Final_Bellows.ppt

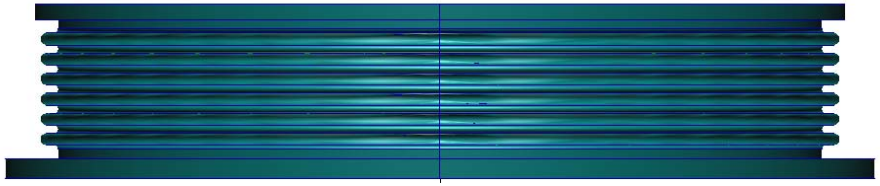
Executive Summary

The purpose for these analyses was to justify and select the appropriate NSTX Center Stack Update project VV Bellows. The bellows should provide and absorb the existing relative motions between the redesigned Center Stack and the Vacuum Vessel within the acceptable stress limits for the selected material for a combination of load conditions.

The analyses were completed using two methods:

* EJMA standard equations, and,
* Nastran finite element code.

COMPLETE ASSEMBLY



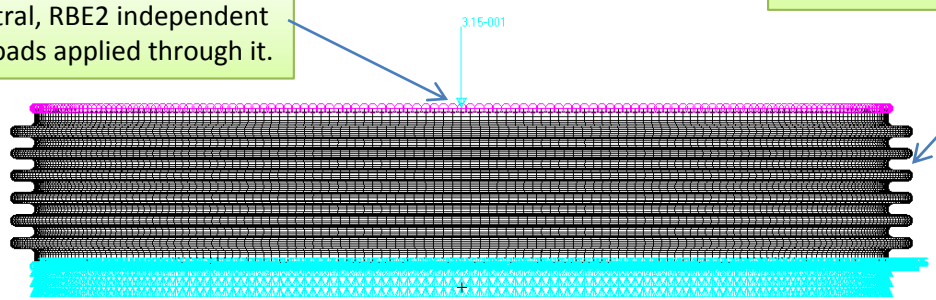
Modulus of Elasticity = 29,000,000.
stainless steel (FEA and EJMA)
t = variable (.02, .025, .03) in.

Di = 38.0 inches
Do =40.25 inches

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

COMPLETE FEM MODEL

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
```

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

Design justification for the NSTX Update Bellows

FEM model simulation: Quad4 NASTRAN element with various convolution thicknesses.
For present analyses, .020, .025 and .030 in.

Load conditions:

1) 8 mm - Axial compression due to the CS expansion.
2) Static Pressure = 14.5 psi.
3) TORSIONAL deformation = .00315 in. (Applied as pure moment values. which were calculated from P. Titus inputs).
4) Halo Loads Reactions at the bellows (variable as per bellows thickness as calculated from A. Brooks inputs).

Note: Conditions #3 and #4 change, based on the selected material thickness.

EJMA equations and related constants were used to test and justify the validity of the FEM simulation using <u>axial deformation and pressure loads</u>:

Eq. 4-30, 4-31, 4-32, 4-33 and 4-37.

EJMA constants: Cp, Cf and Cd.

Figures 4.16, 4.17, 4.18.

Figure 4-20 for fatigue life estimates.

Comparison between pure EJMA equations and NASTRAN results

Final_bellows.xls [Compatibility Mode]

	A	B	C	D	E	F	G	H
1								
2								
3		EJMA -Stress		NASTRAN -Stress		Shear rate	Torque	
4		psi		psi		lbs/in	in-lbs	
5	Thickness	Pressure	Axial	Pressure	Axial			
6								
7								
8	.020 in	15,200.0	25,600.0	15,600	23.300.0	71,120.0	98,211.0	
9						2800#/mm		
10	.025 in	9,736.0	31,990.6	9,640.0	28,800.0	128,200.0	122,800.0	
11						5040#/mm		
12	.030 in	6,762.0	38,386.0	6,970.0	34,400.0	204,200.0	147,400.0	
13				8,190.0		8,040#/mm		
14								
15		Note:	w= 1.095 for all calculations					
16			q=1.0 inches		Torsional delta = .00315in = .8e-4m			
17			1.0 mm= .0394 in					
18								

Summary of EJMA calculations

	EJMA Equations					
Thickness	S_3	S_4	S_5	S_6	S_t	Spring Rate
inch	psi	psi	psi	psi	psi	lbs/in
0.02	269.0	15,211.0	137.0	25,594.2	36,567.0	1,136.5
0.025	322.2	9,737.0	213.4	31,991.0	39,245.0	2,219.6
0.03	269	6,762.4	307.2	38,386.3	43,615.2	3,835.2

All equations are listed in the EJMA spread sheets

"St" Is Total stress used for Fatigue Life (Nc)

This data is only valid for Axial deformation and pressure loads

EXPLANATIONS

Following can be concluded by examining the above table.

* “EJMA” and “MSC/NASTRAN FEA 2010” results compare favorably.

* For constant axial deformation of the convoluted bellows (in our case .315 inch), maximum stresses:
  - decrease with decreasing thickness (t),
  - decrease with increasing convolution height (w).
    (function of the allowable space)

* For constant pressure (in our case atmospheric , always present) stresses:
  - increase with decreasing thickness (t)
  - increase slightly with increase of (w).

* For Halo loads, it is necessary to calculate the bellows Spring Rate in the pure shear mode. Since the spring rate changes with changing thickness, the absorbed amount of the Halo Energy , reacts at the bellows to form the shear deformation. Then this calculated deformation is used, as an enforced load case, in the static FEM simulation.

* Toroidal deformation is constant/maximum (.8e-4 m = .00315 inches) and produce decreasing Torque values with the decrease of (t)

Total Loads

Calculations when all load conditions are applied simultaneously .

* CS thermal expansion
* Pressure
* Halo Loads effects
* Toroidal motion

MSC FEA 2010.1.2 64-Bit 20-Jan-11 15:40:56

Fringe: Totalloads020, A39:Static Subcase, Stress Tensor, , von Mises, At Z2

Units in Psi

COMPLETE FEM MODEL with combined loads

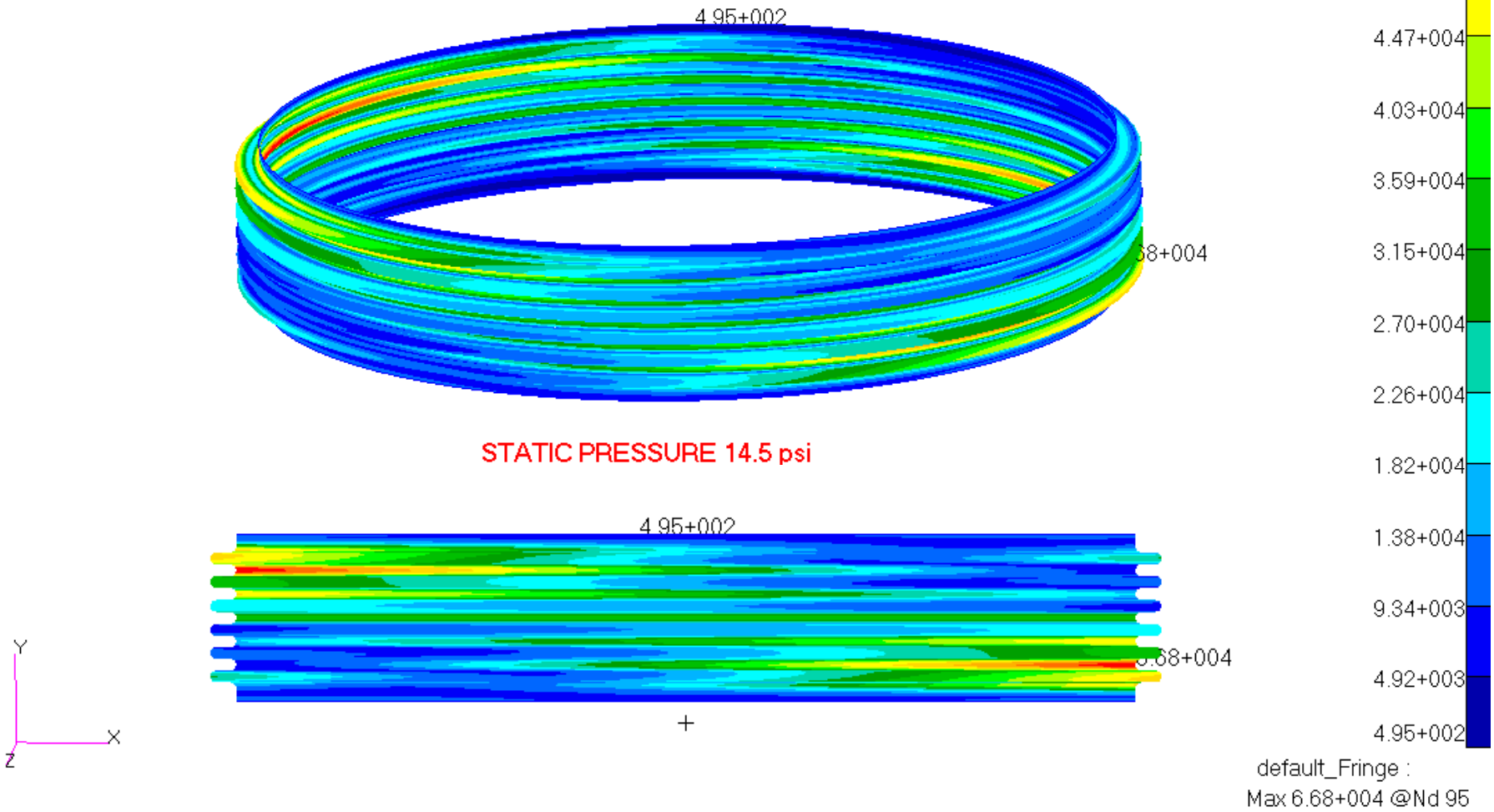
Delta Y = -.315 in = 8 mm (CS thermal expansion)

Delta X = .0374 in = .95 mm (from 71,120. shear rate) Halo Loads

tn = .02 in, w = 1.095 in, q= 1.0 in.

Torque = 98,211. in-lbs (.00315 in torsion)

Spring Rate, X-Dir = 71,200. lbs/inch



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Fringe: Totalloads025, A40:Static Subcase, Stress Tensor, , von Mises, At Z2

COMPLETE FEM MODEL with combined loads

Delta Y = -.315 in = 8 mm (CS thermal expansion)

Delta X = .0284 in = .72 mm (from 128,200. shear rate) Halo Load

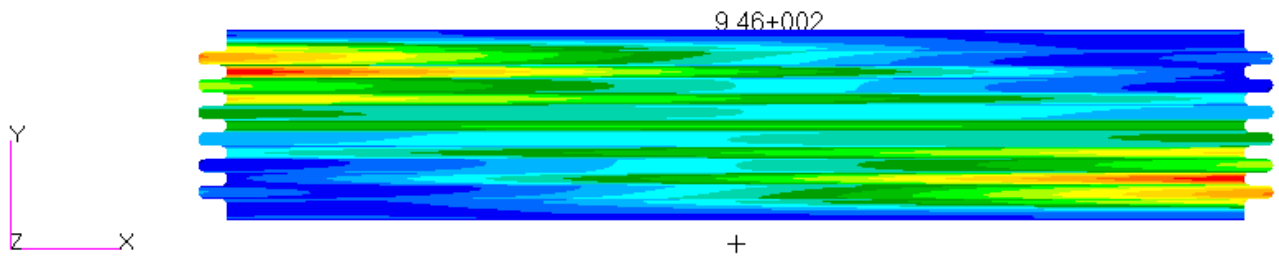
tn = .025 in, w = 1.095 in, q = 1.0 in.

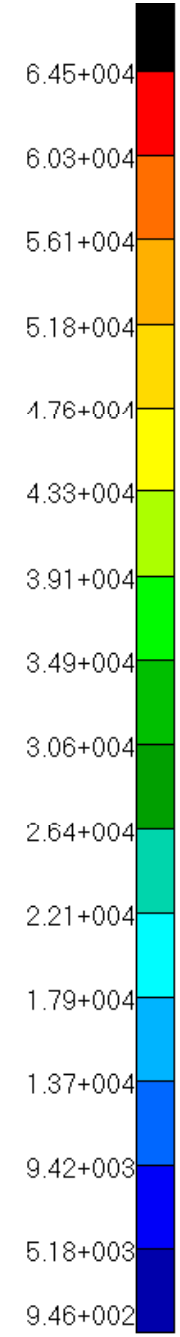
Torque = 122,800 in-lbs (.00315 in torsion)

Spring Rate, X-Dir = 128,200 lbs/inch

STATIC PRESSURE 14.5 psi

Halo





default_Fringe :

Max 6.45+004 @Nd 24937

MSC FEA 2010.1.2 64-Bit 20-Jan-11 16:06:36

Fringe: Totalloads030, A38:Static Subcase, Stress Tensor, , von Mises, At Z2

COMPLETE FEM MODEL with combined loads

Delta Y = -.315 in = 8 mm (CS thermal expansion)

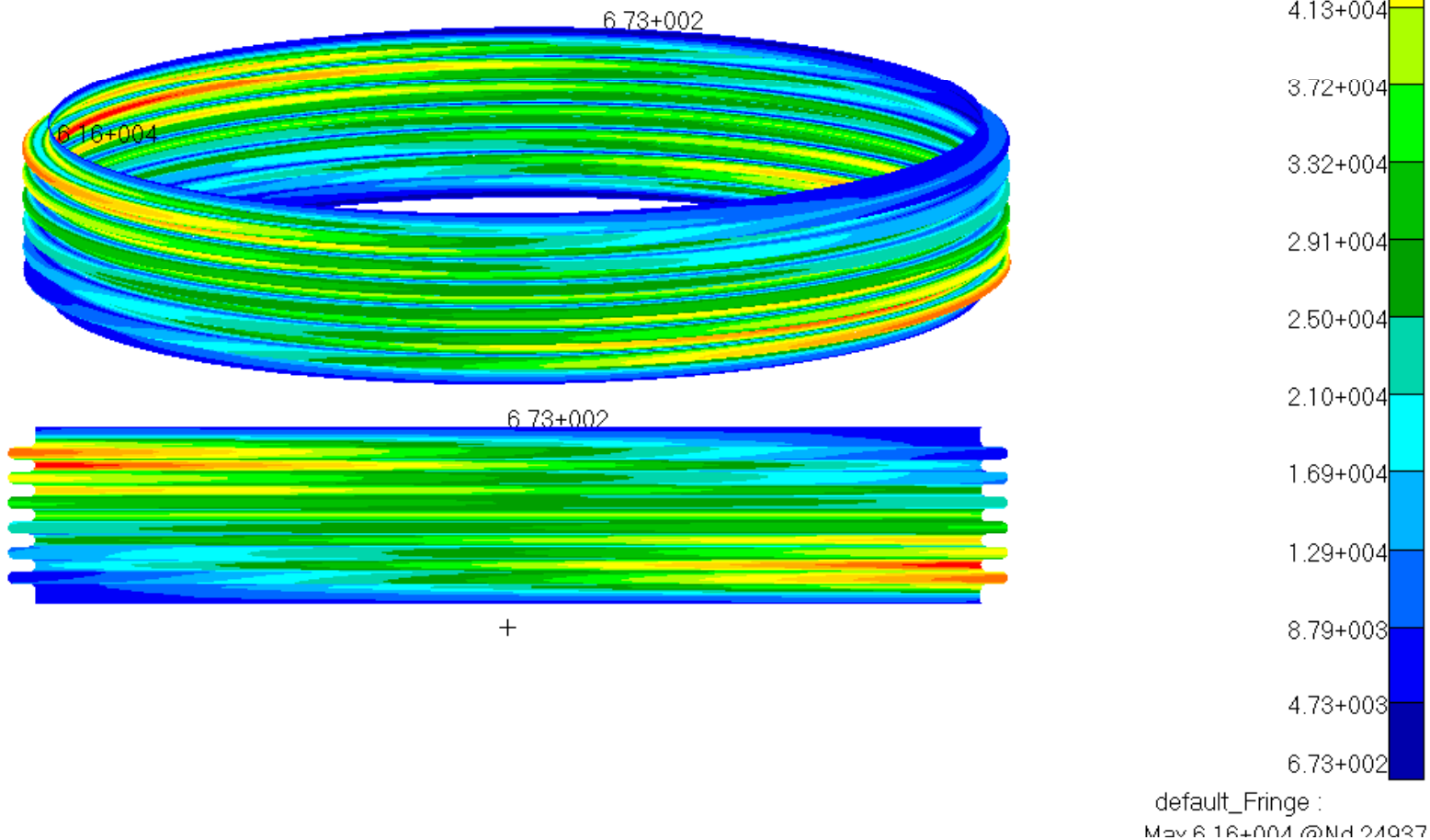
Delta X = .02 in = .508 mm (from 204,200. shear rate) Halo load

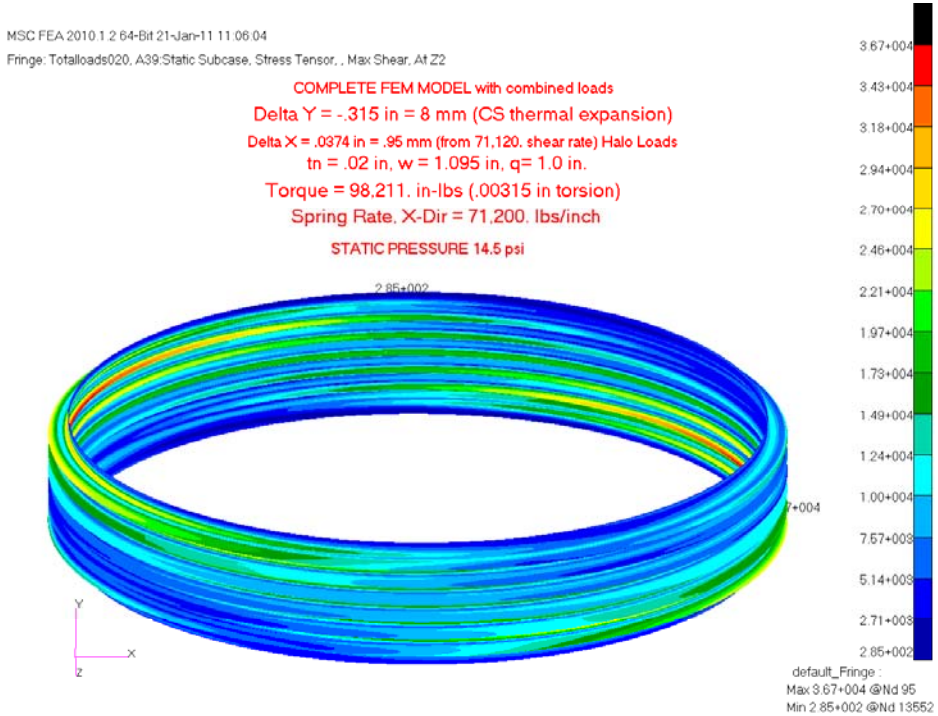
tn = .03 in, w = 1.095 in, q= 1.0 in.

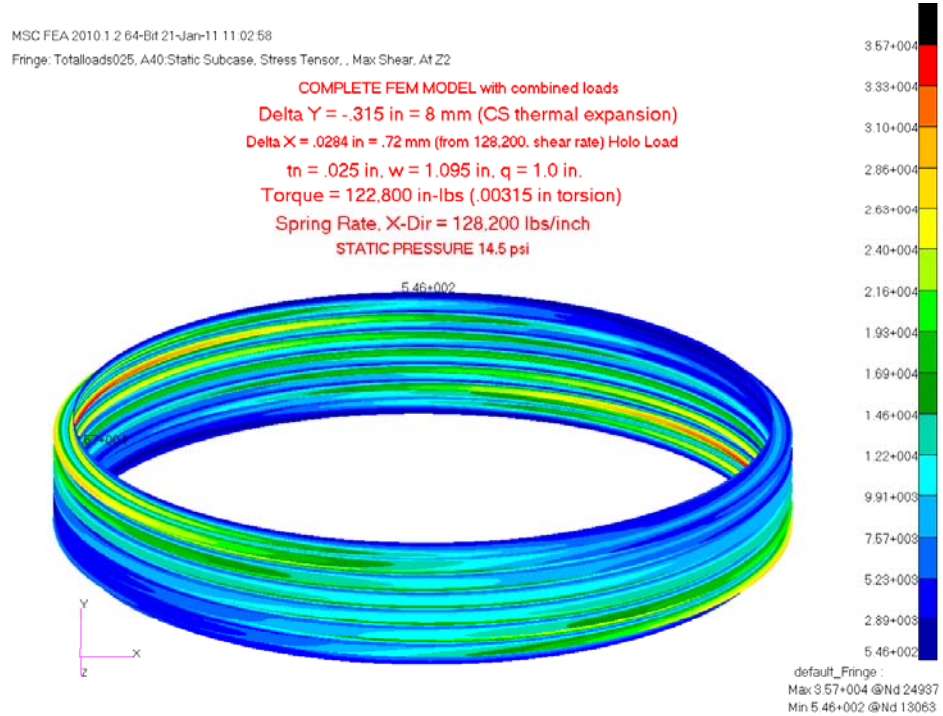
Torque = 147,400. in-lbs (.00315 in torsion)

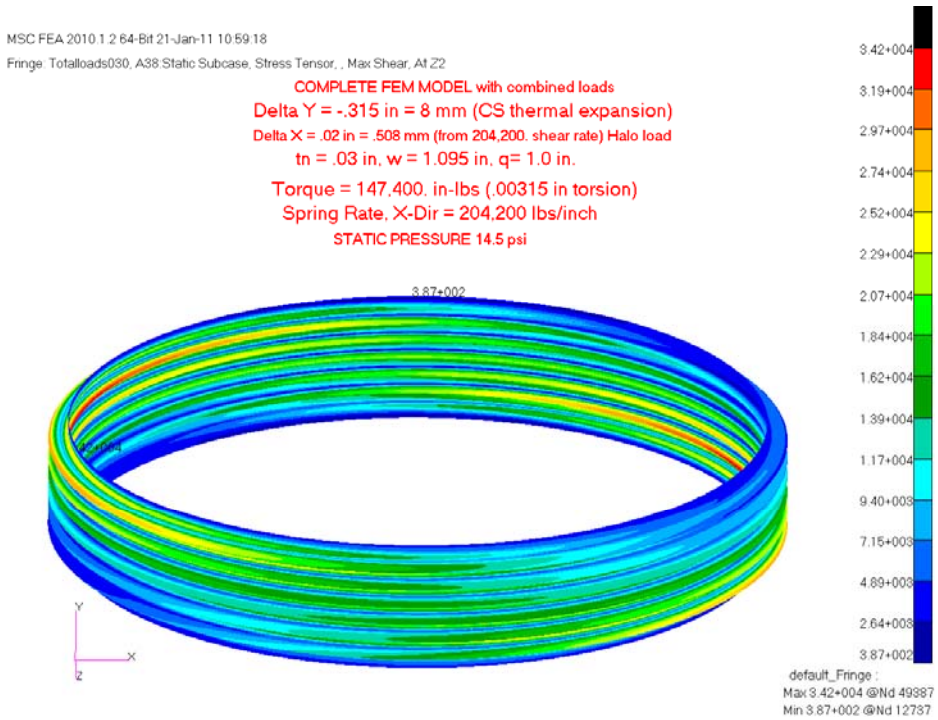
Spring Rate, X-Dir = 204,200 lbs/inch

STATIC PRESSURE 14.5 psi









All load applied Max Shear

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.

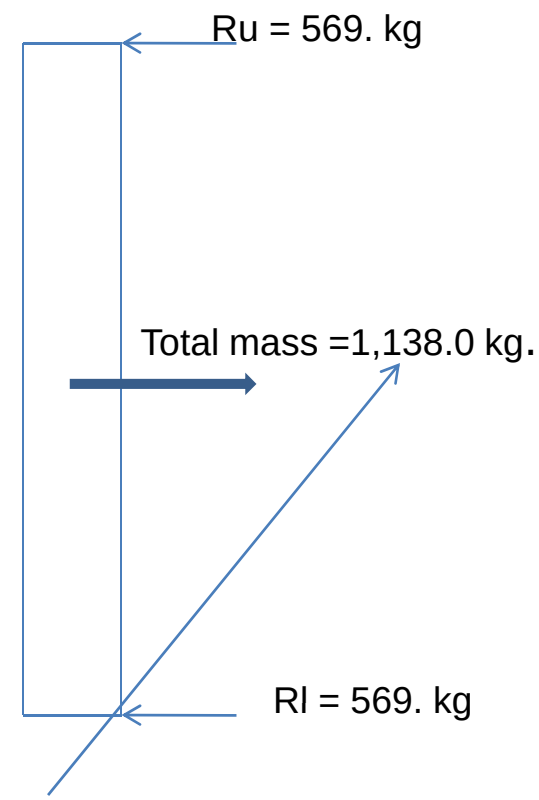
Torgue is based on the toroidal deformation (.8e-4 m) of the selected bellows thickness
Applied at Node # 49436 as "Moment Y" (d.o.f. "Ry" through Nastran "Coord 0")

Delta Y due to the CS thermal expansion

Pressure always present

Seismic force/reaction calculation

CS assembly



Reff. E-mail from A. Brooks/A. Jarivala

Use acceleration = .5 Gs.

(P. Titus)

Reaction at bellows = 569. x .5 x 2.204 lbs.
= 627.0 lbs

Note: this is considering maximum spring rate reaction at Ru and Rl. Since in our case, spring rates are much lower, shear reaction at the bellows will decrease accordingly.

Chances for this event are minimal.

Maximum Stresses due to individual Load conditions

W = 1.095 in. (convolution height), q=1.0 in (convolution pitch)

Thicknes inch	Axial psi	Presure psi	Halo psi	Halo Shear psi	Torsional psi
0.02	23,200.0	15,600.0	38,500.0	19,900.0	3,790.0
0.025	28,800.0	10,900.0	34,500.0	18,100.0	3,820.0
0.03	34,400.0	8,100.0	27,500.0	14,500.0	3,850.0

For Halo Loads --- Variable spring rate (function of thickness).

For Torsion -- Constant deformation along the upper edje of the bellows. (=.00315 in)

Note : These stresses do not show at different locations of the bellows, and, therefore, do not add linearly (see stresses due to the combined loads above)

All stresses are von Mises at element fiber "Z2"

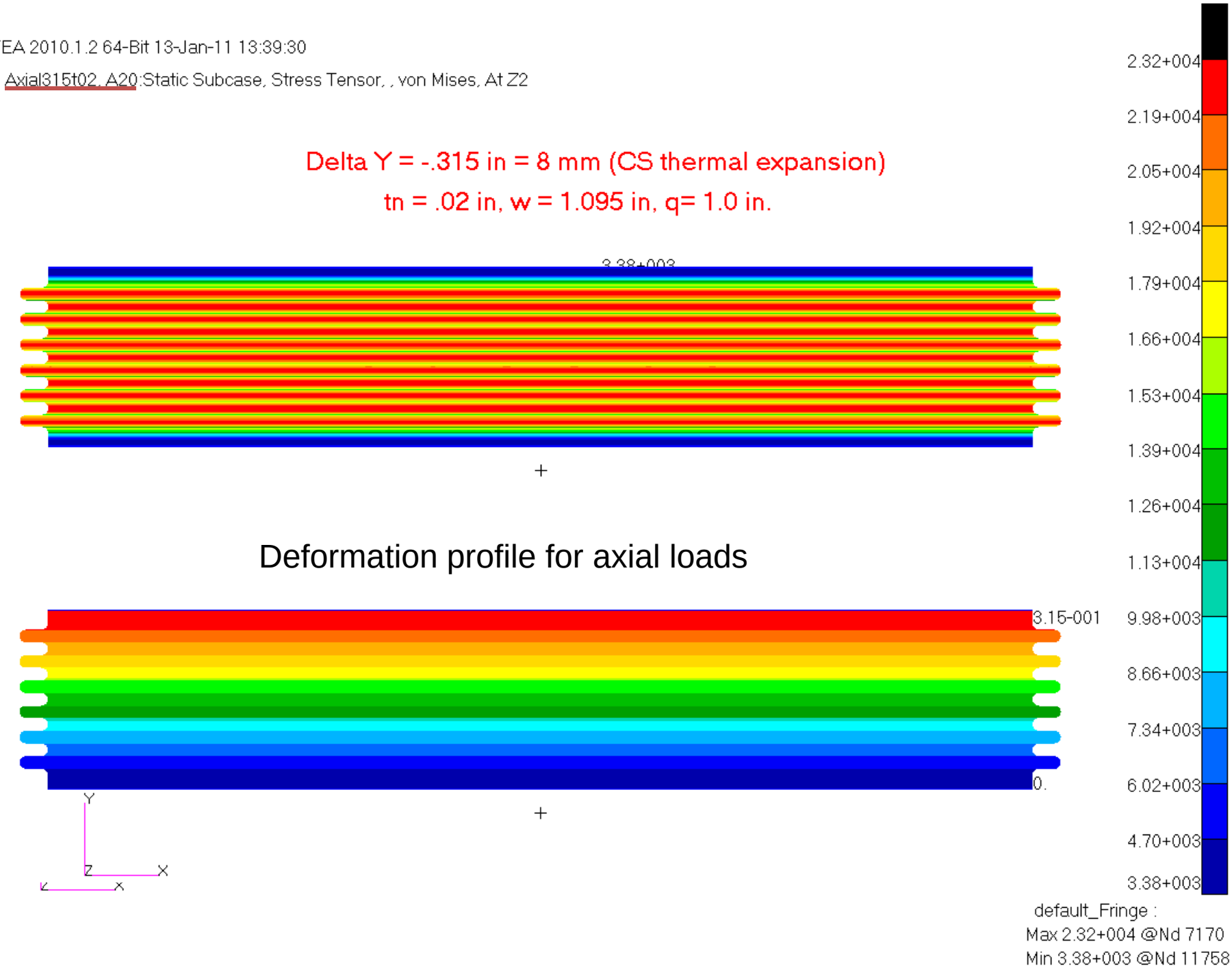
Calculations for each load case independently.
This is provided for better understanding of bellows reaction to various load conditions and for easier selection based on material thickness.

MSC FEA 2010.1.2 64-Bit 13-Jan-11 13:39:30

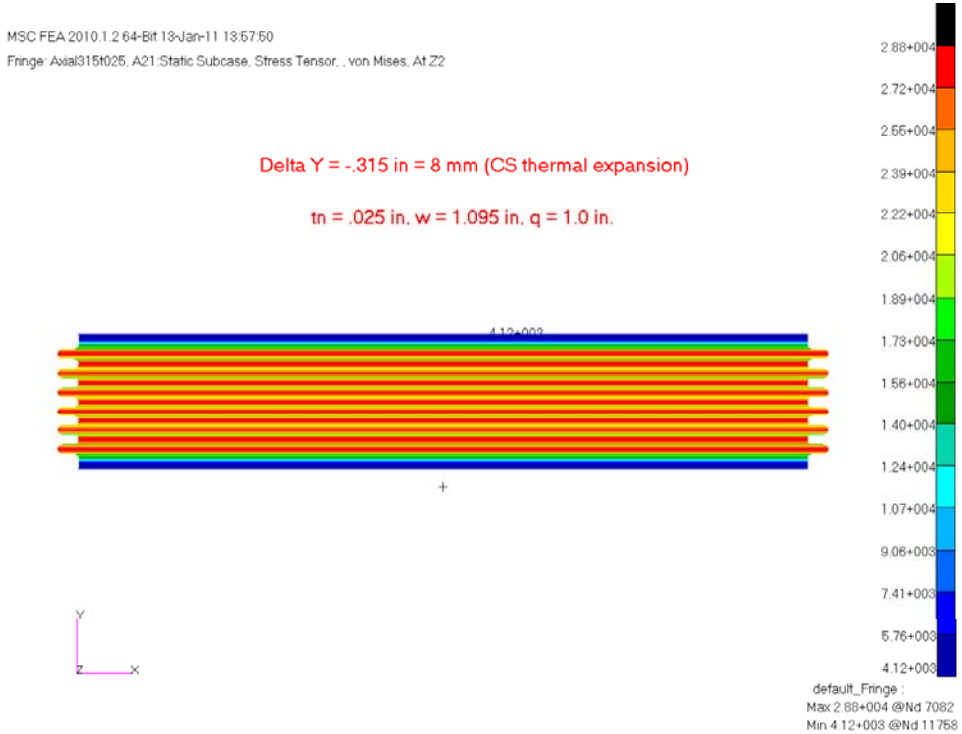
Fringe: Axial315t02, A20:Static Subcase, Stress Tensor, , von Mises, At Z2

Delta Y = -.315 in = 8 mm (CS thermal expansion)

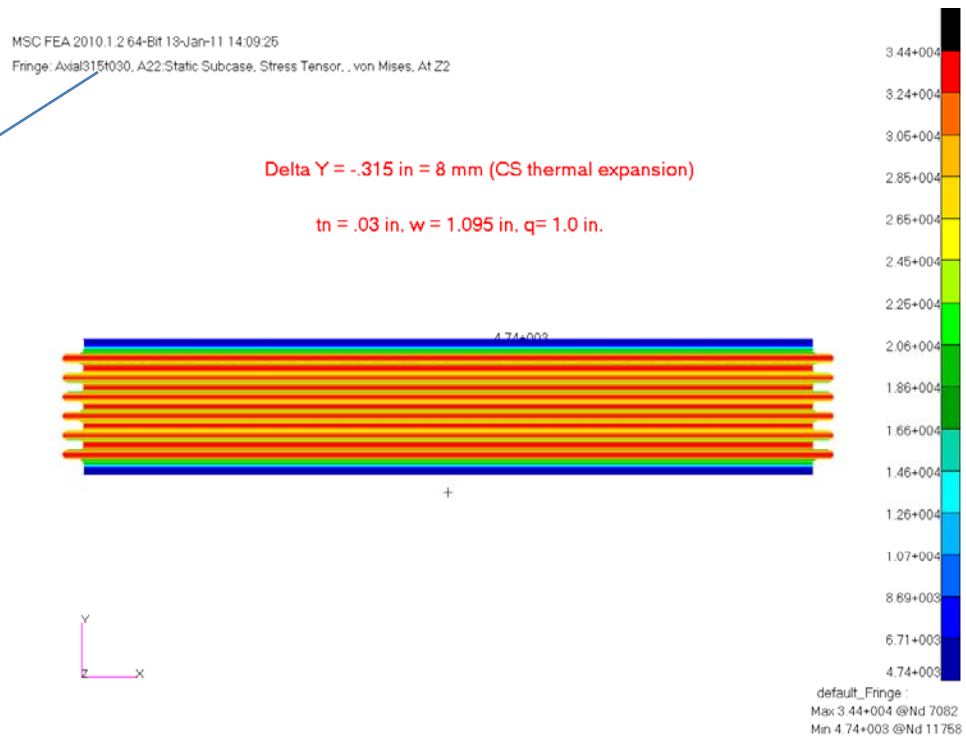
tn = .02 in, w = 1.095 in, q= 1.0 in.



Deformation profile for axial loads

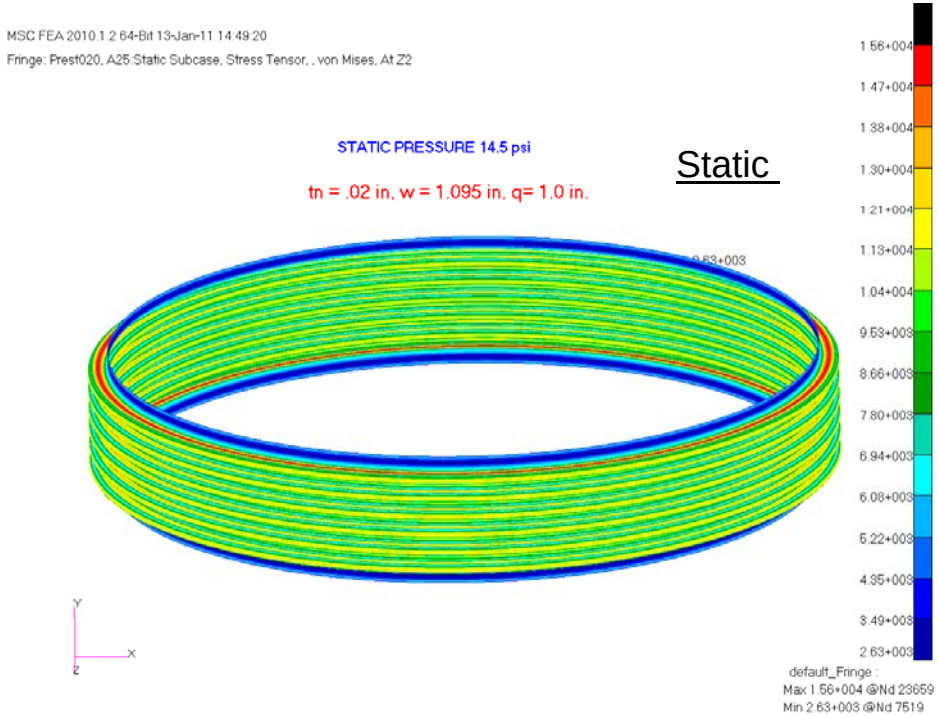


Thickness	Max. stress von Mises
.020 in.	23,200 psi
	Delta =5,600. psi
.025 in.	28,800 psi
	Delta =5,600. psi
.030 in.	34,400 psi



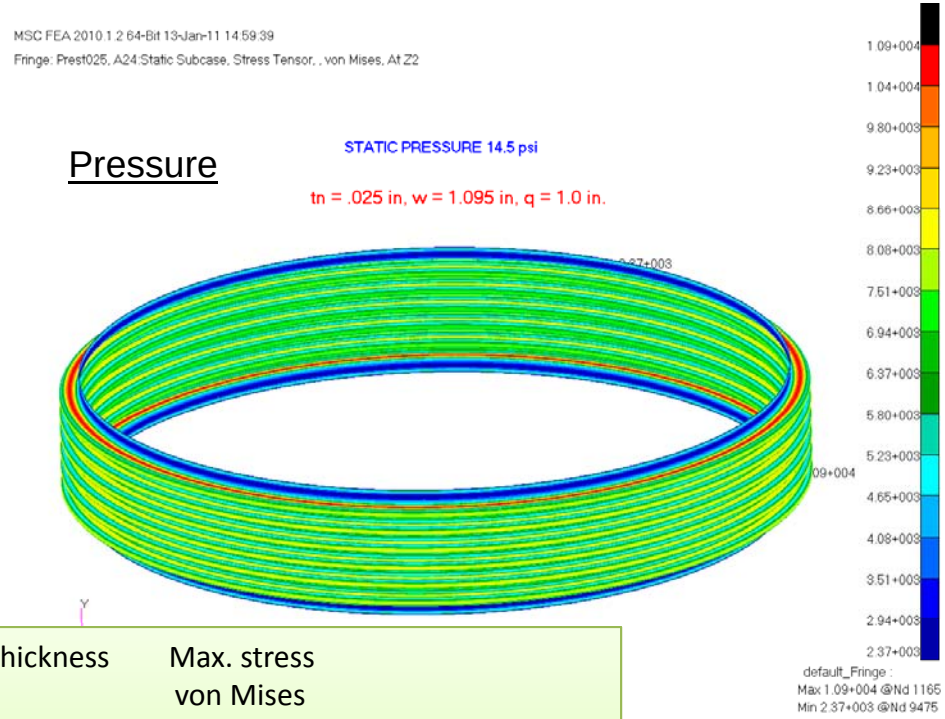
Axial315t030,A22
(Load case designation
for each configuration)

See Appendix for description
of all cases

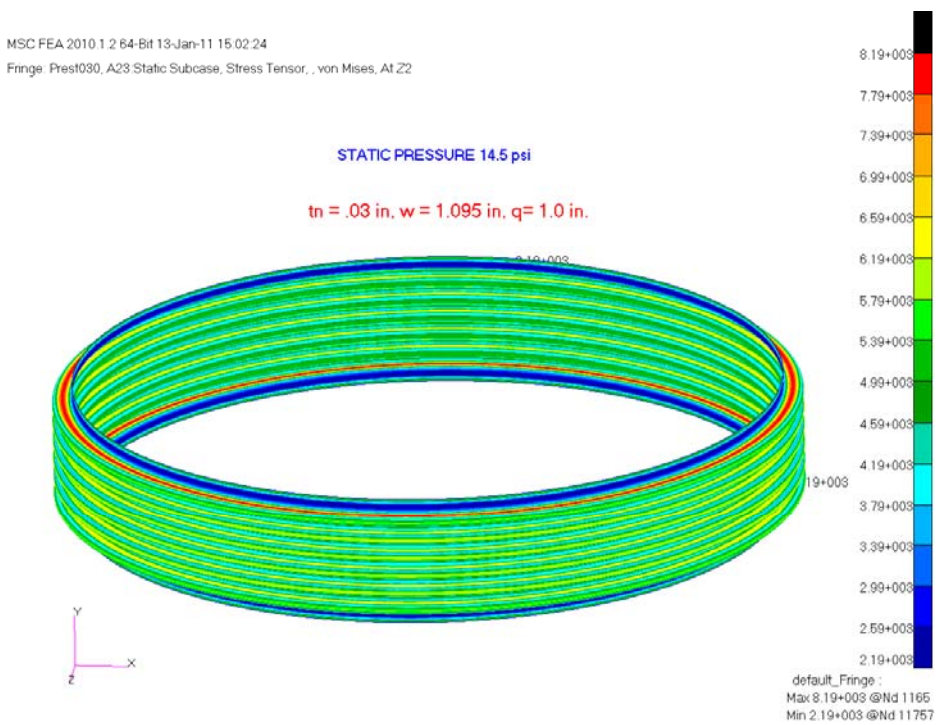


Static

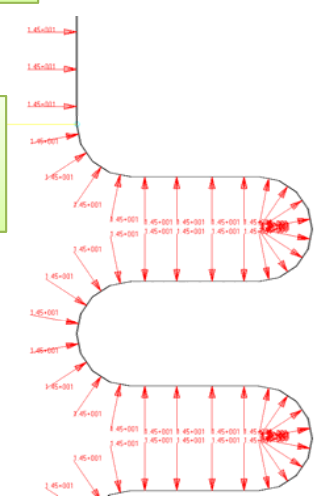
Pressure

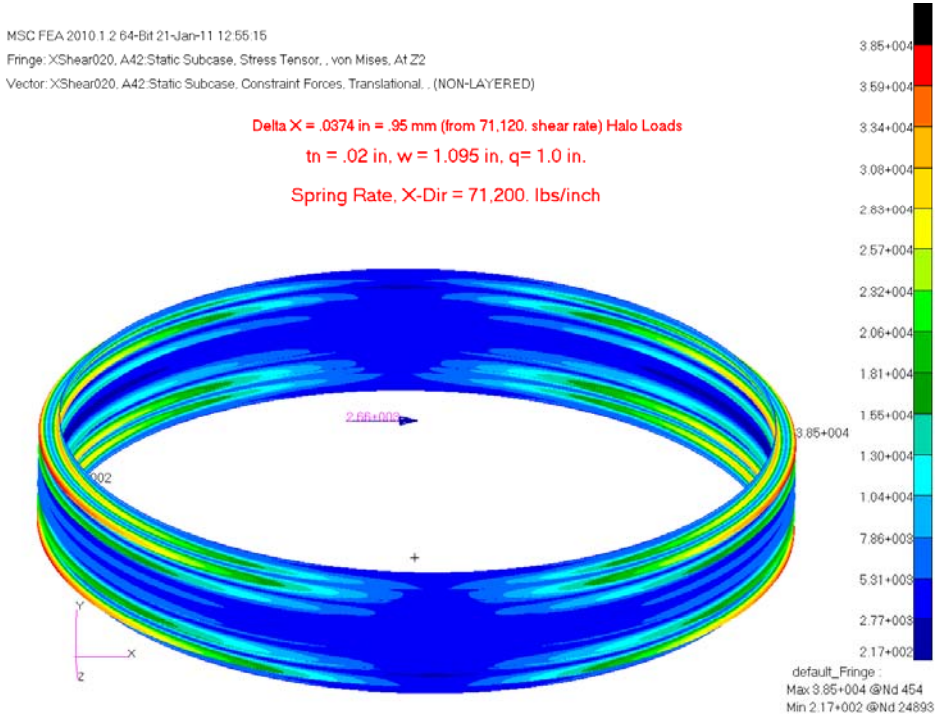


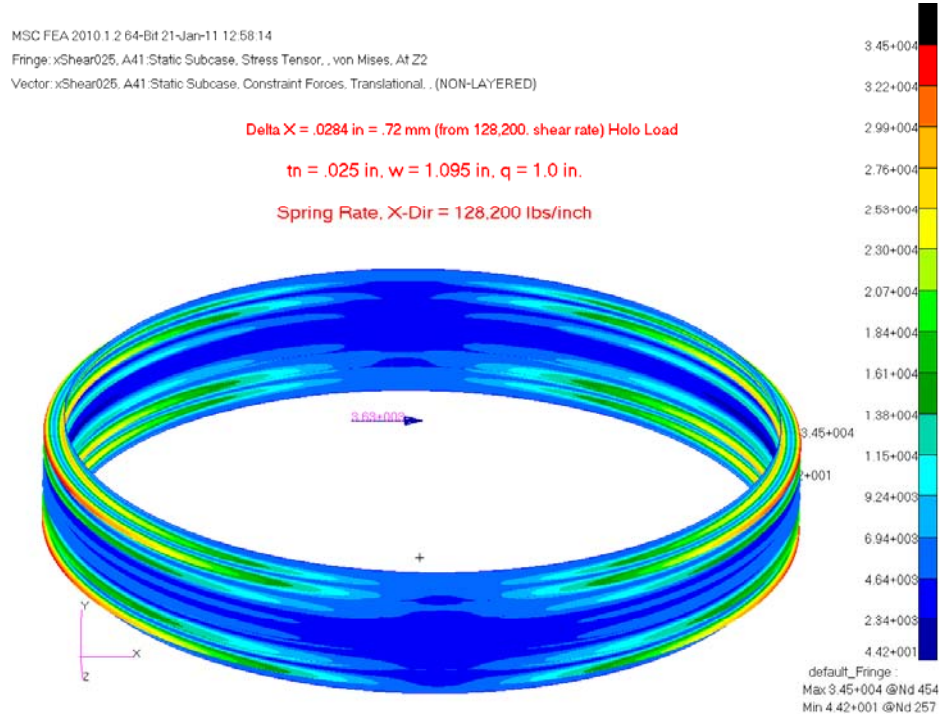
Thickness	Max. stress von Mises
.020 in.	15,600. psi
	Delta = 4,700. psi
.025 in.	10,900. psi
	Delta = 2,710. psi
.030 in.	8,190.psi

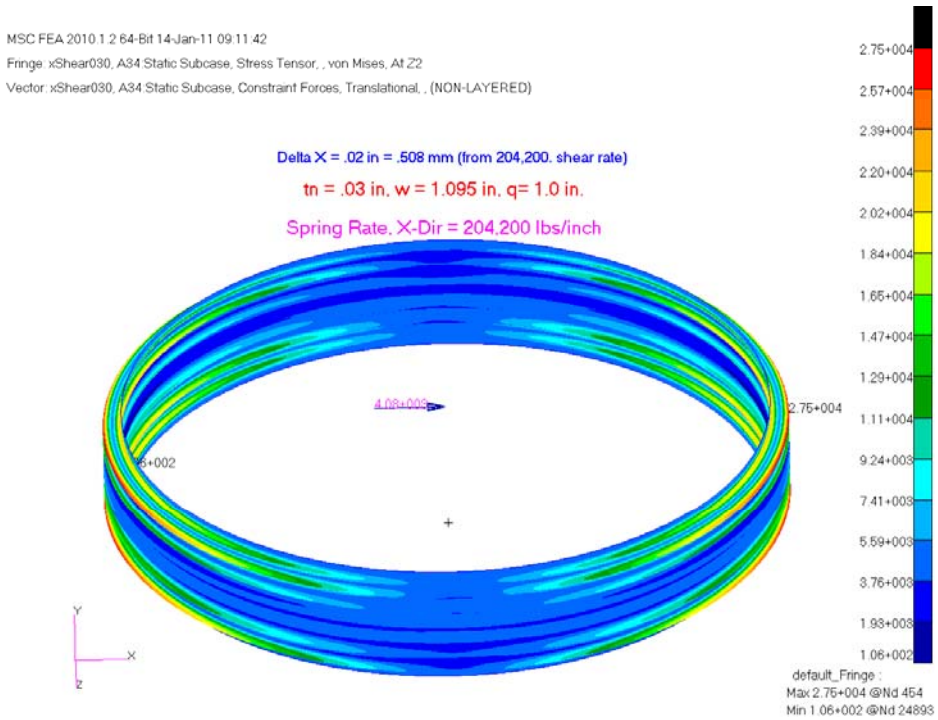


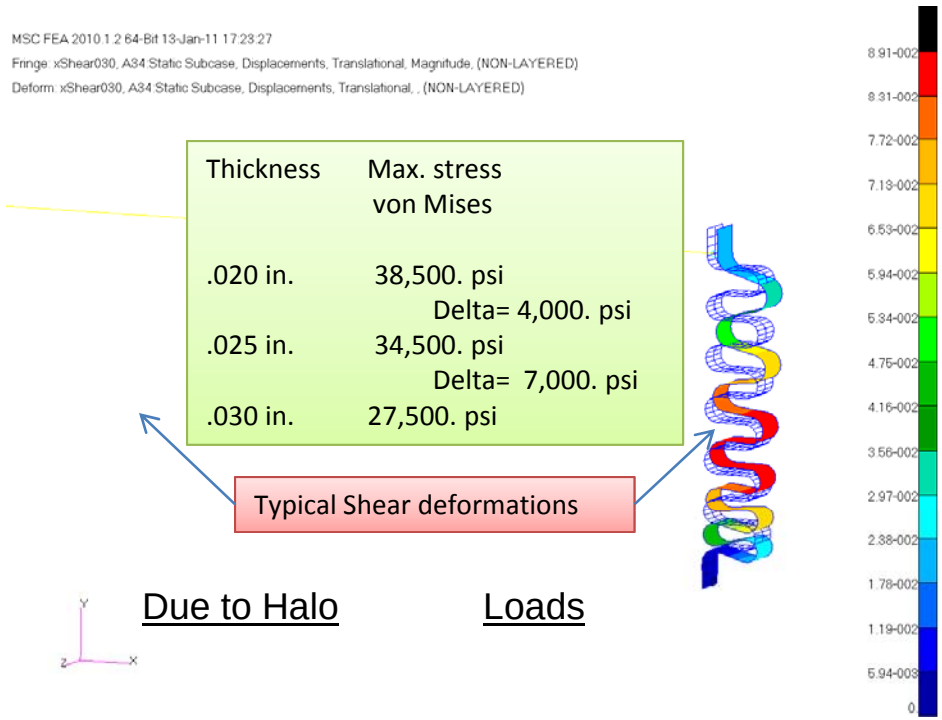
General pressure application

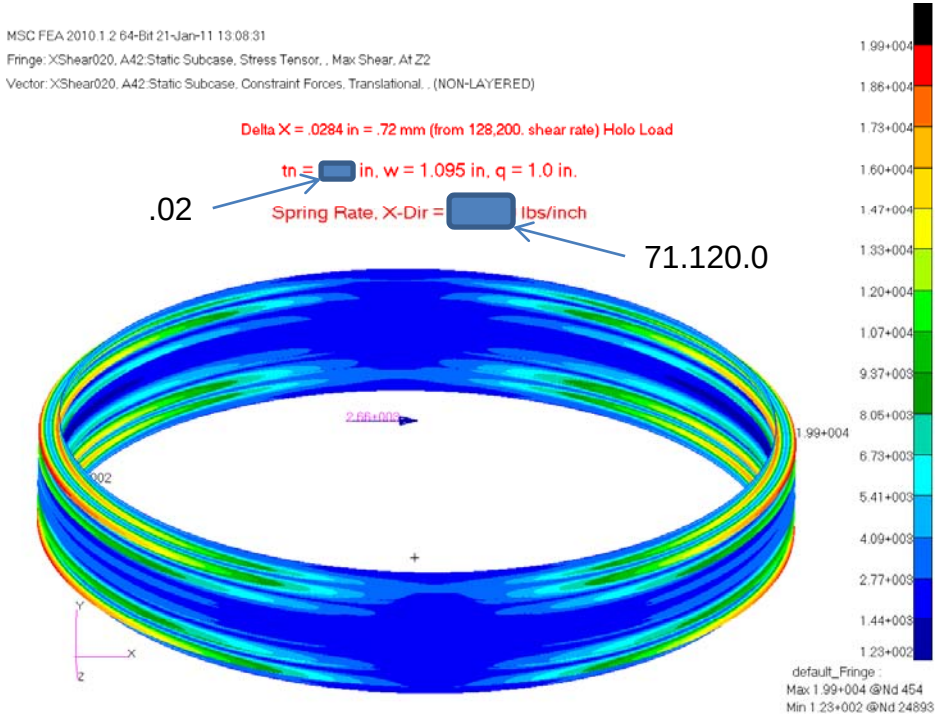


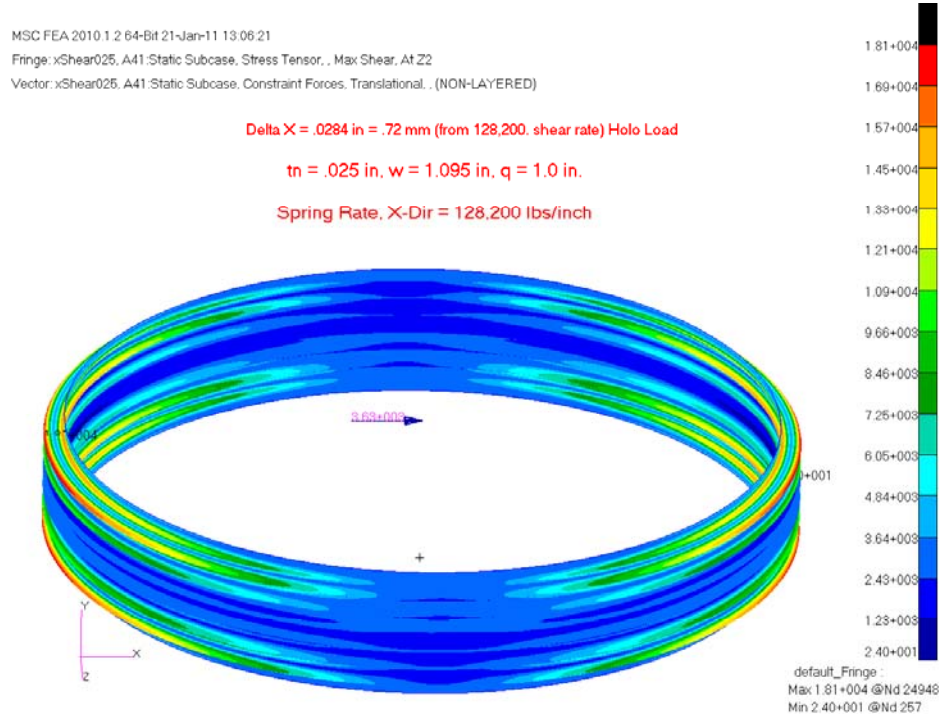

MSC FEA 2010.1.2 64-Bit 21-Jan-11 12:55:15
Fringe: XShear020, A42:Static Subcase, Stress Tensor, , von Mises, At Z2
Vector: XShear020, A42:Static Subcase, Constraint Forces, Translational, , (NON-LAYERED)
Delta X = .0374 in = .95 mm (from 71,120. shear rate) Halo Loads
tn = .02 in, w = 1.095 in, q= 1.0 in.
Spring Rate, X-Dir = 71,200. lbs/inch
3.85+004
3.69+004
3.34+004
3.08+004
2.83+004
2.57+004
2.32+004
2.06+004
1.81+004
1.55+004
1.30+004
1.04+004
7.86+003
5.31+003
2.77+003
2.17+002
default_Fringe :
Max 3.85+004 @Nd 454
Min 2.17+002 @Nd 24893

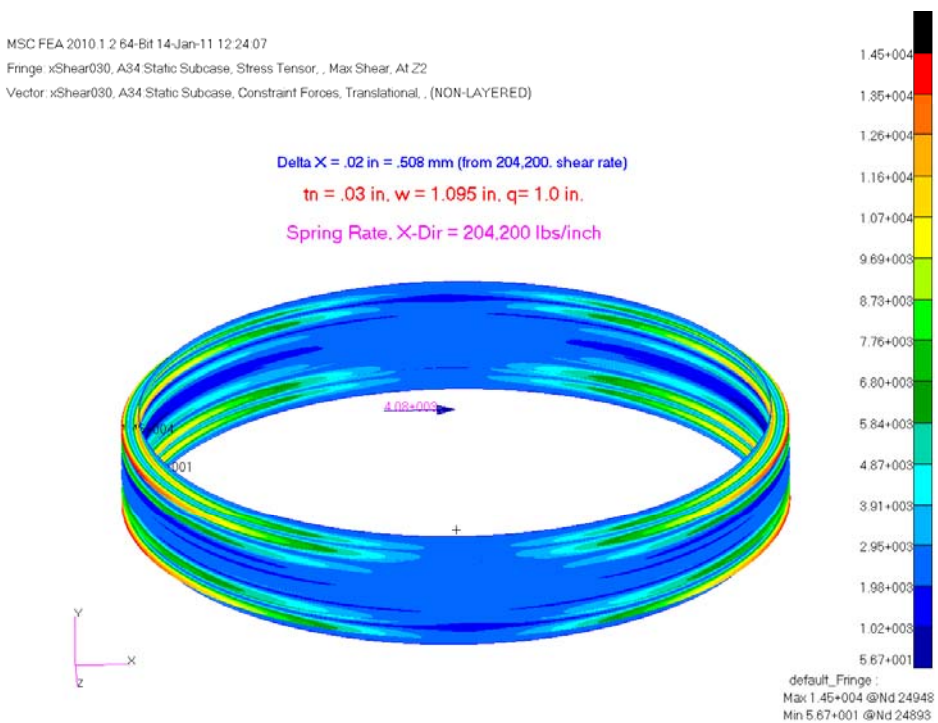

MSC FEA 2010.1.2 64-Bit 21-Jan-11 12:58:14
Fringe: xShear025, A41:Static Subcase, Stress Tensor, , von Mises, At Z2
Vector: xShear025, A41:Static Subcase, Constraint Forces, Translational, , (NON-LAYERED)
Delta X = .0284 in = .72 mm (from 128,200. shear rate) Holo Load
tn = .025 in, w = 1.095 in, q = 1.0 in.
Spring Rate, X-Dir = 128,200 lbs/inch
3.45+004
3.22+004
2.99+004
2.76+004
2.53+004
2.30+004
2.07+004
1.84+004
1.61+004
1.38+004
1.15+004
9.24+003
6.94+003
4.64+003
2.34+003
4.42+001
default_Fringe :
Max 3.45+004 @Nd 454
Min 4.42+001 @Nd 257


MSC FEA 2010.1.2 64-Bit 14-Jan-11 09:11:42
Fringe: xShear030, A34:Static Subcase, Stress Tensor, , von Mises, At Z2
Vector: xShear030, A34:Static Subcase, Constraint Forces, Translational, , (NON-LAYERED)
Delta X = .02 in = .508 mm (from 204,200. shear rate)
tn = .03 in, w = 1.095 in, q= 1.0 in.
Spring Rate, X-Dir = 204,200 lbs/inch
2.75+004
2.57+004
2.39+004
2.20+004
2.02+004
1.84+004
1.65+004
1.47+004
1.29+004
1.11+004
9.24+003
7.41+003
5.59+003
3.76+003
1.93+003
1.06+002
default_Fringe :
Max 2.75+004 @Nd 454
Min 1.06+002 @Nd 24893


MSC FEA 2010.1.2 64-Bit 13-Jan-11 17:23:27
Fringe: xShear030, A34:Static Subcase, Displacements, Translational, Magnitude, (NON-LAYERED)
Deform: xShear030, A34:Static Subcase, Displacements, Translational, , (NON-LAYERED)
Thickness Max. stress von Mises
.020 in. 38,500. psi
Delta= 4,000. psi
.025 in. 34,500. psi
Delta= 7,000. psi
.030 in. 27,500. psi
Typical Shear deformations
Due to Halo Loads
8.91-002
8.31-002
7.72-002
7.13-002
6.53-002
5.94-002
5.34-002
4.75-002
4.16-002
3.56-002
2.97-002
2.38-002
1.78-002
1.19-002
5.94-003
0

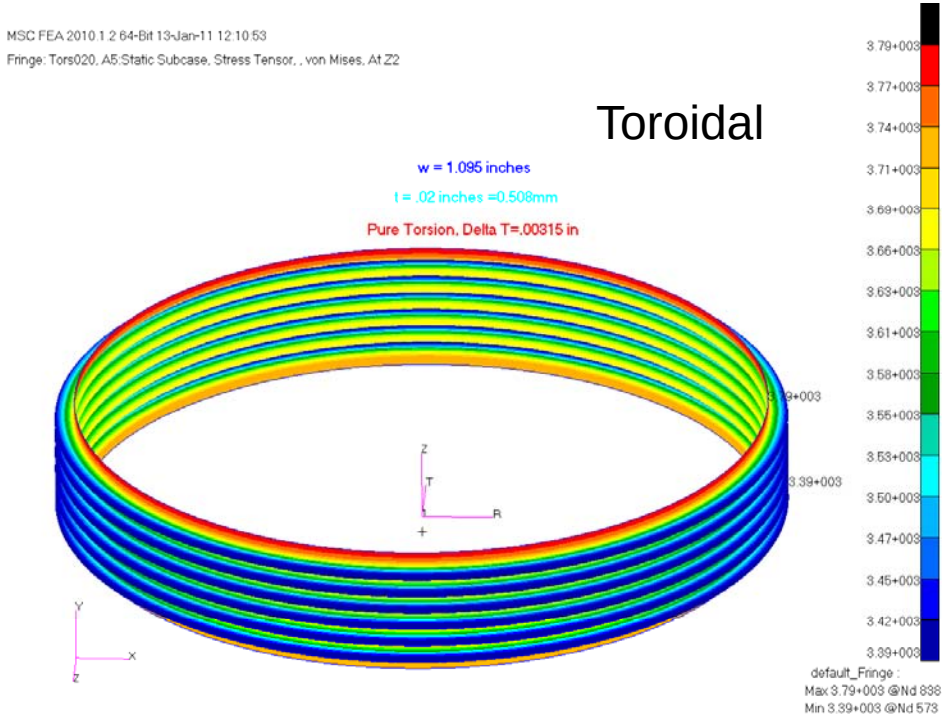


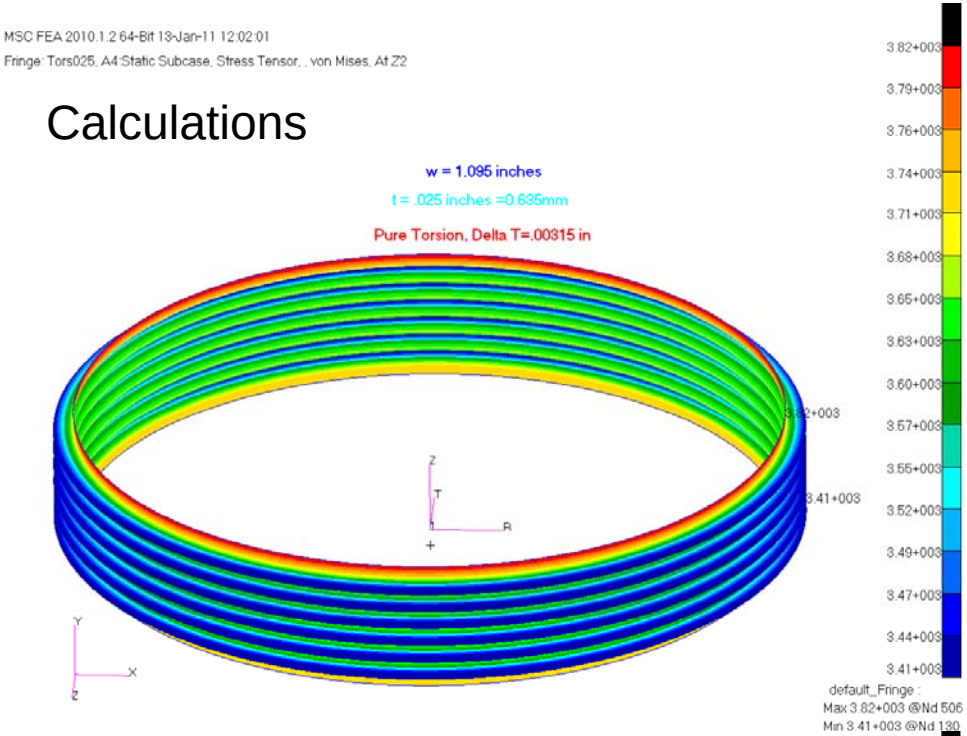


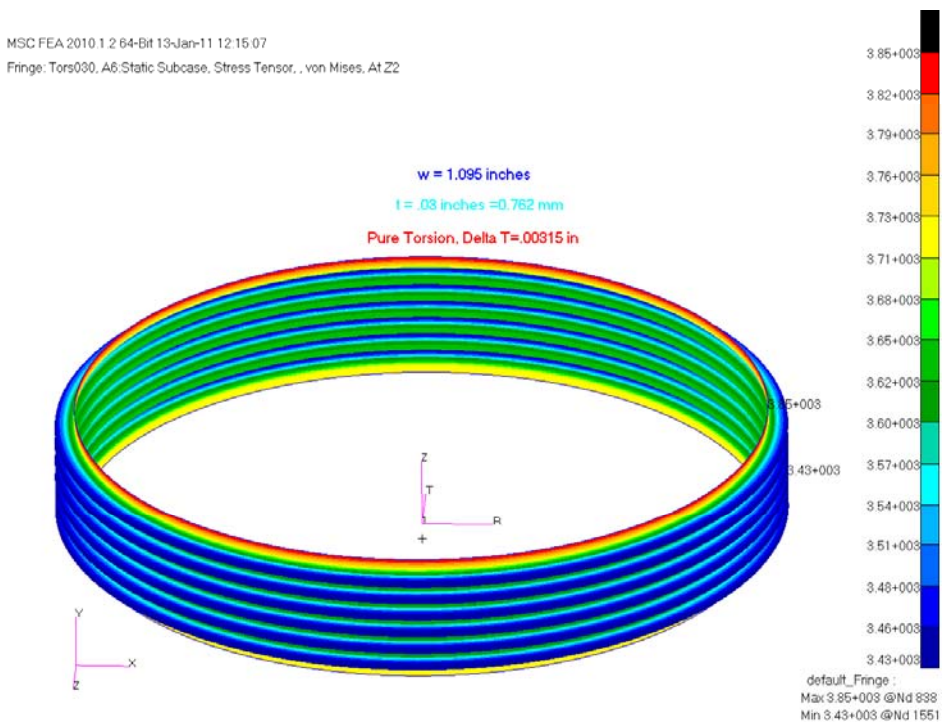


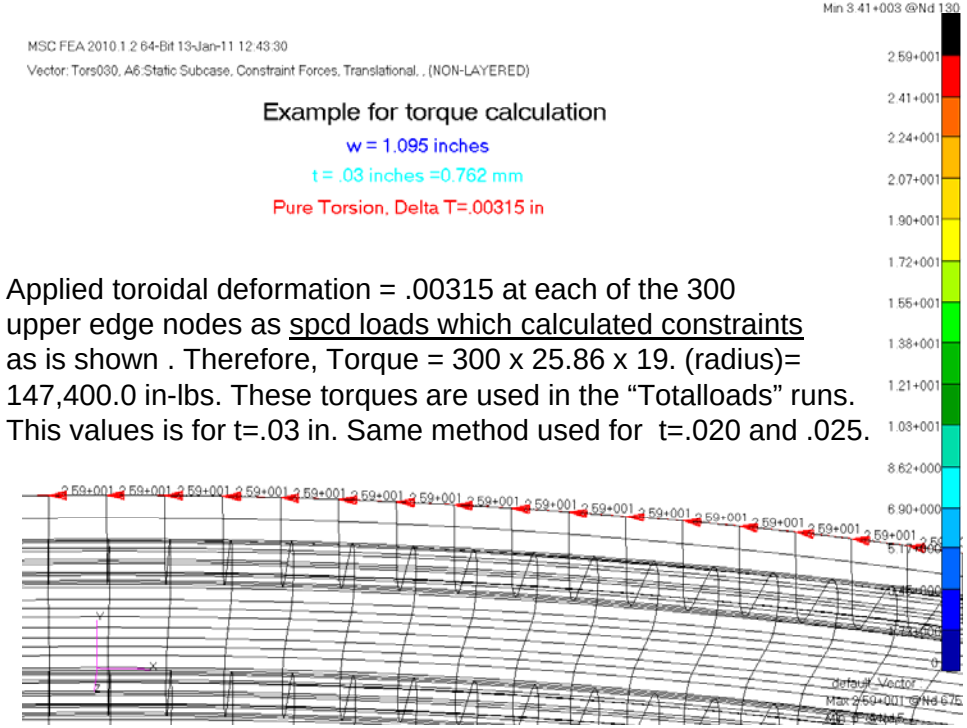
Halo Loads	Shear Stresses
Thickness	Stresses Max Shear
.020 in.	19,900. psi Delta = 1,800. psi
.025 in.	18,100. psi Delta = 3,600. psi
.030 in.	14,500. psi

Toroidal Calculations









Applied toroidal deformation = .00315 at each of the 300 upper edge nodes as <u>spcd loads which calculated constraints</u> as is shown . Therefore, Torque = 300 x 25.86 x 19. (radius)= 147,400.0 in-lbs. These torques are used in the “Totalloads” runs. This values is for t=.03 in. Same method used for t=.020 and .025.

Appendix A

Complete list of the NASTRAN runs and post processing Data Base files:

Bellows_3.db: Individual runs

Axial315t02, A20 – (for X= -.315 and t=.02 inches)
Axial315t025, A21 – (for X=-.315 and t=.025 inches)
Axial315t030, A22 – (for X=-.315 and t=.030 inches

Prest030, A23 – (only pressure and t=.030 inch)
Prest025, A24 – (only pressure and t=.025 inch)
Prest020, A25 – (only pressure and t=.020 inch)

XShear020, A42 – (Halo x-deformation for t=.020 inch)
xShear025, A41 – (Halo x-deformation for t=.025 inch)
xShear030, A34 – (Halo x-deformation for t=.030 inch)

Totalloads020, A39 – (combined loads and t=.020 inch)
Totalloads025, A40 – (combined loads and t=.025 inch)
Totalloads030, A38 – (combined loads and t=.030 inch)

Bellows_3Tor.db:These runs were made in order to calculate the required Torque values for the use in "Totalloads" runs.

Tor020, A4 – (constant toroidal deformation and t=.020 inch)
Tor025, A5 – (constant toroidal deformation and t=.025 inch)
Toro30, A6 – (constant toroidal deformation and t=.030 inch)

Located at : asalehz-64c/My Computer/My Book(G:)/NASTRAN P.R./BELLOWS

Executive Summary

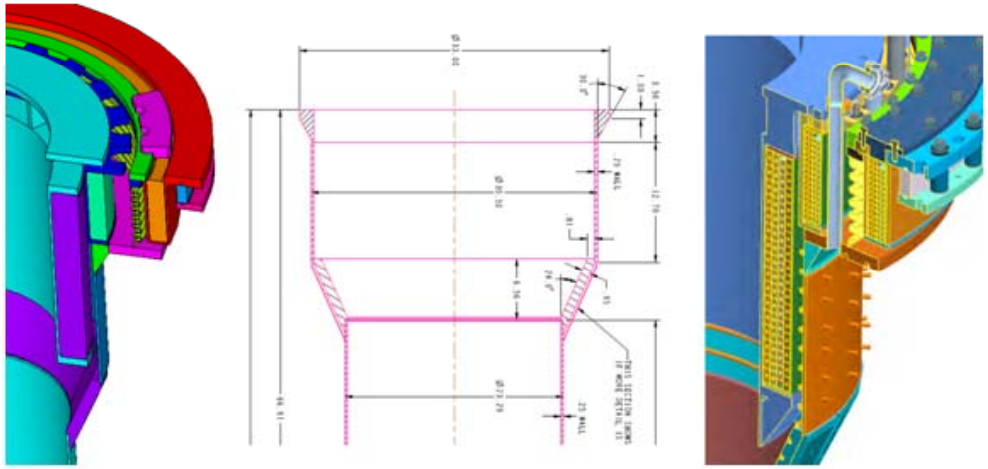
There are two bellows used on the centerstack, The upper and lower bellows. These form the vacuum connection between the centerstack casing and the insulated ceramic electrical break that allows the CHI system to impose a voltage difference between the inside and outside of the vessel internals. the upper and lower bellows assemblies must allow relative (primarily thermal) motion between the centerstack casing and the rest of the vacuum vessel. During bake-out and during operation, the centerstack casing may develop temperatures well above the rest of the vessel.

Purpose

This calculation is intended to recommend convolution geometry and a thickness of the bellows as an initial sizing exercise, and then provide a performance specification for the purchase of the bellows. Ultimately the bellows manufacturer shall provide the qualification of the bellows, but to ensure an adequate initial design this calculation shall qualify the stress state and performance for the following loading and requirements:

- Halo Current Loads (upper bellows only). Reference calculation #NSTX CALC 133-04-00
- The upper bellows must allow thermal motions expected during bake-out, and normal operation in which heat from the plasma is transferred to the centerstack casing through the tiles. Reference Calculation # NSTX CALC-11-01-00
- The bellows must be stiff enough to ensure adequate magnetic stability of the PF1a/OH system (see end of this calc - will be split off in a different calc)
- The upper bellows must support the seismic inertia loads Reference Calculation # NSTX CALC 10-01-02
- The upper and lower bellows must transmit some portion of the torsional moment from the outer vessel structure to the centerstack casing. In the centerstack, the casing is a redundant load path for the torsional moment, most of which is transferred through the umbrella structure to inner TF collar. The torsional Shear stresses will be quantified in the global analysis calculation # NSTX CALC 10-01-02.
- There may be local moments, or displacements from the vessel or centerstack casing that need to be considered in addition to those predicted by the global model.

Additionally, this calculation will consider and qualify the stresses in the ceramic break and Viton seal. The ceramic break and Viton seal are considered in the global analysis calculation # NSTX CALC 10-01-02, and the inner PF coil calculations #NSTX CALC 133-01-00. Local and detailed stresses in the ceramic break and viton seal will be quantified in this calculation

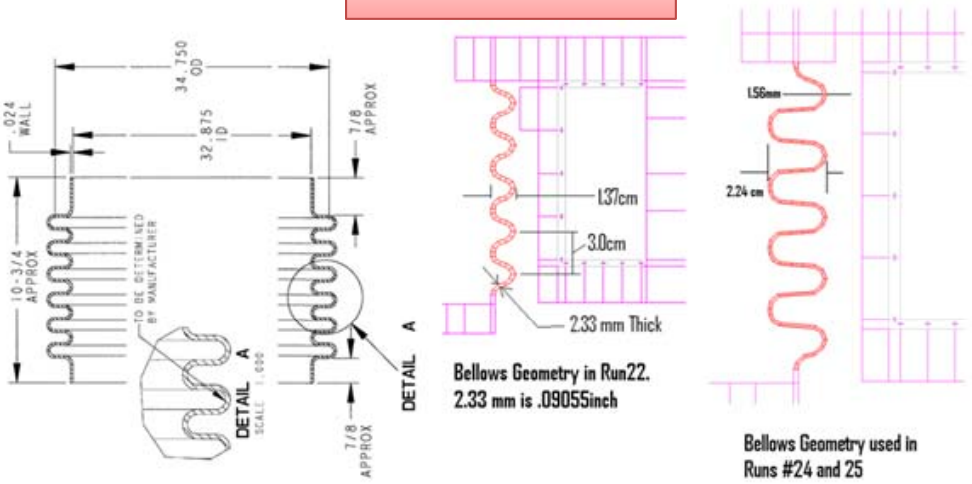


APPENDIX B

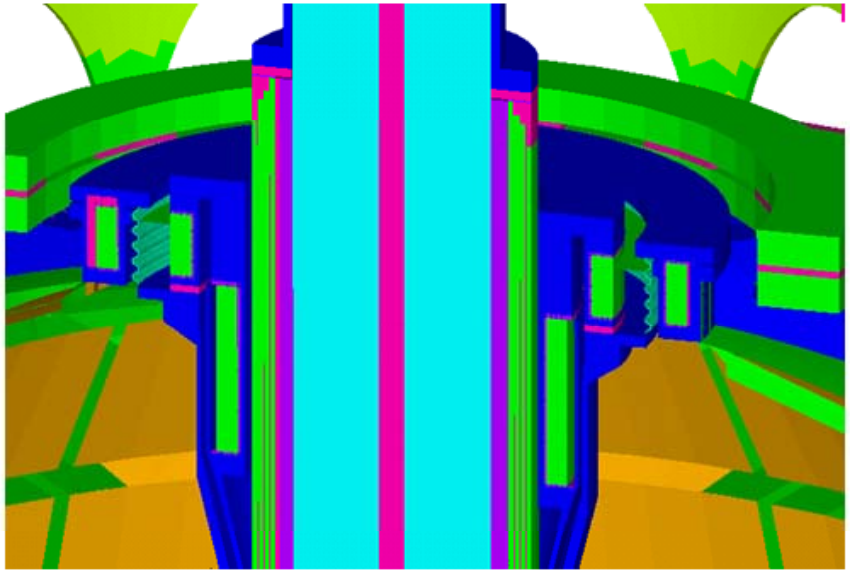
Previous calculations – Included here only as reference and deeper understanding of various loads.

Note: This data was presented under the present calculation number and it was considered preliminary. It is included here simply because it describes the flow process for the required load considerations.

APPENDIX B

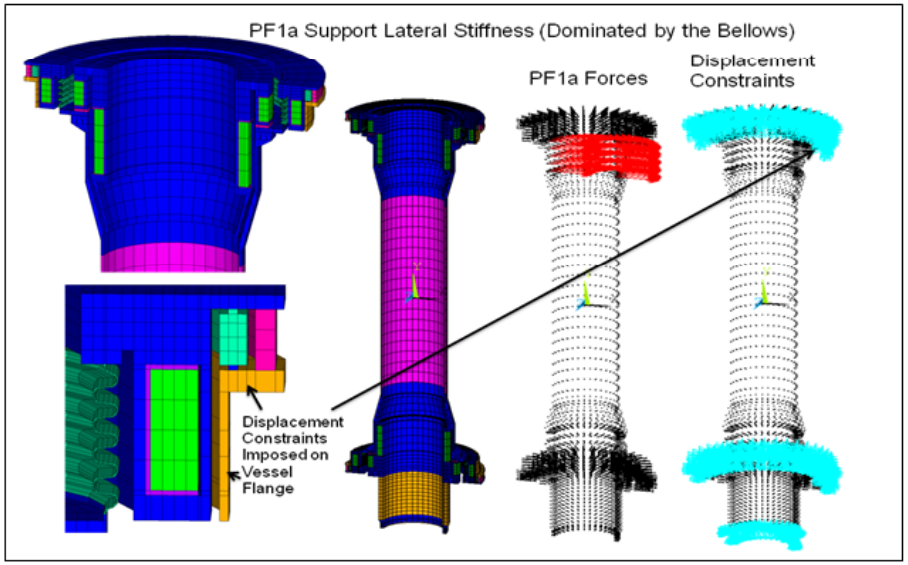


Upper Bellows geometry in the Global Model, NSTX CALC 10-01-02

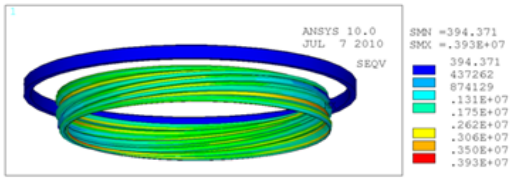


Upper Bellows model in the Global Model, NSTX CALC 10-01-02

APPENDIX B



The Upper Bellows Supplies the Needed Structural Stiffness. The CS Casing is fixed to the Skirt at the Bottom



Structural Stiffness for Lateral Loading of PF1a Alone

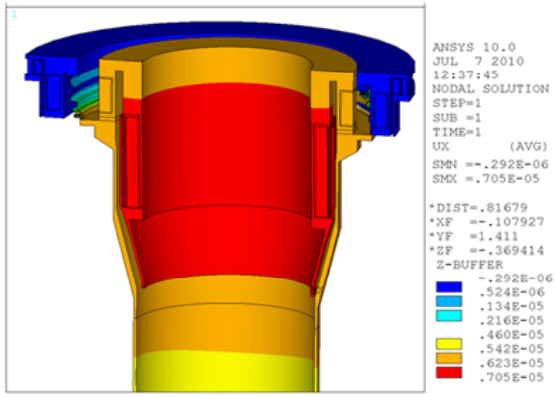
3000N total applied as nodal forces

Structural Stiffness= 3000N/.705e-5 = 425MN/m

>>>>>

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

PF1a is stable



Vertical Expansion of the Centerstac Casing

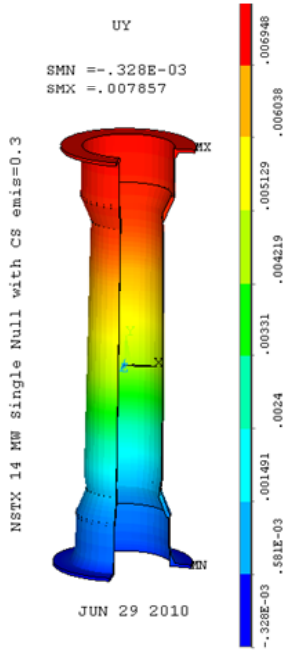


Figure Vertical Displacement of the Centerstack Casing for the calculated operating heat loads from Calculation # NSTX CALC-11-01-00