NSTX Upgrade

OH-PF1a/b Magnetic Stability

NSTXU-CALC-133-11-00

Rev 0

March 2 2010

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Jim Chrzanowski, NSTX Cognizant Engineer

PPPL Calculation Form

Calculation # **NSTXU-CALC-133-11-00** Revision # **00** WP #: **1672** (ENG-032)

Purpose of Calculation: (Define why the calculation is being performed.)

To demonstrate that the structural elements that center the centerstack are stiff enough to overcome magnetic instabilites between the OH and PF1a, and b which are mounted on the centerstack casing. This calculation has been prepared in response to a PDR CHIT.

References (List any source of design information including computer program titles and revision levels.)

[1] NSTX-CALC-13-001-00 Rev 1 Global Model – Model Description, Mesh Generation, Results, Peter H. Titus February 2011
[2] NSTX Structural Design Criteria Document, NSTX_DesCrit_IZ_080103.doc I. Zatz
[3] NSTX Design Point June 3 2010 http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html
[4] Centerstack Casing Bellows, Peter Rogoff, NSTXU-CALC-133-10-00
[5] OH Preload System and Belleville Spring Stack Design, Peter Rogoff, NSTXU-CALC-133-04-00
[6] Email from Jim Chrzanowski Sent: ______ Wed 3/9/2011 9:09 AM
Pete
We can probably hold the current centers +/- 0.060 inch or better
Jim
[7] NSTX Upgrade Centerstack Casing and Lower Skirt Stress Summary NSTXU-CALC-133-03-00 Rev 0 August 2011 Prepared by P.Titus

Assumptions (Identify all assumptions made as part of this calculation.)

The only PF interaction that was investigated was the PF1a/b -OH pairing. This is judged to be the most flexible structural interaction in the PF system because at the upper end of the casing and OH, the PF1a,and b are only stabilized by the stiffness of the bellows, and OH preload mechanism.

Calculation (Calculation is either documented here or attached)

Attached in the body of the calculation

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

The magnetic stiffness was calculated to be .637 MN/m and the structural stiffness was calculated to be 100 MN/m (Combined bellows and Belleville Spring Post Stiffness) . The structural stiffness was found to be well in excess of the magnetic stiffness, indicating stability against field errors and manufacturing tolerances. The stress due to the manufacturing tolerance would be a maximum of .43 MPa and the bellows stress would be 9.77 MPa. An assessment of the bellows stress based on ref [4] is included in Appendix A. Bellows stresses are acceptable.

Cognizant Engineer's printed name, signature, and date

Jim Chrzanowski James H. Chrzanowski Digitally signed by James H. Chrzanowski DN: cn=James H. Chrzanowski, o=PPPL, ou=Mech Engineering, email=jchrzano@pppl.gov, c=US Date: 2011.09.23 07:50:35 -04'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

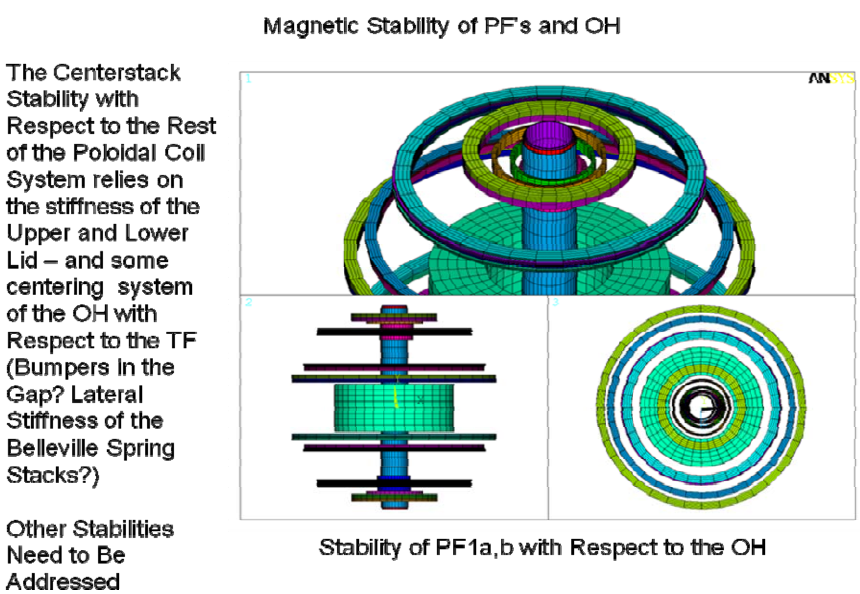
Checker's printed name, signature, and date

A Zolfaghari Ali Zolfaghari Digitally signed by Ali Zolfaghari DN: cn=Ali Zolfaghari, o=PPPL, ou=Engineering, email=azolfagh@pppl.gov, c=US Date: 2011.09.09 11:33:36 -04'00'

Table of Contents

Executive Summary:

The possibility of magnetic instabilities of the various poloidal coils was raised at the CDR and PDR. All the coils are well supported off the vacuum vessel or centerstack casing. There are no coils supported by light, flexible supports. PF 1a and 1b upper and lower are mounted on the centerstack casing. The radial connection between the centerstack casing and the rest of the NSTX structure is rigid and strong at the lower casing connections. A "skirt" connects the lower casing flange to the lower TF flag structures. PF1 a and b lower are aligned stiffly with respect to the OH. At the upper end there is no connection between the centerstack and the TF or the OH. Alignment is maintained by the upper bellows. The OH is also well positioned with respect to the TF at the lower end through the "skirt", but at the upper end, alignment is maintained by the lateral stiffnesses of the belleville preload mechanism. The centerstack TF components are well centered by the spoked lid and collar. This calculation addresses the magnetic stability of the centerstack assembly with respect to the OH coil, Magnetic loads that result from a unit offset of the centers of the coils are computed using a Biot Savart program written by the author of the report and in MAXWELL, by the checker of this report.



The structural stiffness was found to be well in excess of the magnetic stiffness, indicating stability against field errors and manufacturing tolerances. The stress due to the manufacturing tolerance would be a maximum of.43 MPa and the bellows stress would be 9.77 MPa An assessment of the bellows stress based on ref [4] is included in Appendix A. Bellows stresses are acceptable.

DCPS Input

This establishes an Magnetic "stiffness". This is then compared with a structural stiffness. The structural stiffness must exceed the magnetic stiffness for the coils to be stable. The magnetic stiffness was calculated to be .637 MN/m and the structural stiffness was calculated to be 425 MN/m This calculation demonstrates a large stability margin between the inner PF coils and the OH coil, with peak coil currents applied. No interface with the DCPS is required. Stress evaluations of the more significant loads on the centerstack casing are included in ref [7]

Interaction Forces Due to Concentric Misalignment of Inner PF Coils with Respect to the OH Coil Using MAXWELL

Interactions between the inner PF coils and the OH due to deviations in concentricity have been evaluated using the MAXWELL code. MAXWELL is a finite element electromagnetic code used to solve electromagnetic field equations in 2d and 3D. In this analysis we have used MAXWELL 3D to obtain forces on solenoids that represent the OH, PF1a and PF1b coils in NSTX upgrade.

Interaction Forces Due to Concentric Misalignment of PF1a Coil with Respect to the OH Coil

Coil	Current (kA)	Turns	
OH	24	884	reference [3]
PF1a	18.3	64	reference [3]

PF1a and is moved from its concentric position with respect to the OH coil by two different distances of 2mm and 5 mm.

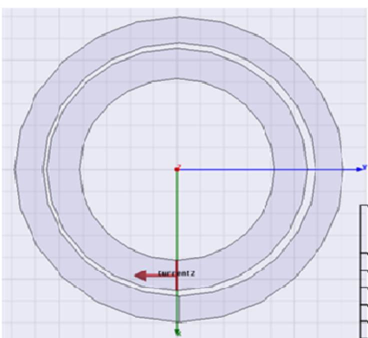
Magnetic Stability of PF1a With Respect to the OH
A Zolfaghari MAXWELL Results

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.

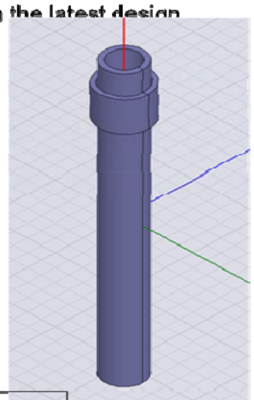
Pf1a and Oh coils dimensions and arrangement were used from the latest design point.

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

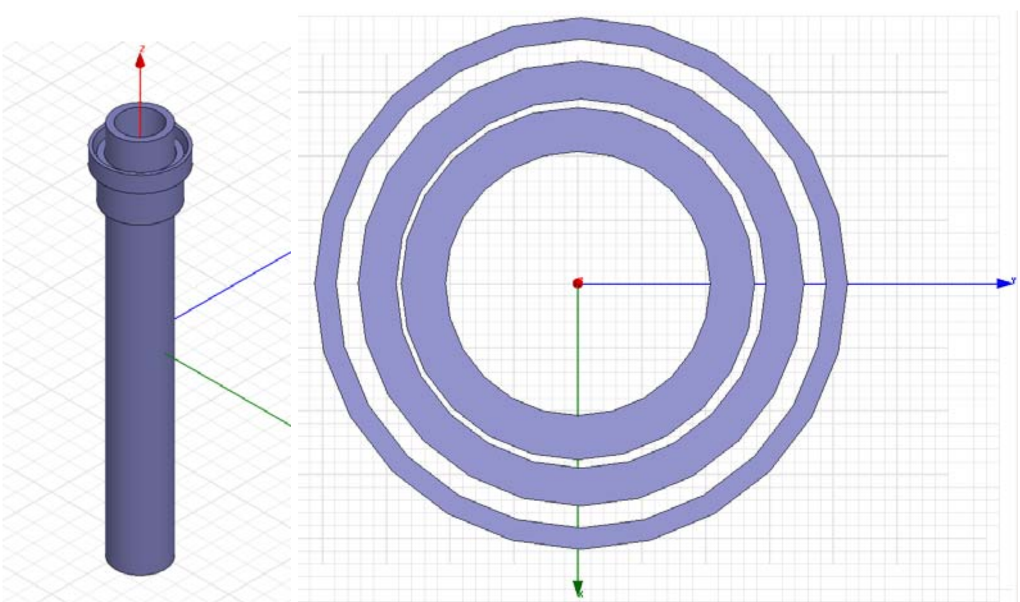
Interaction Forces Due to Concentric Misalignment of PF1a and PF1b Coils with Respect to the OH Coil

PF1a and PF1b are moved from their concentric position with respect to the OH coil by two different distances of 2mm and 5 mm. As expected, if the currents in PF1a and PF1b are in parallel to the current in OH, once the Pf1a and PF1b are moved from their concentric orientation with respect to the OH, a force appears which is increased with the distance and tries to further the distance. This can be interpreted as resulting in a magnetic stiffness equivalent to the magnetic force divided by the distance. The table below list the computed forces vs. distance.

Setup:

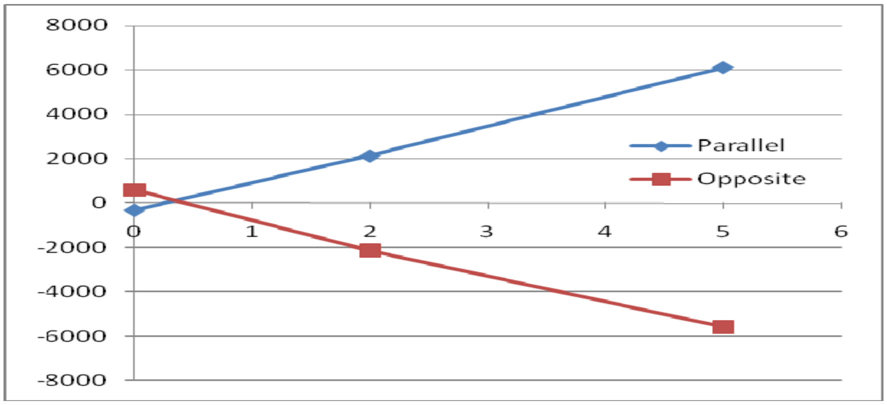
Coil	Current (kA)	Turns	
OH	24	884	Reference [3]
PF1a	18.3	64	Reference [3]
PF1b	13	32	Reference [3]

The PF1a and PF1b are moved together 2mm and 5mm in the positive Y direction.



Orientation of PF1a and PF1b currents with OH current	PF1a and PF1b Offset (mm) with respect to OH in +Y direction	Total Force (N) on PF1a & PF1b in +Y Direction
Parallel	2	2124
Opposite	2	-2140

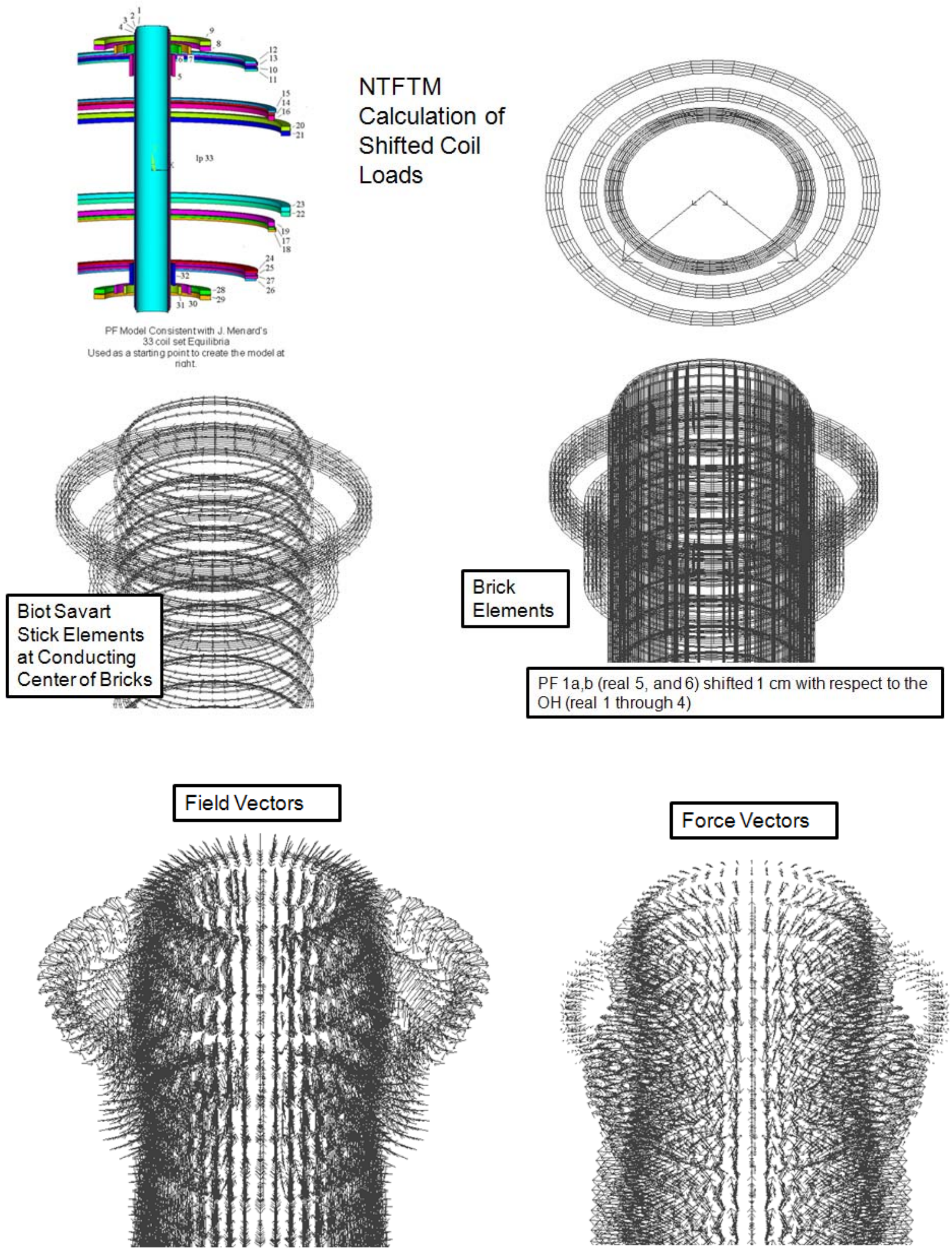
Parallel	5	6099
Opposite	5	-5579
Parallel	0	-311
Opposite	0	576



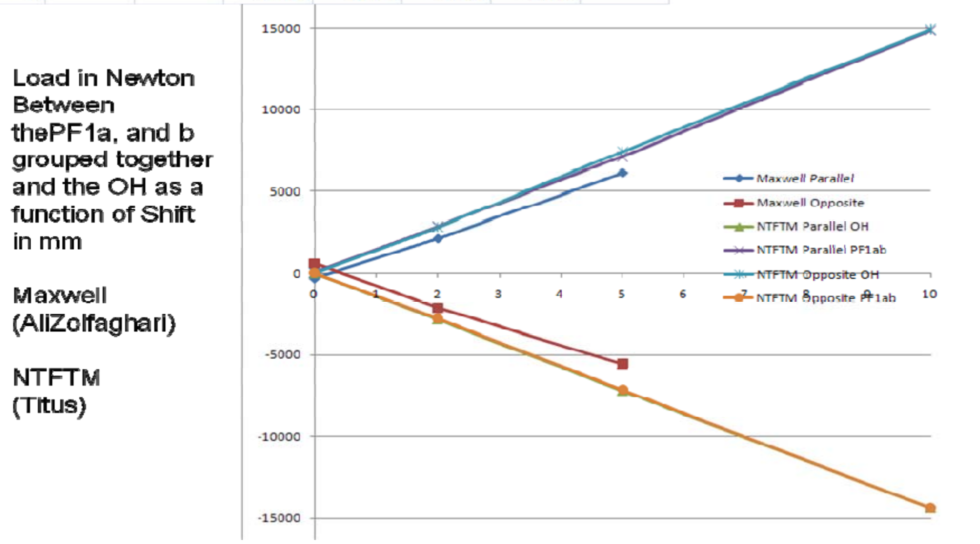
Magnetic Stiffness= 6000/.005 N/m = 1.274MN/m For the combined effects of PF1a,b and the OH

Interaction Forces Due to Concentric Misalignment of Inner PF Coils with Respect to the OH Coil using the NTFTM Code

NTFTM2 is a mesh generation code with some capabilities to calculate magnetic fields and forces. It is used here partly to calculate the lateral forces as a function of lateral offset. It also provides a check of the MAXWELL modeling and the comparison with Maxwell supports the qualification of the NTFTM code as used in ref [1] and elsewhere. The MAXWELL OH PF1a,b force calculations are are the same as those calculated by NTFTM2.


NTFTM
Calculation of
Shifted Coil
Loads
PF Model Consistent with J. Menard's
33 coil set Equilibria
Used as a starting point to create the model at
right.
Biot Savart
Stick Elements
at Conducting
Center of Bricks
Brick
Elements
PF 1a,b (real 5, and 6) shifted 1 cm with respect to the
OH (real 1 through 4)
Field Vectors
Force Vectors

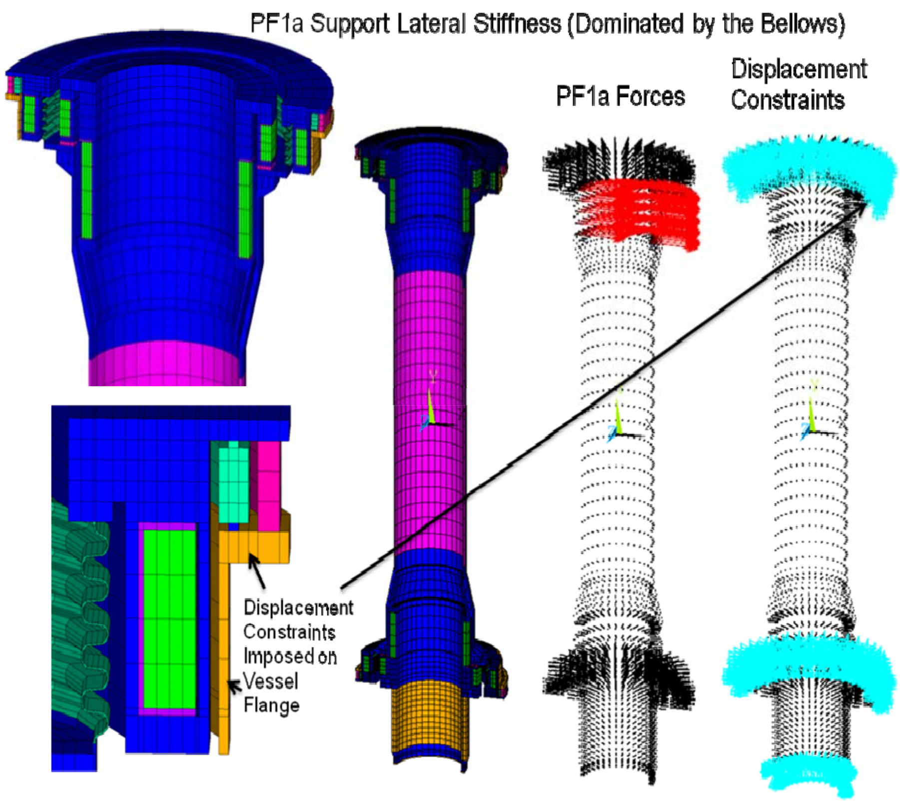
	Maxwell P	Maxwell C	NTFTM Pa	NTFTM Pa	NTFTM Op	NTFTM Opposite PF1a
0	-311	576	1.26	26.53	10	10
2	2124	-2140	-2877	2847	2800	-2800
5	6099	-5579	-7210	7133	7450	-7132
10			-14396	14858	14950	-14395

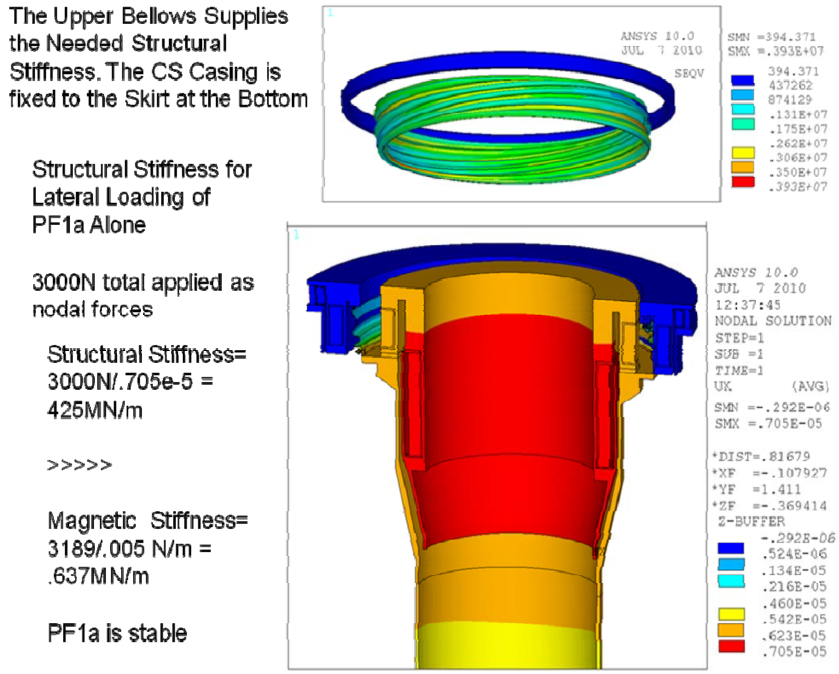


Load in Newton, Between thePF1a, and b grouped together and the OH as a function of Shift in mm - MAXWELL (Ali Zolfaghari) - NTFTM (Titus)

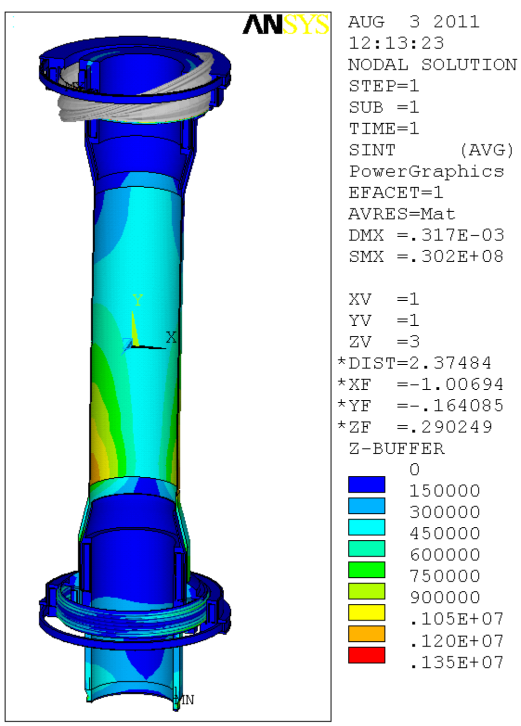
Lateral Structural Stiffness - Bellows and Cantilevered Centerstack Casing

A portion of the global model [1] was extracted to obtain an estimate of the structural lateral stiffness. The model is shown below, and the results of the analysis are shown in the following Figure:



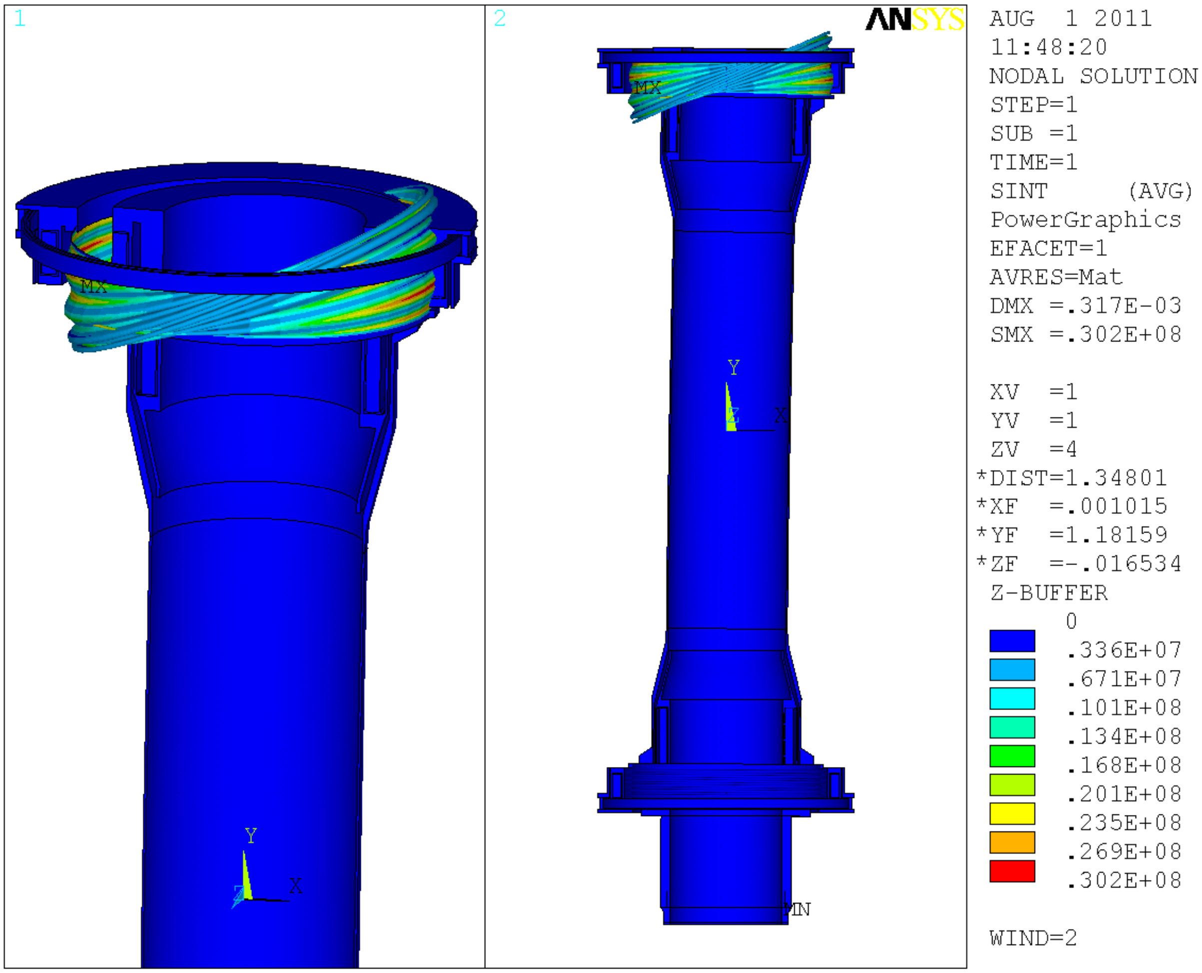


The bellows detail in this analysis is old and could be updated to be consistent with ref [4], but the margins are large and the small change in bellows stiffness will not alter the conclusions of this calculation.



Stress Due to 3000N Load

Jim Chrzanowski estimated the tolerance in the manufacture of the coils as .060 inches on the alignment of the magnetic centers with respect to the geometric centers of the coils [6]. This is 1.524mm. The magnetic load would be .627e6*.001524 = 971 N or 218 lbs. This would produce an additional offset of 971/425e6 = 2.28e-6 m.

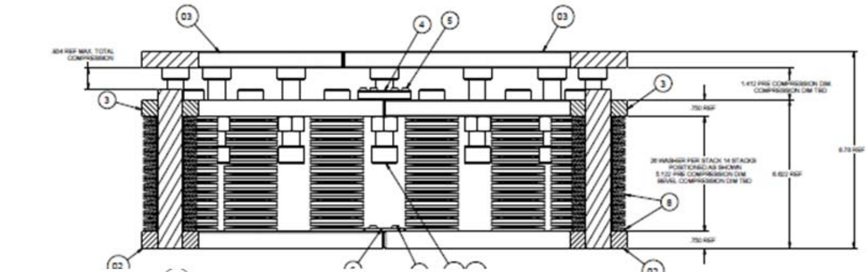


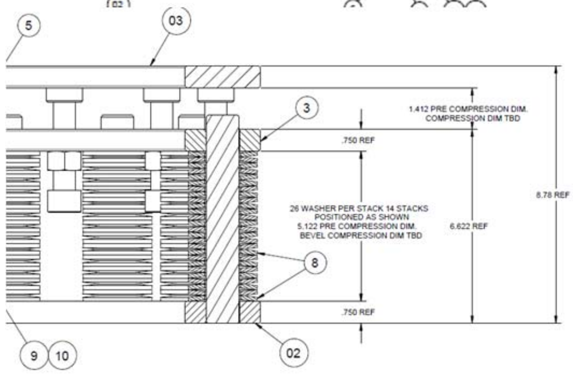
Bellows Stress Due to 3000N Load

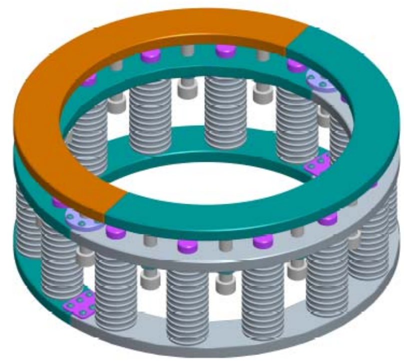
Scaling the centerstack casing stress from the 3000 N stiffness calculation, The stress due to the manufacturing tolerance would be 971/3000*1.35MPa = .43 MPa and the bellows stress would be 30.2 MPa*971/3000 = 9.77 MPa

Compliance of the Belleville Spring Preload System.

The lateral stiffness of this assembly is complex, but a major contributor is the cantilevered posts that center the Bellevilles. These are simply represented by 14 cantilevered beams.



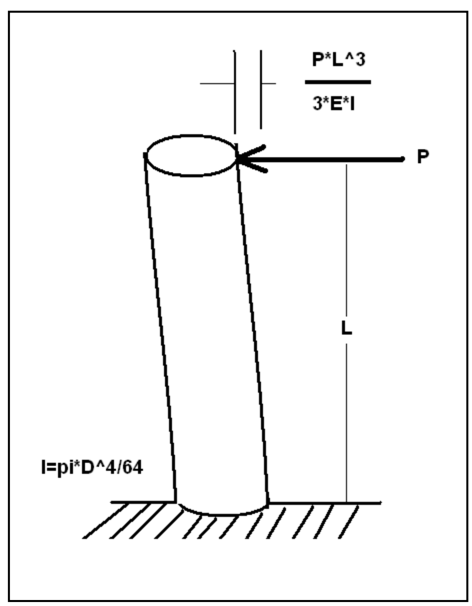




The lateral stiffness of the posts is 131 MN/m (see below) The combined bellows and post stiffness is (1/K bellows + 1/K Belleville posts)^-1 or (1/131+1/425)^-1= 100 MN/m

The bending stiffness per post is 3*E*I/L^3

Num of Spring Stacks	14	
Post Diameter	1.2	inches
Post Mom of Inertia=	-0.08482	inches^3
Post Height, L=	5.2	Inches
Modulus	2.95E+07	
	-	
Bend Stiff per Post	5.34E+04	
	-	
Bend Stiff all Posts	7.47E+05	lbs/in
	-	
Bend Stiff All Posts	1.31E+02	MN/m



Appendix A
Bellows Extra 9 MPa Check

Magnetic Stability Re-calculation

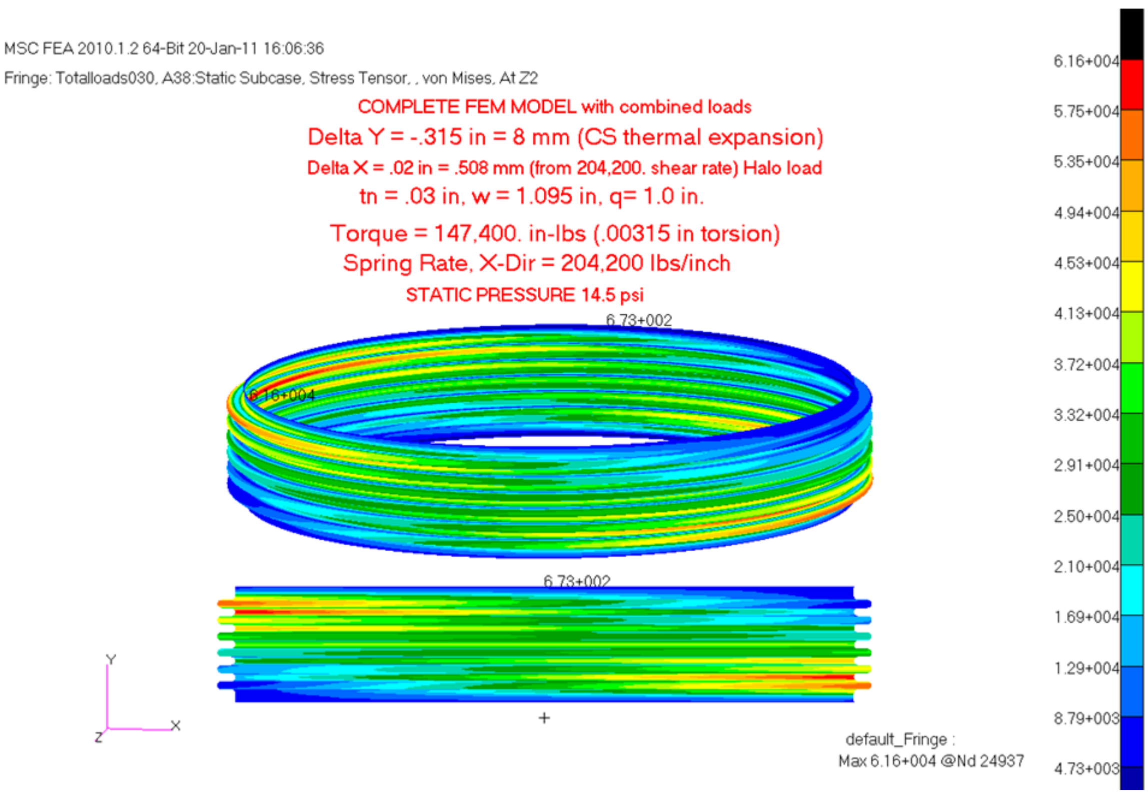
Due to the Magnetic Stability calculations, The Bellows see an additional 9Mpa of stress. (E-mail from P. Titus 8/27/2011)

This is equivalent to about 1,300 Psi.

As calculated originally in “NSTXU-CALC-133-10-00” this changes bellows max stress as follows:

By adding this value to the Max combined stress of 61,600 psi (see slide #3) for bellows thickness = .03 inches, the max stress becomes 62,900 psi. This is acceptable and O.K. for INCONEL 2/3Sy = 63,300 psi.

P.R. 8/31/2011



Summary of stresses for total loads combination

Thickness	von Misses	Max Shear	delta Y	Delta X	Pressure	Torque	X-Spring Rate
inches	psi	psi	inch	inch	psi	in-lbs	lbs/inch
0.02	66,800.0	36,700.0	-0.315	0.0374	14.5	98,211.0	71,200.0
0.025	64,500.0	35,700.0	-0.315	0.0284	14.5	122,800.0	128,200.0
0.03	61,600.00	34,200.0	-0.315	0.02	14.5	147,400.0	204,200.0

Notes: For INCONEL, say, Sy=95,000 psi, 2/3Sy = 63,300 psi, Bellows thickness of .030 in can be selected

X-Spring Rate is based on 1 .0 mm (.0394 inch) shear deformation and for selected bellows thickness,
Delta X is calculated using this spring rate.

Torgue is based on the toroidal deformation (.8e-4 m) of the selected bellows thickness
Applied at Node # 49436 as "Moment Y" (d.o.f. "Ry" through Nastran "Coord 0")

Delta Y due to the CS thermal expansion

Pressure always present