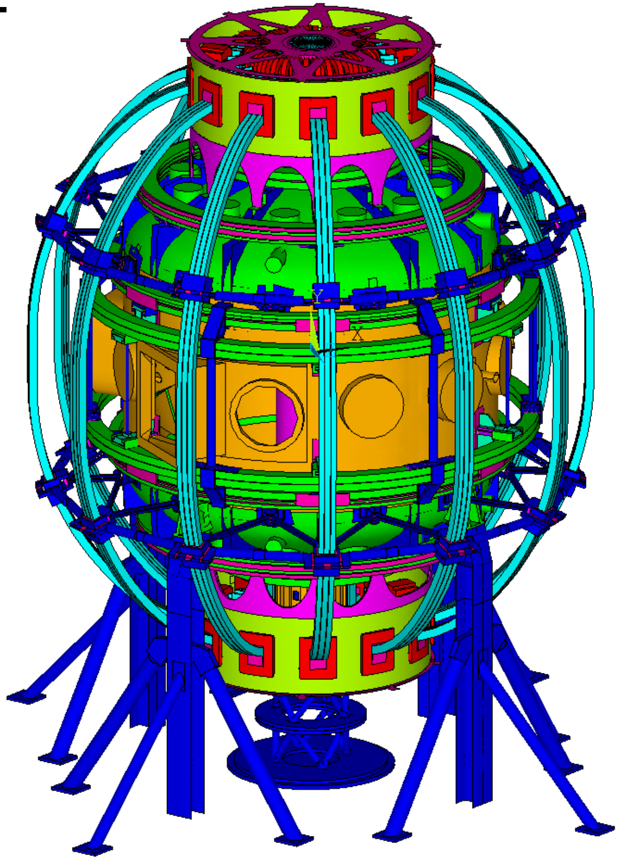
Addressing Statically Indeterminate Structures
Selecting Worst Cases
Scoping Studies
Providing Boundary Conditions for Other Models
Cross-Checking other Models
Seismic Analysis



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

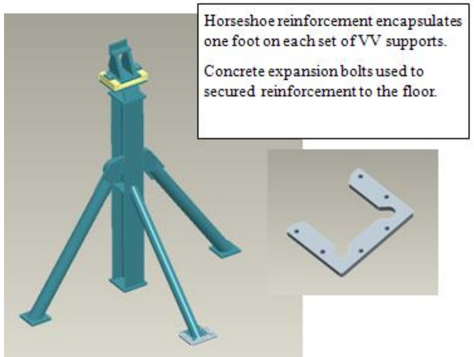


WP 1.1.1 Seismic Analysis NSTXU-CALC-10-02-00, Prepared by Peter Titus, Reviewed by F. Dahlgren, Cognizant Engineer: Peter Titus



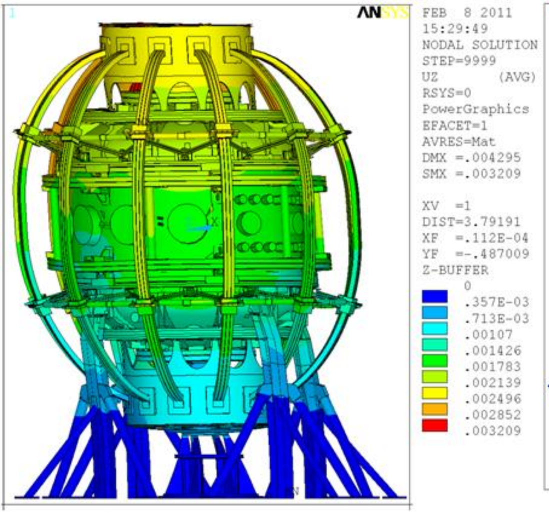
WP 1.1.0 NSTX Upgrade Global Model – Model Description, Mesh Generation, and Results NSTXU-CALC-10-01-02 Prepared by Peter Titus, Reviewed by Han Zhang, Cognizant Engineer: Peter Titus

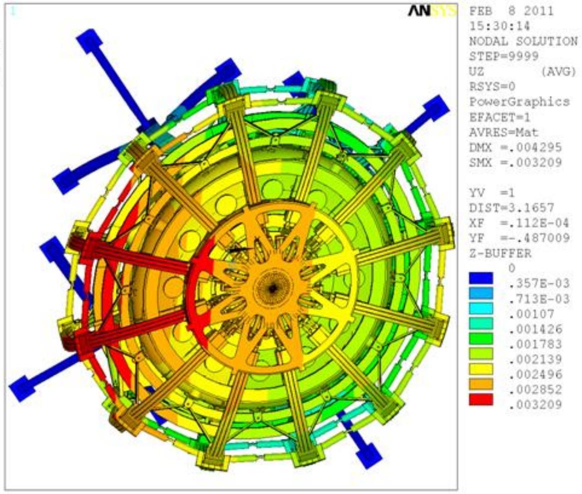
Global Model Model is Used for the Seismic Analysis

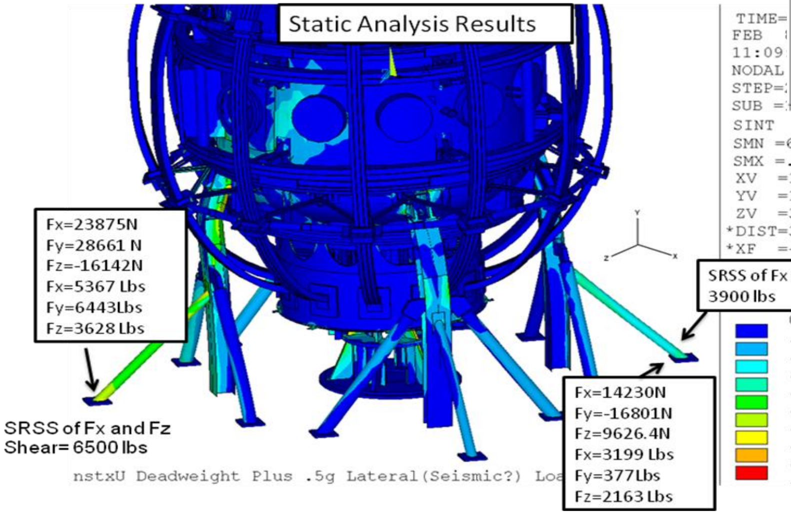


Horseshoe reinforcement encapsulates one foot on each set of VV supports.

Concrete expansion bolts used to secured reinforcement to the floor.







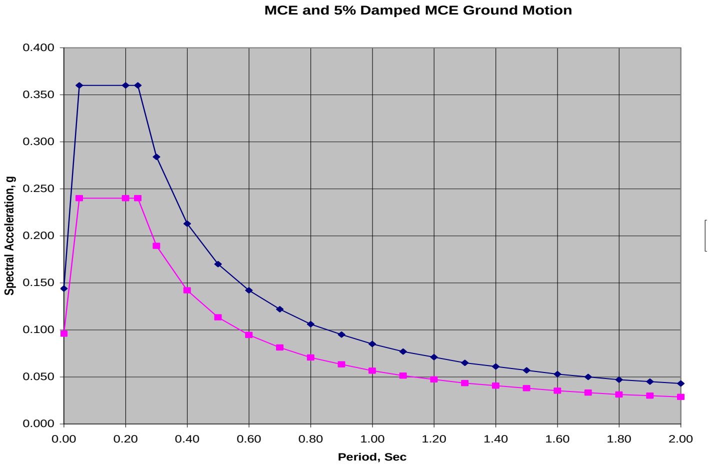
Static Analysis Results

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

SRSS of Fx and Fz
Shear= 6500 lbs

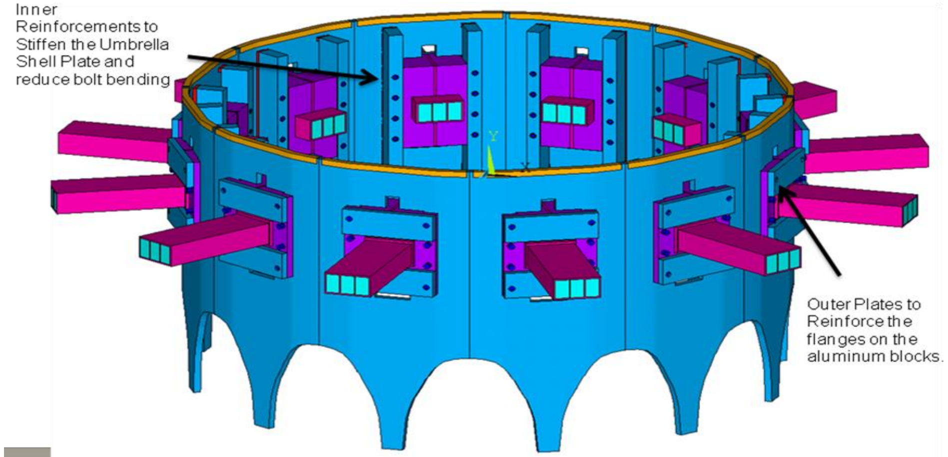
SRSS of Fx and Fz Shear=
3900 lbs

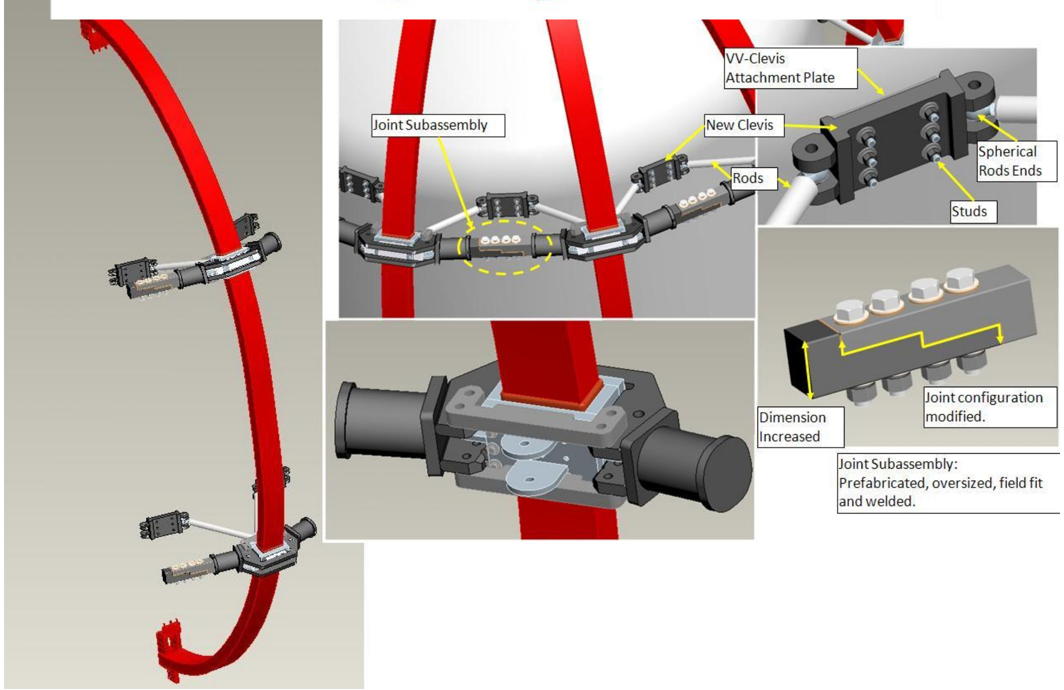
Fx=14230N
Fy=-16801N
Fz=9626.4N
Fx=3199 Lbs
Fy=377Lbs
Fz=2163 Lbs



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





Aluminum Blocks are Cast, Not Forged

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

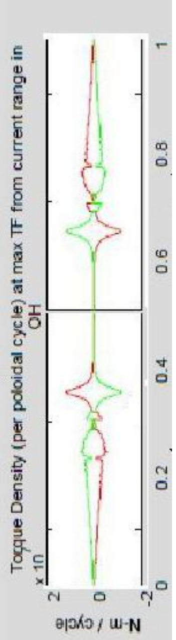
Analysis of TF Outer Leg, NSTXU-CALC-132-04-00, Prepared By: Han Zhang, Reviewed by Peter Titus Cognizant Engineer: Mark Smith

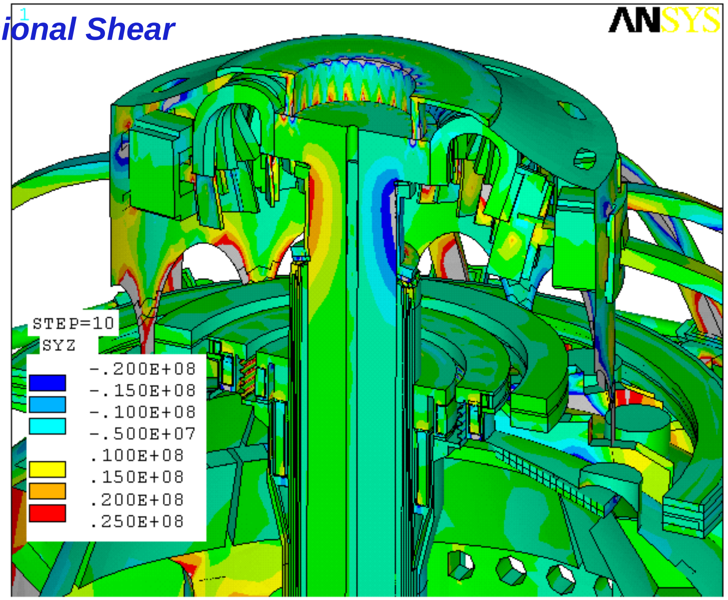
WBS 1.1.2 Ring Bolted Joint, NSTXU-CALC-132-11-00 Prepared By: Peter Rogoff, Reviewed By Irv Zatz, Cognizant Engineer: Mark Smith

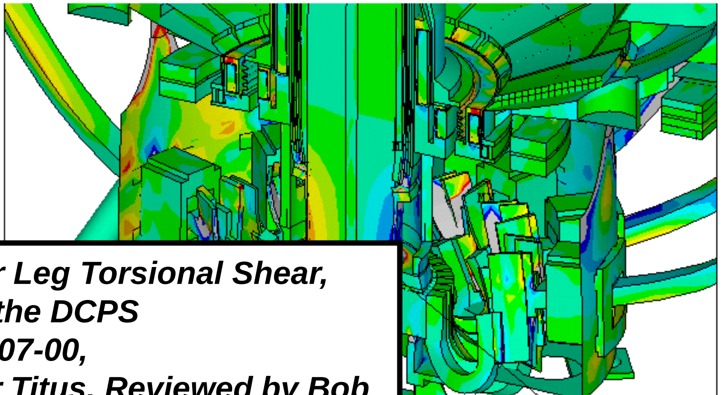
Out-of-Plane Torque is Much Larger Inner Leg Torsional Shear is Limiting

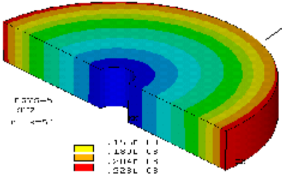
TF Inner Leg Torsional Shear

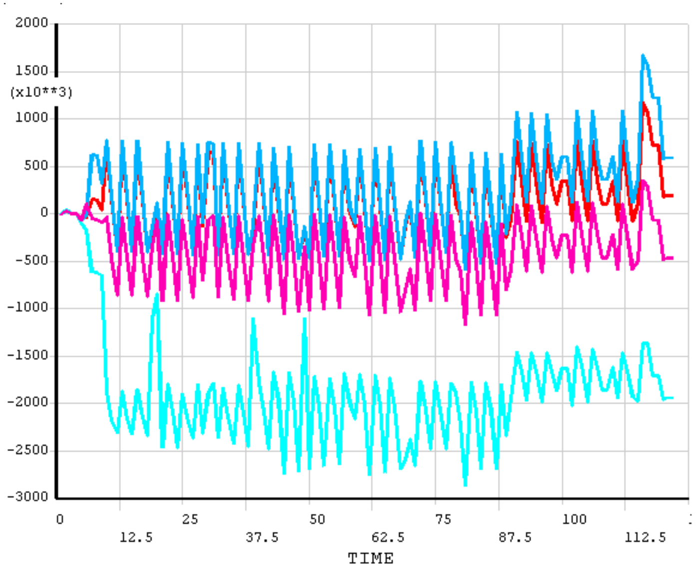
Bob Woolley's Moment Sum

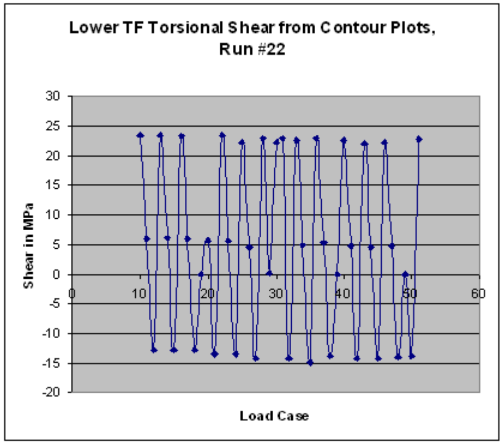








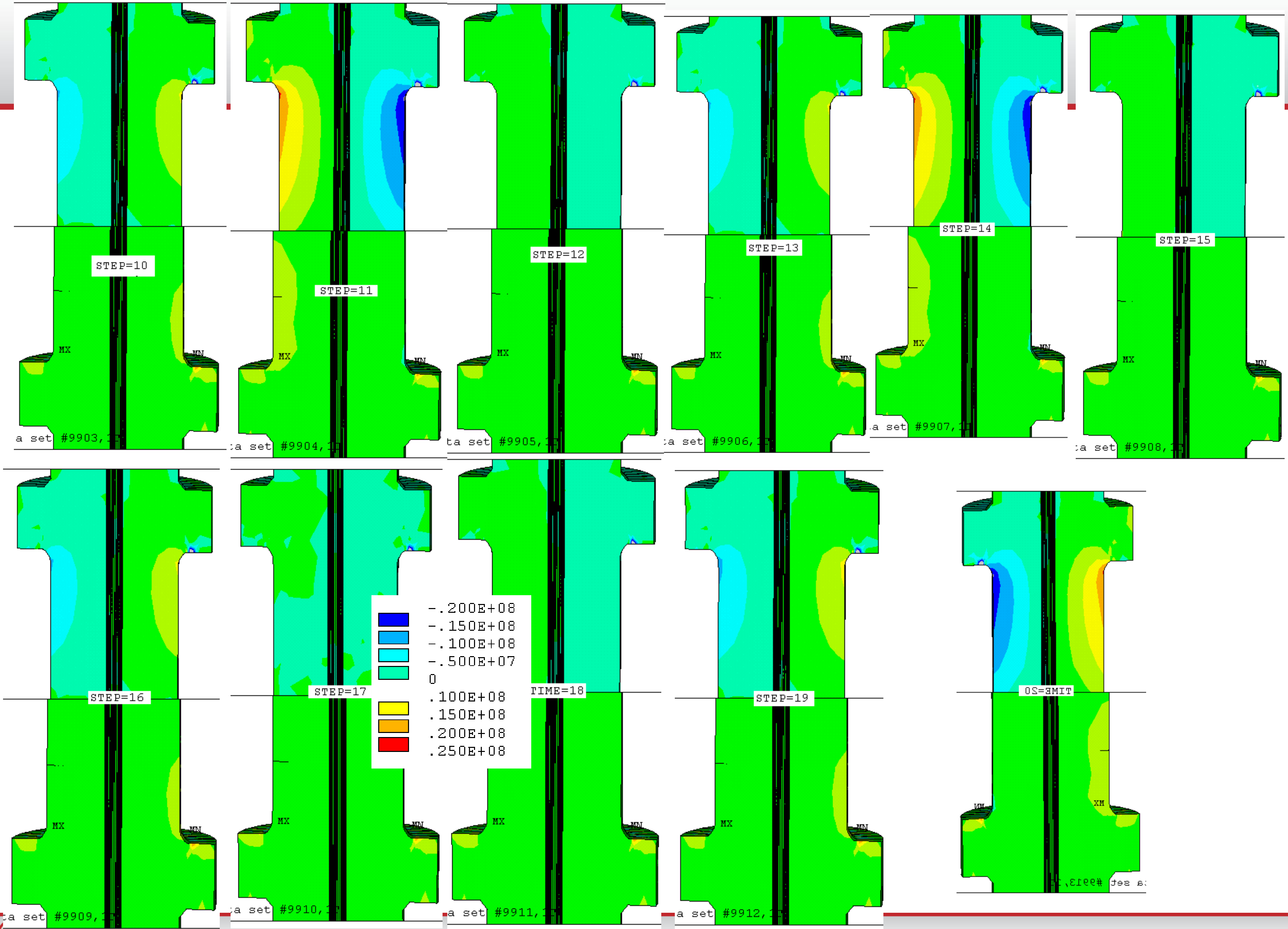




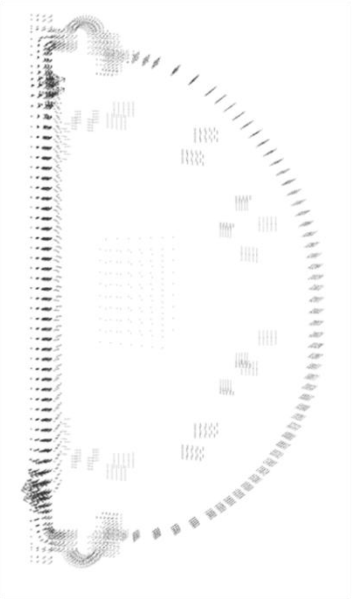
WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS NSTXU-CALC-132-07-00,
Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski

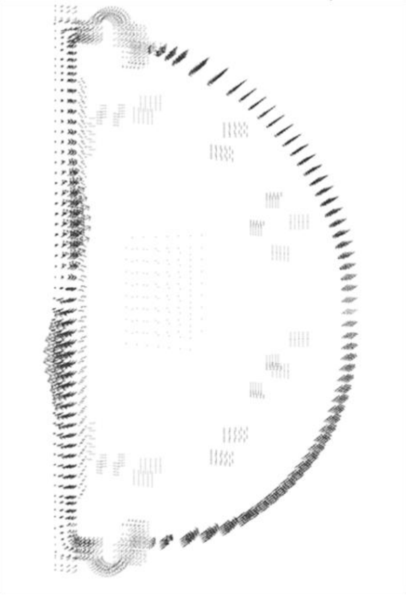
nstxU,Therm+TFON,data set #9901,1

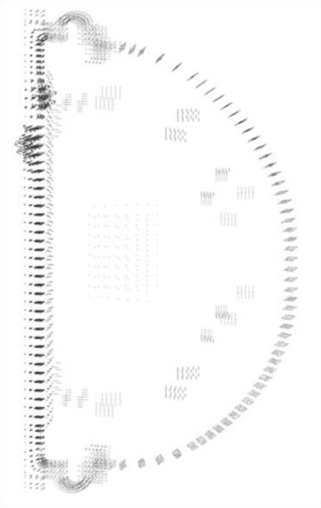
The Max torsional shear is 24 MPa with an allowable of ***21.7 MPa***

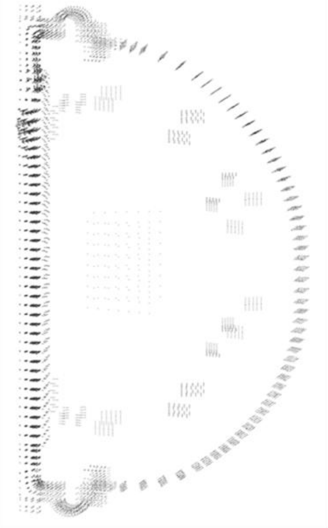

STEP=10
STEP=11
STEP=12
STEP=13
STEP=14
STEP=15
STEP=16
STEP=17
TIME=18
STEP=19
TIME=20
MX
MN
a set #9903,
a set #9904,
a set #9905,
a set #9906,
a set #9907,
a set #9908,
a set #9909,
a set #9910,
a set #9911,
a set #9912,
a set #9913,
-.200E+08
-.150E+08
-.100E+08
-.500E+07
0
.100E+08
.150E+08
.200E+08
.250E+08

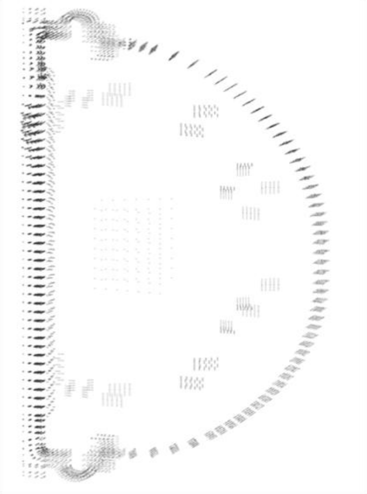
Calculation of Inner Leg Torsional Shear Using the Global Model Derived Influence Coefficients

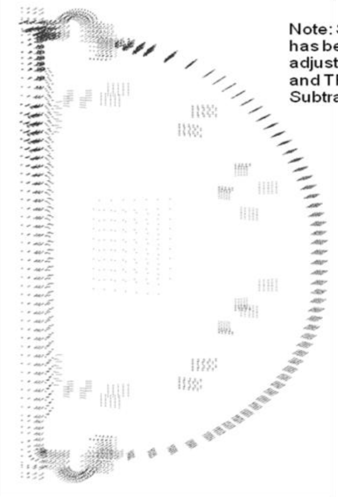

Due to Unit Current in OH si01


Due to Unit Current in Ip


Due to Unit Current in PF1aU


Due to Unit Current in PF1bU, si03

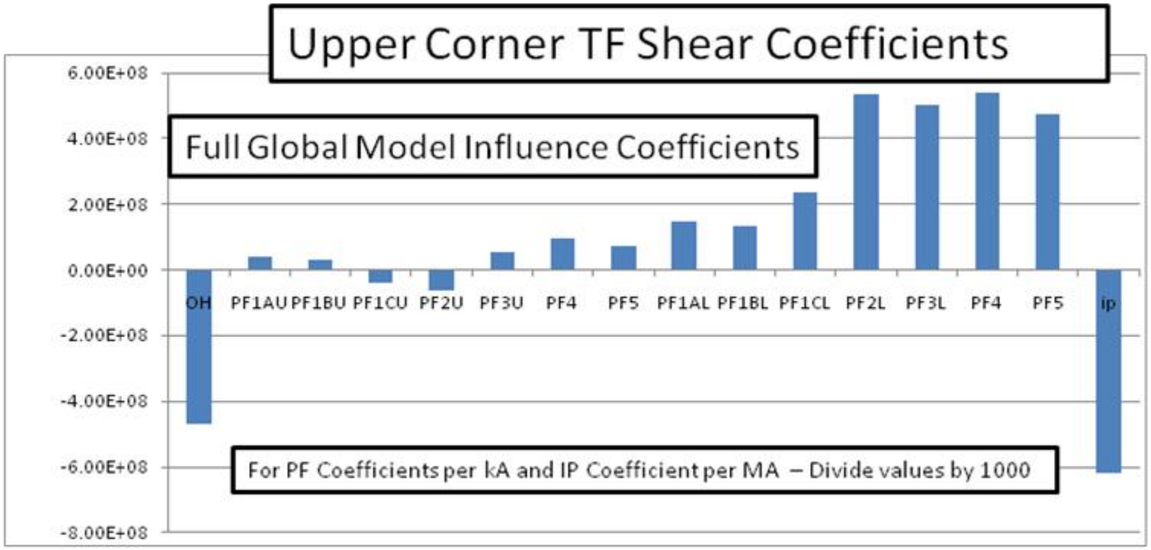

Due to Unit Current in PF1cU, si04


Due to Unit Current in PF2U, si05

Note: Scale has been adjusted, and TFON Subtracted

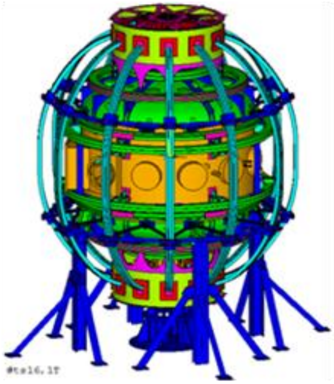
WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS
NSTXU-CALC-132-07-00, Prepared By: Peter Titus, Reviewed by Bob Woolley
Cognizant Engineer: Jim Chrzanowski

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

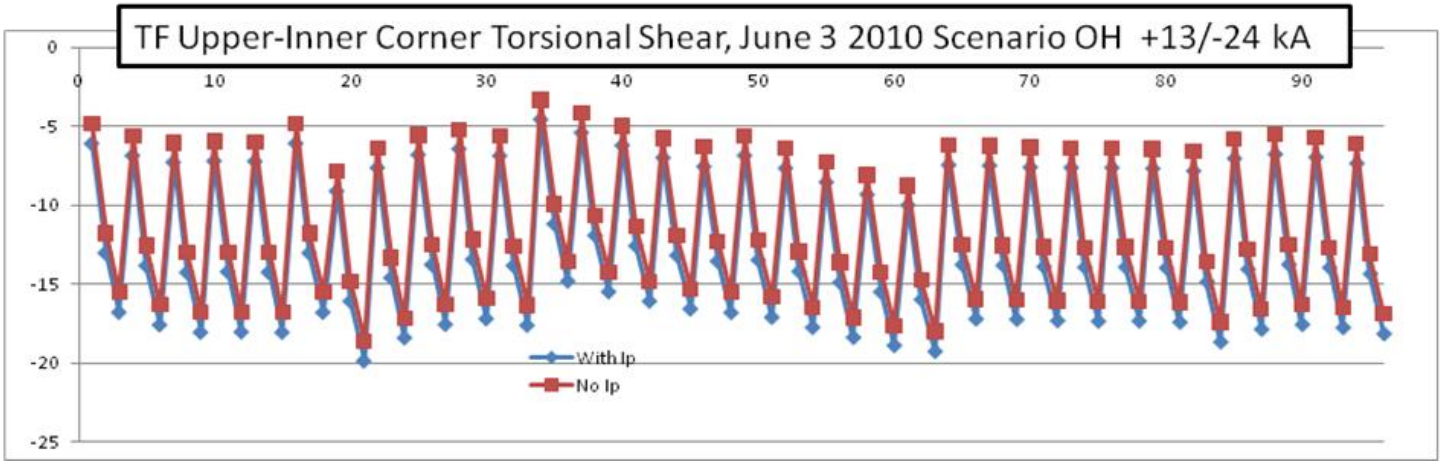

Upper Corner TF Shear Coefficients

Full Global Model Influence Coefficients

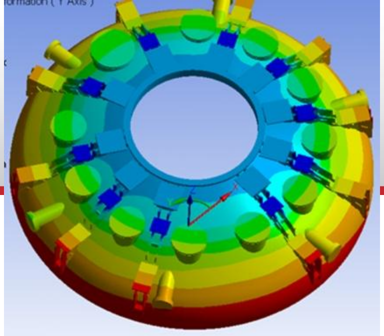
For PF Coefficients per kA and IP Coefficient per MA – Divide values by 1000

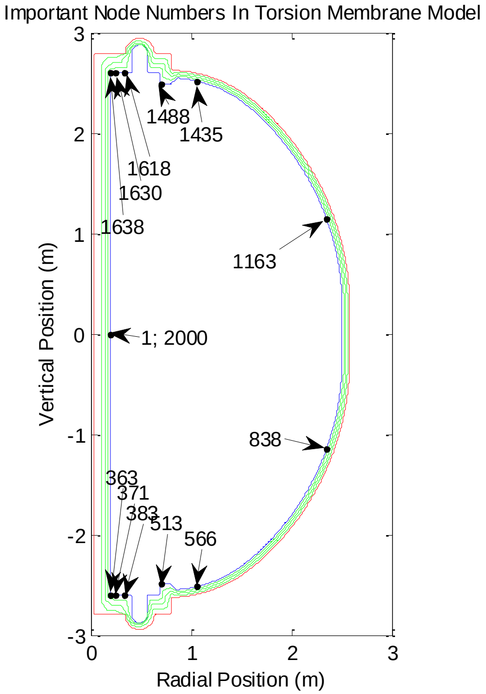


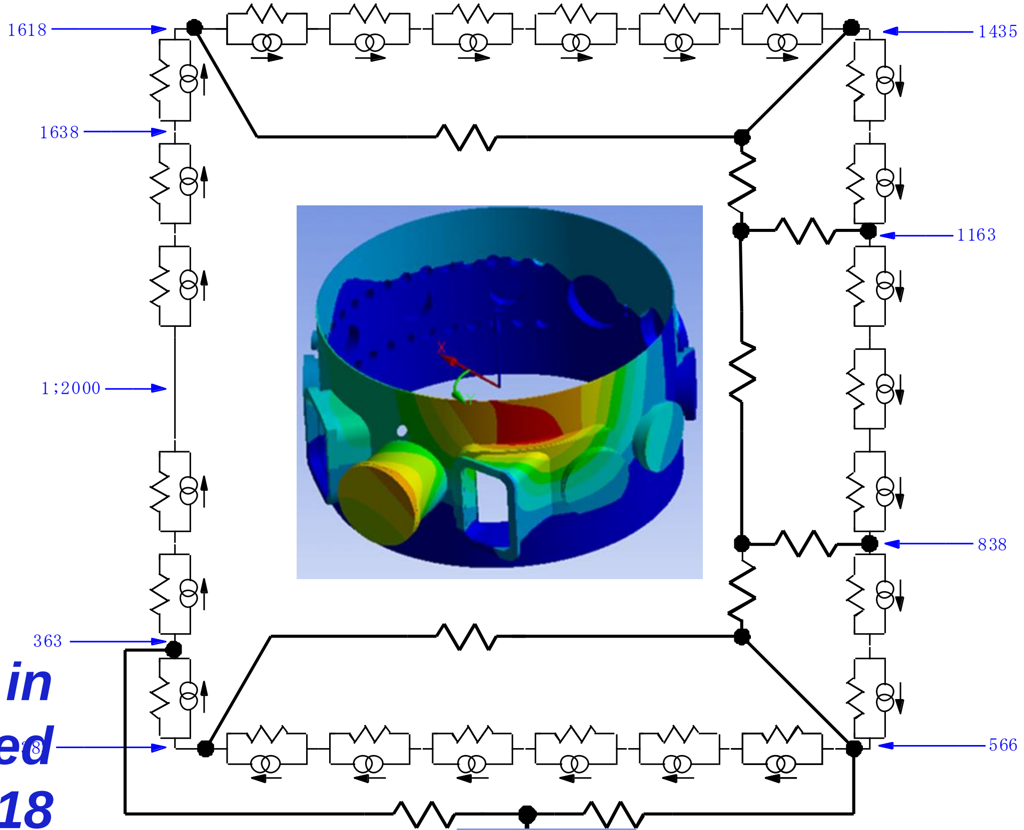
WBS 1.1.3 TF Inner Leg Torsional Shear, Including Input to the DCPS NSTXU-CALC-132-07-00, Prepared By: Peter Titus, Reviewed by Bob Woolley Cognizant Engineer: Jim Chrzanowski


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

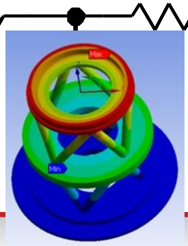
Bob Wooley's Calculation of Inner Leg Torsional Shear Using Mark Smith's Global Model Stiffnesses







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

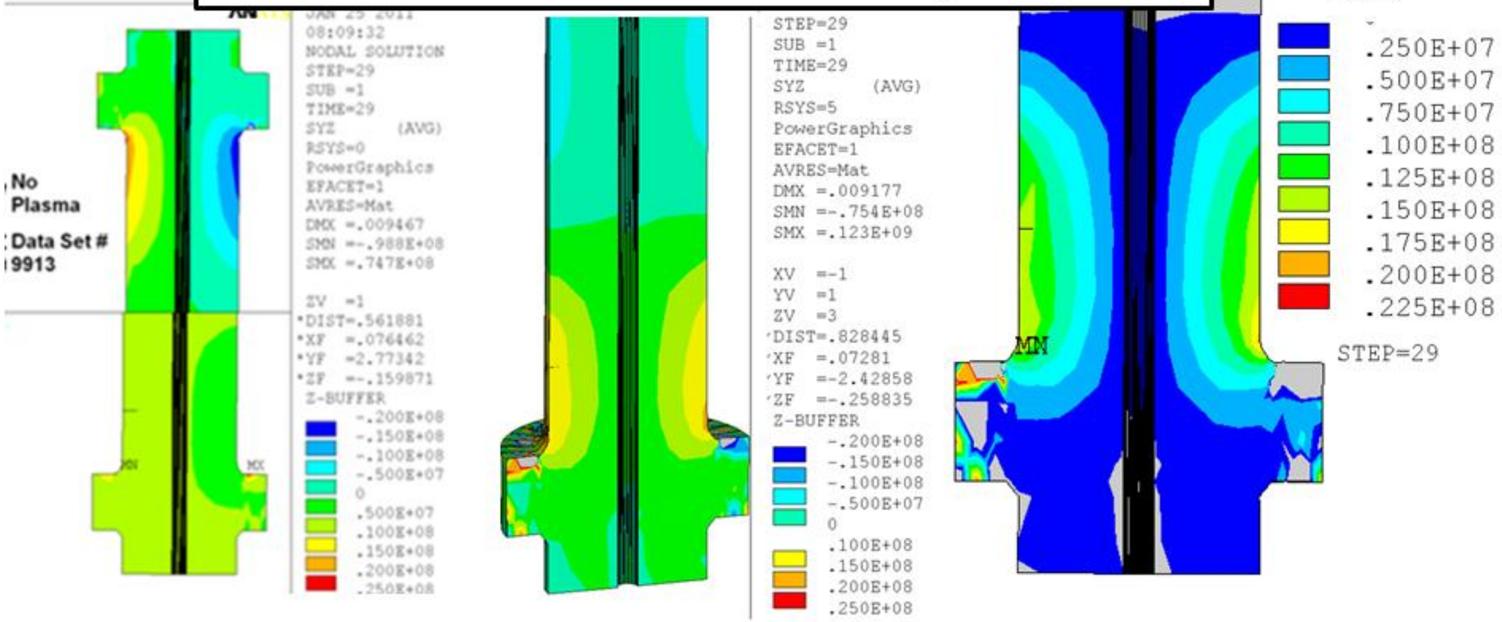


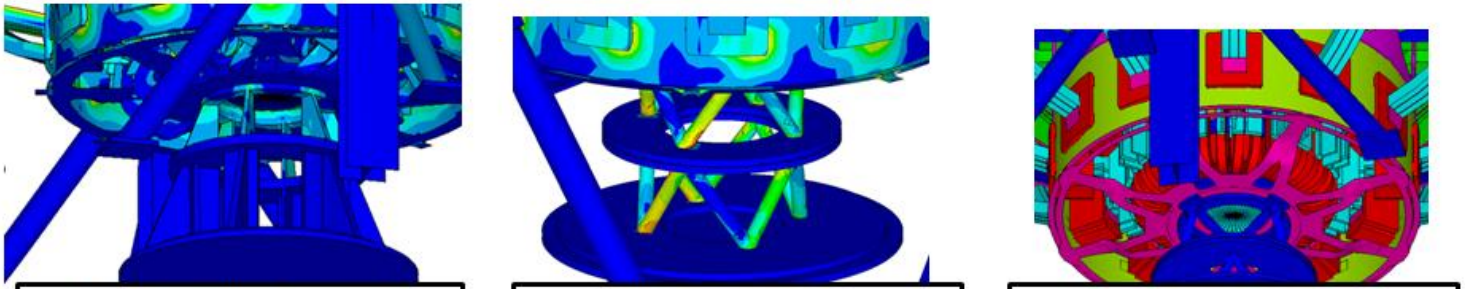
With Similar Stiffnesses to Bob Woolley/Mark Smith, Titus's Analysis Produces Up-Down Symmetry

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

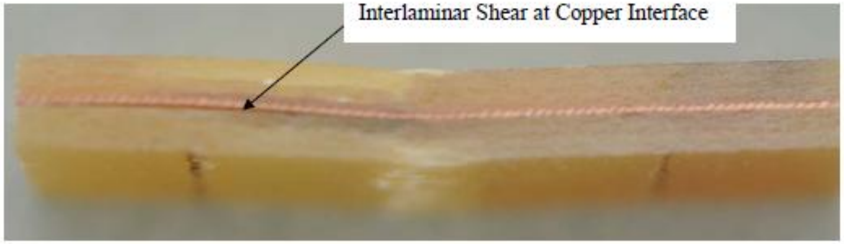




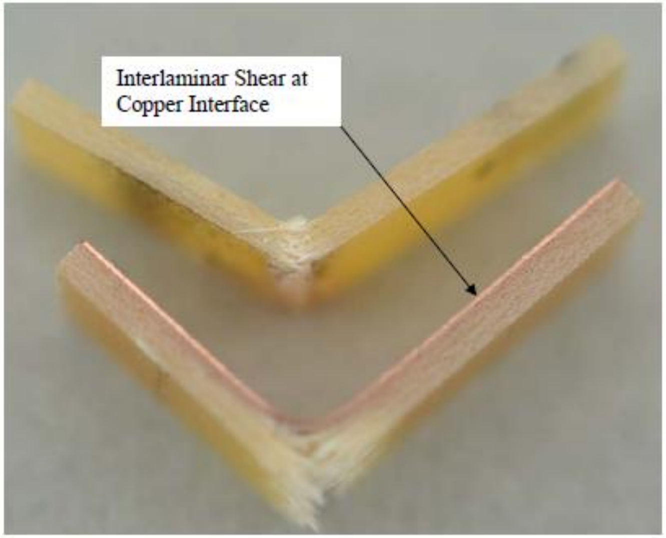
Rotationally Compliant Pedestal/Stiff Lower Lid

Rotationally Stiff Pedestal/Stiff Lower Lid

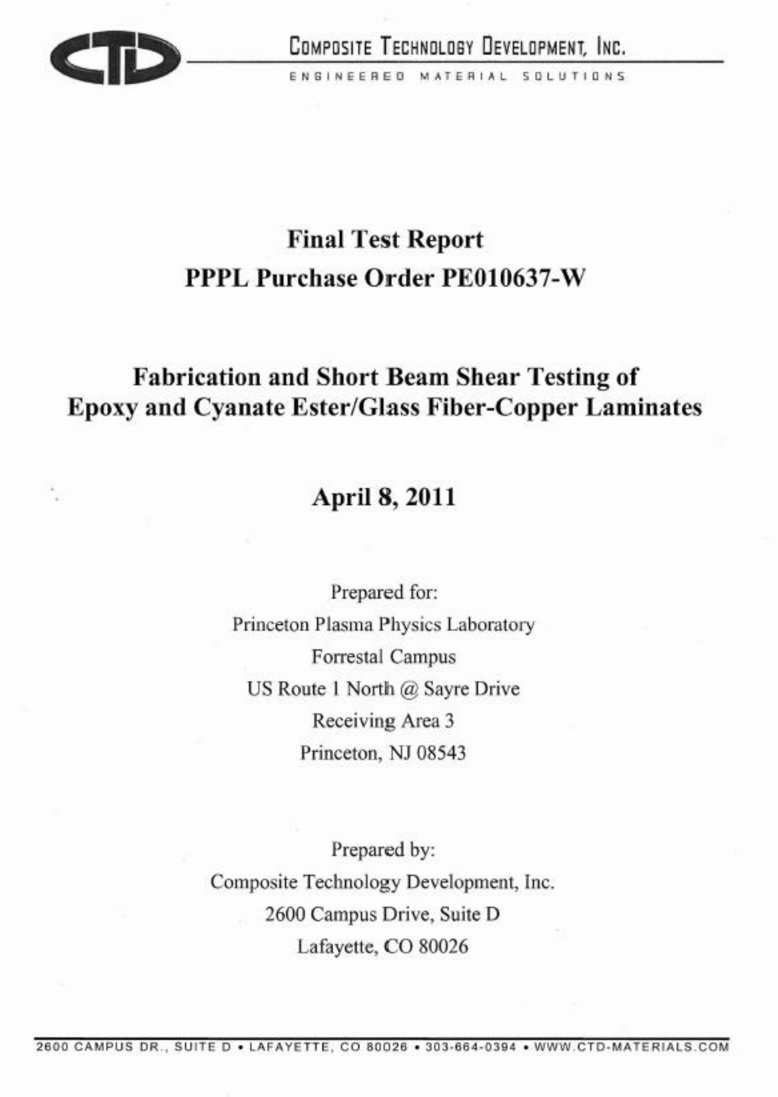
Rotationally Stiff Pedestal/Compliant Lower Lid



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

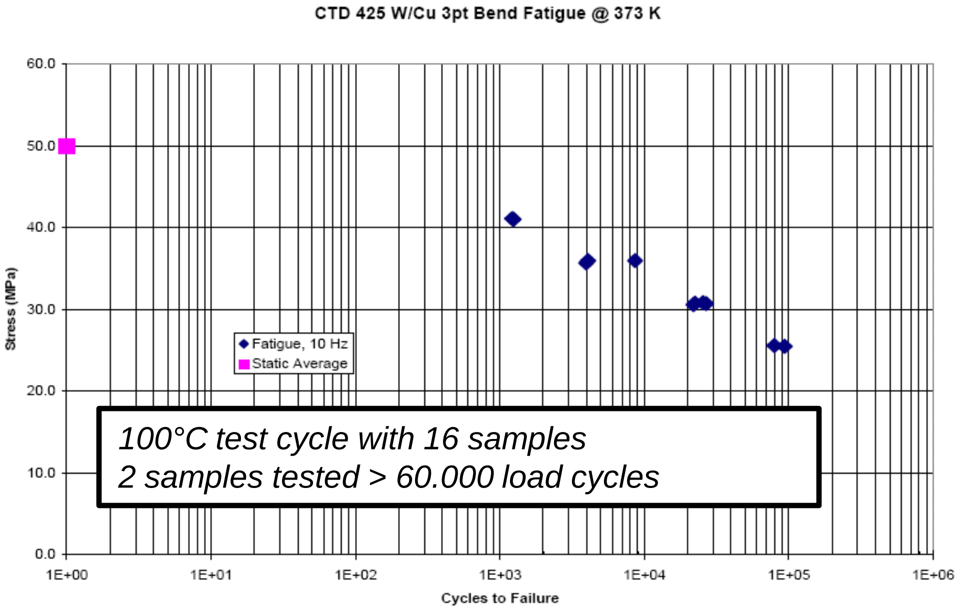
April 8, 2011

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

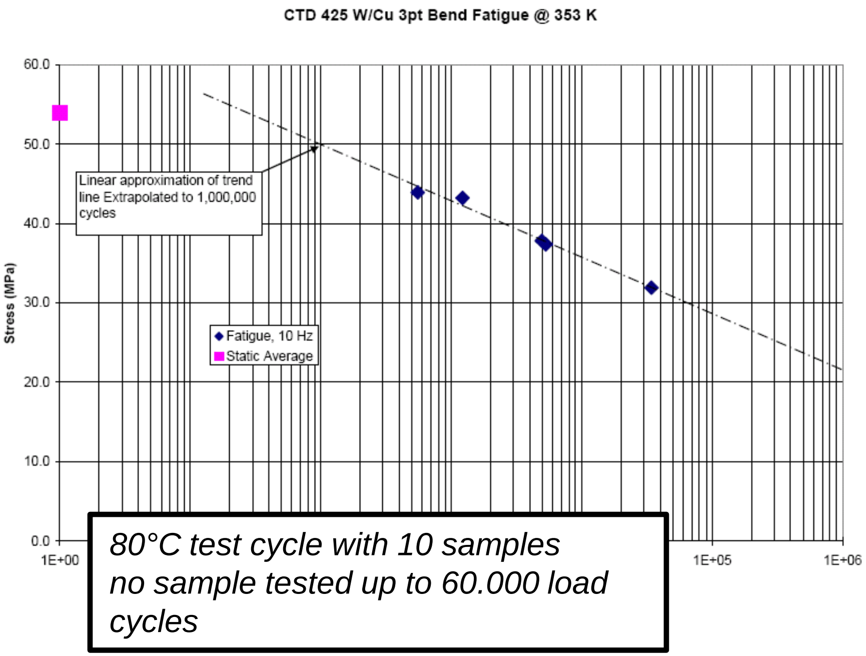
Prepared by:
Composite Technology Development, Inc.
2600 Campus Drive, Suite D
Lafayette, CO 80026

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

CTD Fatigue Tests

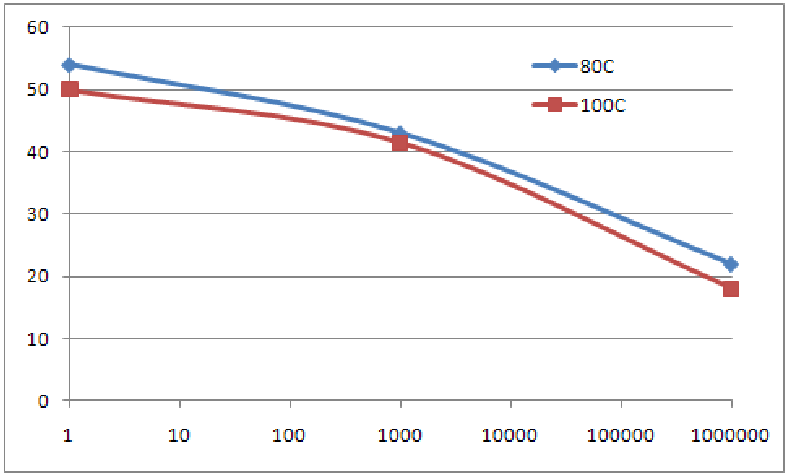


100°C test cycle with 16 samples
2 samples tested > 60.000 load cycles

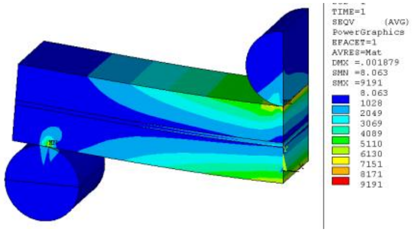


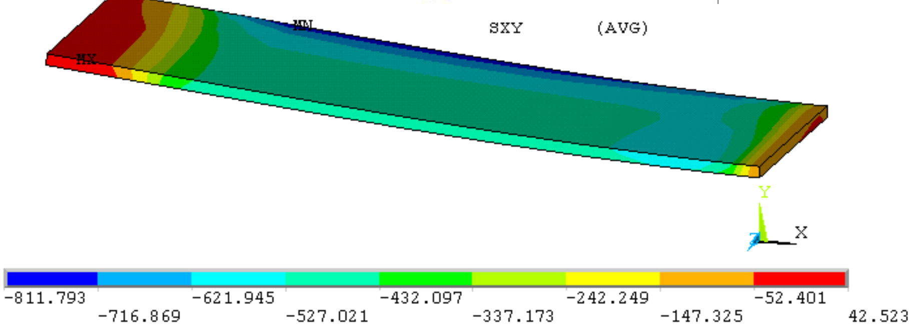
80°C test cycle with 10 samples
no sample tested up to 60.000 load cycles

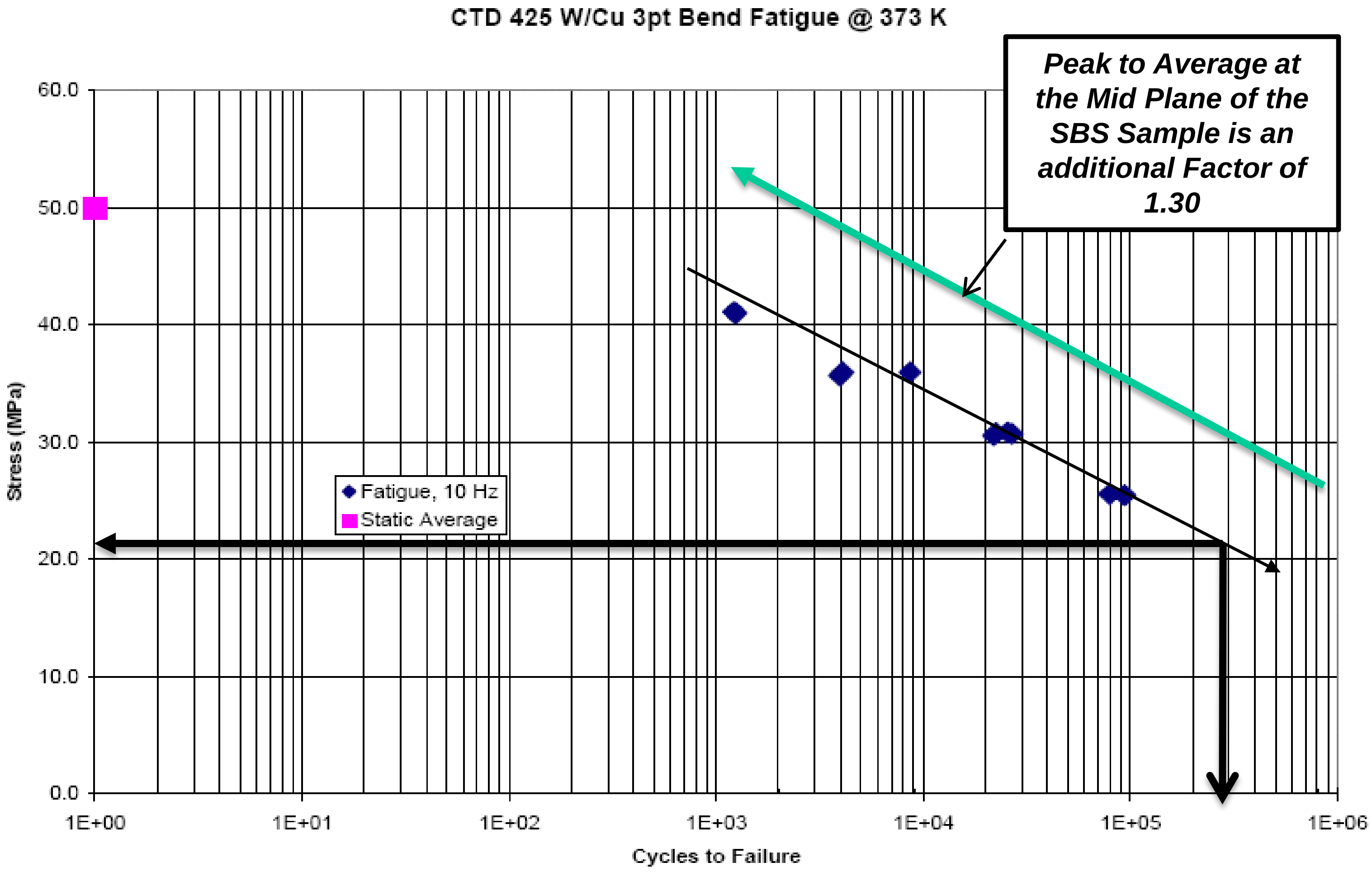
Figure 2: CTD-425 S-N chart



Peak to Average at the Mid Plane of the SBS Sample is an additional Factor of 1.30

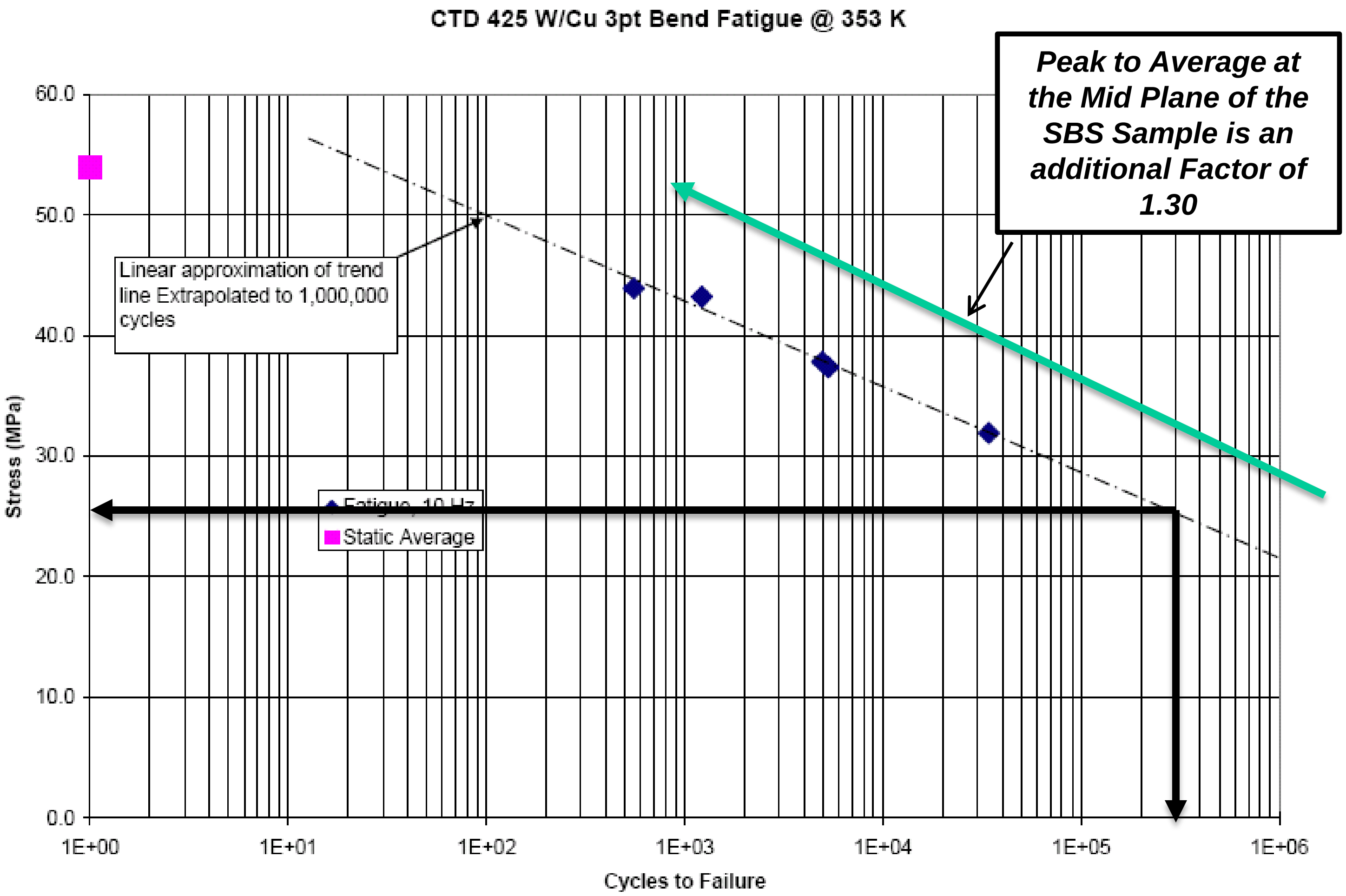






Peak to Average at the Mid Plane of the SBS Sample is an additional Factor of 1.30

Figure 2: CTD-425 S-N chart



Peak to Average at the Mid Plane of the SBS Sample is an additional Factor of 1.30

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.

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

-And We Have DCPS Input Algorithm for TF Torsional Shear

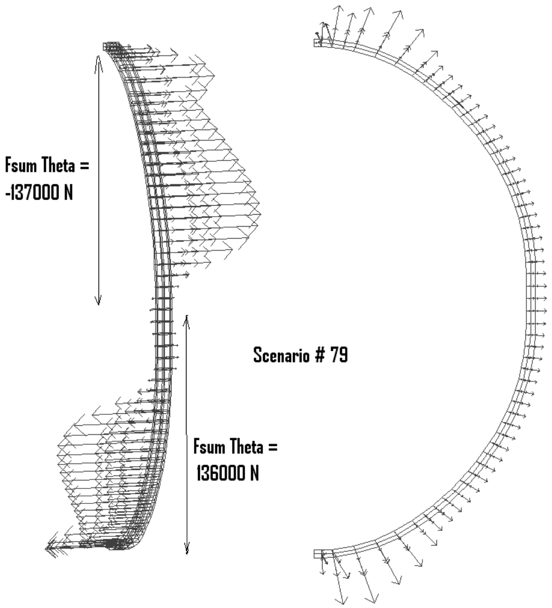
Out-of-Plane Torque Equations in the Design Point Spreadsheet

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

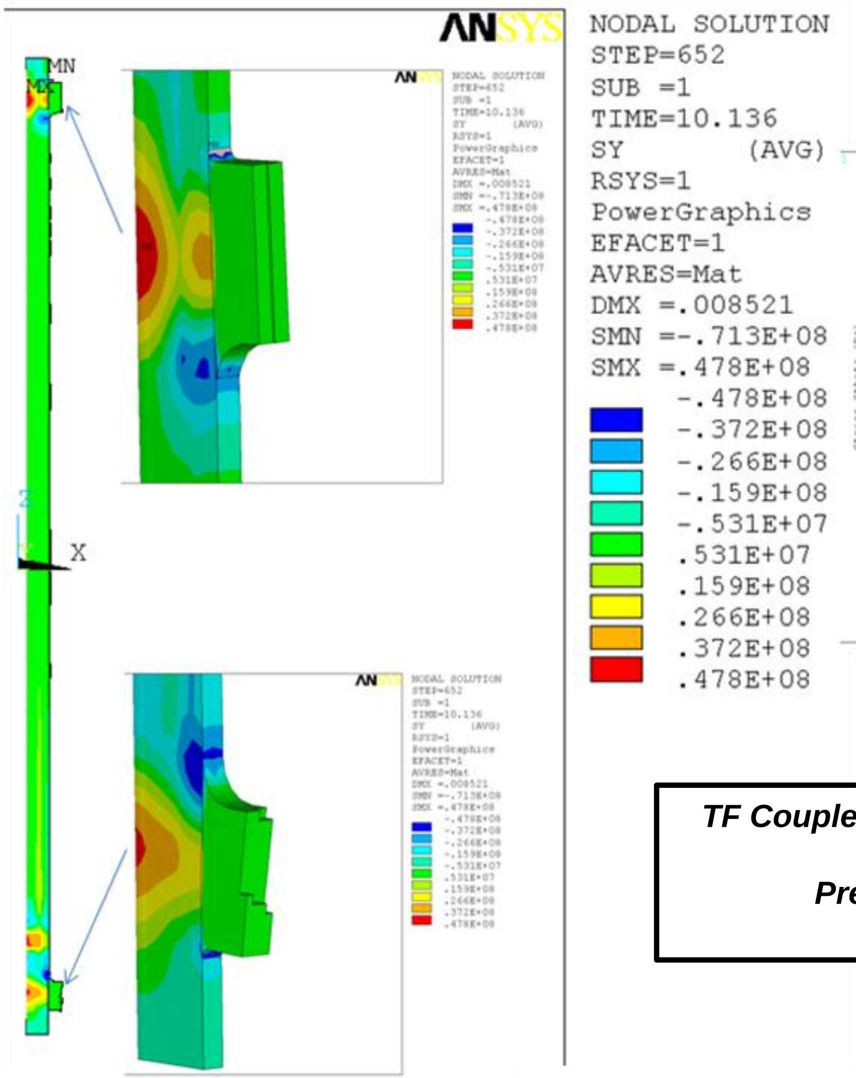
$$\left[\frac{\text{Net TF System Outer Leg Torque}}{1\,\text{N - m}}\right] = 3519.9\left[\frac{I_{\text{PF1AU}} - I_{\text{PF1AL}}}{1\,\text{kA}}\right] + 3692.0\left[\frac{I_{\text{PF1BU}} - I_{\text{PF1BL}}}{1\,\text{kA}}\right] + 4293.8\left[\frac{I_{\text{PF1CU}} - I_{\text{PF1CL}}}{1\,\text{kA}}\right]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

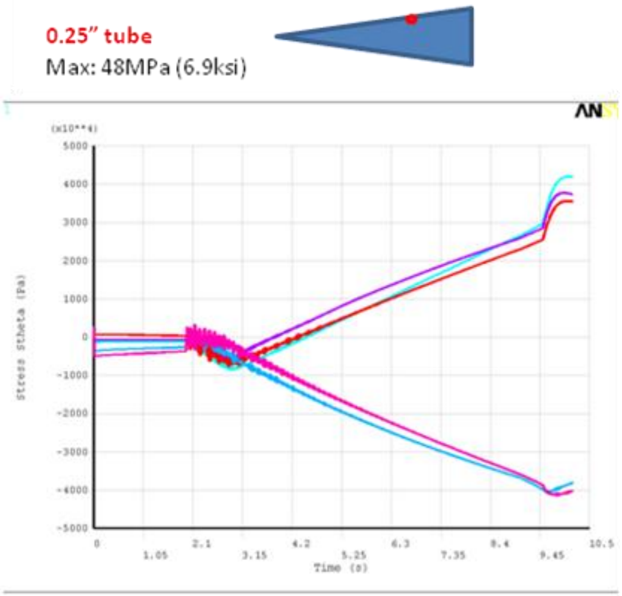
$$\left[\frac{\text{Net Upper Half TF System Torque}}{1\,\text{N - m}}\right] = 13563.1\left[\frac{I_{\text{OH}}}{1\,\text{kA}}\right] + 2260.9\left[\frac{I_{\text{PF1AU}} + I_{\text{PF1AL}}}{1\,\text{kA}}\right] + 1580.6\left[\frac{I_{\text{PF1BU}} + I_{\text{PF1BL}}}{1\,\text{kA}}\right] + 1851.5\left[\frac{I_{\text{PF1CU}}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

Global Torque Sums Agree with FEA Calculations by Willard and Titus



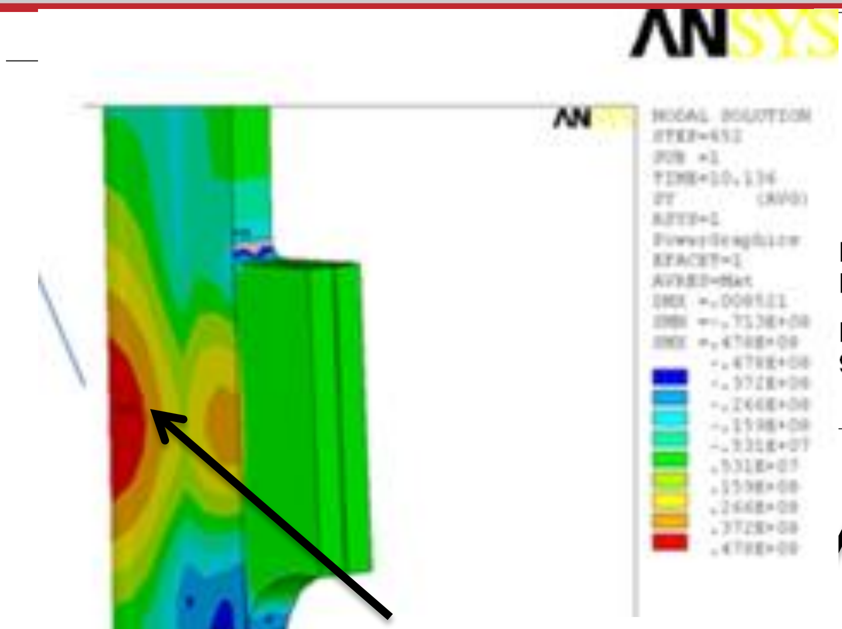
Hoop Tension Develops from Thermal Distribution

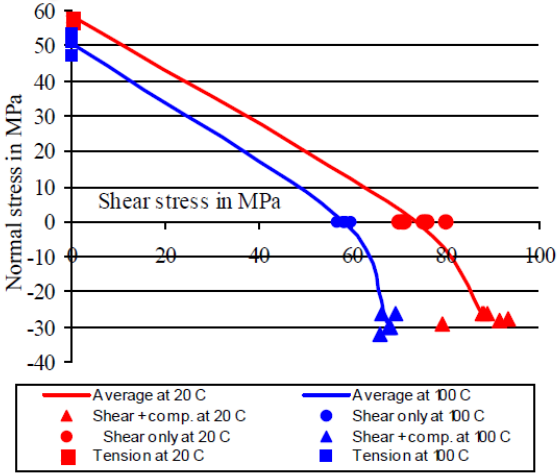


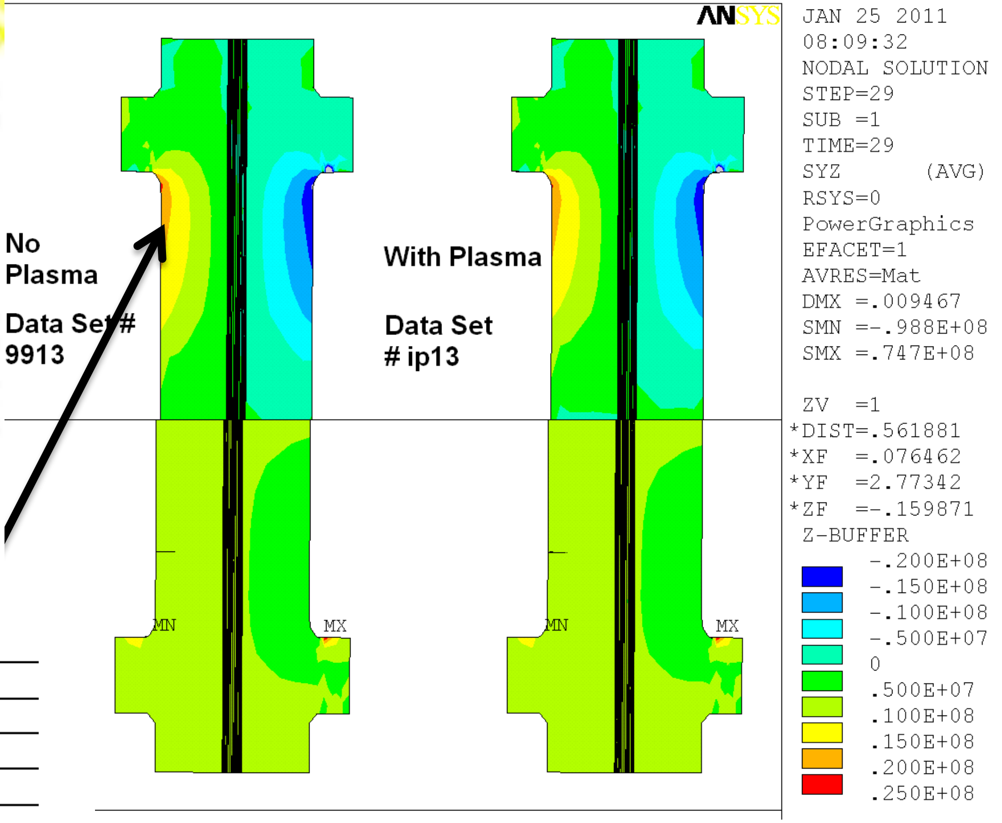


TF Coupled Thermal Electromagnetic Diffusion Analysis, (Part 2)
NSTXU-CALC-132-05-01,
Prepared By: Han Zhang, Reviewed by Yuhu Zhai,
Cognizant Engineer: Jim Chrzanowski

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







No Plasma

Data Set# 9913

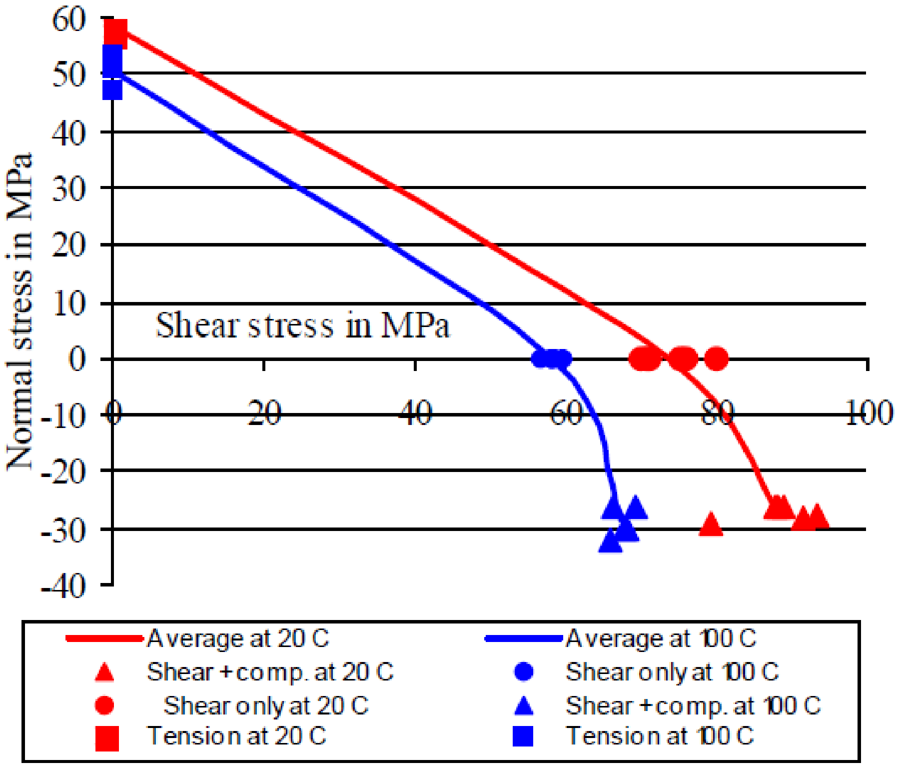
With Plasma

Data Set # ip13

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

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

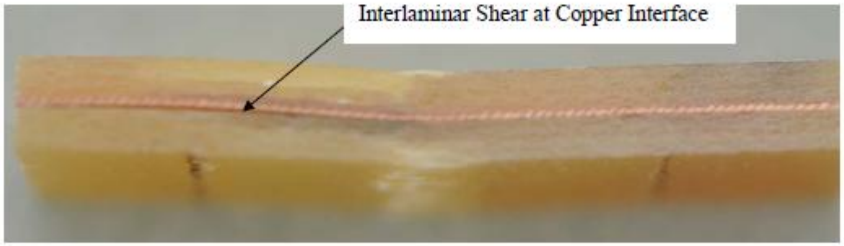
CTD 425 is a Blend which Uses the CTD 450 Cyanate Ester Primer . Adhesion of the insulation is expected to be governed by Cyanate Ester Properties. Zero Shear Tension Capacity at 80C is 60 Mpa.



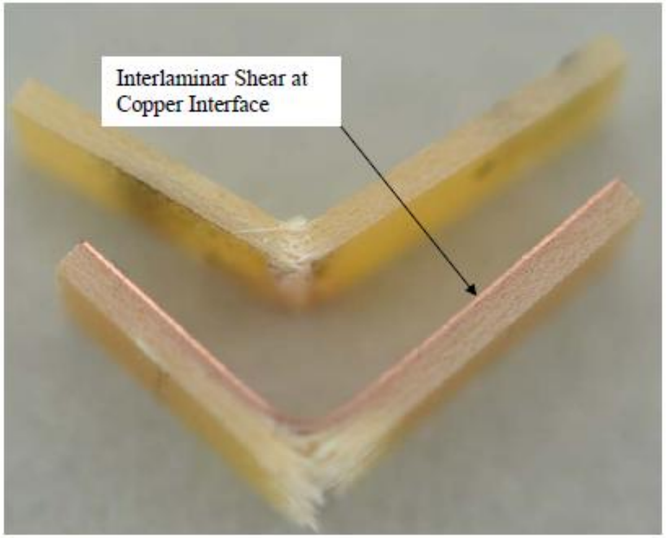
From Gary Voss Paper on Cyanate Ester

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

From the CTD 425 Fatigue Qualification:



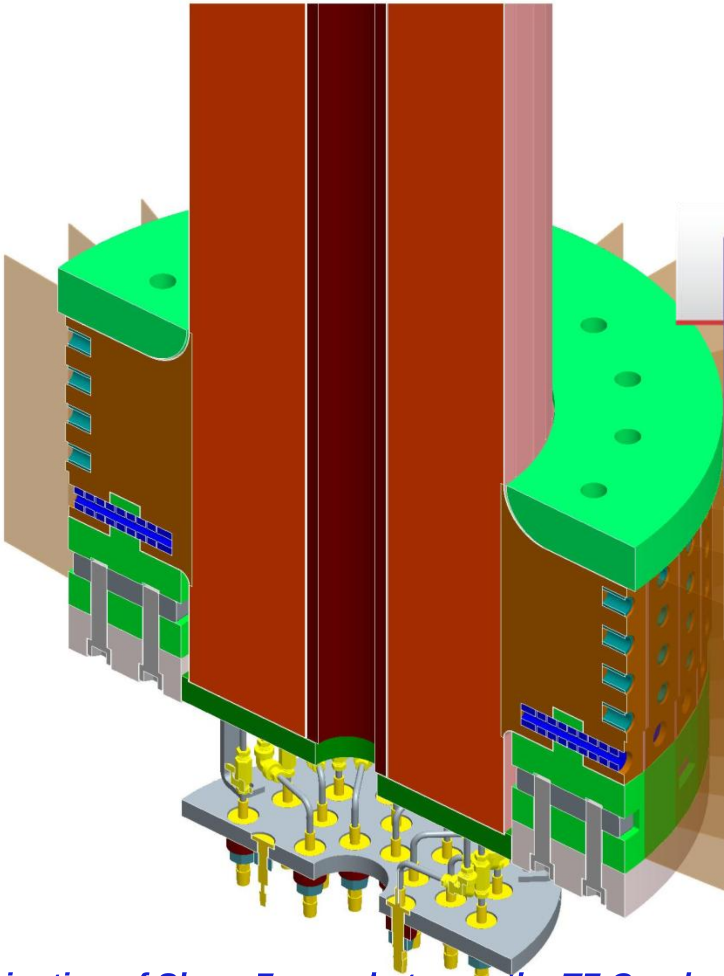
CTD-425 Specimen #15- Fatigue at 60% of Ultimate Stress (31 MPa, 21867 cycles)

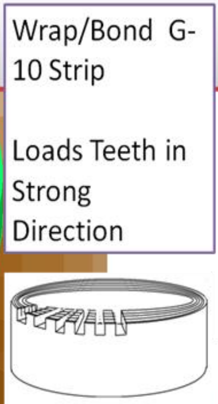


CTD-425 Specimen #14- Fatigue at 60% of Ultimate Stress (31 MPa, 26851 cycles)

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

The Upper and Lower G-10 Crowns Transmit Torsional Shear from the Spoked Lids to the TF Flag Extensions

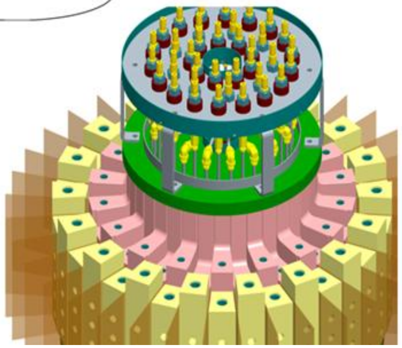


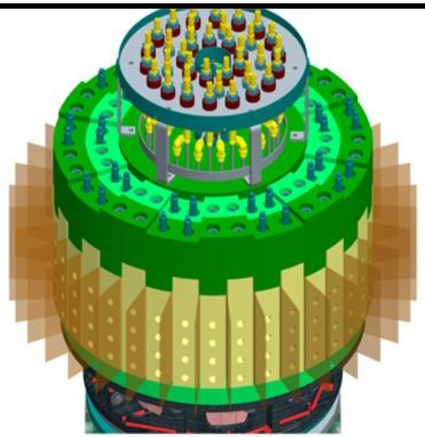


Wrap/Bond G-10 Strip

Loads Teeth in Strong Direction

The Final Design uses a Friction based Preloaded "Clutch Face" Approach. Figures Below Show Earlier Designs that Illustrate the Mechanics of the Interface

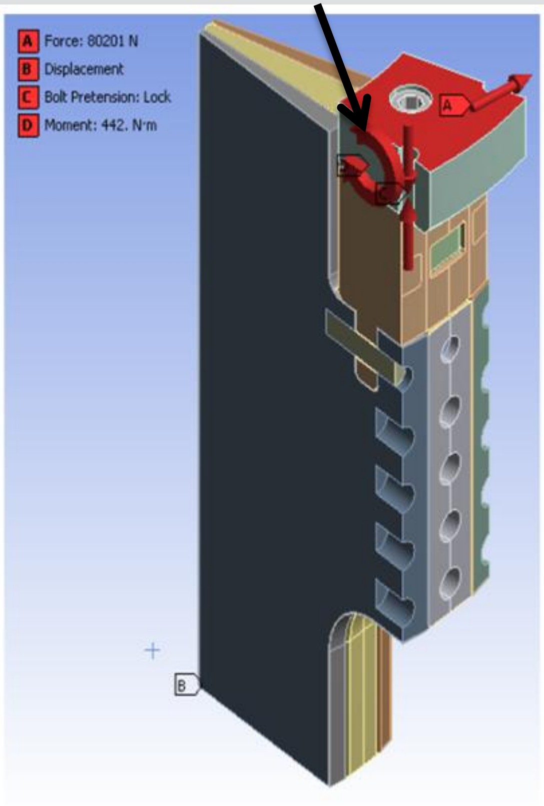


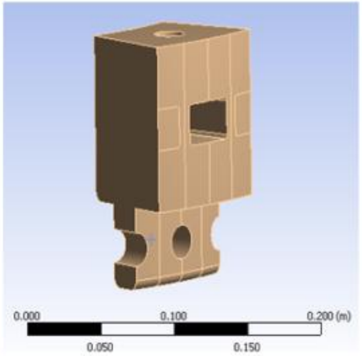


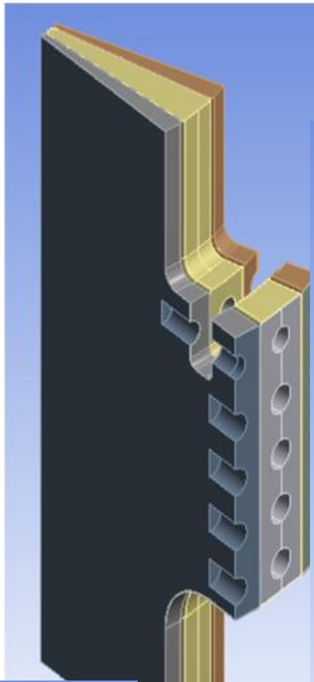
Determination of Shear Forces between the TF Conductors
NSTX-CALC-132-08-00
Prepared by: Ali Zolfaghari, Reviewed by: Tom Willard
Cognizant Engineering: Jim Chrzanowski

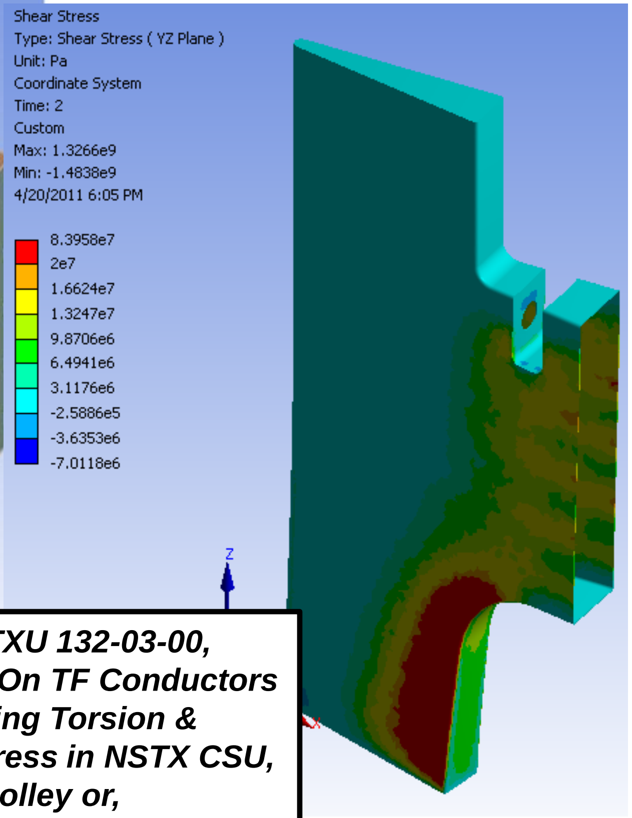
Pinned Connections are Used on Top and Bottom

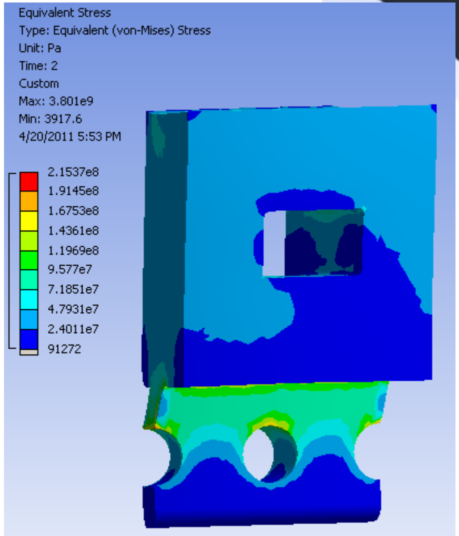
Moment From Spoked Lid Analysis









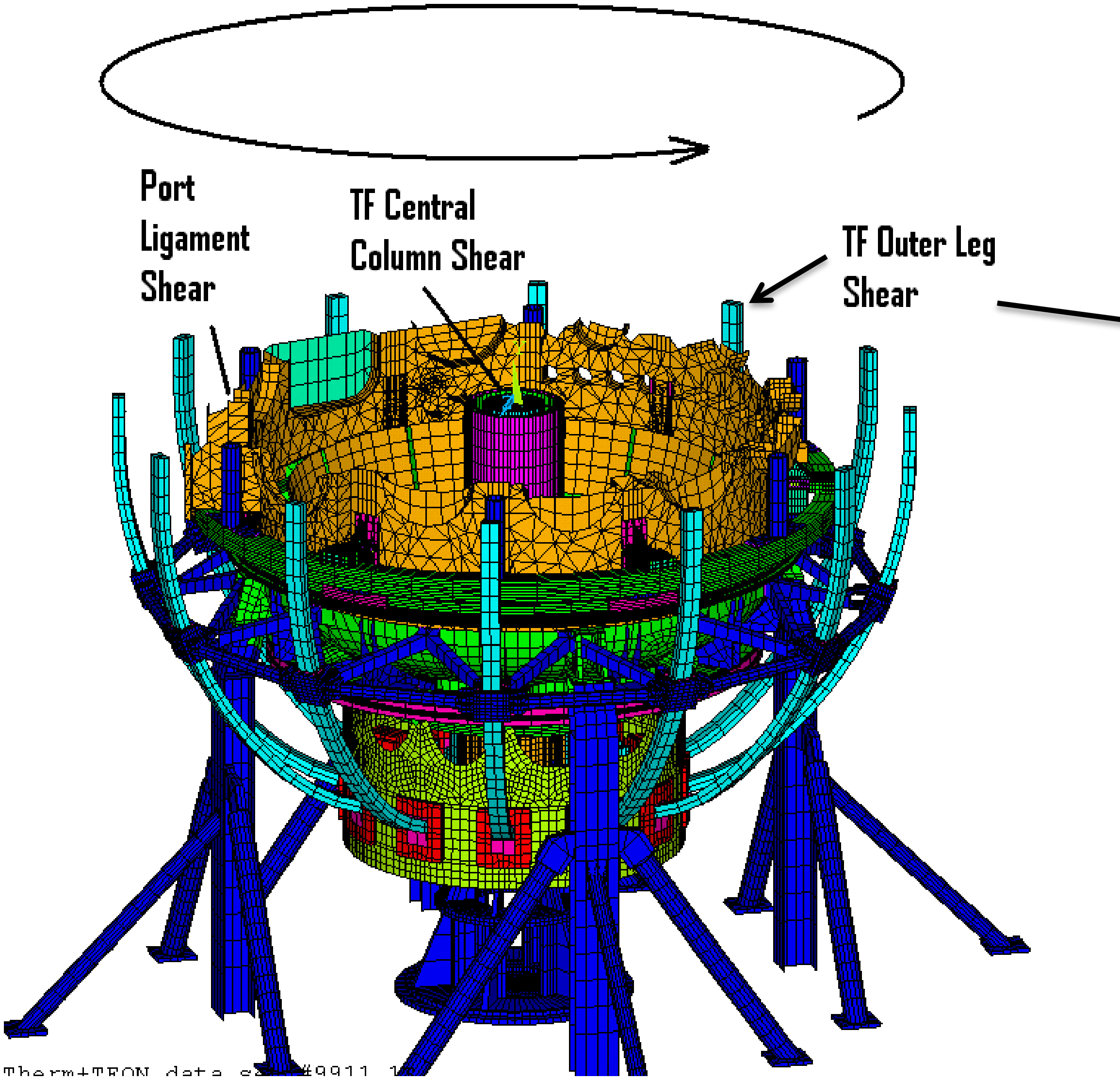


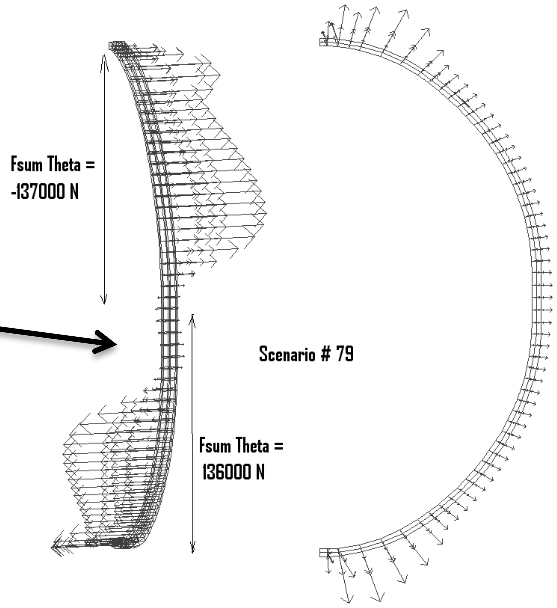
Determination of Shear Forces between the TF Conductors NSTX-CALC-132-08-00 Prepared by: Ali Zolfaghari, Reviewed by: Tom Willard Cognizant Engineering: Jim Chrzanowski

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.

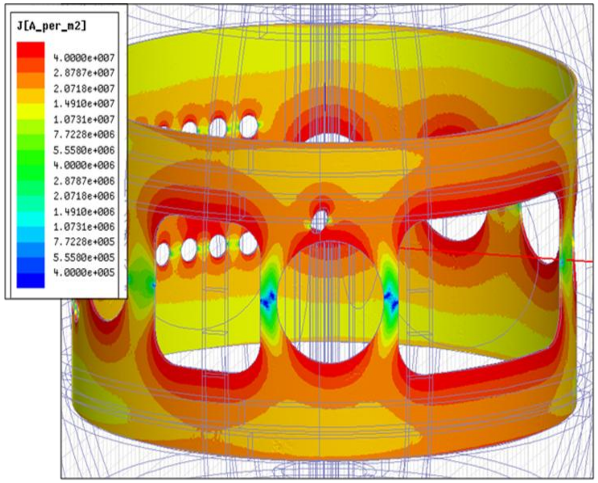
Out-of-Plane Torque Must be Taken by Existing Structural Load Paths – Can the Vessel Take It?

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

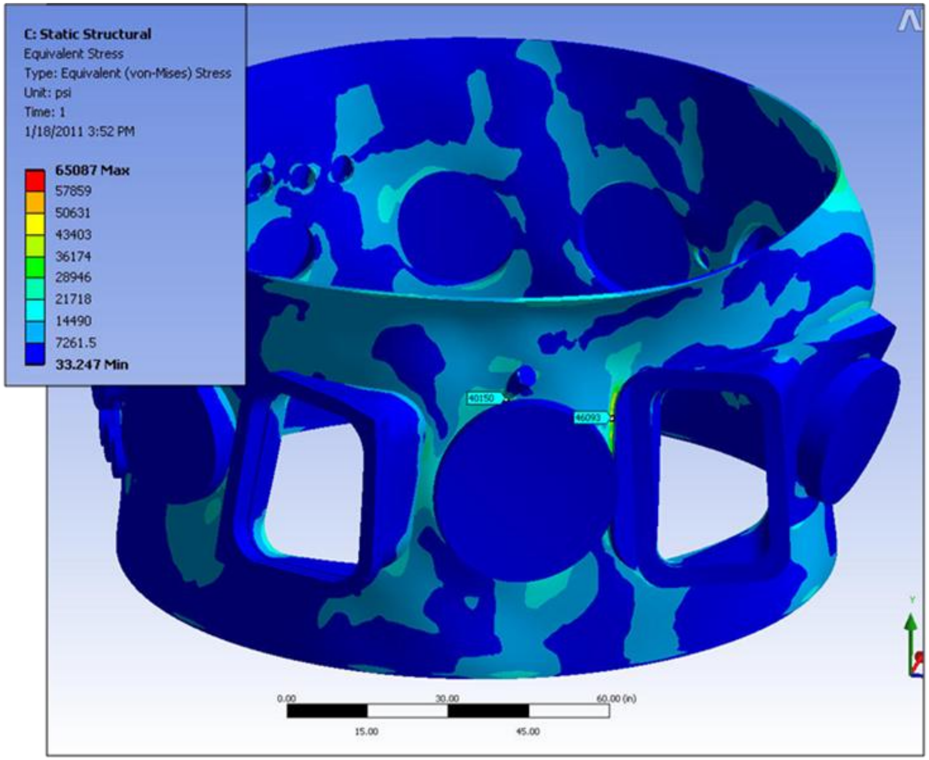
TF OOP Loads are Still transferred to Umbrella Structure and Knuckle Clevis

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

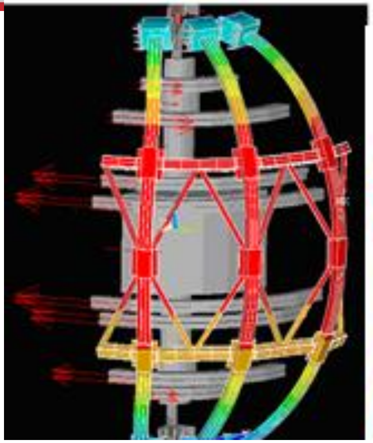


Eddy Current Density on Vacuum Vessel w/o Ports: End of Quench
1ms Centered-Plasma Disruption: Current Scenario #79 w/ Headroom Background Field

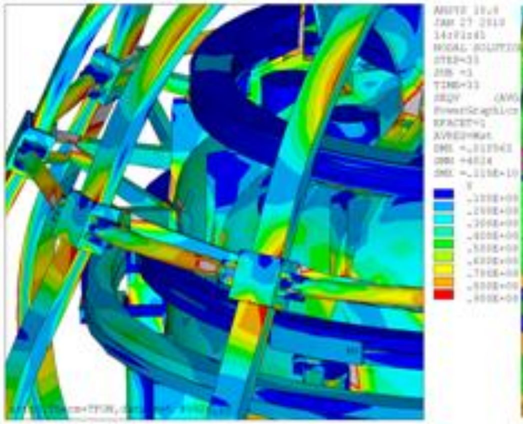


Static Structural Results, Ports Excluded from EM Solution: von Mises Stress
1ms Centered-Plasma Disruption: Current Scenario #79 w/ Headroom Background Field

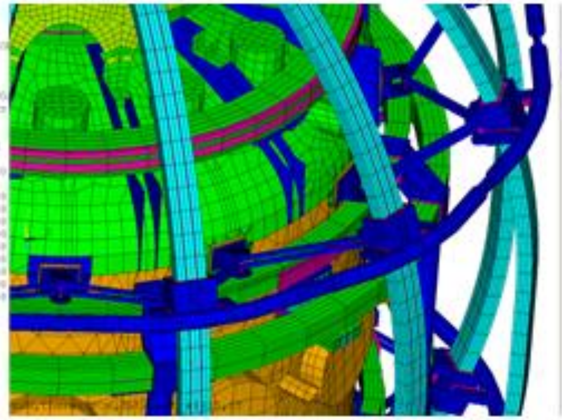
Outer Leg In-Plane and Out-of-Plane Support Many Concepts Were Tried – Many had Interference Problems



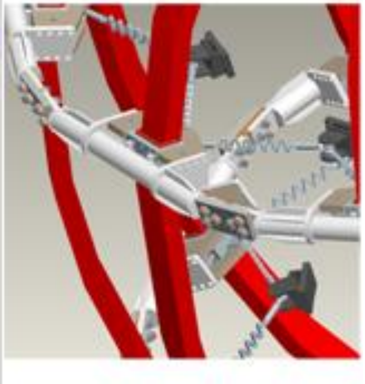
Diamond Truss



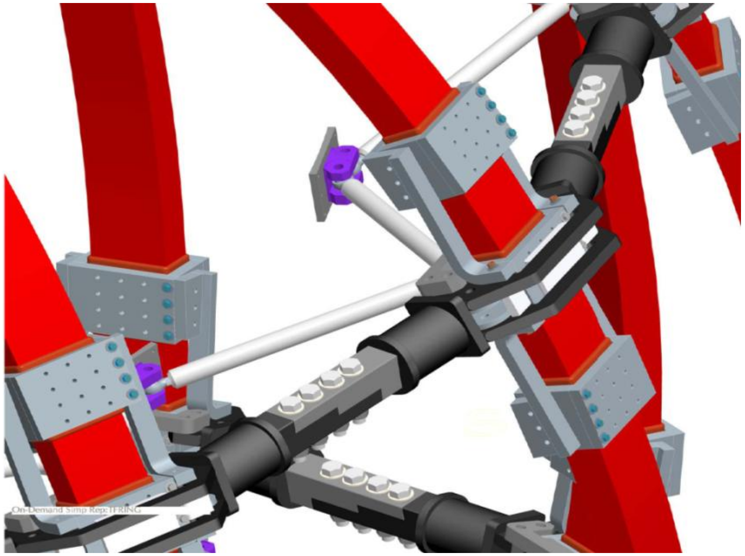
Pinned Ring Rigid Truss



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

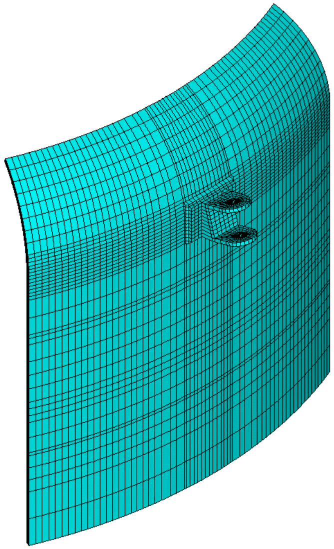
Displacements

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

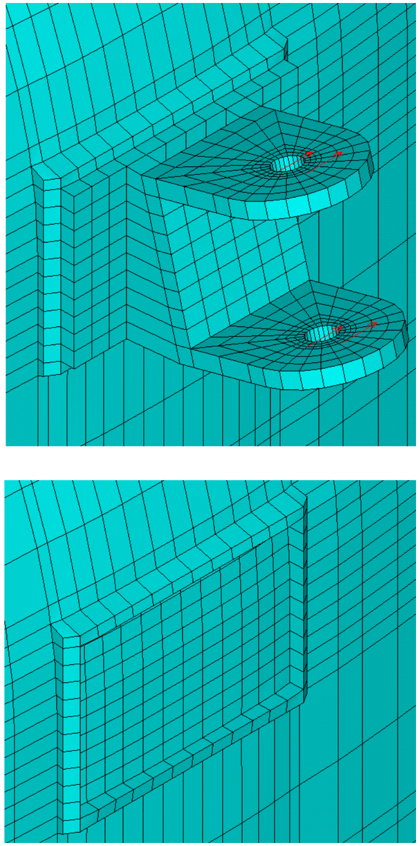
Existing Clevis Was Offset From the Surface of the Vessel and Was Held On by 5/16 Screws – It Had Little Load Capacity

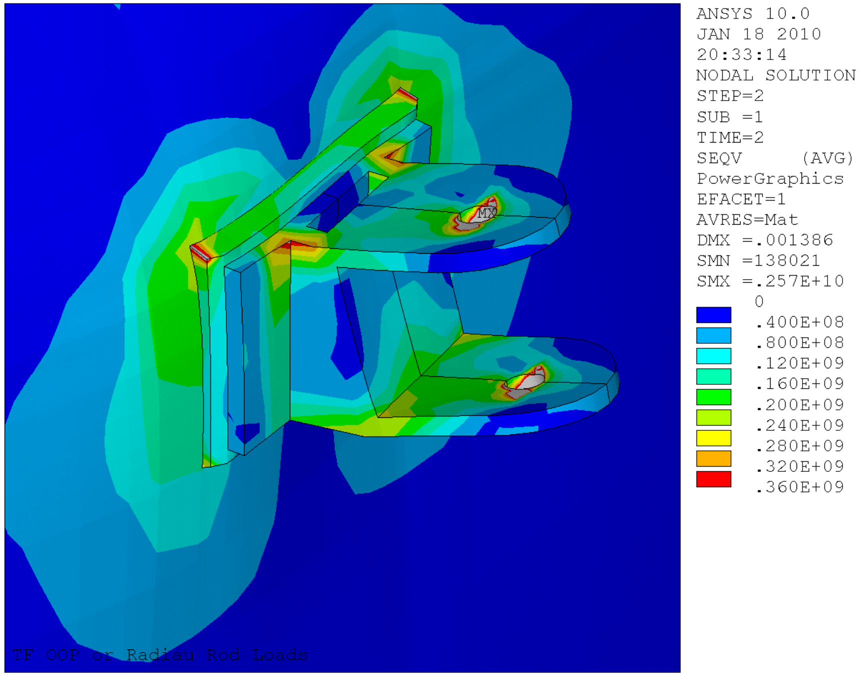
TF Truss or Radius Rod Lug

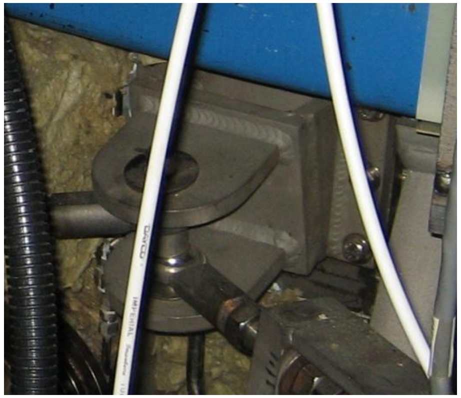


Actual (2009) Weld Size is 3/16

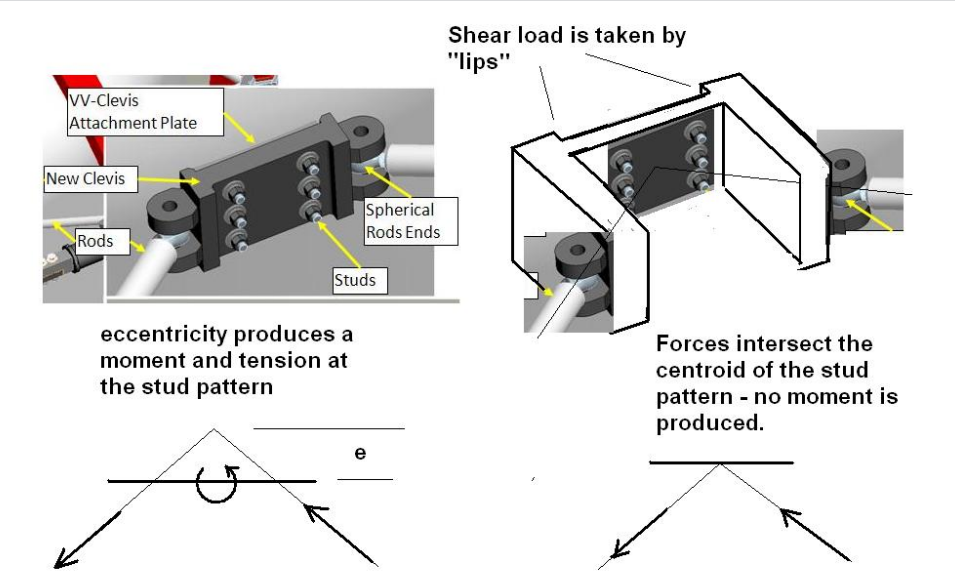
Model Weld is 8.6mm







Welded Clevis Replacement

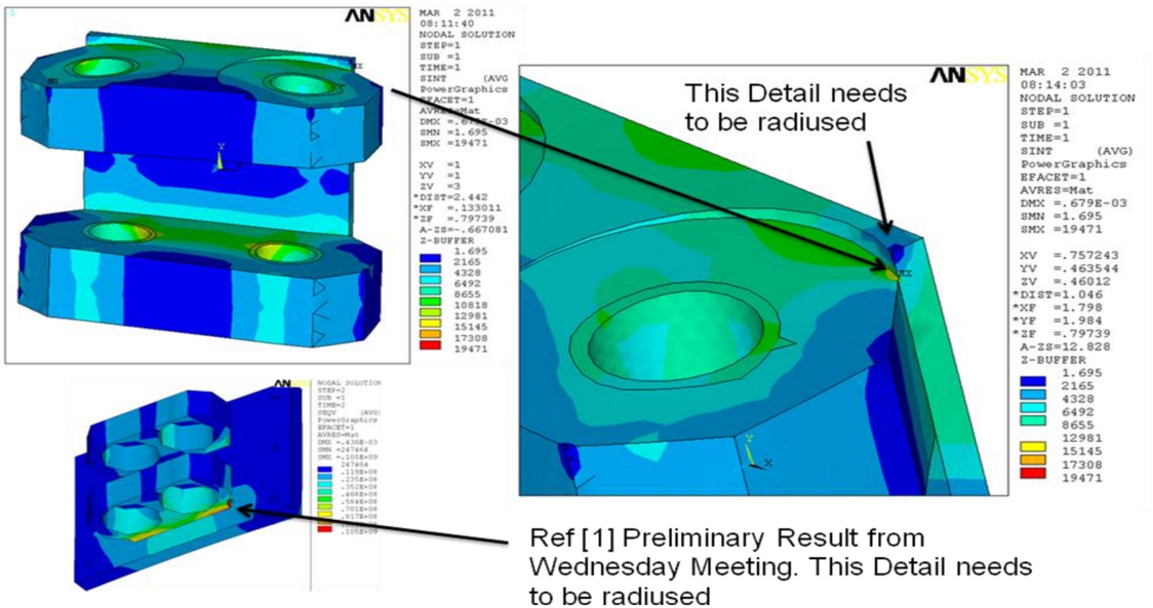


Shear load is taken by "lips"

eccentricity produces a moment and tension at the stud pattern

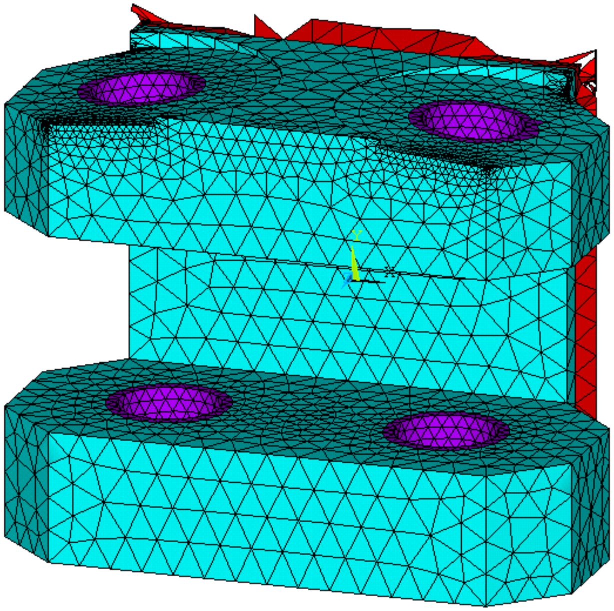
Forces intersect the centroid of the stud pattern - no moment is produced.

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



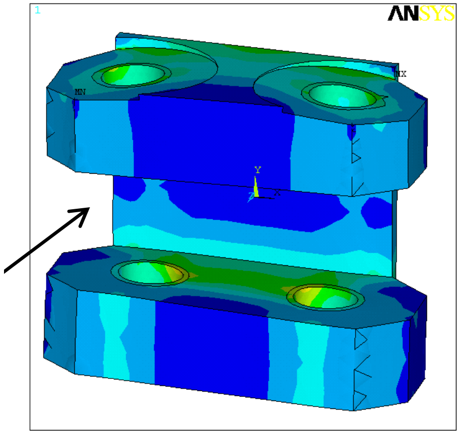
Materials and Allowables

718 Typical Mechanical Properties At Room Temperature:

Ultimate Tensile Strength	*Yield Strength (0.2 % offset)*	*Elongation in 50 mm (2")*	*Elastic Modulus (Tension)*
MPa ksi	*MPa ksi %*		*GPa 10^6 psi*
1240 180	*1036 150*	*12*	*211 30.6*

1/3 Ult=60ksi *2/3 yield=100 ksi* *Sm=60ksi*

*The allowed shear stress is .6*sm = 36 ksi Ref NSTX Criteria Doc*



Pins are .75 inch in this model, but they must be tight fitting or there are bending Stresses.

*The pin shear is 22185/(.75^2*pi/4)/2 = 24.1ksi for 3/4 pins in double shear*

*The pin shear is 22185/(1.0^2*pi/4)/2 = 14.1ksi for 1 inch pins in double shear*

*Actual Pin shear with 1.5 shear stress peak for ¾ in pins is 24.1*1.5 =36.75ksi*

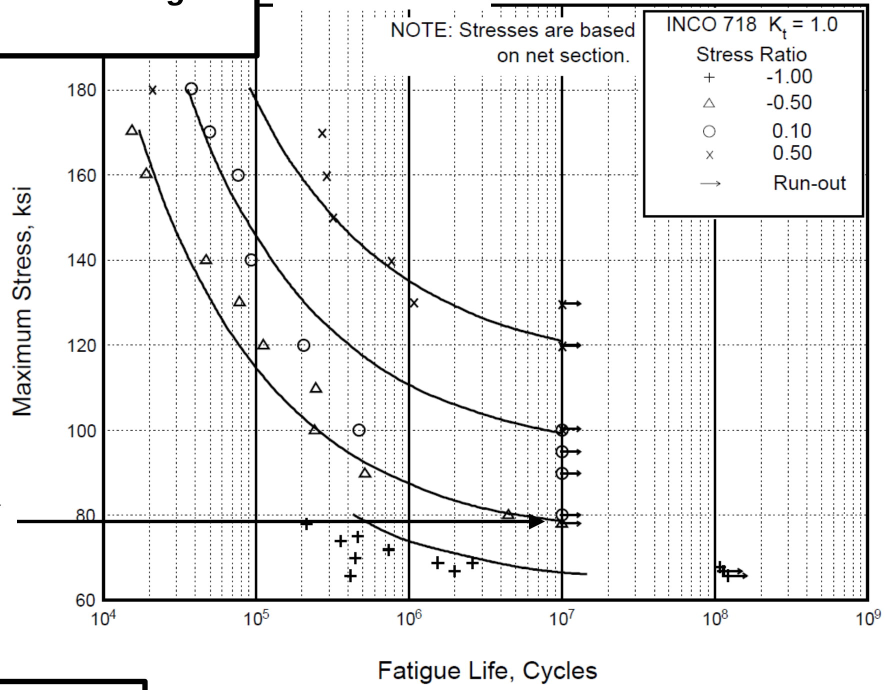
Tresca is then 73.5 ksi,

for 2 on stress or
147 ksi for r=0 (circles), Life = ~90000 cycles

90000>60000 (NSTX GRD)

For Tresca = 73.6, life>1e7

1e7/60000 = 167 >> 20

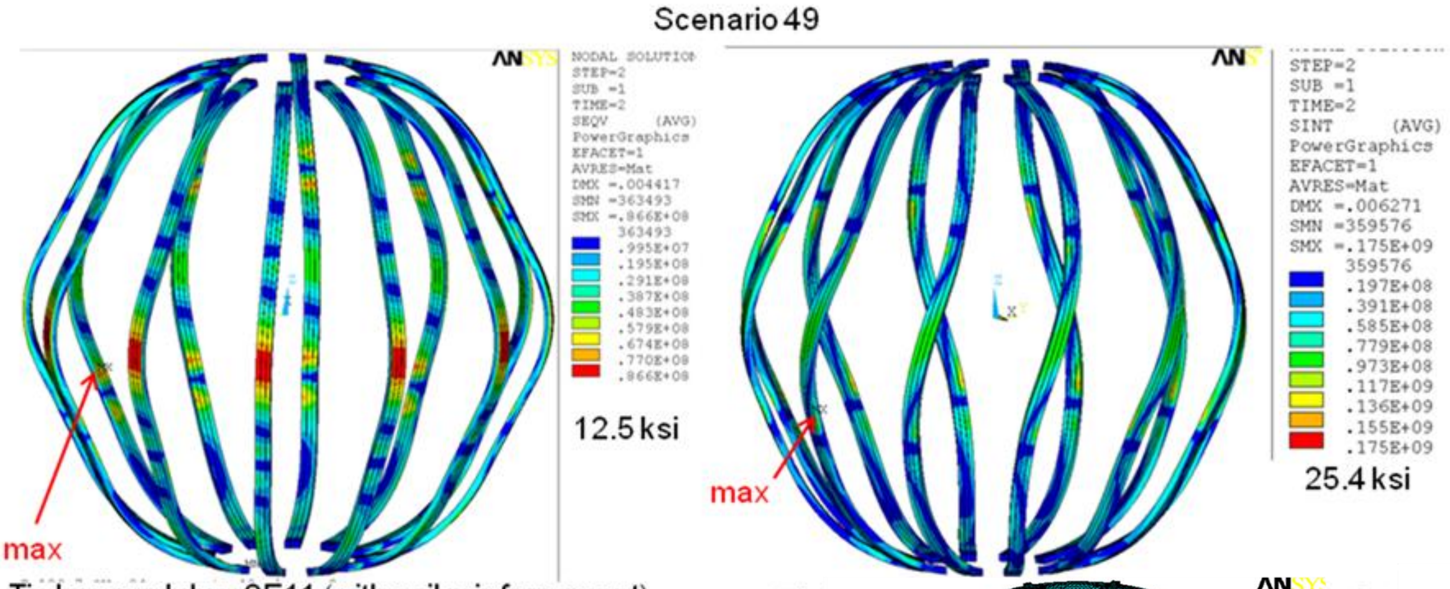


Best-fit S/N curves for unnotched Inconel 718 bar and plate at ro udinal direction.

Satisfies the GRD Requirement for 60,000 cycles

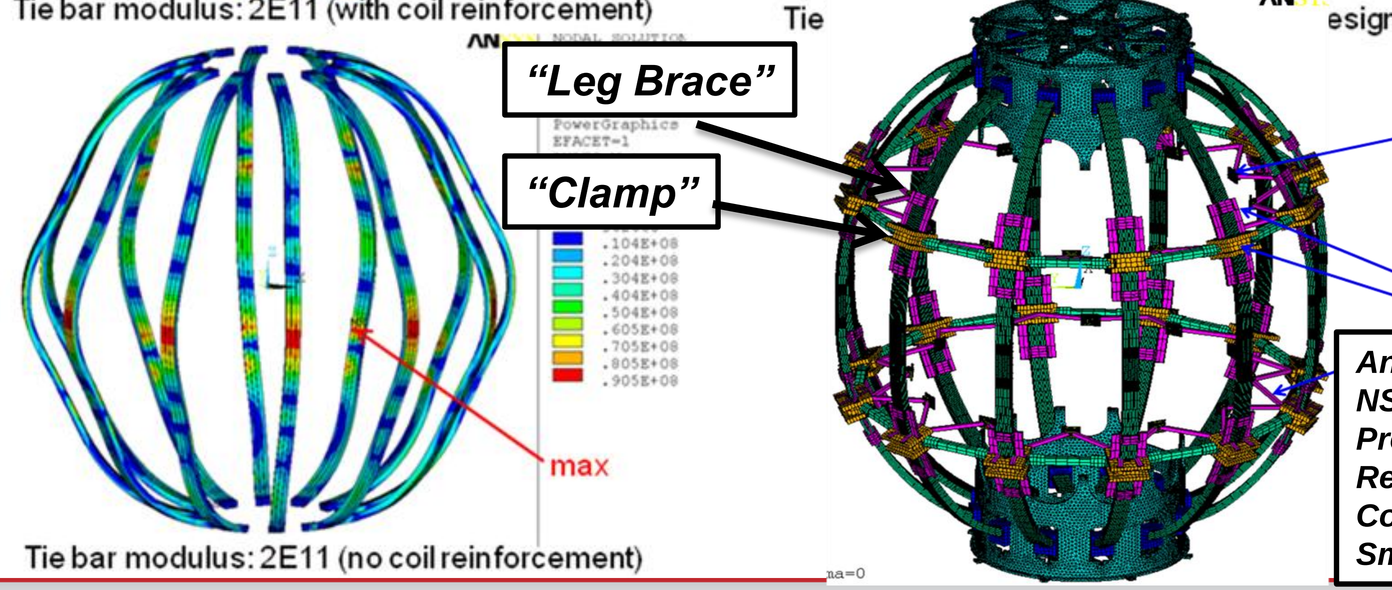
Clamps Produce Local Stress Concentrations – Leg Braces Help – Do we Need Them?

Scenario 49



Tie bar modulus: 2E11 (with coil reinforcement)

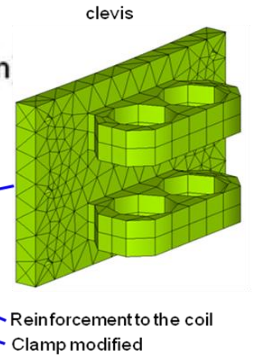
This is the result with/without coil reinforcement. Without reinforcement, max stress is 90MPa. With reinforcement, it reduces to 86MPa. Comparing with previous spring design, 175MPa, it seems the tie bar stiffness is the main factor for coil stress..



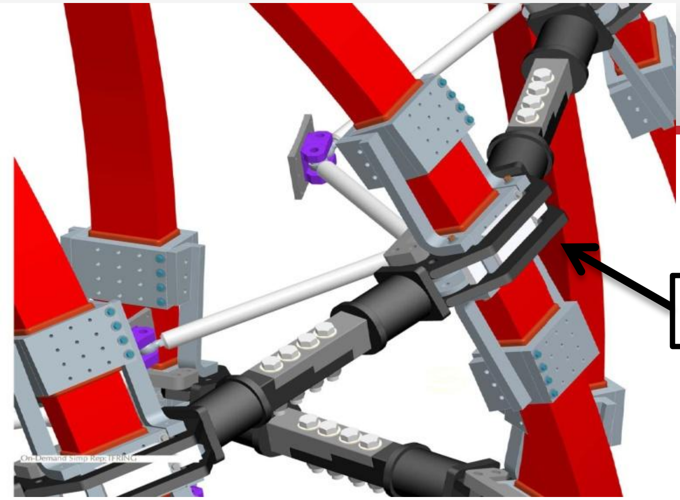
"Leg Brace"

"Clamp"

Tie bar modulus: 2E11 (no coil reinforcement)

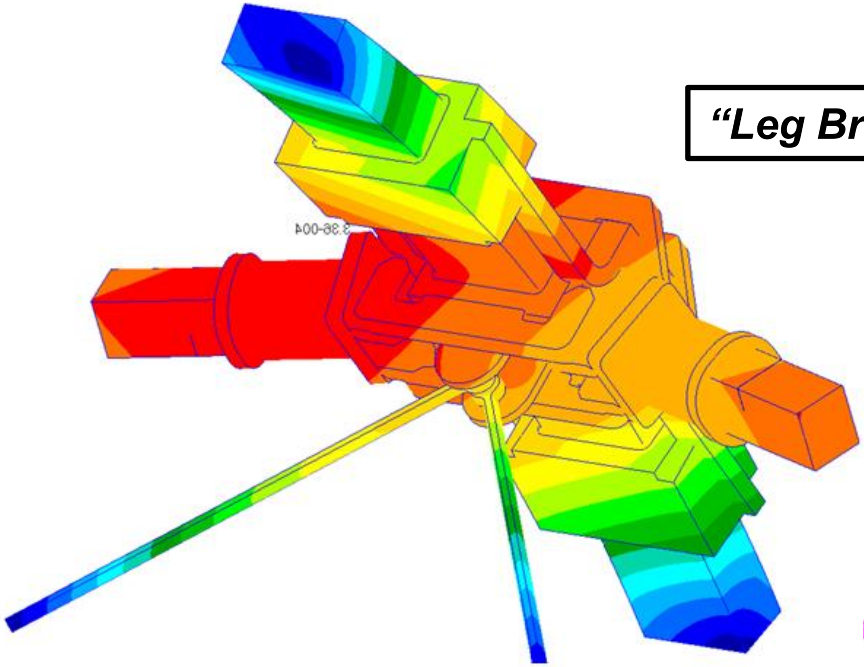


Analysis of TF Outer Leg, NSTXU-CALC-132-04-00, Prepared By: Han Zhang, Reviewed by Peter Titus Cognizant Engineer: Mark Smith



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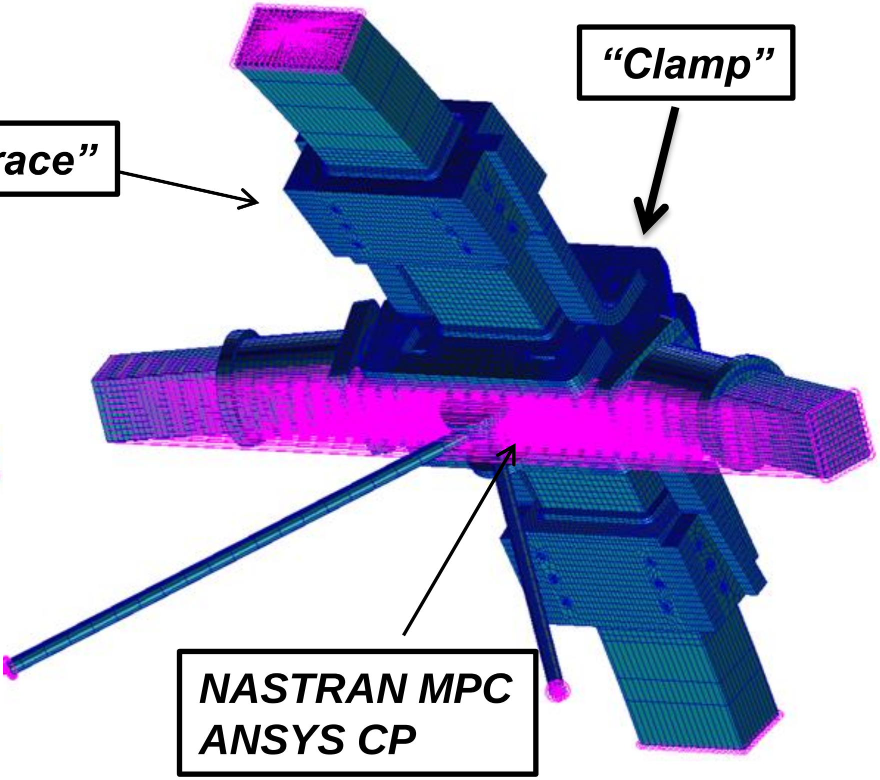
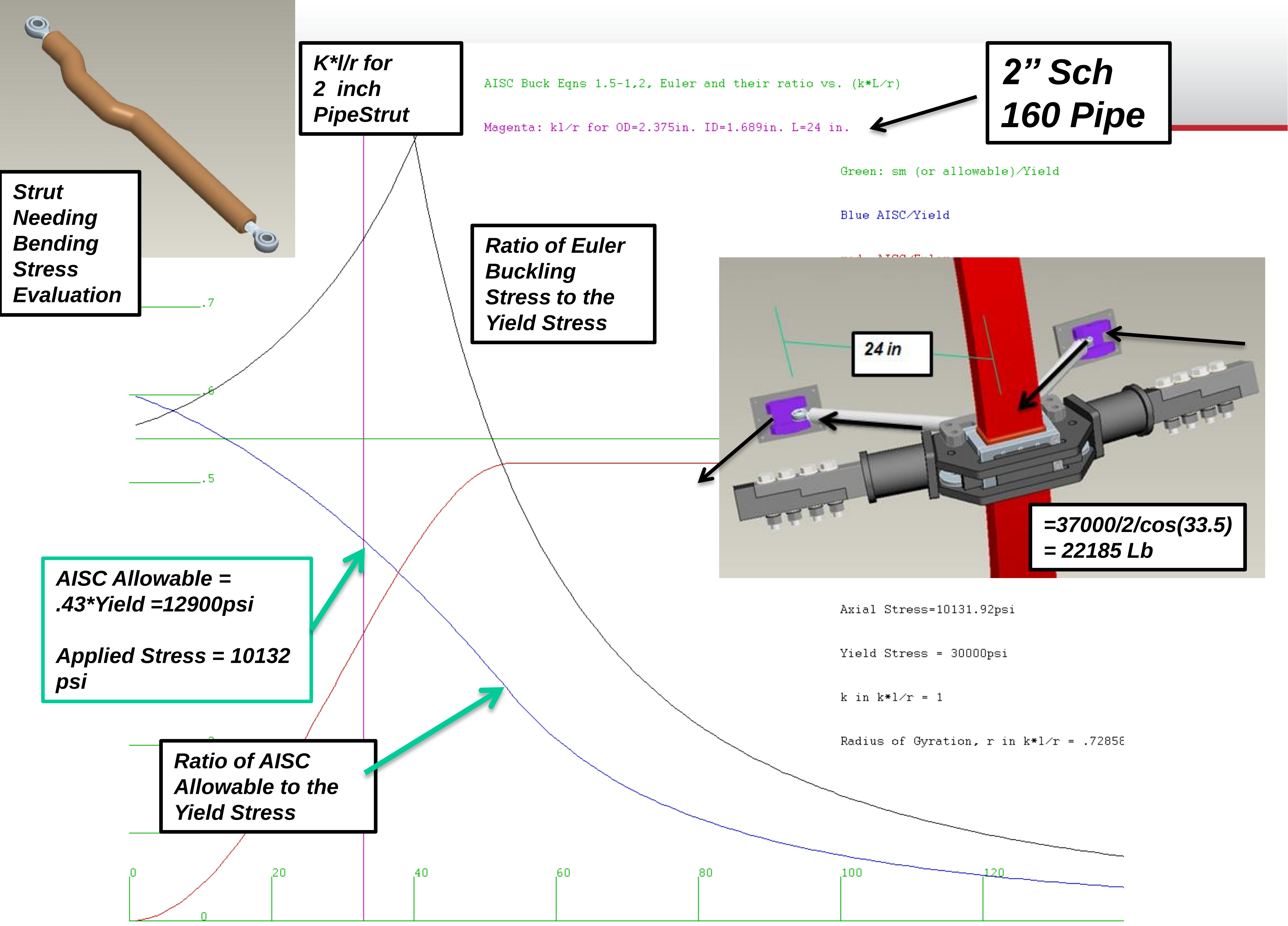
Fringe: Default, A1:Static Subcase, Displacements, Translational, Magnitude, (NON-LAYERED)

“Leg Brace”



“Clamp”

NASTRAN MPC
ANSYS CP



Strut Needing Bending Stress Evaluation

K*l/r for 2 inch PipeStrut

2" Sch 160 Pipe

```
AISC Buck Eqns 1.5-1,2, Euler and their ratio vs. (k*L/r)

Magenta: kl/r for OD=2.375in. ID=1.689in. L=24 in.

Green: sm (or allowable)/Yield

Blue AISC/Yield
```

Ratio of Euler Buckling Stress to the Yield Stress

=37000/2/cos(33.5) = 22185 Lb

```
Axial Stress=10131.92psi

Yield Stress = 30000psi

k in k*l/r = 1

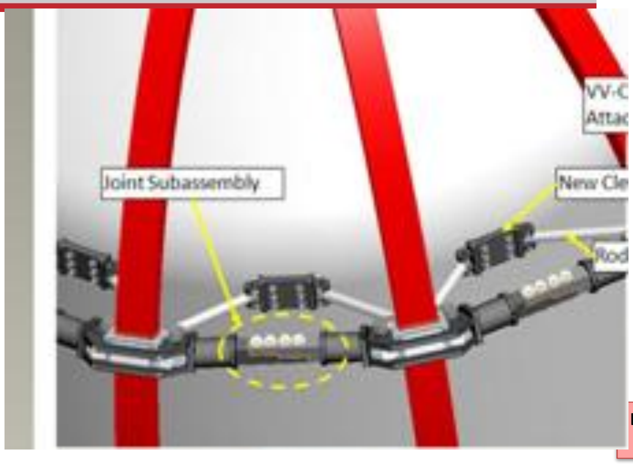
Radius of Gyration, r in k*l/r = .7285
```

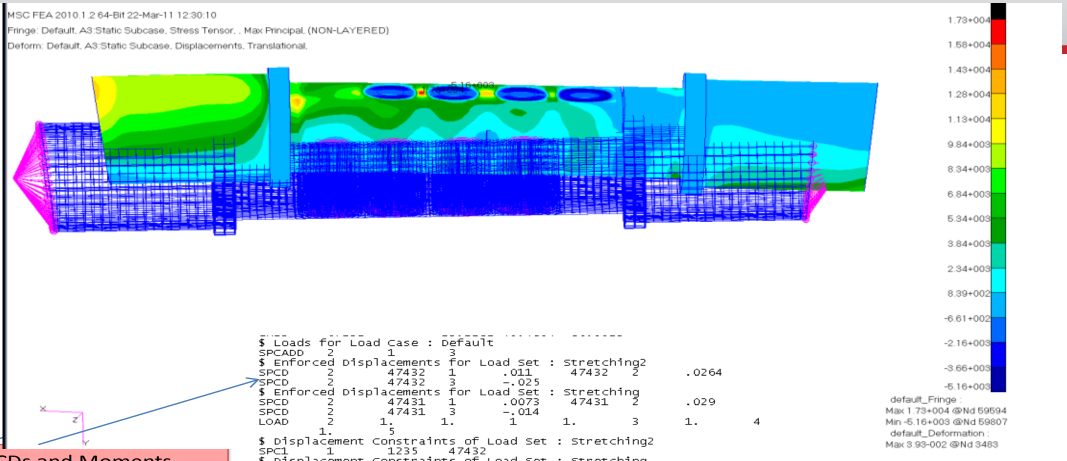
AISC Allowable = .43*Yield =12900psi

Applied Stress = 10132 psi

Ratio of AISC Allowable to the Yield Stress

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

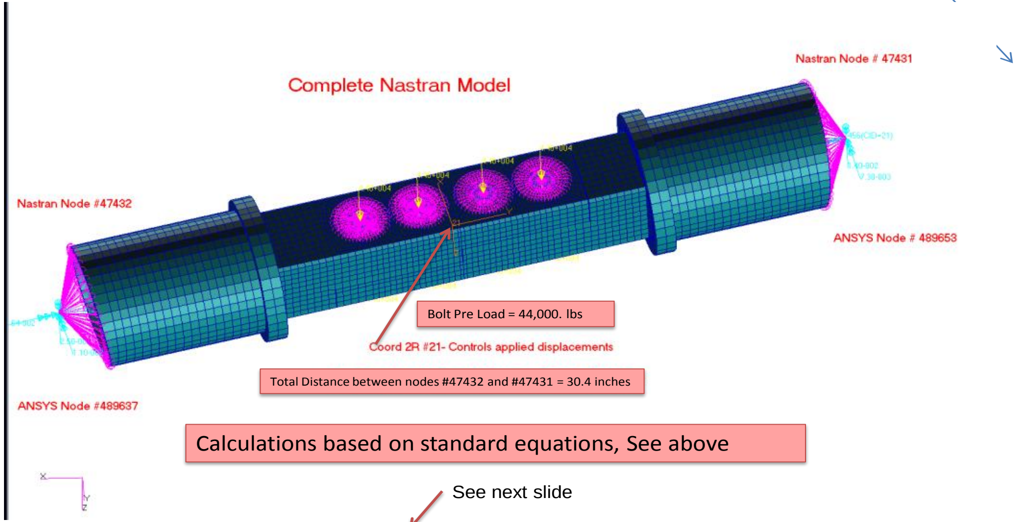




Loads with SPCDs and Moments
Total Loads

```
$ 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
```

Complete Nastran Model



Nastran Node # 47431

Nastran Node #47432

ANSYS Node # 489653

ANSYS Node #489637

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

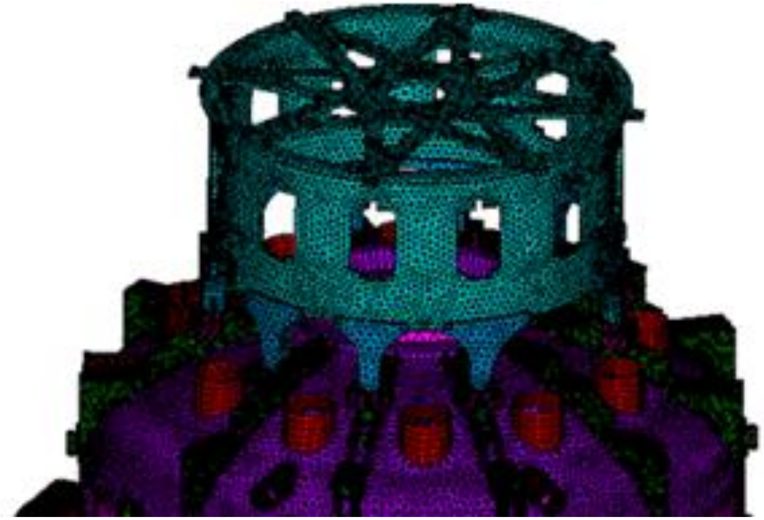
See next slide

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

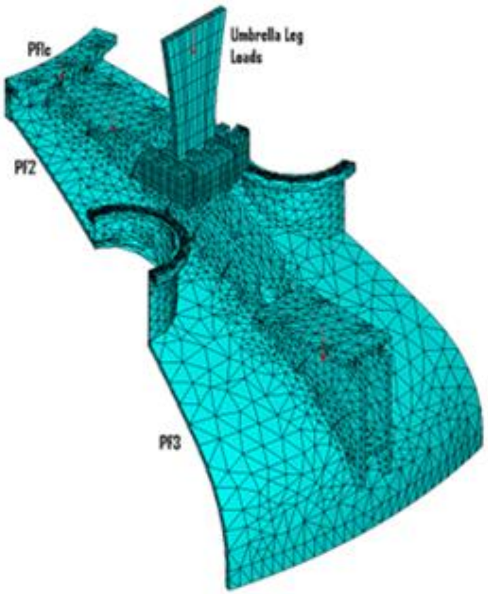
Fp = 66.7ksi x .663in^2 = 44.22 Kips per bolt, If mu = .3, Fs = 44.22 Kips X .3 = 13,266 lbs/bolt
Typical “nut factor” see the torque equation
For two bolts Fs= 26532. lbs And required torque = 44,220 lbs. x .2 x 1.0 in.= 8,844 lb-in

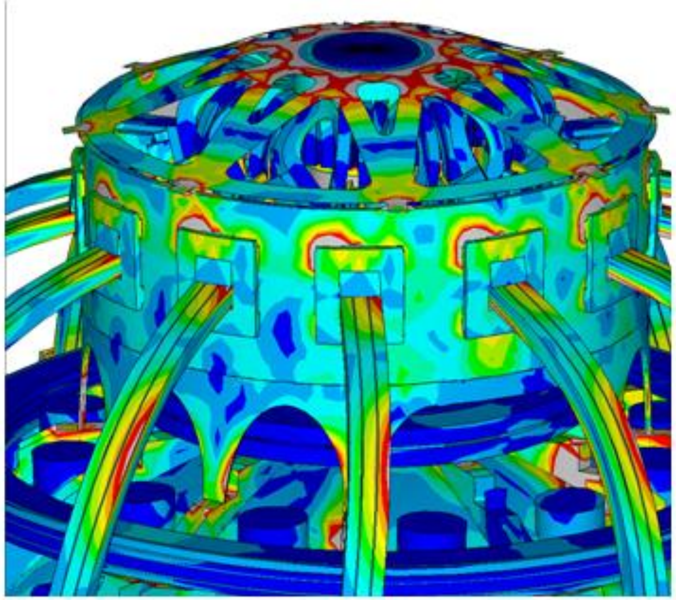
WBS 1.1.2 Ring Bolted Joint,
NSTXU-CALC-132-11-00
Prepared By: Peter Rogoff,
Reviewed By Irv Zatz,
Cognizant Engineer: Mark Smith

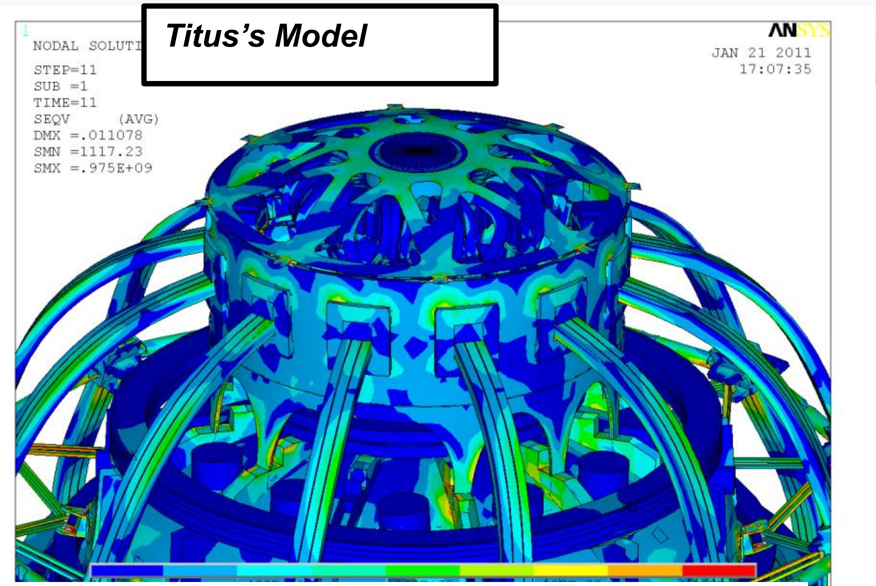
Out-of-Plane Loads Are Transferred from the TF to the Vessel Via the Umbrella Structure as Well. Original Legs Were Too Weak



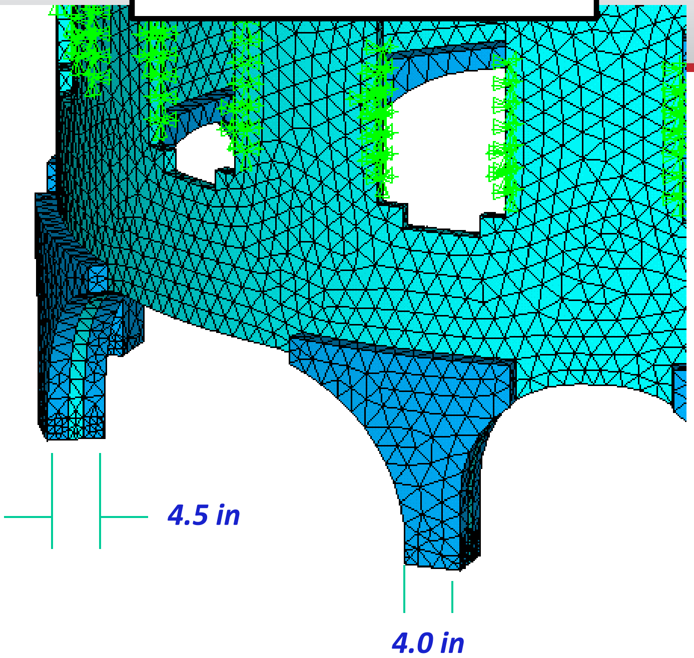
WBS 1.1.2 NSTX Upgrade Umbrella Arch and Foot Reinforcements, Local Dome Details, NSTXU-CALC-12-07-00 May 2011Prepared by: Peter Titus, Han Zhang, Reviewed By: Irv Zatz, Cognizant Engineer: Mark Smith



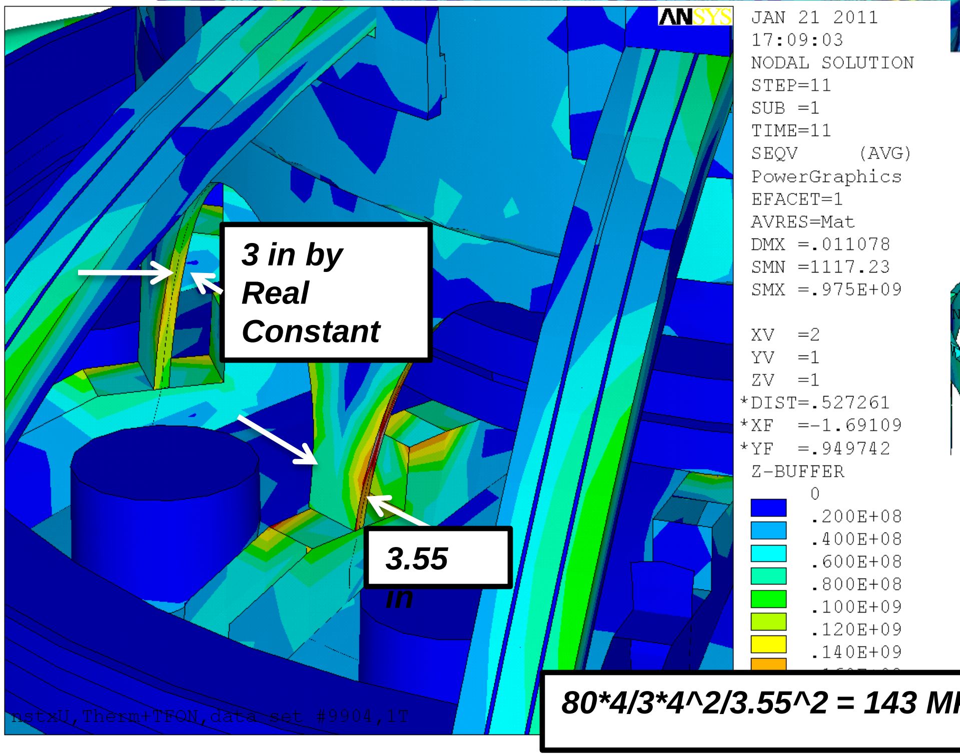




Titus's Model



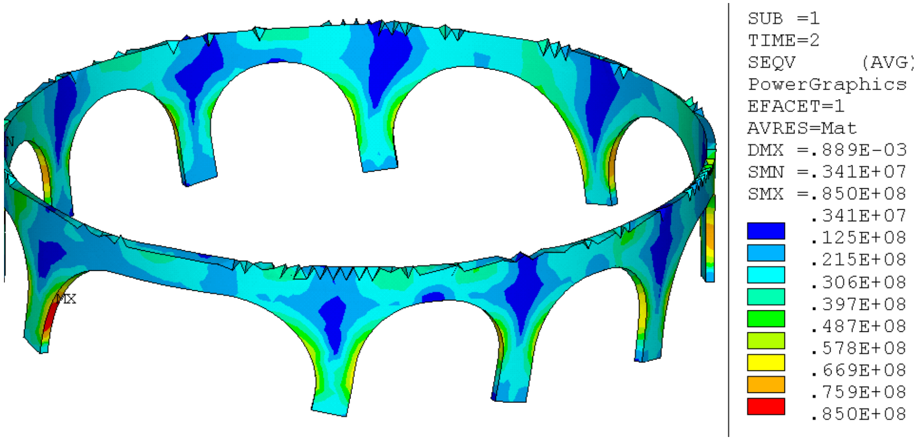
Han Zhang's Model



3 in by Real Constant

3.55 in

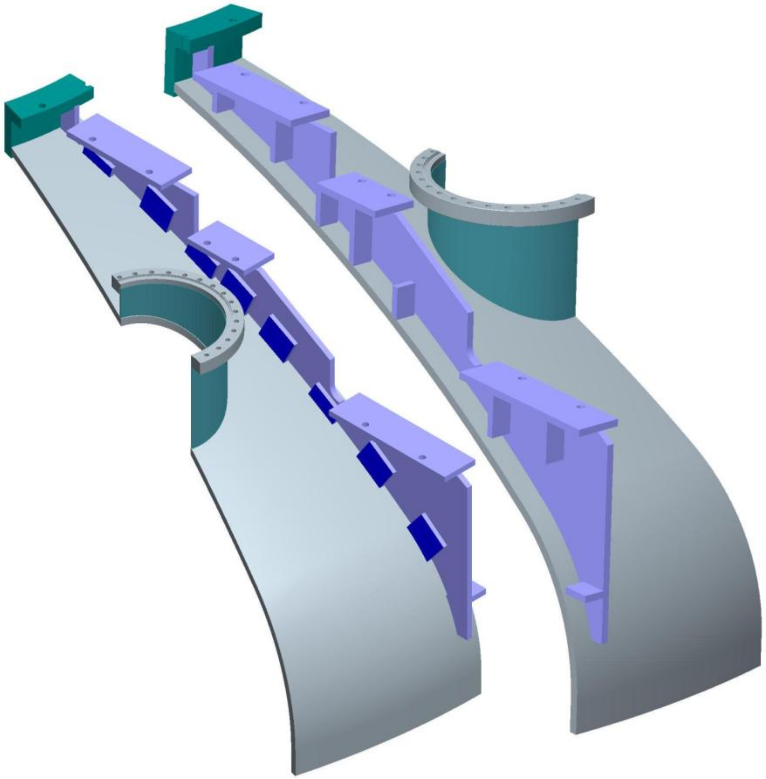
80*4/3*4^2/3.55^2 = 143 MPa

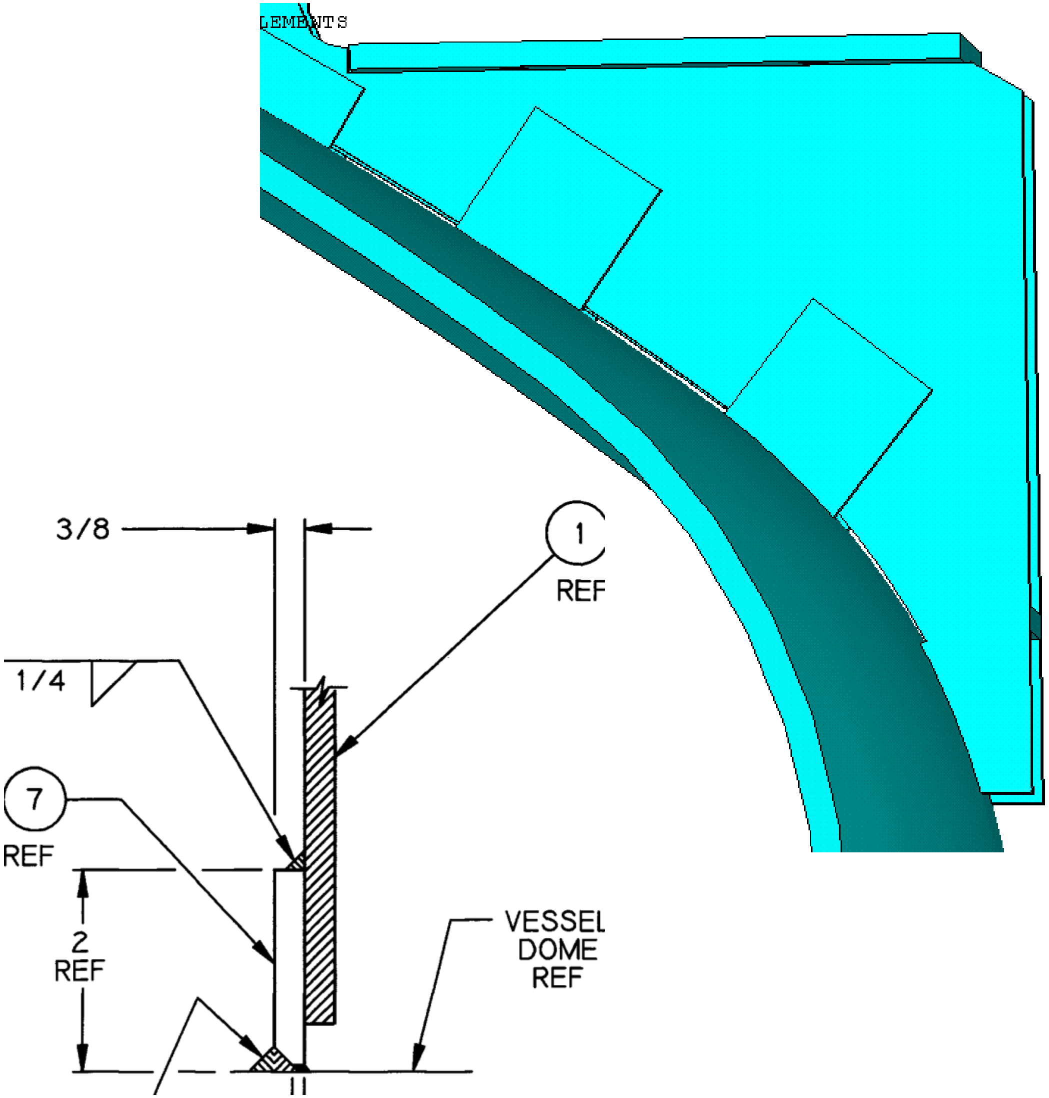


WBS 1.1.2 NSTX Upgrade Umbrella Arch and Foot Reinforcements, Local Dome Details, NSTXU-CALC-12-07-00 May 2011Prepared by: Peter Titus, Han Zhang, Reviewed By: Irv Zatz, Cognizant Engineer: Mark Smith

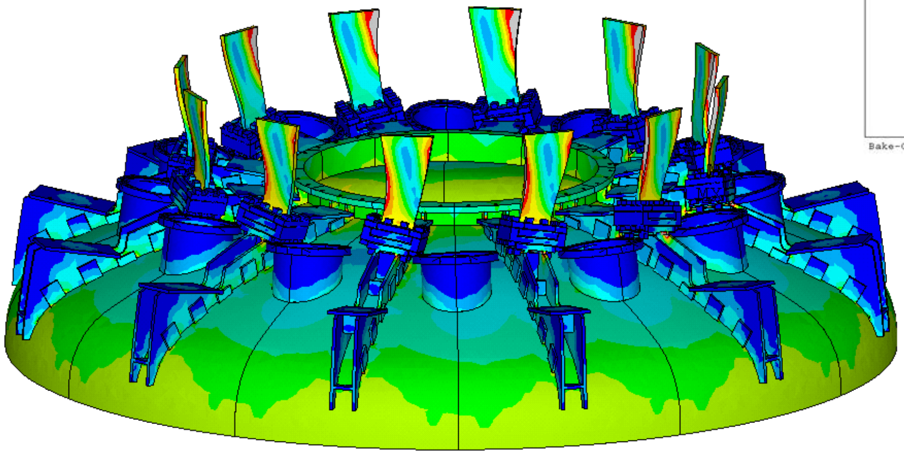
OOP and Vertical Load from Umbrella Legs, PF1c 2,and 3 Loads are Applied to the Ribs. Solid Models Needed Updating

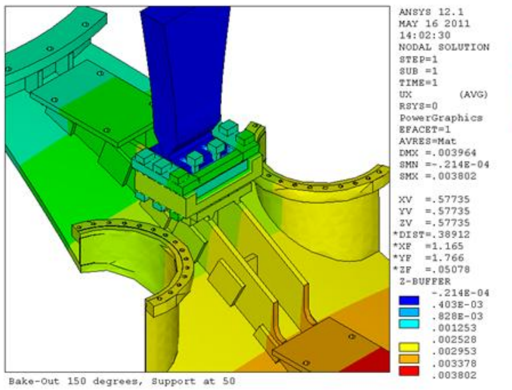
Bruce Paul Built the Solid Model of the Dome Rib Based on Non-Conformance Report

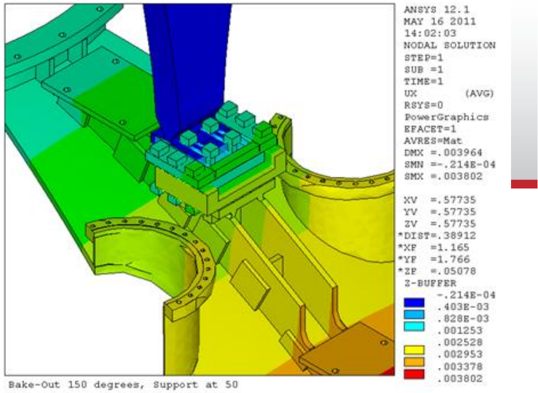




Dished Head Supports PF1c,2, and 3 Loads



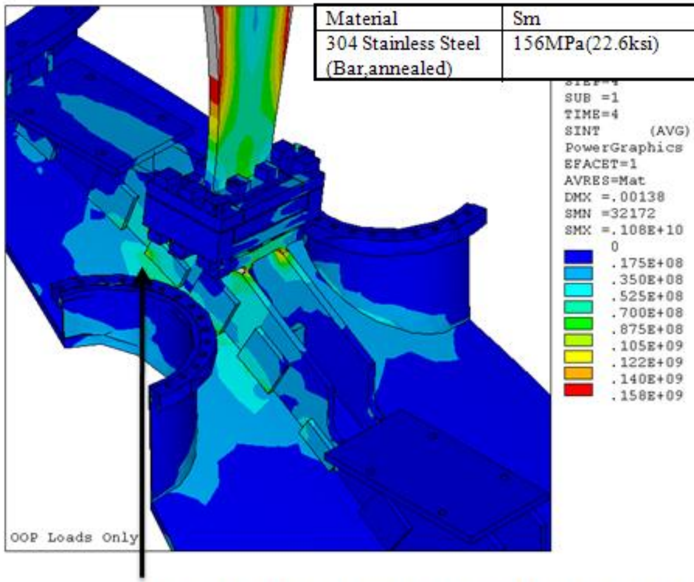


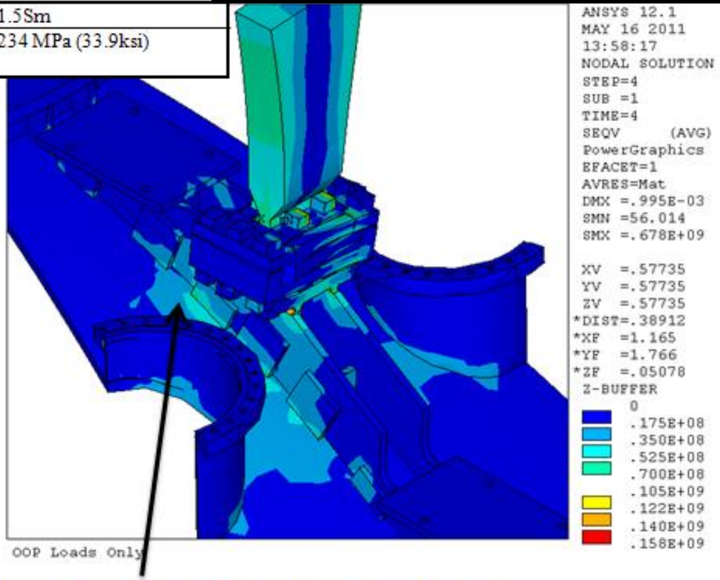


Sliding Block Allows Bake-Out Motion

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

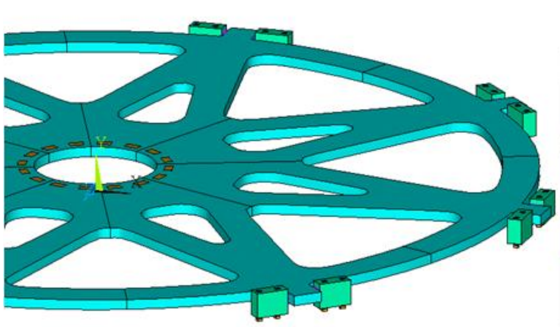
Material	Sm	1.5Sm
304 Stainless Steel (Bar,annealed)	156MPa(22.6ksi)	234 MPa (33.9ksi)



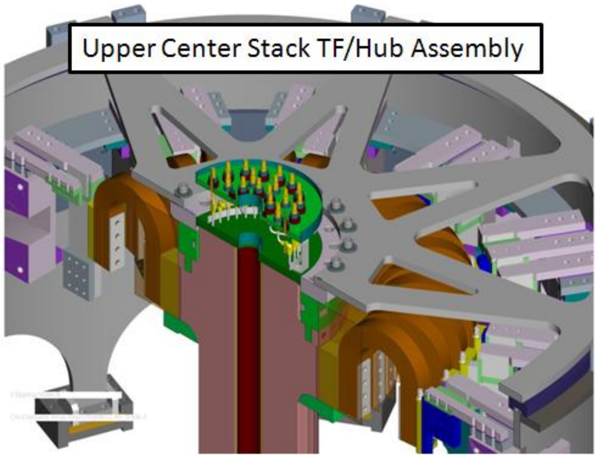


The Thicker Umbrella Structure Slightly Reduces the Dome Stress

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

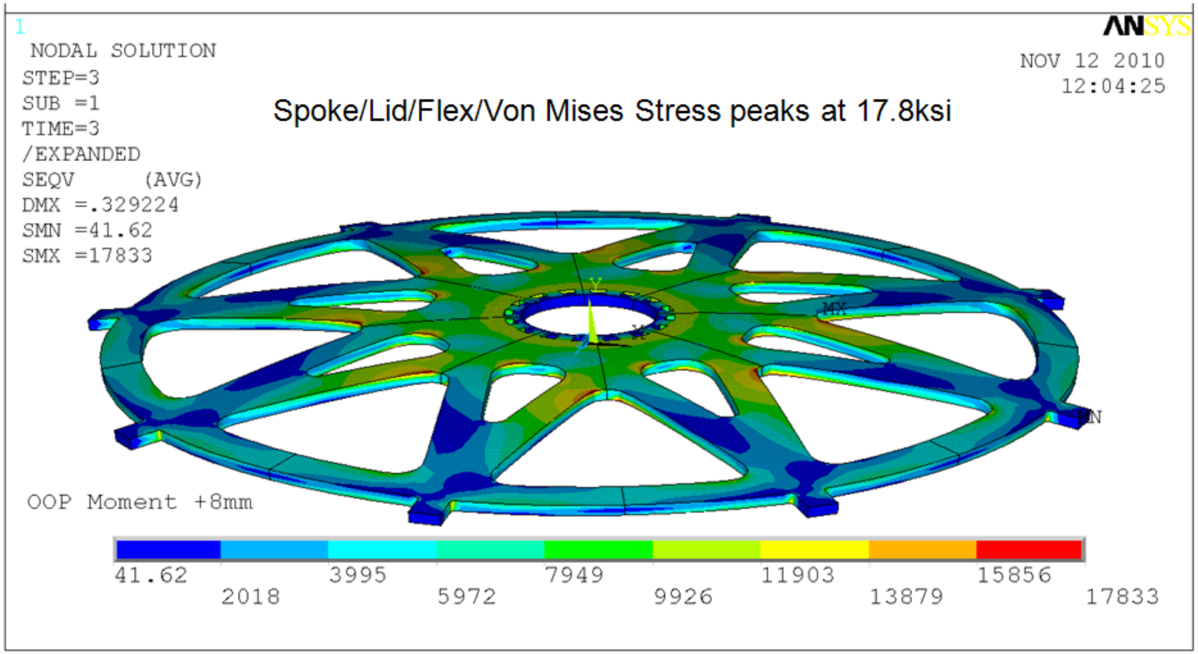


Spoked Lid/Flex 45 degree FEA Model – With Symmetry Expansion



Upper Center Stack TF/Hub Assembly

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

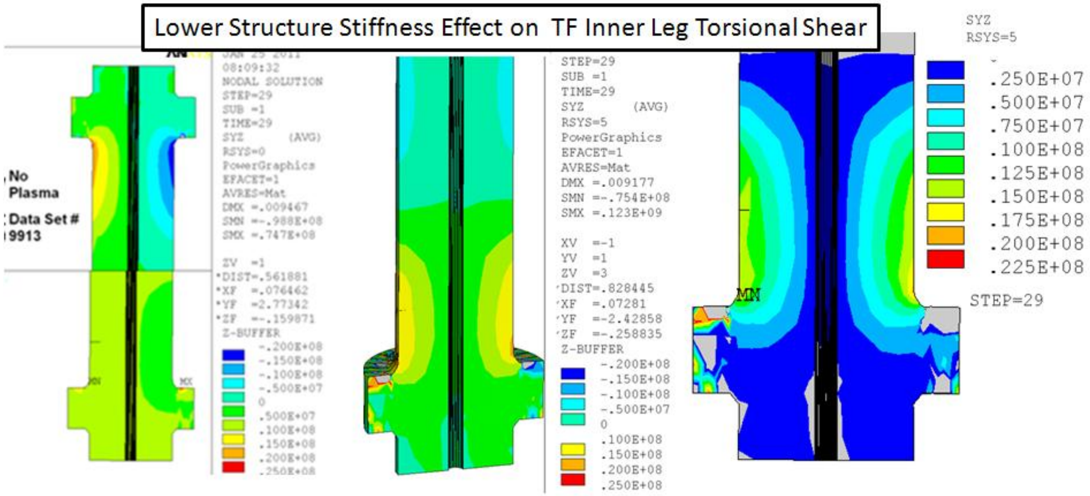


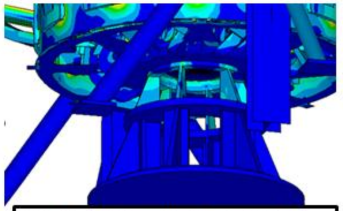
Spoke/Lid/Flex/Von Mises Stress peaks at 17.8ksi

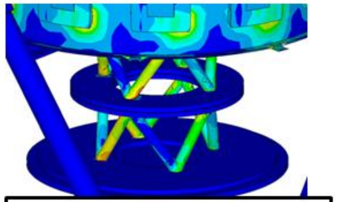
OOP Moment +8mm

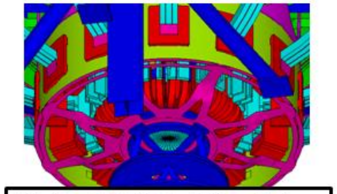
Upper Spoked Lid Must Flex Upward to Allow Thermal Growth of the Centerstack

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

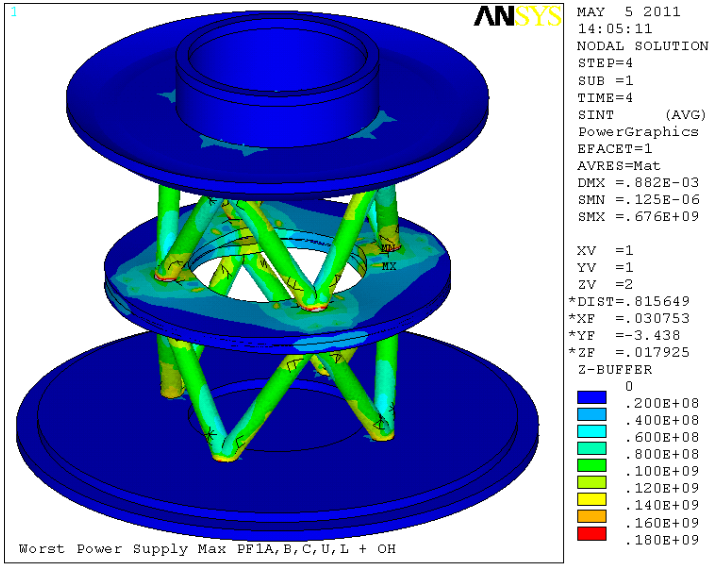

Lower Structure Stiffness Effect on TF Inner Leg Torsional Shear


Rotationally Compliant Pedestal/Stiff Lower Lid


Rotationally Stiff Pedestal/Stiff Lower Lid

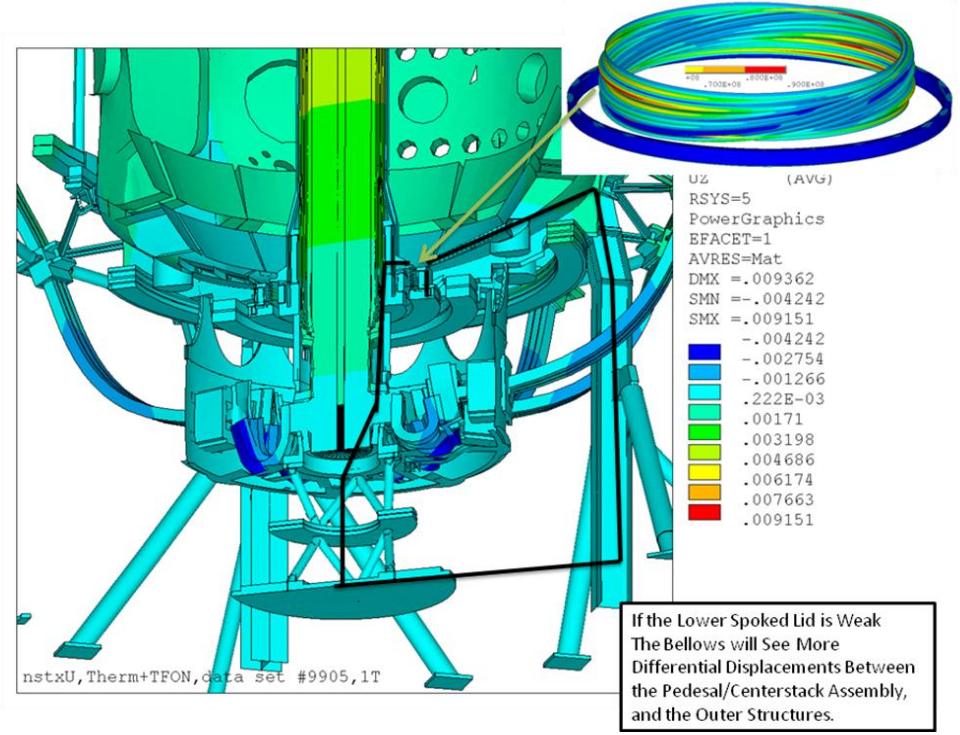

Rotationally Stiff Pedestal/Compliant Lower Lid

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

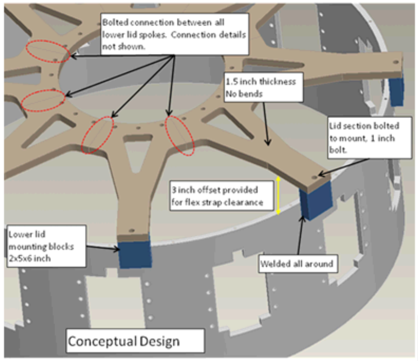


If the Lower Spoked Lid is Weak The Bellows will See More Differential Displacements Between the Pedesal/Centerstack Assembly, and the Outer Structures.

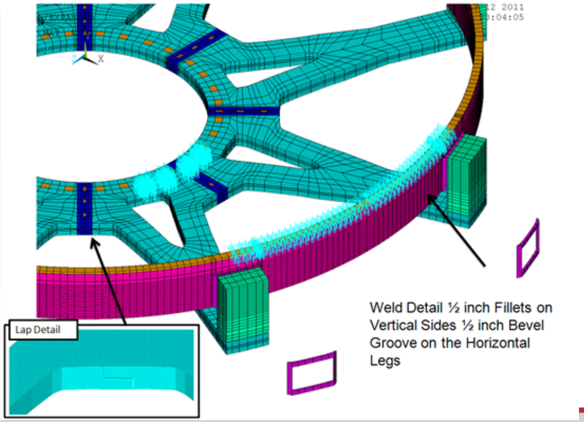
WBS 1.1.2 Lid/Spoke Assembly, Upper & Lower
NSTX-CALC-12-08-00 Rev 0 May 2011
Prepared by: Peter Titus, Reviewed By: Unassigned,
Cognizant Engineer: Mark Smith

Soft “Bent Spoke” Lower Lid was Considered.

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



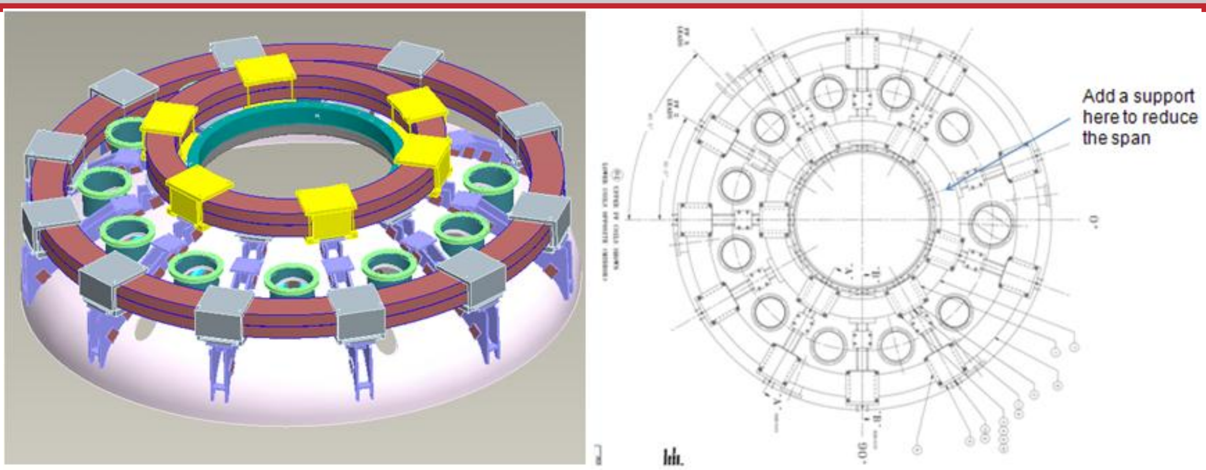
Conceptual Design



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

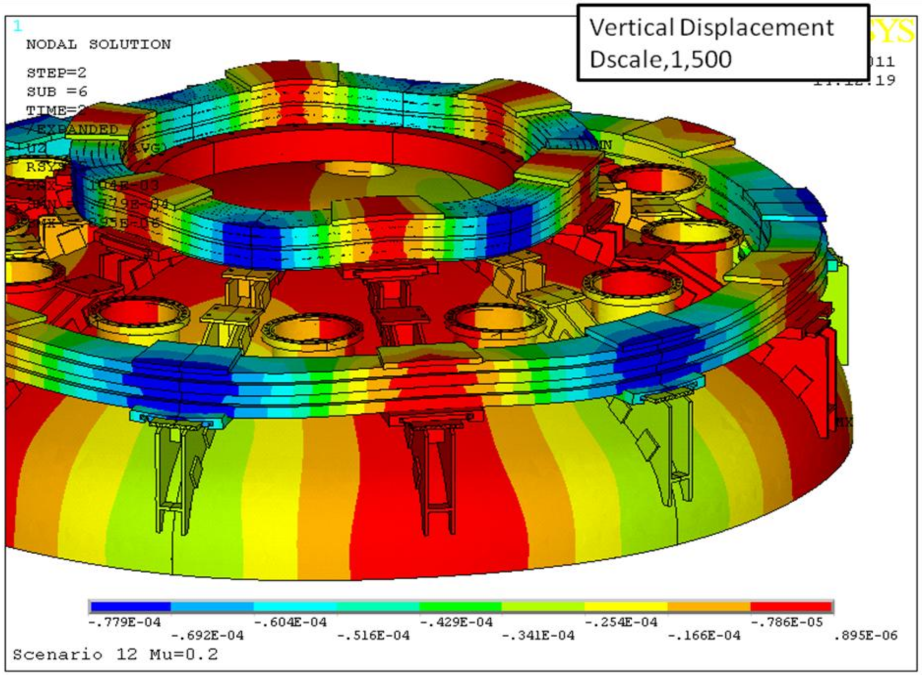
PF Vertical or Axial Loads are Larger to Support 2 MA Operation

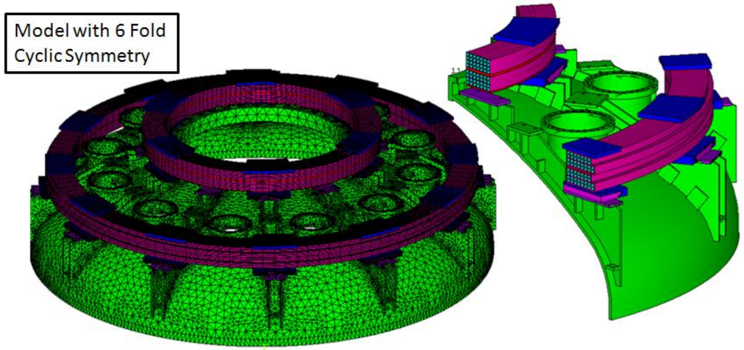


Current (2010) locations of the PF2 supports, and the proposed location of the seventh support

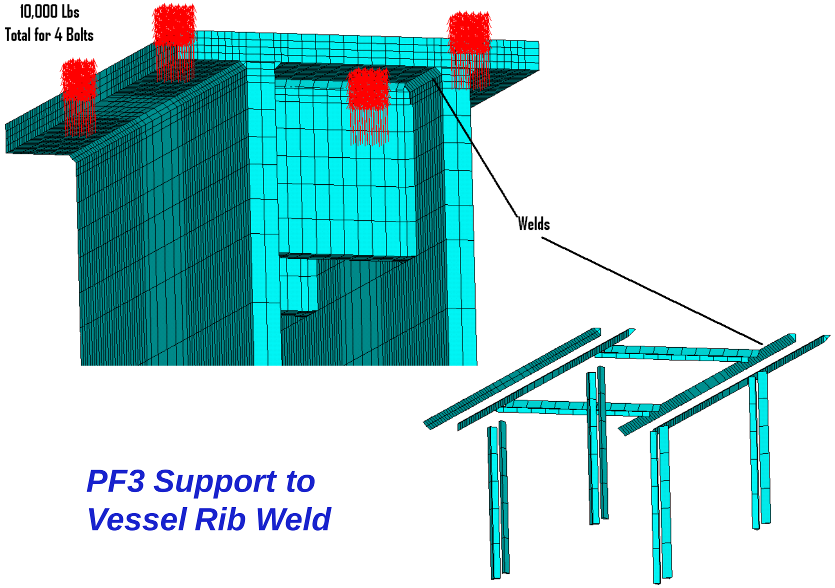
PF2,3 Analysis

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

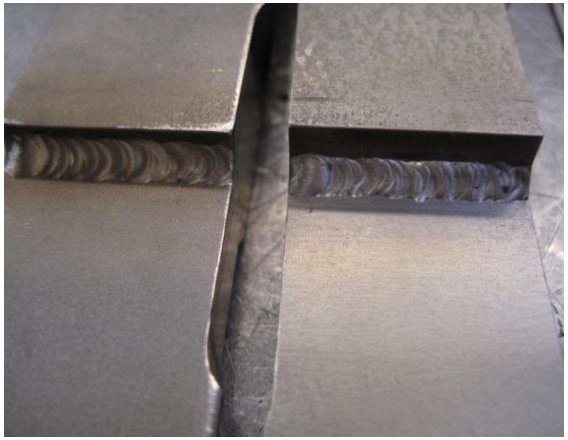


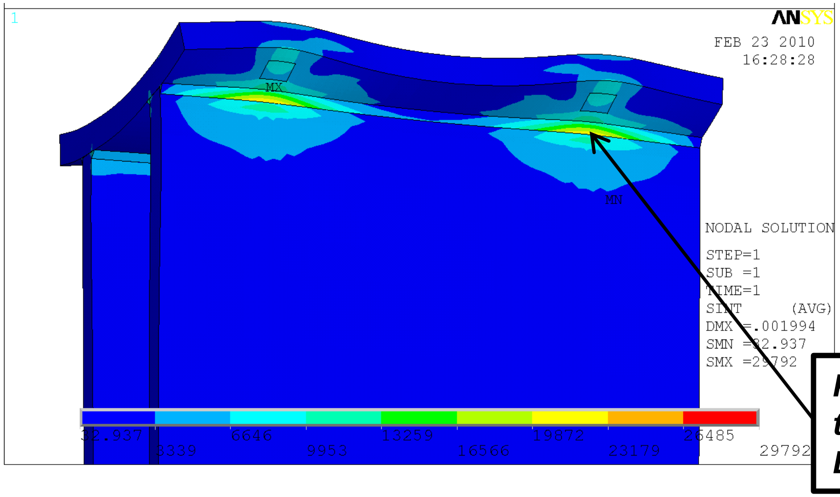


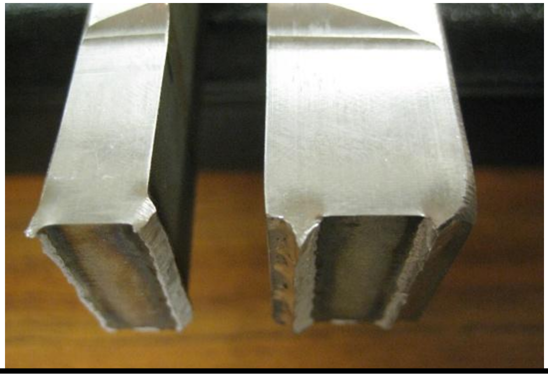
1/8 inch Fillets on ¼ inch and greater stock are not accepted by AISC an AWS – But were used on NSTX. These were qualified by test.



PF3 Support to Vessel Rib Weld



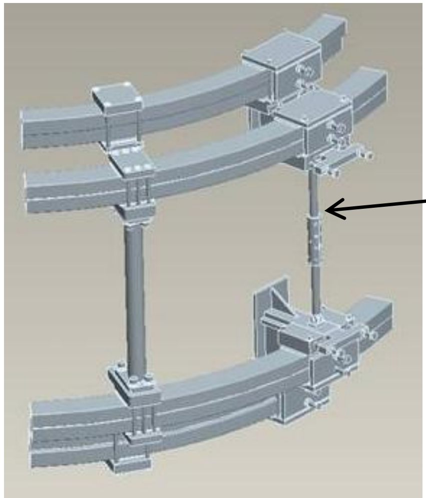




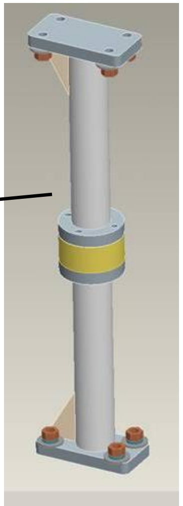
PF3 Support Welds are Still Locally too High and Will be Increased Locally.

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

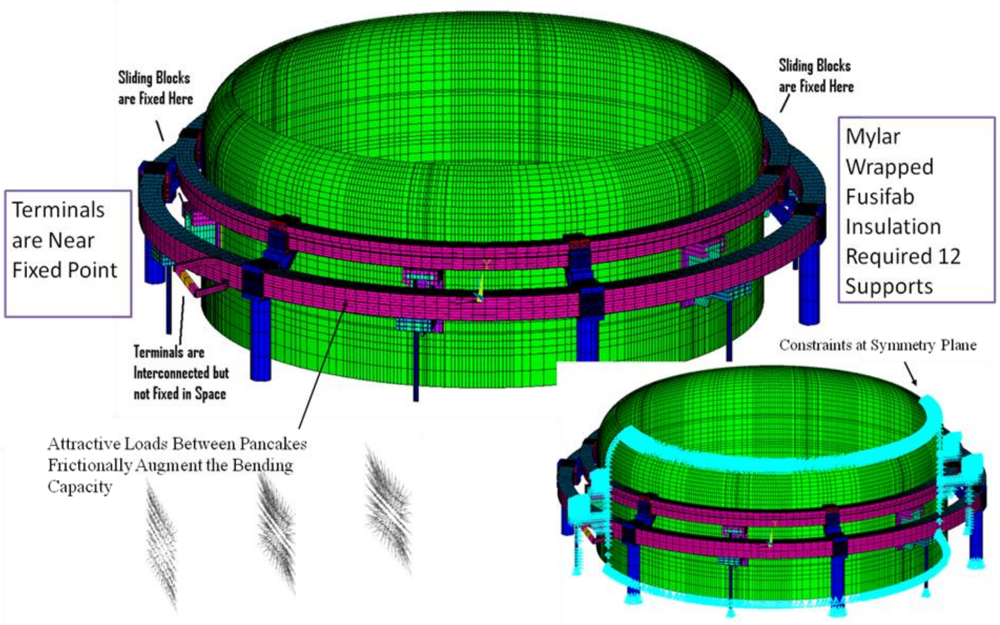
PF4,5 Analysis



New Stiffer Column



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

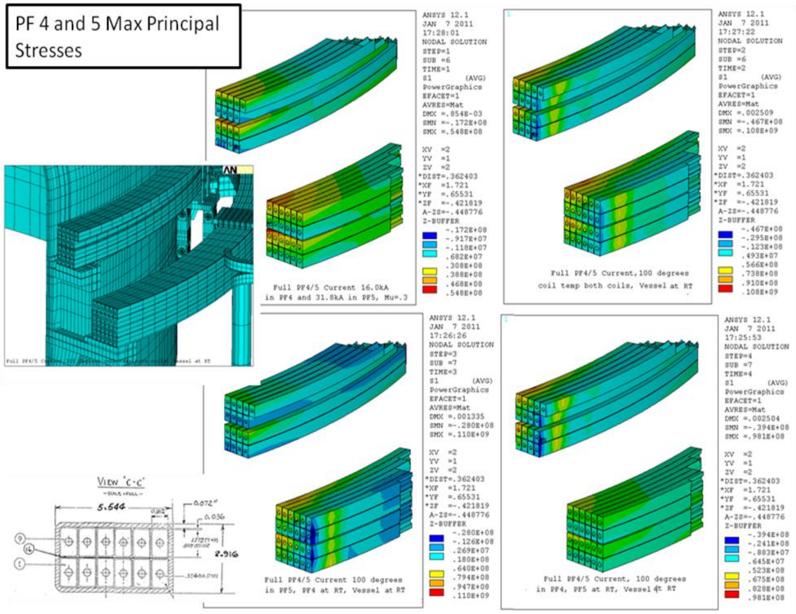


Terminals are Near Fixed Point

Mylar Wrapped Fusifab Insulation Required 12 Supports

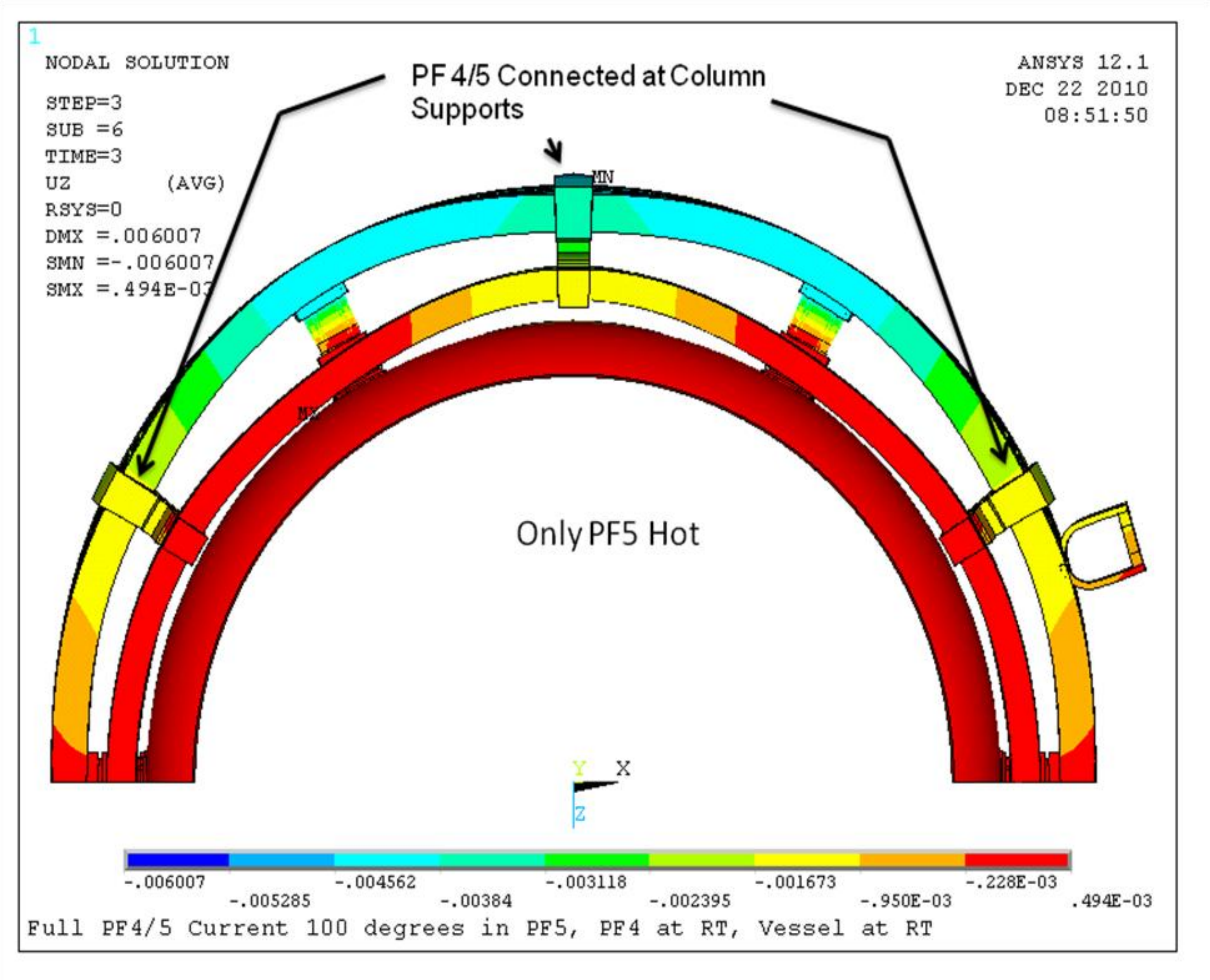
Attractive Loads Between Pancakes Frictionally Augment the Bending Capacity

PF 4 and 5 Max Principal Stresses



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



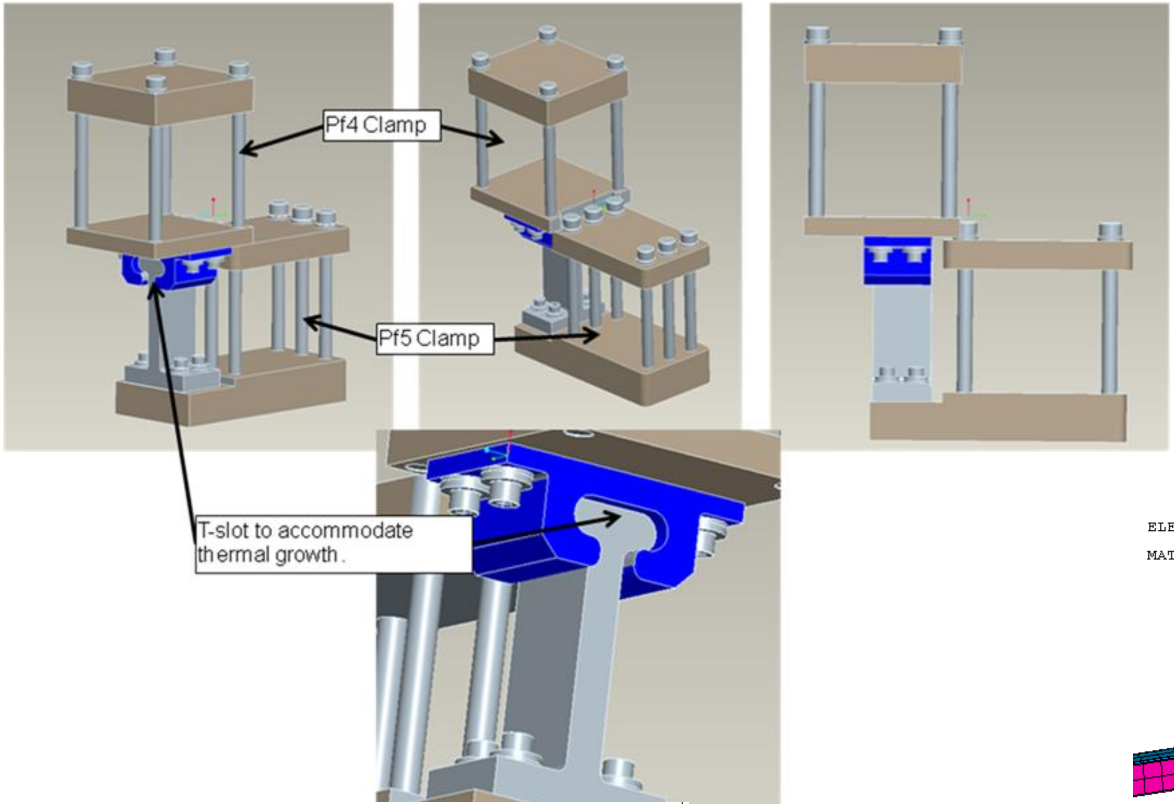
Full PF4/5 Current 100 degrees in PF5, PF4 at RT, Vessel at RT

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

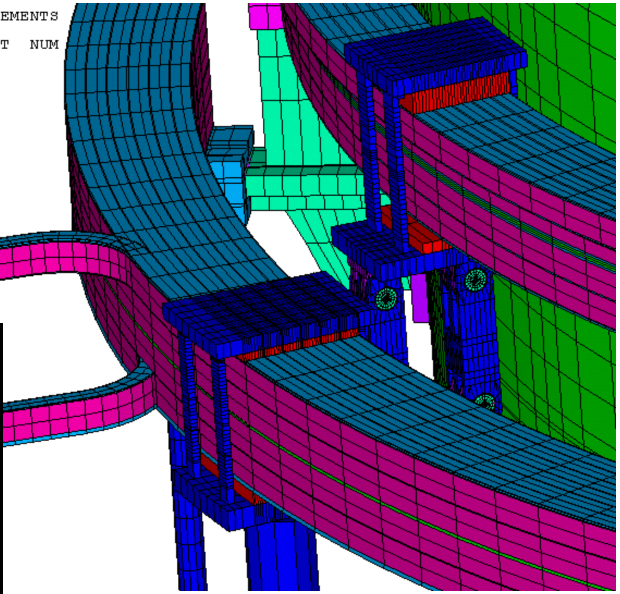
WBS 1.1.3 Structural Analysis of the PF1 Coils Leads and Supports, Rev1
NSTX-CALC-133-01-01
Prepared By: Leonard Myatt,
Reviewed by: TBD, Cognizant Engineer: Jim Chrzanowski

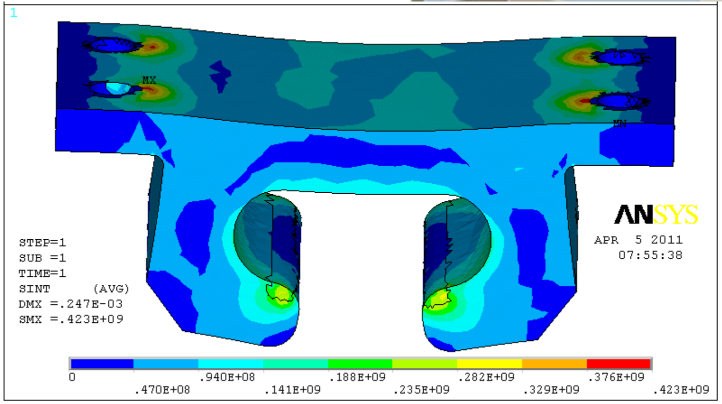
WBS 1.1.2 Analysis of Existing & Upgrade PF4/5 Coils & Supports – With Alternating Columns, NSTXU-CALC-12-05-00,
Prepared By: Peter Titus,
Reviewed by Irv Zatz,
Cognizant Engineer: Mark Smith

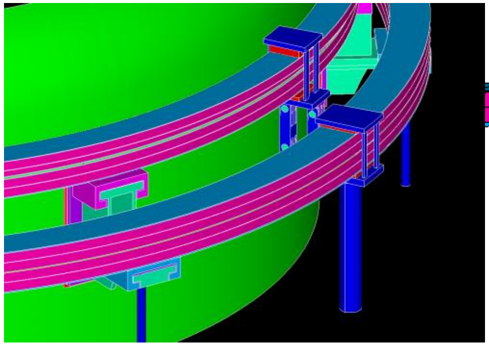
5 Second Pulse Adds More Joule Heat in the Coils



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







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

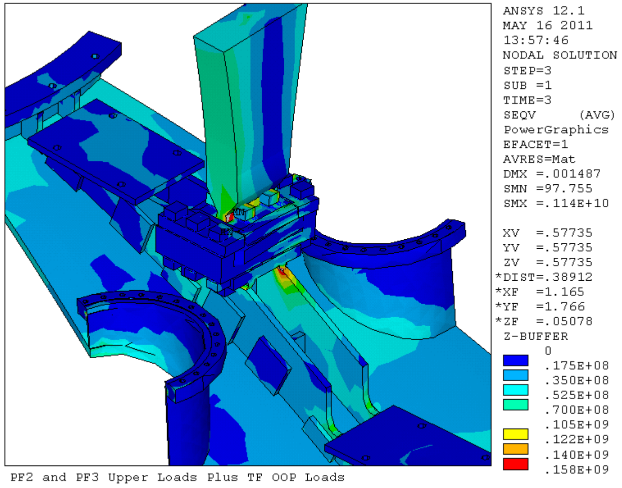
Qualify Analytically Where Possible

Add Reinforcements/Radii

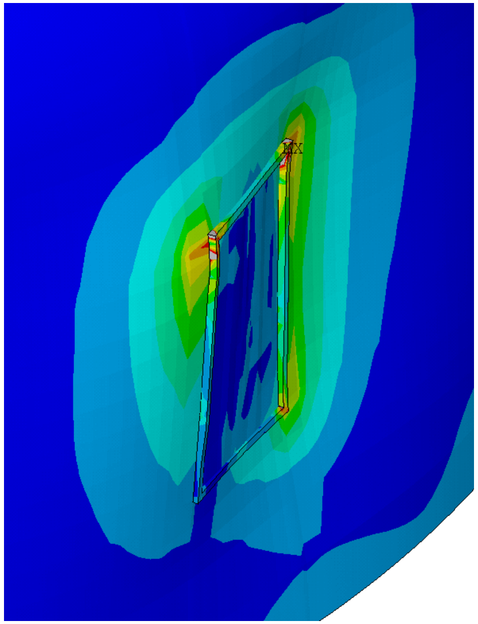
Inspect

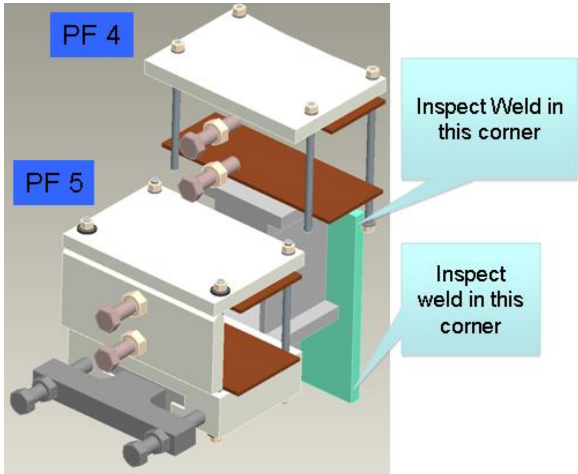
Avoid Fatigue Sensitive Welds
  - *Small Fillets?*
  - *Intermittent Welds?*
  - *Partial Penetration*

Consider Peening



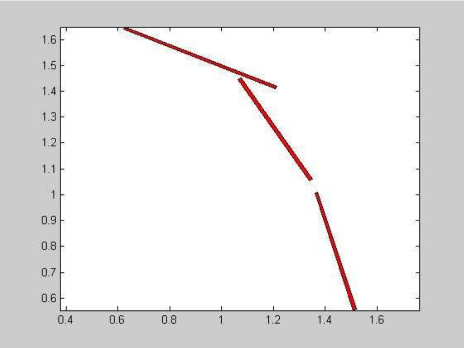
PF2 and PF3 Upper Loads Plus TF OOP Loads

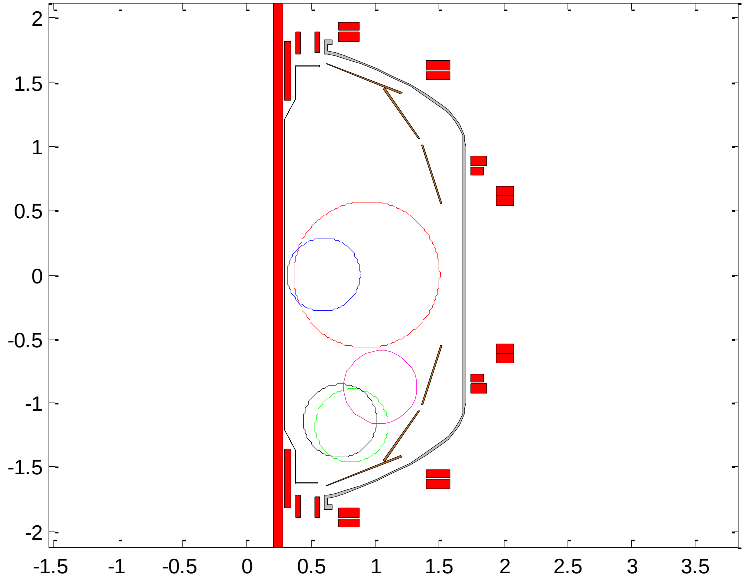


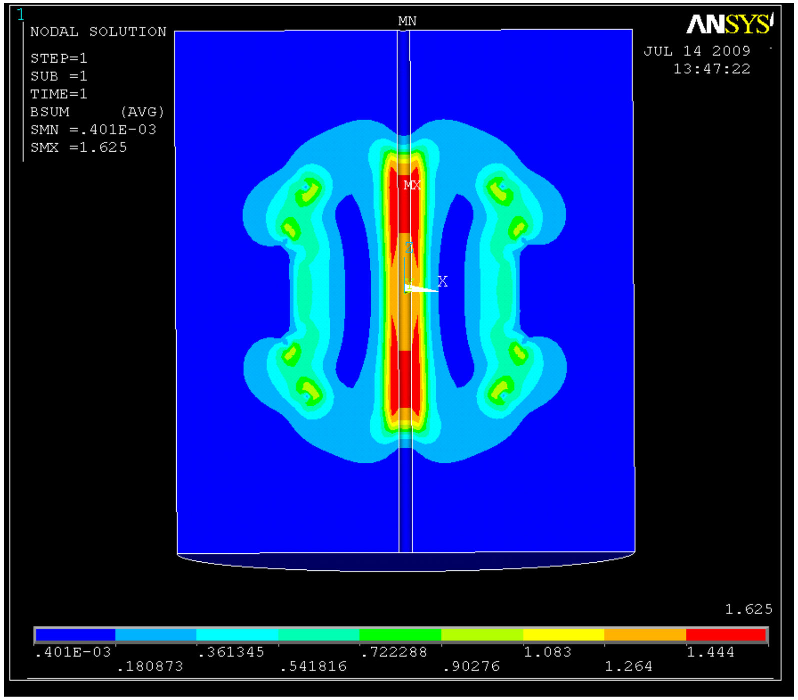


More Plasma Current, Higher TF Field, Higher PF Field, Increase Disruption Electromagnetic Loads in In-Vessel and Ex Vessel Components

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





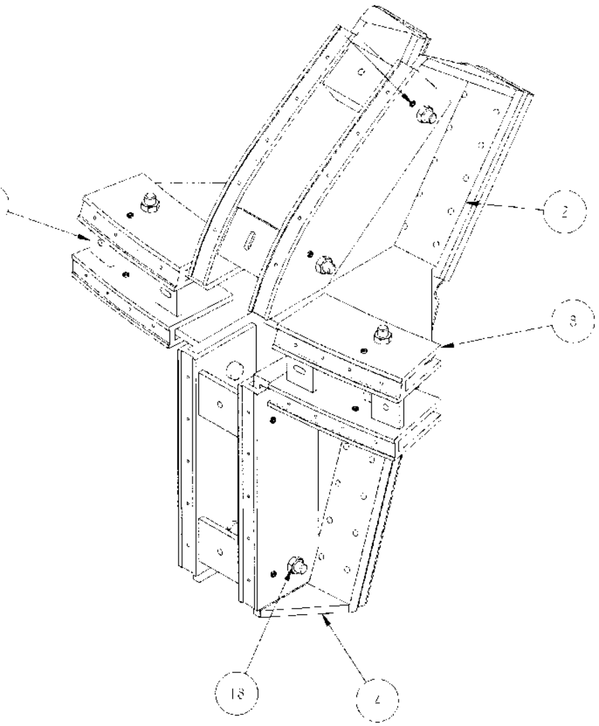


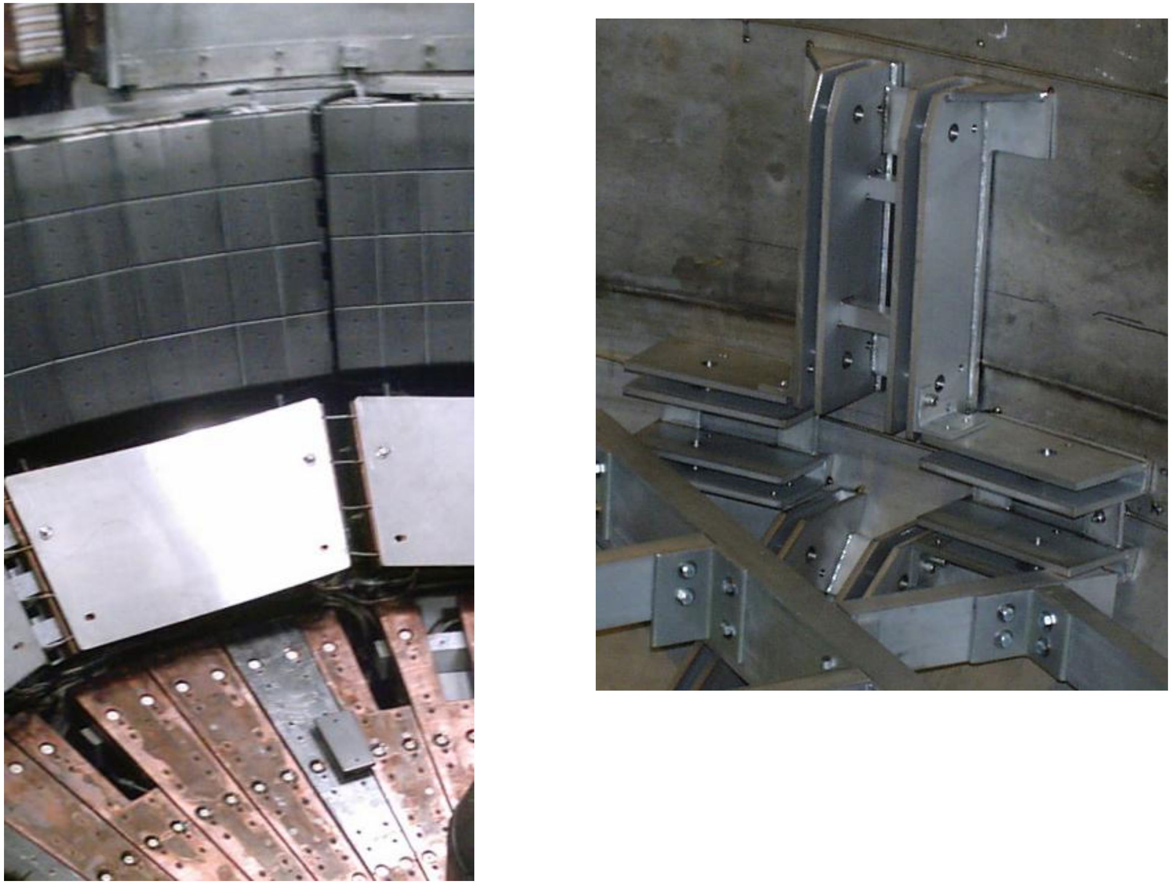
```
NODAL SOLUTION

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



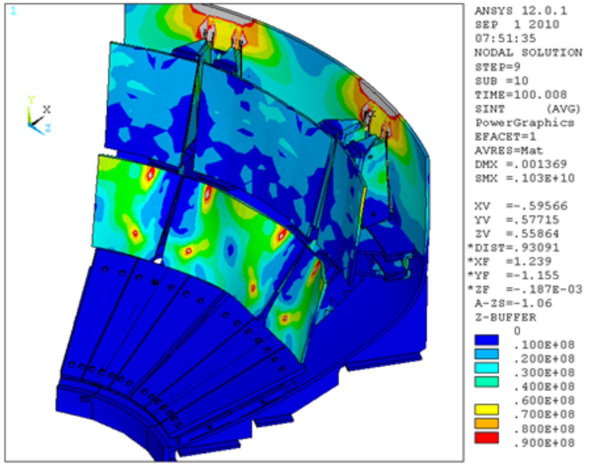


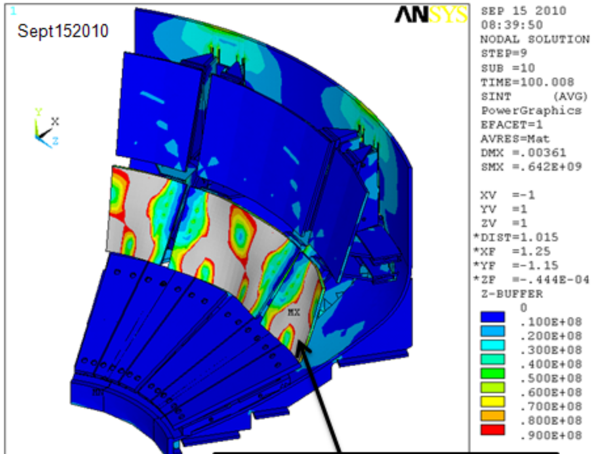
Complicated Components Needed to be Qualified. Large Models With Air Were Difficult to Mesh and Analyze Dynamically

Dynamic Analysis Results
Mid Plane Disruption
Fast Quench of Plasma 1

Same /Contour Scale as for the Mid Plane Disruption

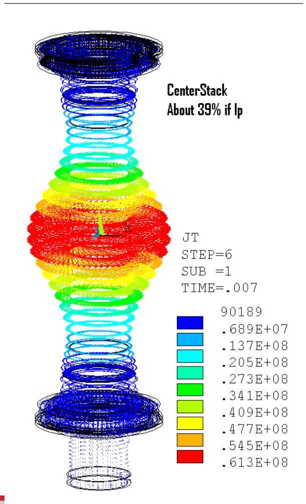
Dynamic Analysis Results
Disruption Near Secondary Passive Plate
Fast Quench of Plasma 4

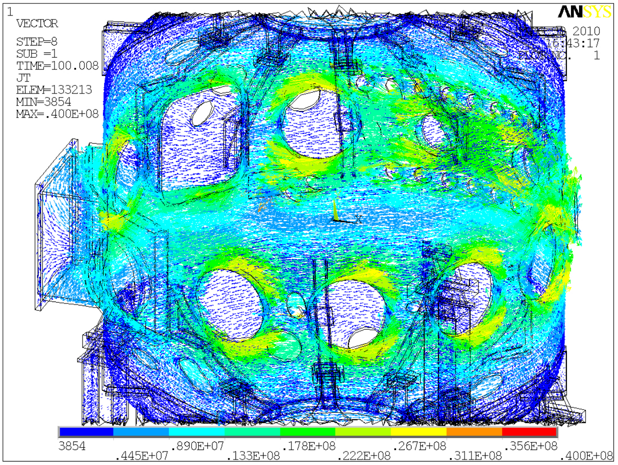




Gray means > 90 MPa

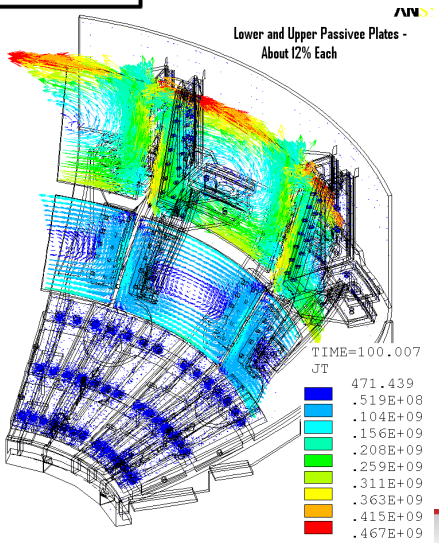
2D Opera Results Were Imposed as Boundary Conditionns on 3D ANSYS Electromagnetic Models, Then Passsed to Dynamic Structural Analyses





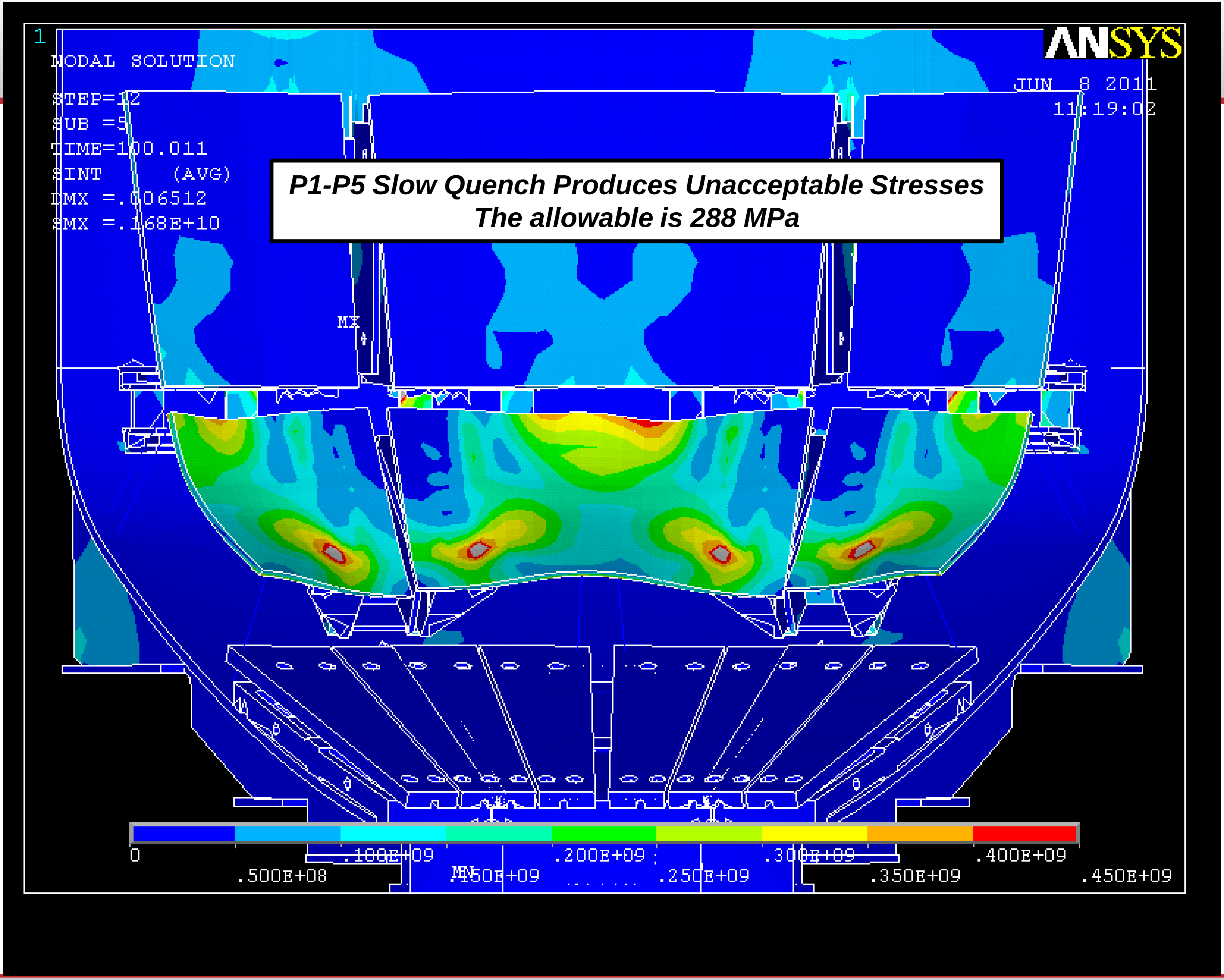
Vessel Outer Region - About 33% of Ip

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



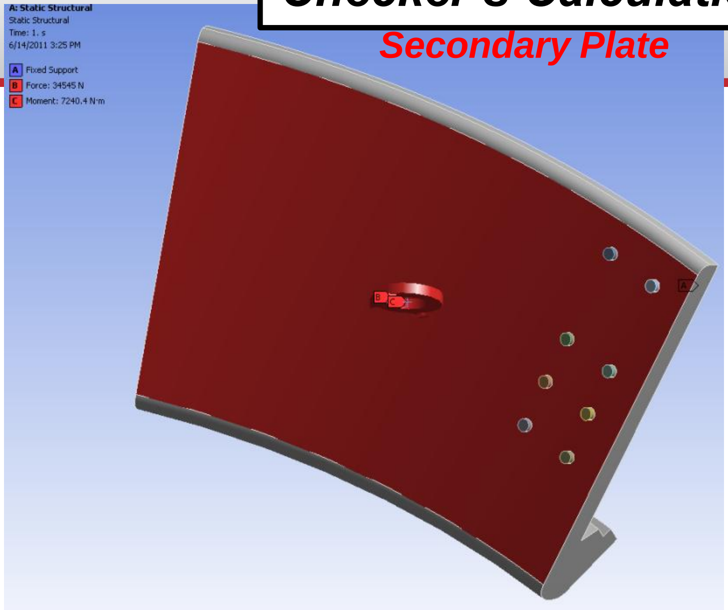
WBS 1.1.1 Disruption Analysis of Passive Plates, Vacuum Vessel & Components NSTXU-CALC-12-01-01 Rev 1 April, 2011 Prepared By: Peter Titus, Contributing Authors: A. Brooks, Srinivas Avasarala, J. Boales Reviewed By: Yu Hu Zhai, Cognizant Engineer: Peter Titus

P1-P5 Slow Quench Produces Unacceptable Stresses
The allowable is 288 MPa



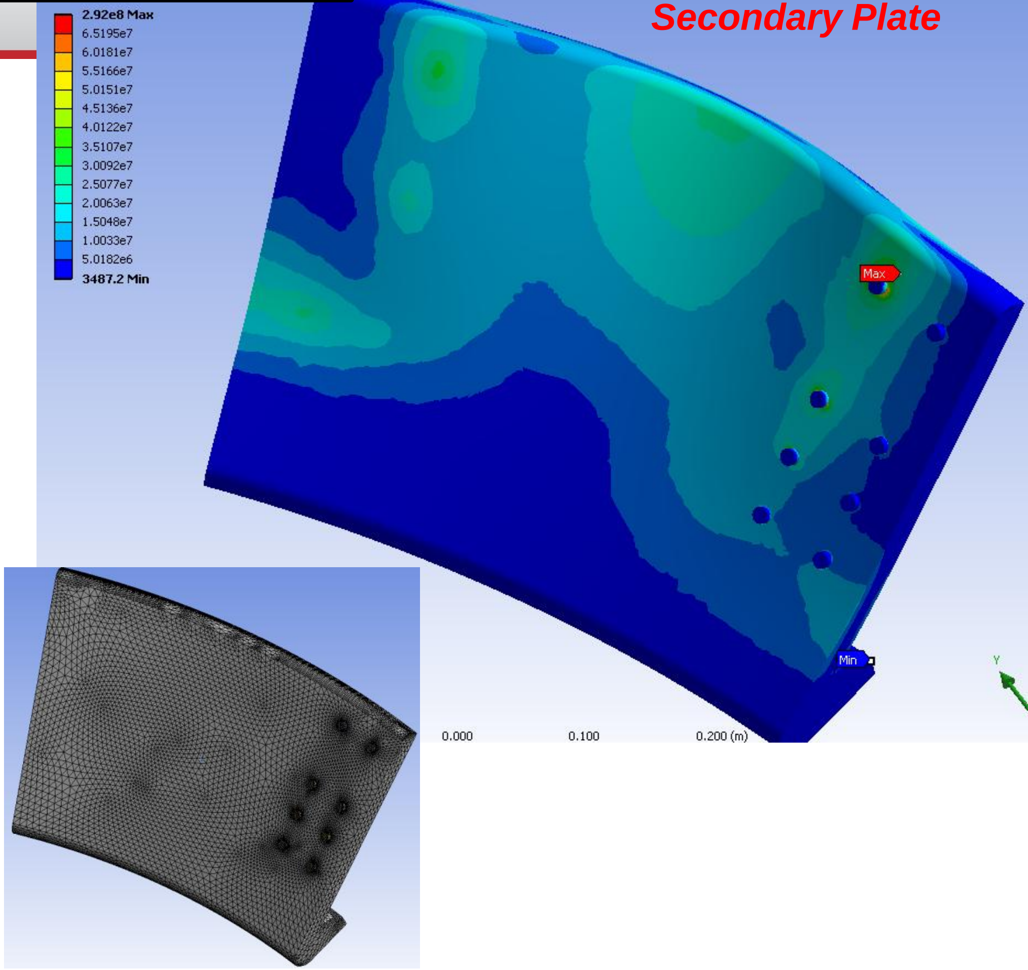
Stress and deflection of SPPs Checker’s Calculations are Much Lower

0.5” thick plate

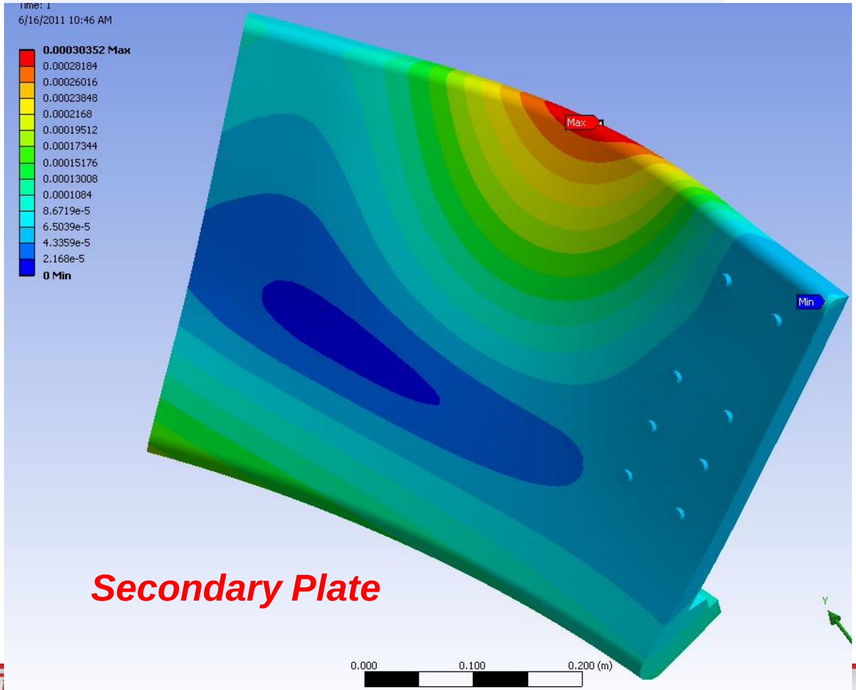


Secondary Plate

P1-P5 VDE SLOW disruption



Secondary Plate

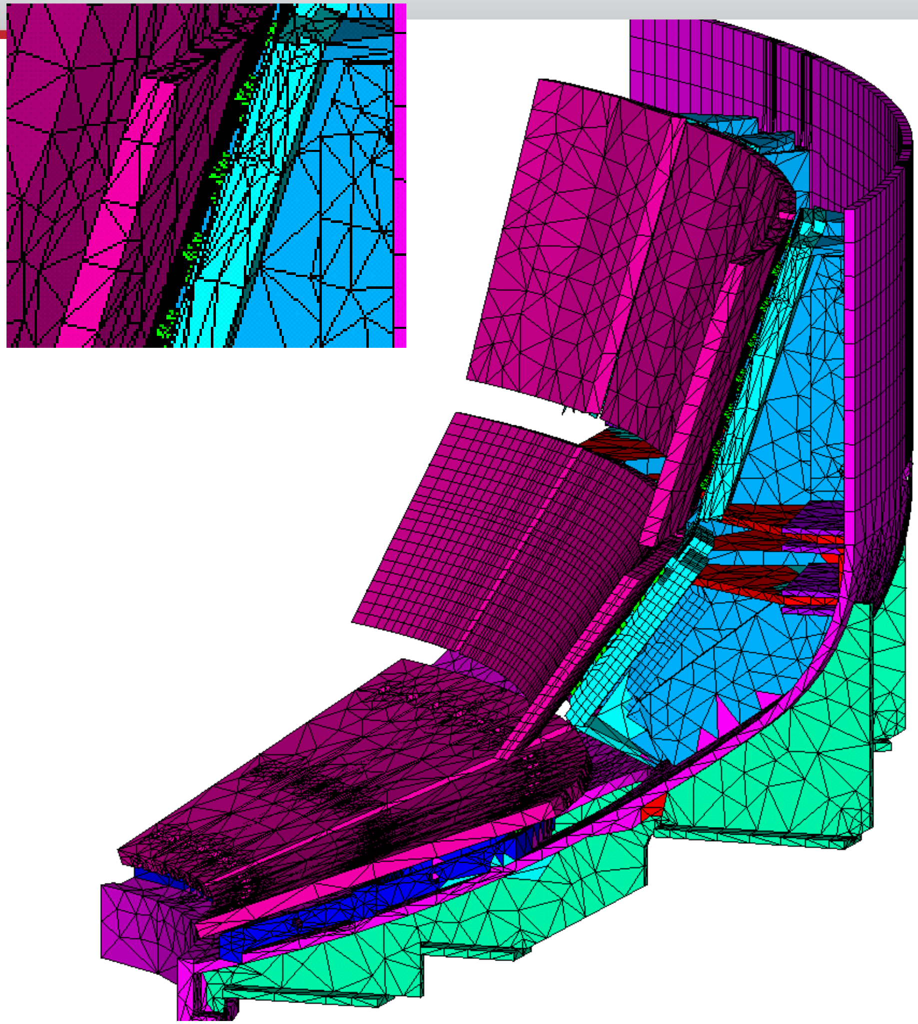


Secondary Plate

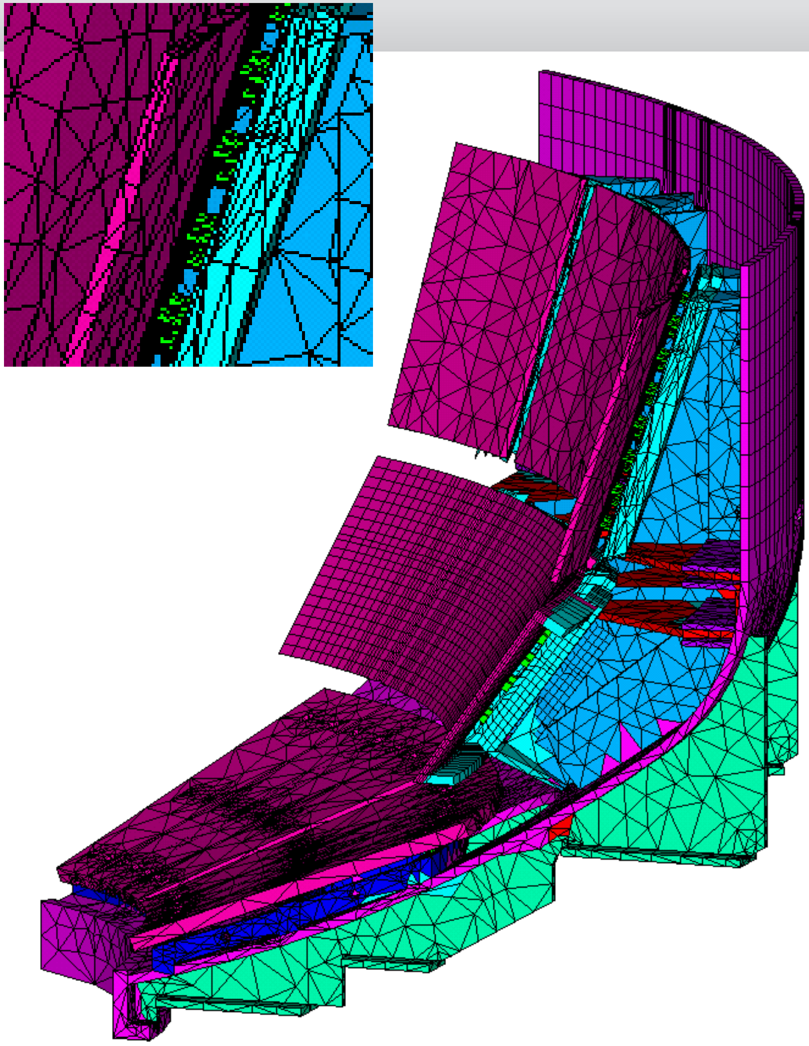
High stress region in SPP: overall stress < 30 MPa

Max deflection on top of SPP ~0.3 mm

1 inch thick plate

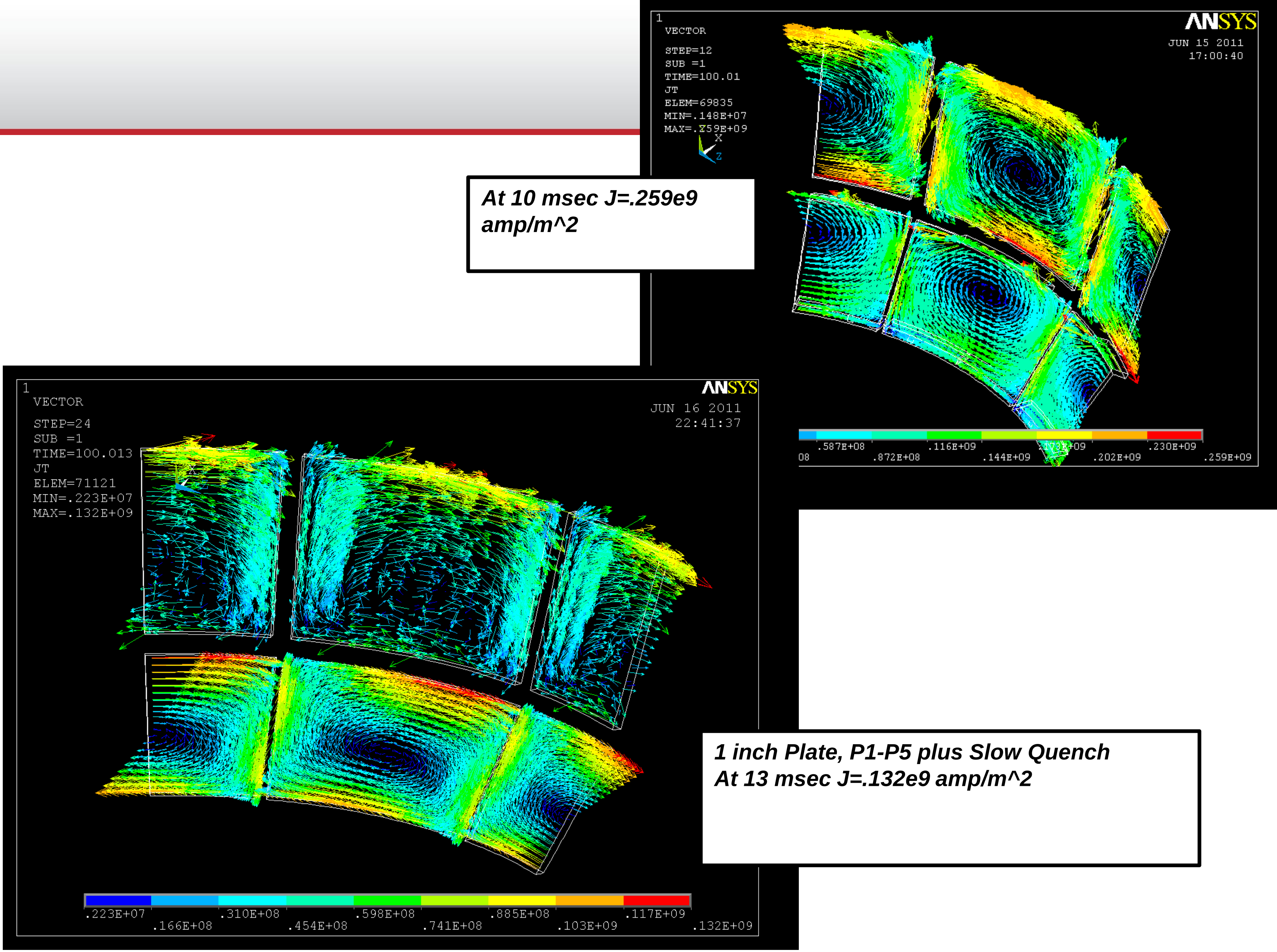


1/2 inch thick plate



Exclusive of EM effects One Inch Plate Which is 2 times the thickness should have a stress improvement by a factor of 4

1 Inch Plate Replacement is being Carried as the Final Design – but Pending Resolution of Checking – May not ne needed.



```
1
VECTOR

STEP=12
SUB =1
TIME=100.01
JT
ELEM=69835
MIN=.148E+07
MAX=.259E+09
```

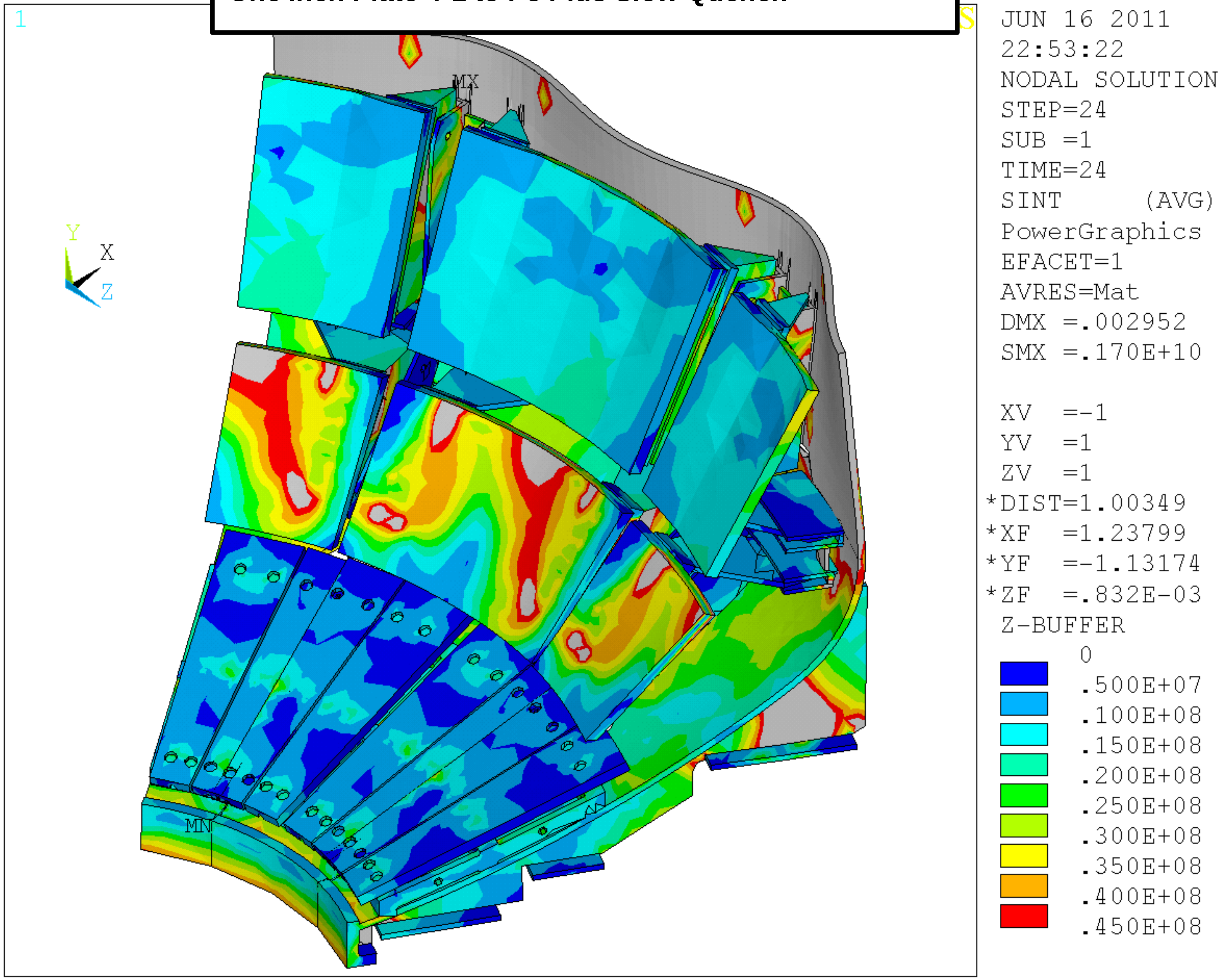
At 10 msec J=.259e9 amp/m^2

```
1
VECTOR

STEP=24
SUB =1
TIME=100.013
JT
ELEM=71121
MIN=.223E+07
MAX=.132E+09
```

1 inch Plate, P1-P5 plus Slow Quench
At 13 msec J=.132e9 amp/m^2

One Inch Plate P1 to P5 Plus Slow Quench



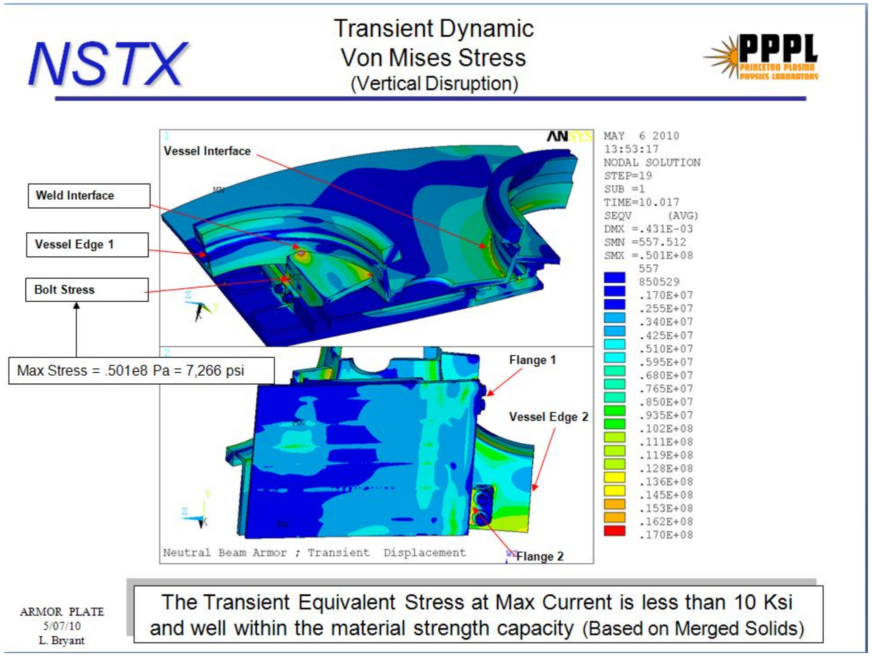
```
JUN 16 2011
22:53:22
NODAL SOLUTION
STEP=24
SUB =1
TIME=24
SINT       (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.002952
SMX =.170E+10

 XV   =-1
 YV   =1
 ZV   =1
*DIST=1.00349
*XF   =1.23799
*YF   =-1.13174
*ZF   =.832E-03
 Z-BUFFER
      0
      .500E+07
      .100E+08
      .150E+08
      .200E+08
      .250E+08
      .300E+08
      .350E+08
      .400E+08
      .450E+08
```

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

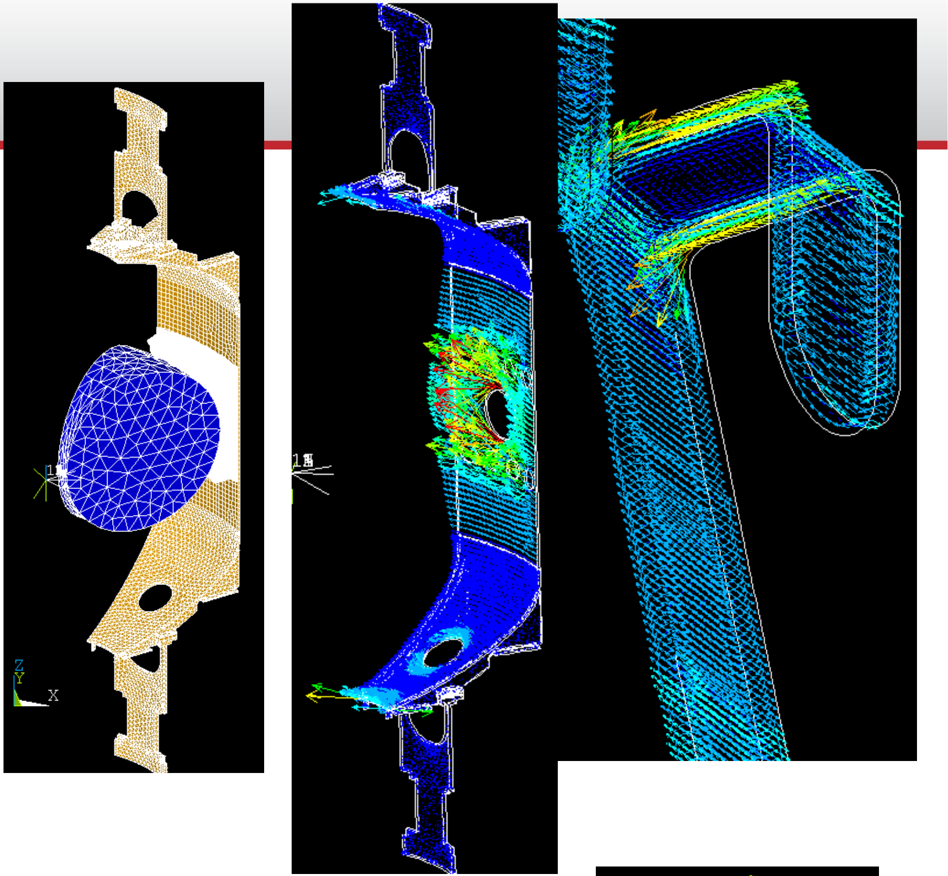
Transient Dynamic
Von Mises Stress
(Vertical Disruption)

PPPL PRINCETON PLASMA PHYSICS LABORATORY

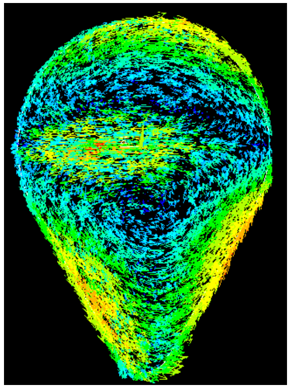
Max Stress = .501e8 Pa = 7,266 psi

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

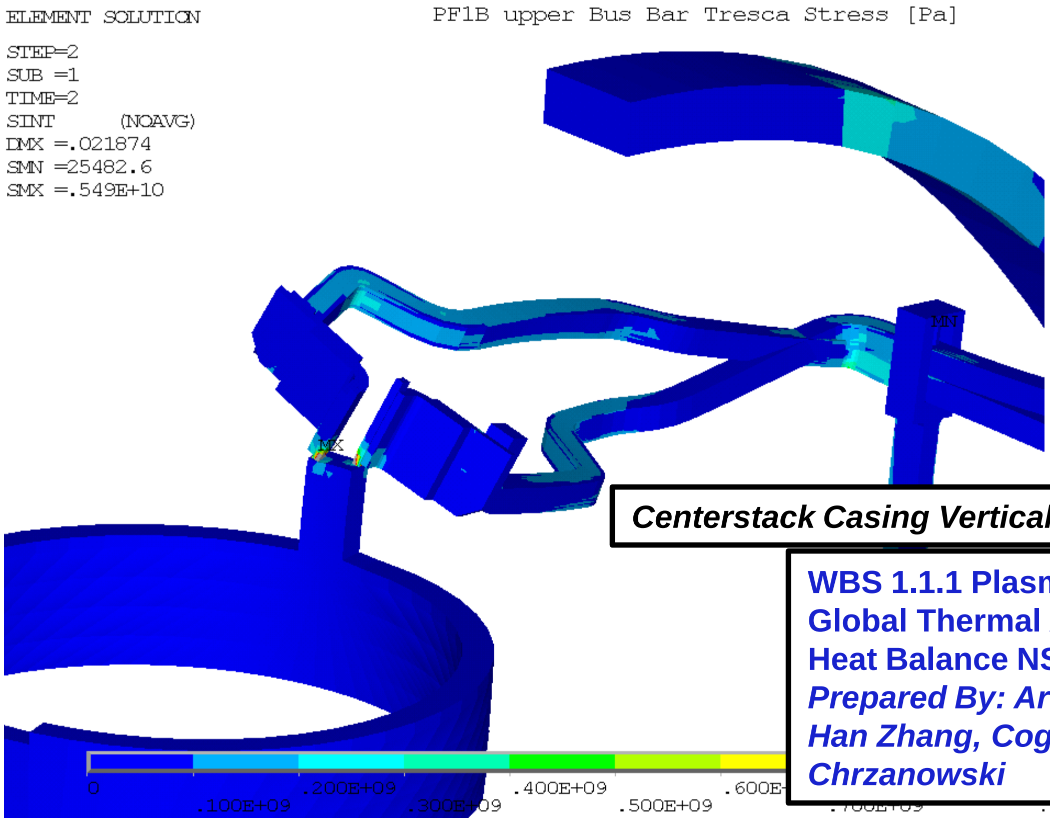


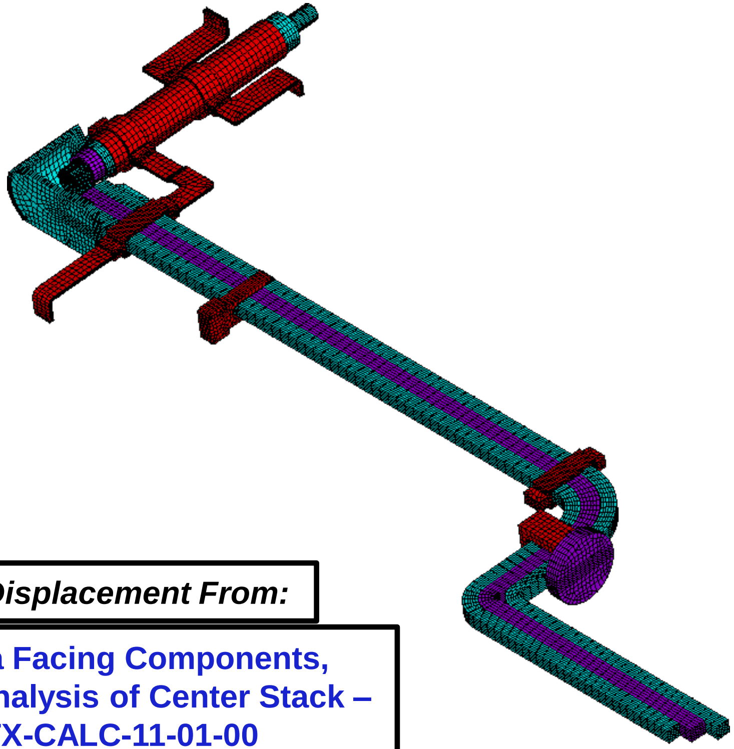
WBS 1.2.3 NSTXU Diagnostics Review and Database NSTXU-CALC-40-01-00 September 2010 Prepared By: Joe Boales, Reviewed By: Yuhu Zhai, NSTX Cognizant Engineer Bob Kiata



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





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

Conclusion

As you have seen, the NSTX Upgrade design is well supported by careful analyses and redundant calculations for key components.

- In addition to component analyses, systems analyses were performed on center stack, upgraded VV design, upgraded PF support design, and upgraded TF support design.
- Furthermore, a Digital Coil Protection System, similar to the one used on TFTR, is also planned to assure that programmed conditions do not exceed operational limits.
- Algorithm development is an integral part of the analysis effort.

These analyses show that the NSTX-U Design will be able to satisfy all 96 operational scenarios.

NSTX-U is ready to proceed with construction.

Back-Up

Housekeeping Items – Can be Addressed in a Break-Out Session

Some routine "clean up" is required yet, but we meet DOE's 90% complete requirement. Items include:

"I doting and t crossing " and incorporation of checkers editorial and formatting comments.

PF4/5 coil/support calculation concluded a stiffer PF4/5 column needed. Updated column design has been partially incorporated into the calculation.

Slow VDE loading on passive plates needs design to accept large loads or analysis to show they are not needed. Results of calculations show that 1 inch thick plates work. Checkers calculations indicate they may not be needed.

TF Clamp – No leg brace is needed. Hardware details have been analyzed by Pete Rogoff. Needs to be put into a calculation

Fatigue Data for CTD 425 with Kapton is being tested. Requirements are not demanding – but there is no cyclic data for the 425 no primer epoxy system planned (but it is much better than CTD 101K).

Highly Localized Temperatures in the TF reach 113 degrees C – Testing is being extended to 115C. If tests are not favorable, TF Profile adjustment or control of ramp-down OOP loading will be used.

Centerstack Casing Loads and Stresses for Halo Strikes other than Mid-Plane, (Upward, not in GRD), Inductive Currents due to P1-P2,

PF1a,b Upper Leads to Allow Vertical Motion, Flex of the bus, AND Radial Thermal Growth of the PF's. We just need to pick a concept – Flexible leads or constrained thermal growth of the coils.

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.

The Project has Provided 2 FTE's for these efforts prior to CD-3

Title 3 Support:

DCPS Input and Testing. Running with Partially Cooled Coils
Final Field Run Geometry of Bus Bars – And Cooling Provisions