NSTX

Center Stack Casing Bellows

NSTX-CALC-133-10

Rev 0

January 2011

Prepared By:

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Peter Titus, Branch Head, Engineering Analysis Division

PPPL Calculation Form

Calculation # **NSTXU-133-10-00** Revision #**00** WP # **1672** (ENG-032)

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

There are two bellows used on the NSTX center stack, upper and lower. These form a vacuum connection between the center stack casing and the insulated ceramic break and the rest of the vacuum vessel structure. The bellows must maintain the normal vacuum conditions for the necessary operation of the NSTX device under various load conditions, which include the bake-out and other thermal scenarios.

This calculation is intended to justify and recommend convolution geometry and acceptable thickness of the bellows as an initial sizing exercise, and then provide the design specifications for the purchase of the bellows. Ultimately, the bellows manufacturer shall provide the qualification of the bellows. To ensure an adequate initial design, this calculation provides qualification of the acceptable stress state and performance for the following load conditions:

- 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 condition which is always present during any operations of the machine.

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

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.

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

Three basic thicknesses (.02, .025, and .03 inch) were examined to better understand the general behavior of the bellows under different load conditions.
Since EJMA provides basic equations for the design of the Axial and Pressure conditions based on tests and experience, these results were used to justify the finite element simulation obtained through NASTRAN. Complete table of compared results are included in the power point presentation. NASTRAN simulation was then used to include load conditions which EJMA does not provide. Therefore, once basic calculations were justified, NASTRAN model could include all load conditions which add to calculate the maximum stress conditions on the bellows.
It was assumed that the seismic loads do not combine with the Halo Loads (these are of the very short duration compared to seismic). Therefore, for the maximum possible stresses during the seismic event the following loads are considered: pressure, CS thermal, torsional moment and the seismic loads from the center stack with .5% damping.

Calculation (Calculation is either documented here or attached)

All the calculations are presented in the following attachments:

- Final_Bellows.ppt
- Final_ EJMA.ppt
- Final EJMA Calculator
- Seismic_Stresses.ppt
- LVRBellDisrupt.ppt
- Bellows_ Mode.ppt
- Spare EJMA Order Sheet

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

Comparing the maximum stress for both EJMA and NASTRAN results, bellows of thickness=.03 inch, demonstrates the lowest value. Von Mises combined stress is = 61,600 psi. Considering Inconel plate where Sy = 95,000.psi, this calculated stress value is well within the 2/3 Sy stress condition as specified for the NSTXU project.
For Seismic condition the calculated von Mises stress is = 46,600.psi and this event is extremely unlikely to develop. The combined stresses are well within the acceptable range.
"Global Model" results for seismic analyses show similar acceptable maximum stresses up to 20,000.psi based on standard seismic scenario for the TFTR existing facility.
Lower bellows magnetic disruption analyses, show the maximum stresses for iteration at step #8. These stresses are about 500.psi and considered insignificant.
EJMA Specification Sheet is included bellows and it should be a part of the final drawing.
The specific (selected) bellows design requirements should be as follows:

- t = .030 inch

- w = 1.095 inches, convolution height
- q = 1.0 inches, convolution pitch
- Di = 38.0 inches, Inside diameter
- Do = 40.25 inches (at the outside surface of the convolution), Outside diameter
- General axial length should be determined by the final design. For now it is 7.06 inches.

Cognizant Engineer's printed name, signature, and date

Jim Chrzanowski Digitally signed by Jim Chrzanowski
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Date: 2011.05.31 08:59:51 -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

Irving Zatz Digitally signed by Irving Zatz
DN: cn=Irving Zatz, o=PPPL, ou, email=zatz@pppl.gov, c=US
Date: 2011.05.27 12:24:49 -04'00'

Customer: Princeton Plasma Physics Laboratory			Date:1/25/2011	Page:
Project: NSTXU			Prepared By: P. Rogoff	
Item or Tag Number:				
Quantity:			2	
Size:				
Style or Type (single, universal, hinged, gimbal, etc.)			single	
End Connections		Thickness/Flange Rating	0.030 inch	
		Material		
*Pressure		Design	14.5 psi	
		Operating	14.5 psi	
		Test	14.5 psi	
*Temperature		Design	Room	
		Operating	Room	
		Installation	Room	
Media		Media		
		Flow Velocity		
		Flow Direction		
Movements and Life Cycle	Installation	Axial Extension		
		Axial Compression		
		Lateral		
		Angular		
		Number of Cycles		
	Design	Axial Extension		
		Axial Compression	0.315 inch	
		Lateral	0.020 inch	
		Angular	0.00315 inch	
		Number of Cycles	High	
	Operation	Axial Extension		
		Axial Compression	0.315 inch	
		Lateral	0.02 0 inch	
		Angular	0.00315 inch	
		Number of Cycles	High	
Materials		Bellows	Inconel (high Yield)	
		Liner		
		Cover		
Dimensions		Overall Length	7.06 inch	
		Maximum O.D.	40.25 inch	
		Minimum I.D.	38.0 inch	
Spring Rates		Maximum Axial Spring Rate	3,835.2 lbs/inch	
		Maximum Lateral Spring Rate	204,200.lbs/inch	
		Maximum Angular Spring Rate	147,400. In-lbs, for .00315 in displacement	
Quality Assurance Required Code		Bellows Long. Seam Weld		
		Bellows Attachments Weld		
		Piping		
Applicable Codes and Standards B31.1, B31.3, Section 8 Division 1				

Final_Bellows.ppt

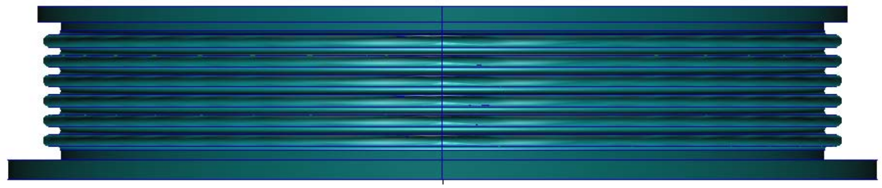
Executive Summary

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



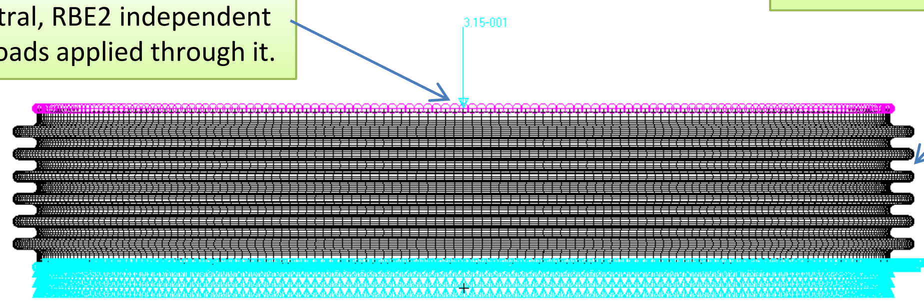
Modulus of Elasticity = 29,000,000.
stainless steel (FEA and EJMA)
t = variable (.02, .025, .03) in.

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

<u>Note</u>: 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]

	EJMA -Stress		NASTRAN -Stress		Shear rate	Torque
	psi		psi		lbs/in	in-lbs
Thickness	Pressure	Axial	Pressure	Axial		
.020 in	15,200.0	25,600.0	15,600	23.300.0	71,120.0	98,211.0
					2800#/mm	
.025 in	9,736.0	31,990.6	9,640.0	28,800.0	128,200.0	122,800.0
					5040#/mm	
.030 in	6,762.0	38,386.0	6,970.0	34,400.0	204,200.0	147,400.0
			8,190.0		8,040#/mm	

Note: w= 1.095 for all calculations

q=1.0 inches

1.0 mm= .0394 in

Torsional delta = .00315in = .8e-4m

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).

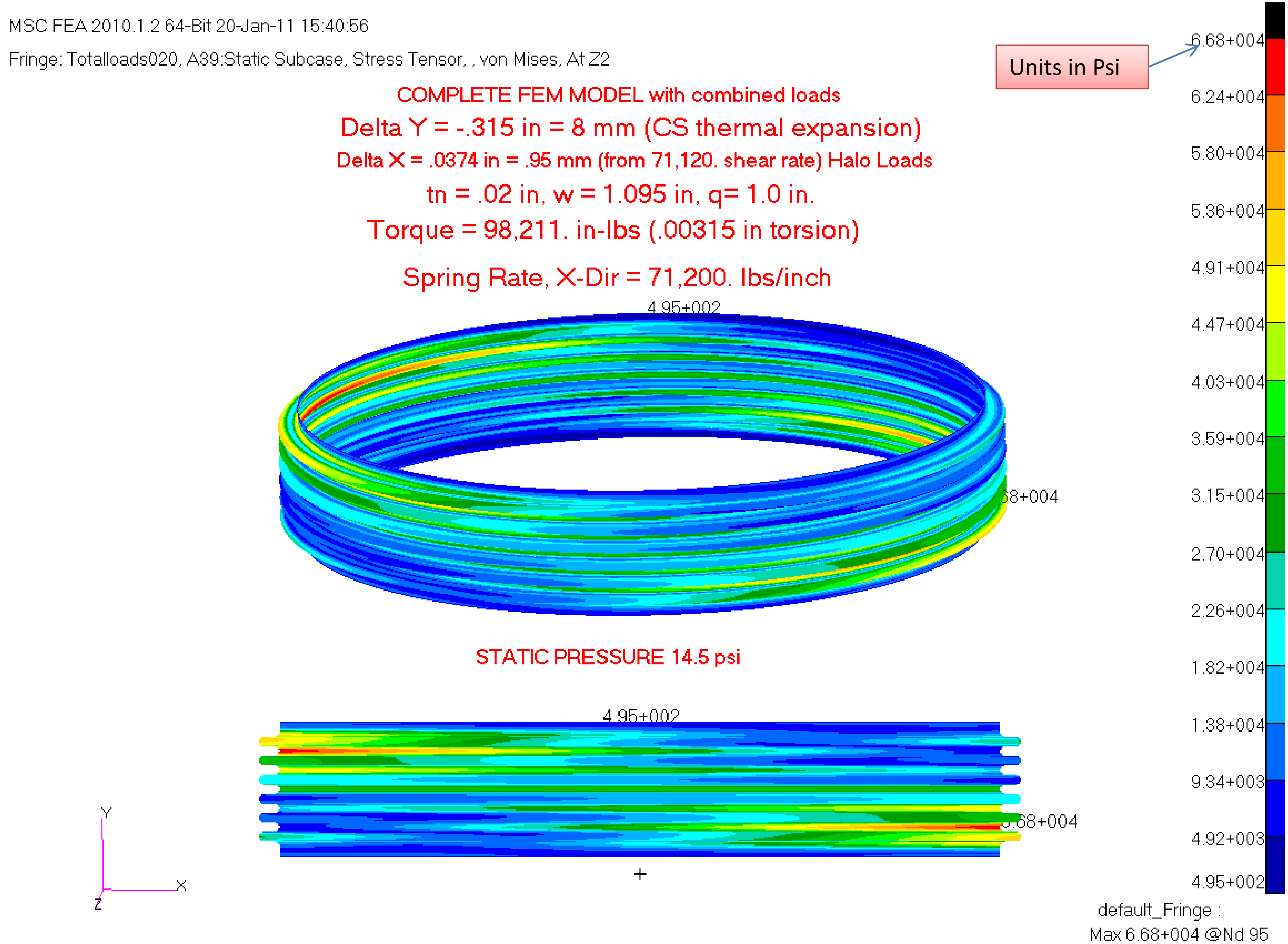
* For Halo loads, it is necessary to calculate the bellows Spring Rate in the pure shear mode. Since the spring rate changes with changing thickness, the absorbed amount of the Halo Energy , reacts at the bellows to form the shear deformation. Then this calculated deformation is used, as an enforced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

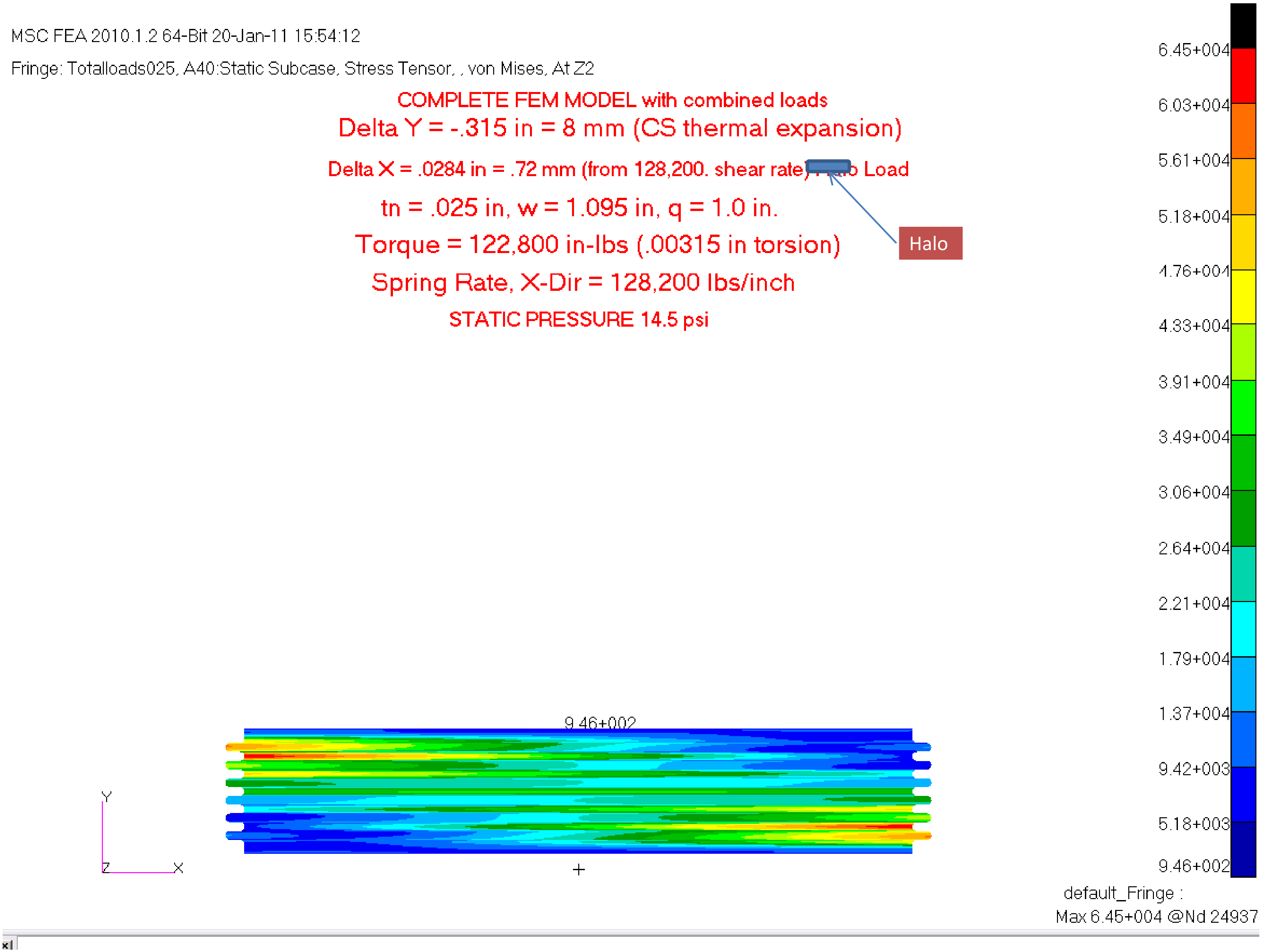
* Toroidal deformation is constant/maximum (.8e-4 m = .00315 inches) and produce decreasing Torque values with the decrease of (t)

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
4.95+002
STATIC PRESSURE 14.5 psi
4.95+002
Y
X
Z
6.68+004
6.24+004
5.80+004
5.36+004
4.91+004
4.47+004
4.03+004
3.59+004
3.15+004
2.70+004
2.26+004
1.82+004
1.38+004
9.34+003
4.92+003
4.95+002
default_Fringe :
Max 6.68+004 @Nd 95



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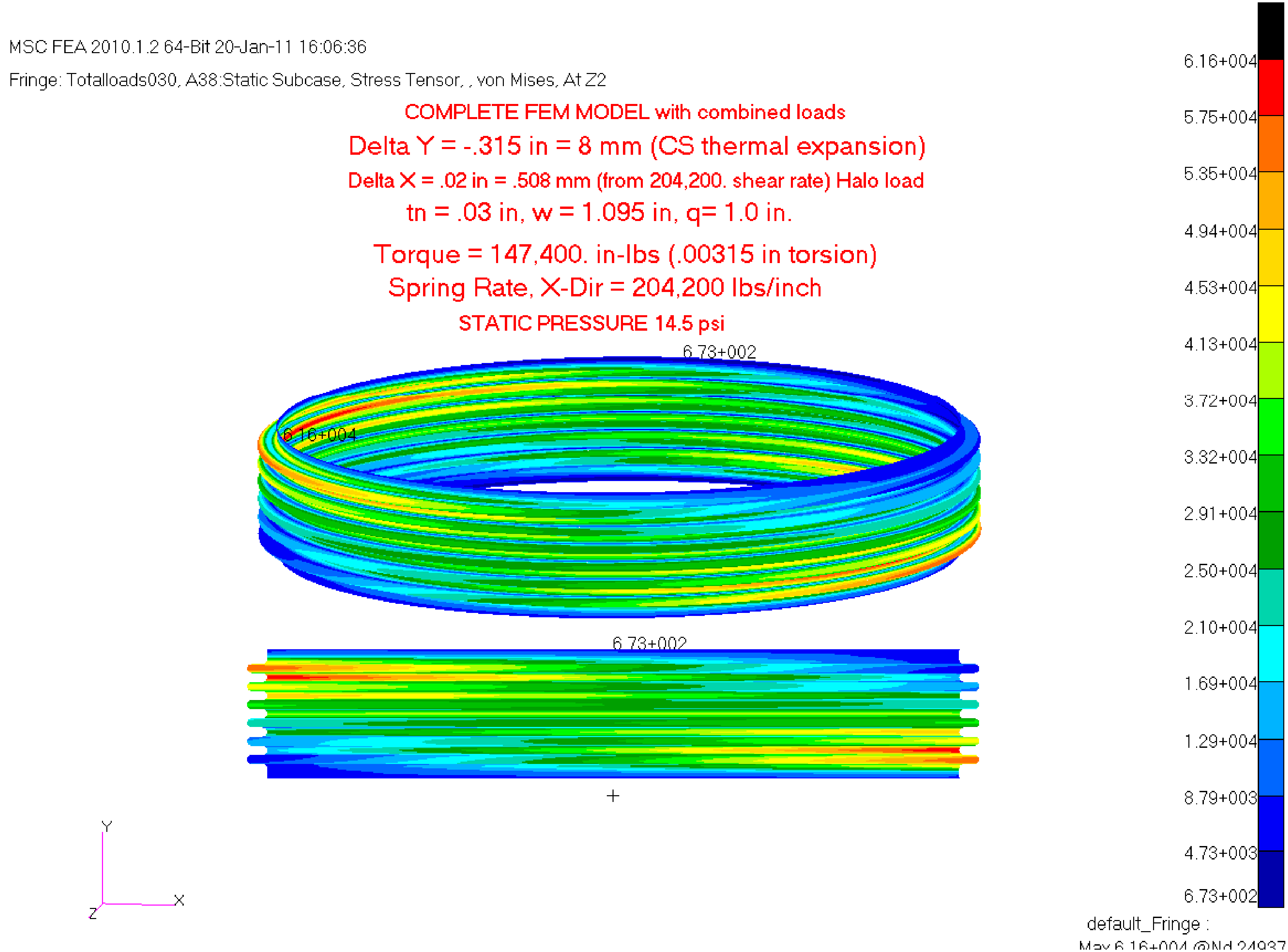
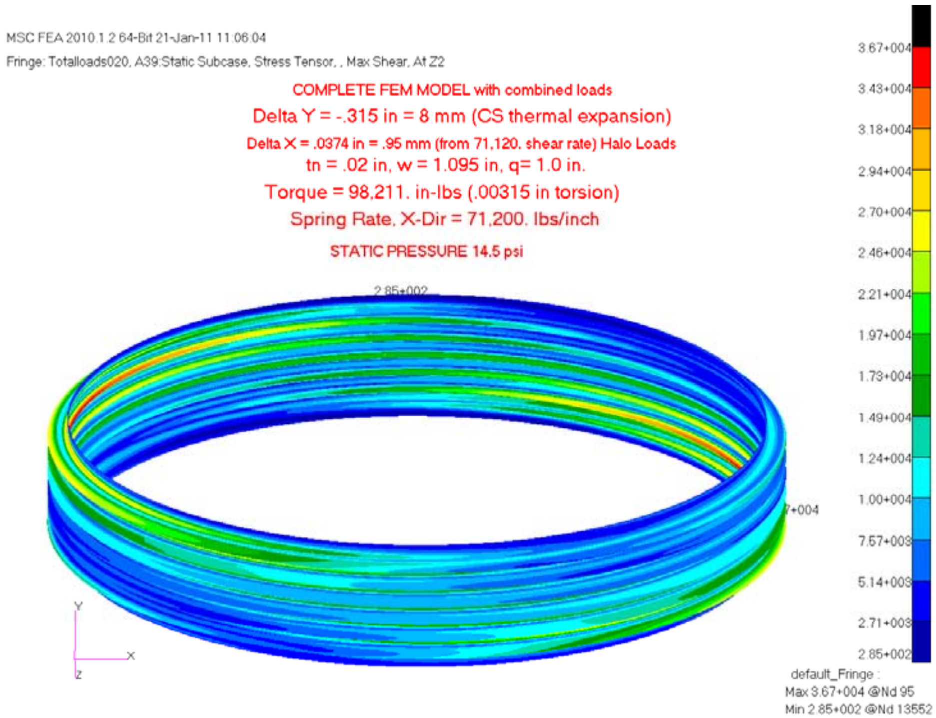
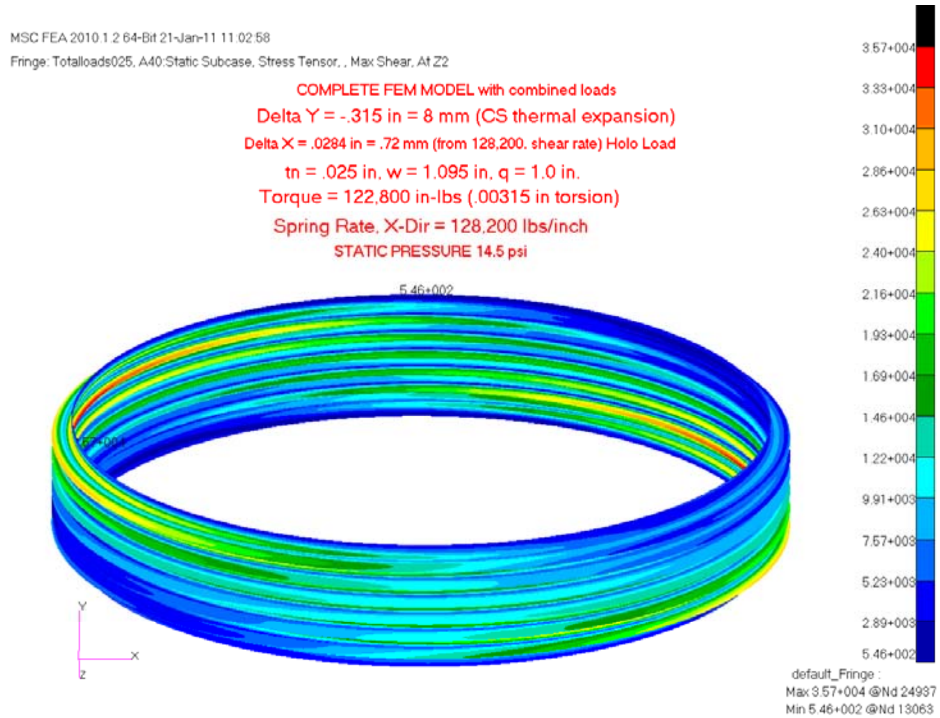
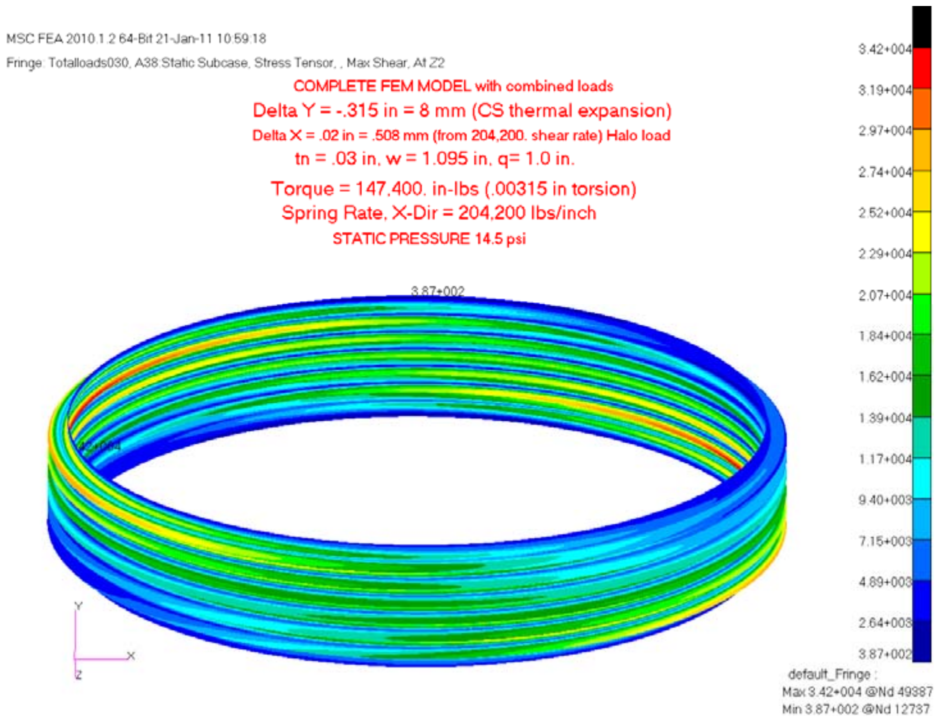
COMPLETE FEM MODEL with combined loads
Delta Y = -.315 in = 8 mm (CS thermal expansion)
Delta X = .0284 in = .72 mm (from 128,200. shear rate) Load
tn = .025 in, w = 1.095 in, q = 1.0 in.
Torque = 122,800 in-lbs (.00315 in torsion)
Spring Rate, X-Dir = 128,200 lbs/inch
STATIC PRESSURE 14.5 psi
Halo
9.46+002
Y
Z
X
6.45+004
6.03+004
5.61+004
5.18+004
4.76+004
4.33+004
3.91+004
3.49+004
3.06+004
2.64+004
2.21+004
1.79+004
1.37+004
9.42+003
5.18+003
9.46+002
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
6.73+002
6.16+004
6.73+002
Y
Z
X
6.16+004
5.75+004
5.35+004
4.94+004
4.53+004
4.13+004
3.72+004
3.32+004
2.91+004
2.50+004
2.10+004
1.69+004
1.29+004
8.79+003
4.73+003
6.73+002
default_Fringe :







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.

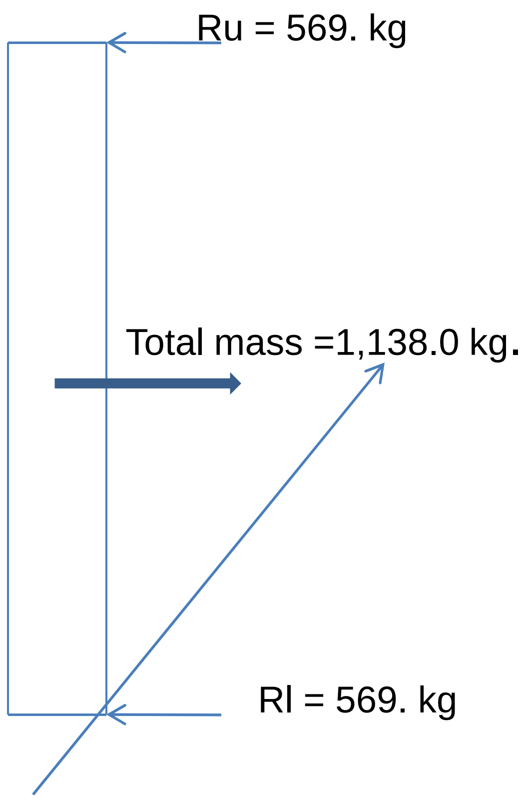
Torgue is based on the toroidal deformation (.8e-4 m) of the selected bellows thickness
Applied at Node # 49436 as "Moment Y" (d.o.f. "Ry" through Nastran "Coord 0")

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

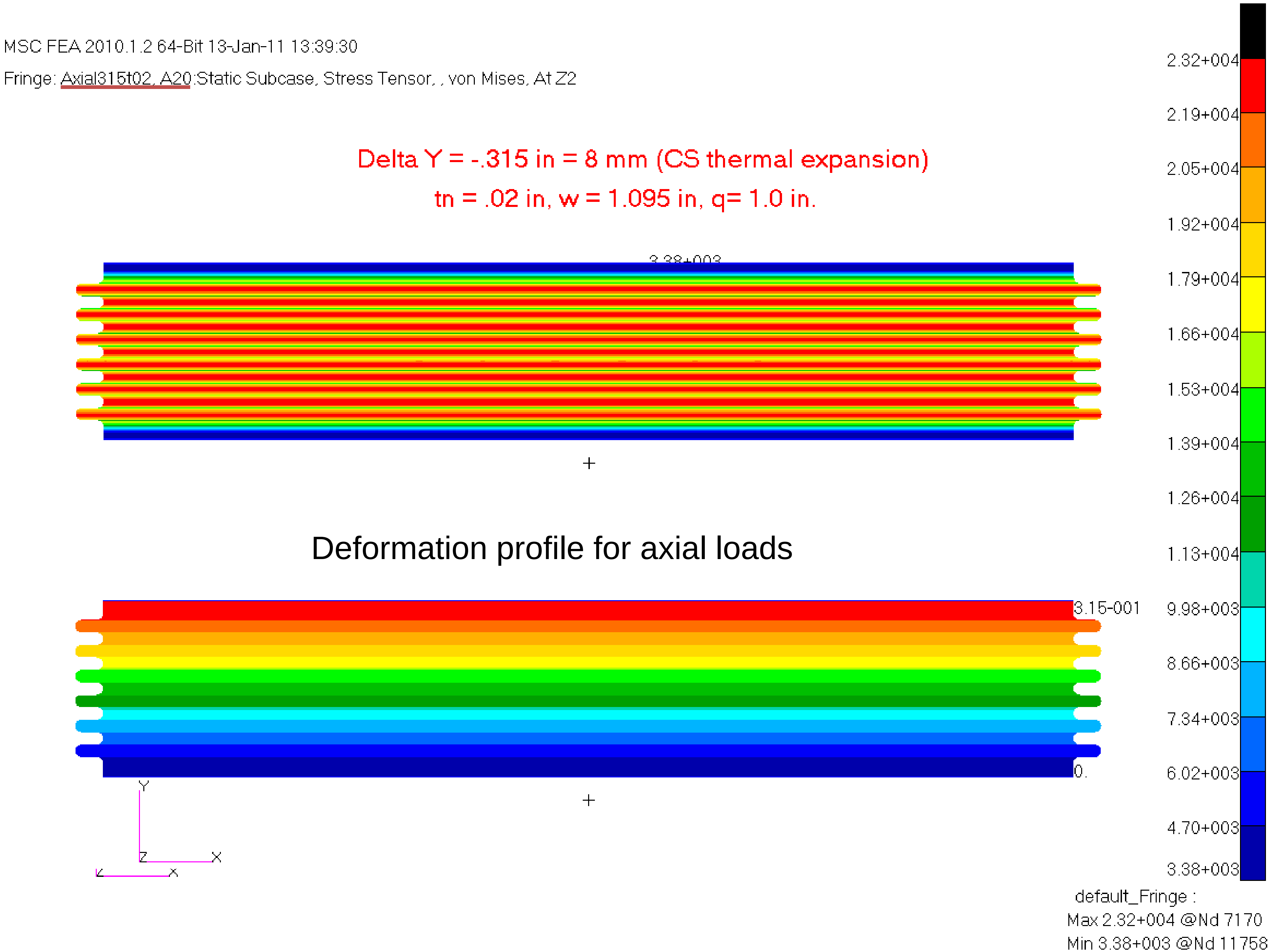
For Halo Loads --- Variable spring rate (function of thickness).

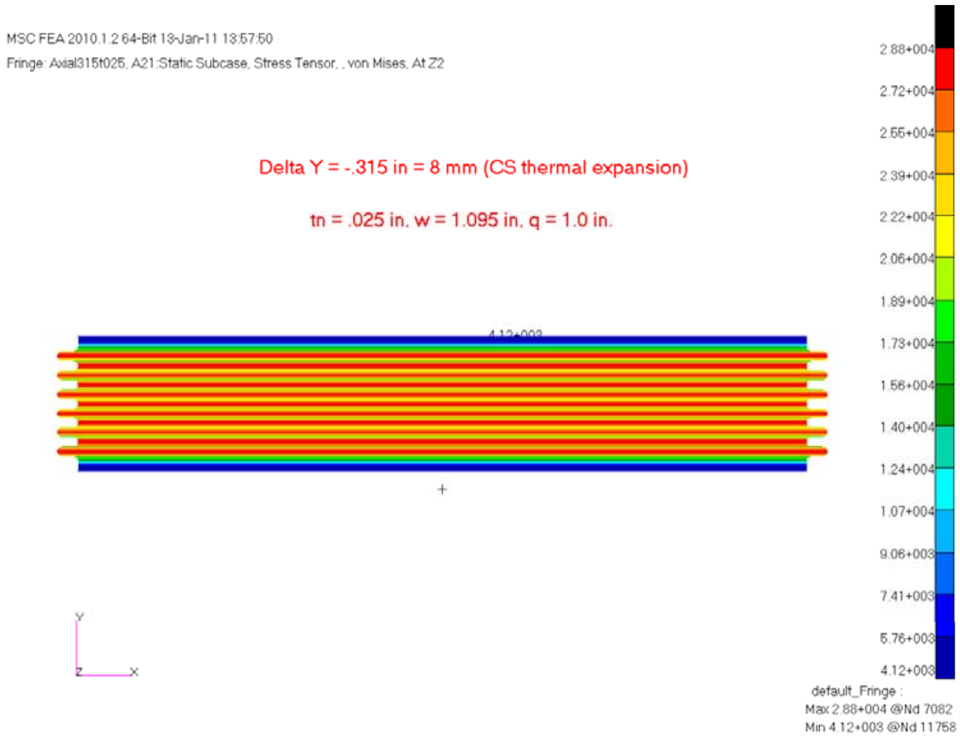
For Torsion -- Constant deformation along the upper edje of the bellows. (=.00315 in)

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)

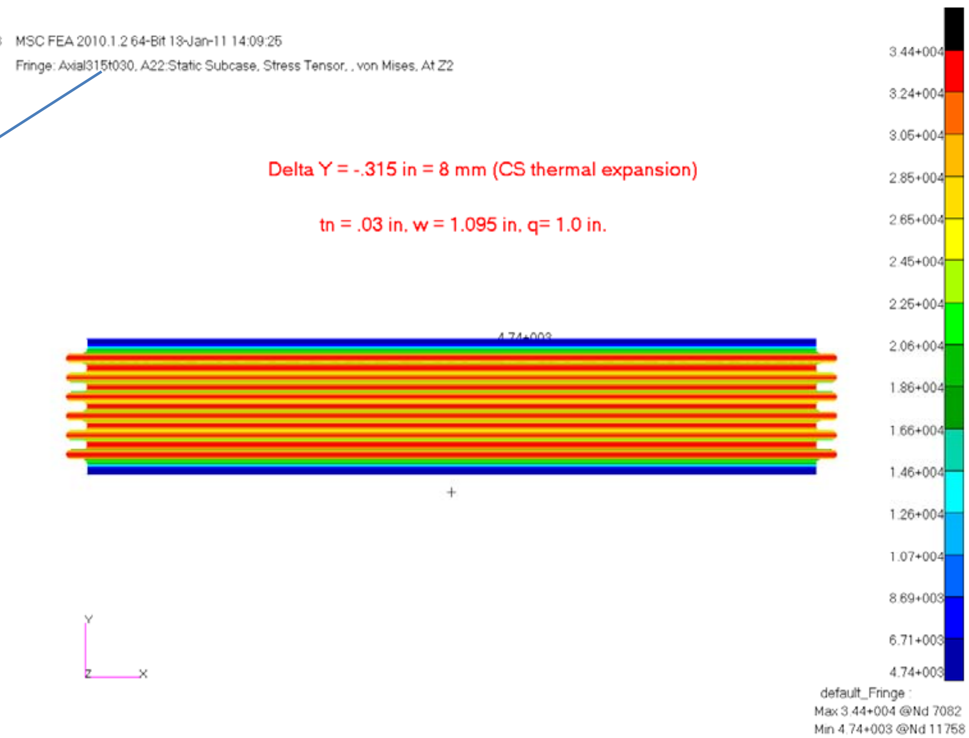
All stresses are von Mises at element fiber "Z2"

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.
3.38+003
Deformation profile for axial loads
3.15-001
0.
Y
Z
X
2.32+004
2.19+004
2.05+004
1.92+004
1.79+004
1.66+004
1.53+004
1.39+004
1.26+004
1.13+004
9.98+003
8.66+003
7.34+003
6.02+003
4.70+003
3.38+003
default_Fringe :
Max 2.32+004 @Nd 7170
Min 3.38+003 @Nd 11758



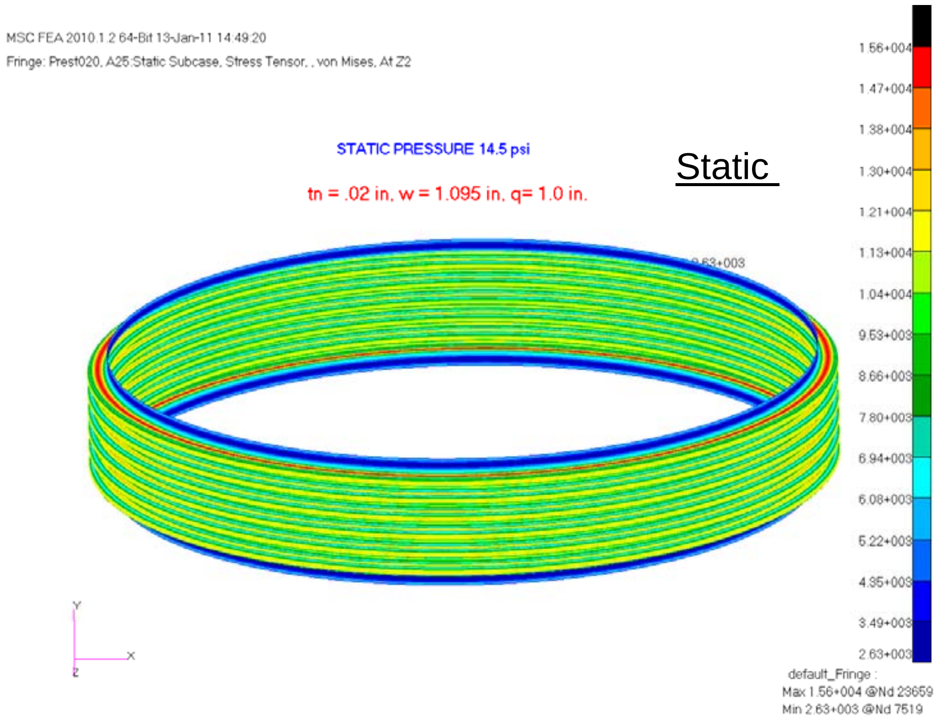
Thickness	Max. stress von Mises
.020 in.	23,200 psi
	Delta =5,600. psi
.025 in.	28,800 psi
	Delta =5,600. psi
.030 in.	34,400 psi

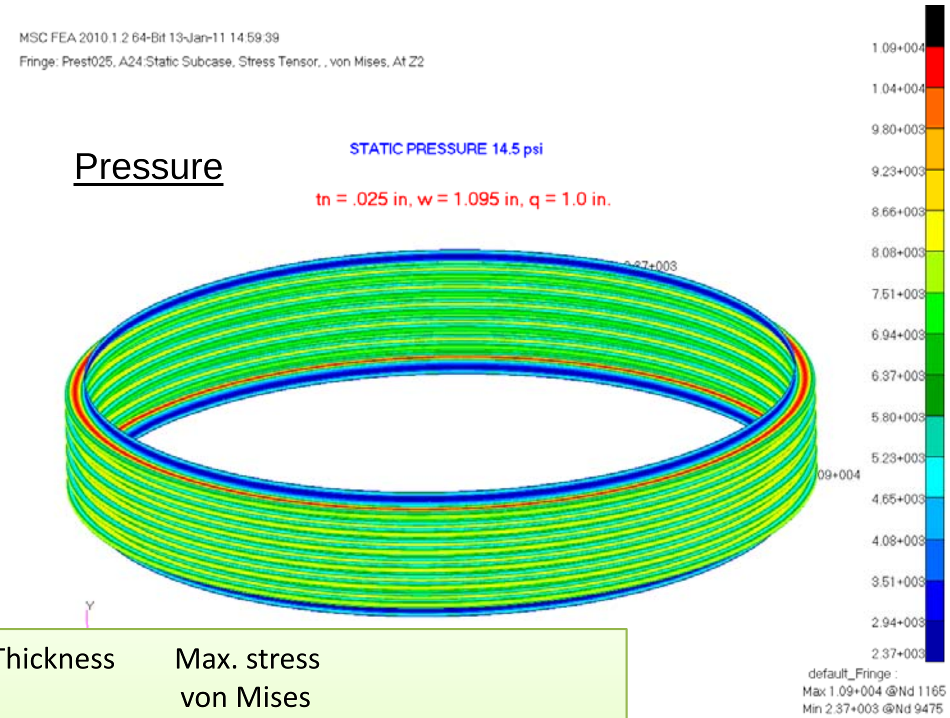


Axial315t030,A22
(Load case designation
for each configuration)

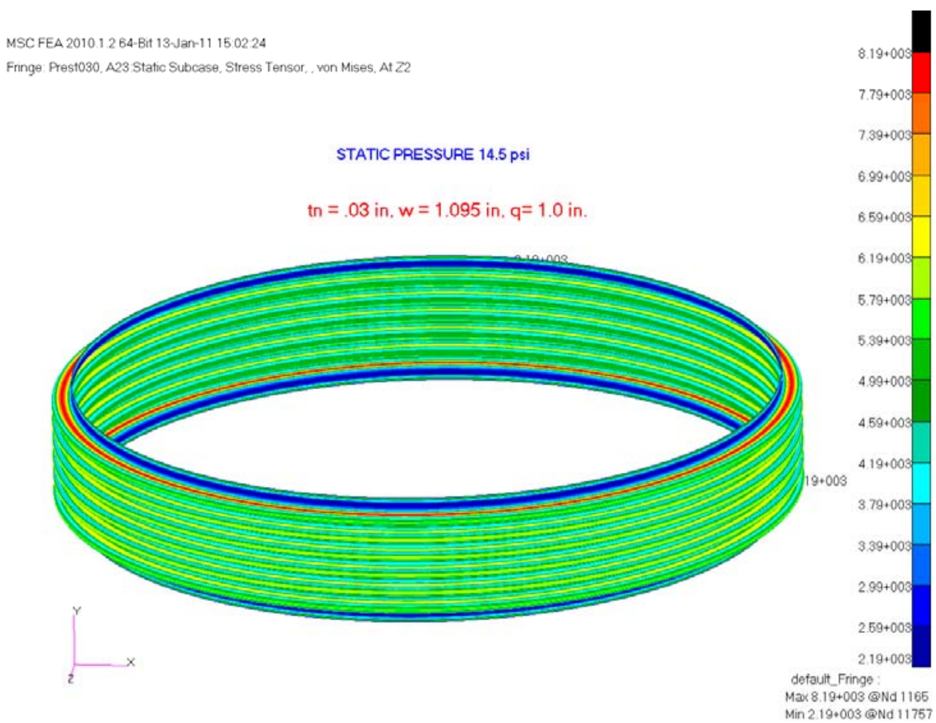
See Appendix for description
of all cases

Static Pressure

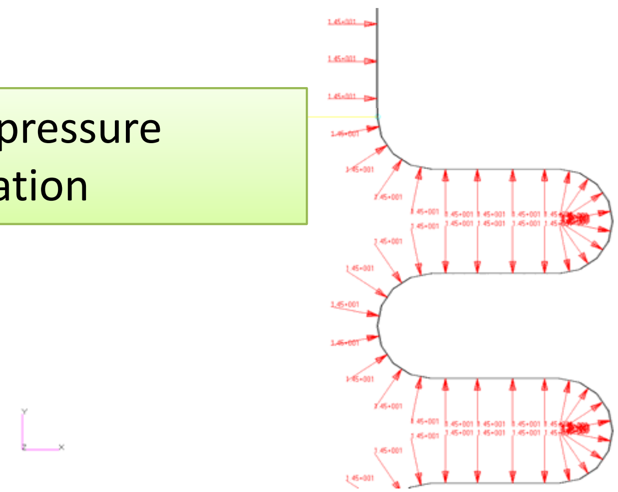


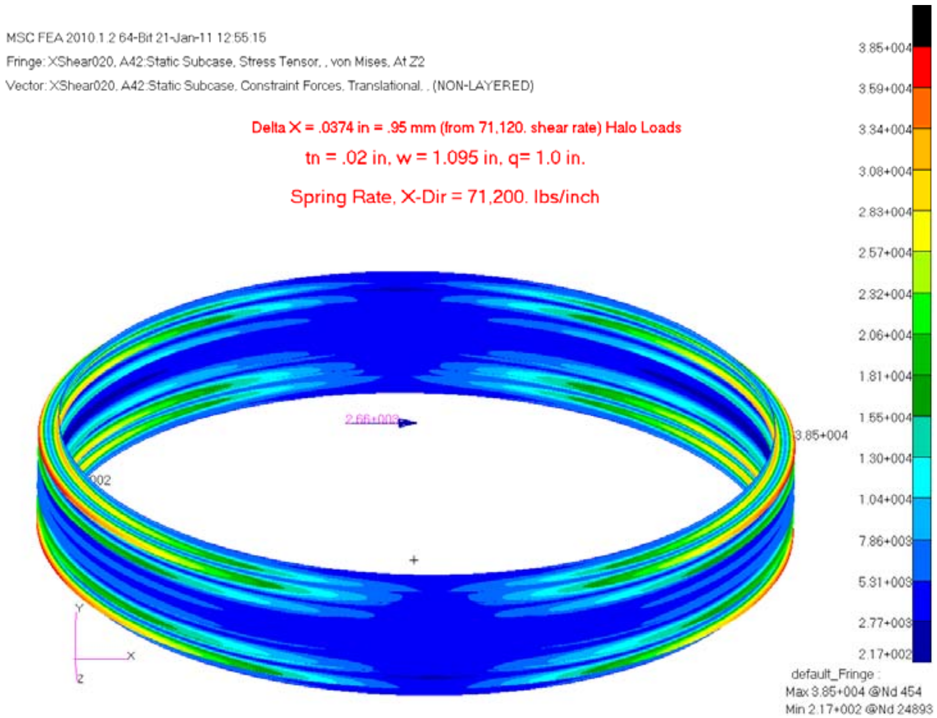


Thickness	Max. stress von Mises	
.020 in.	15,600. psi	
		Delta = 4,700. psi
.025 in.	10,900. psi	
		Delta = 2,710. psi
.030 in.	8,190.psi	



General pressure application

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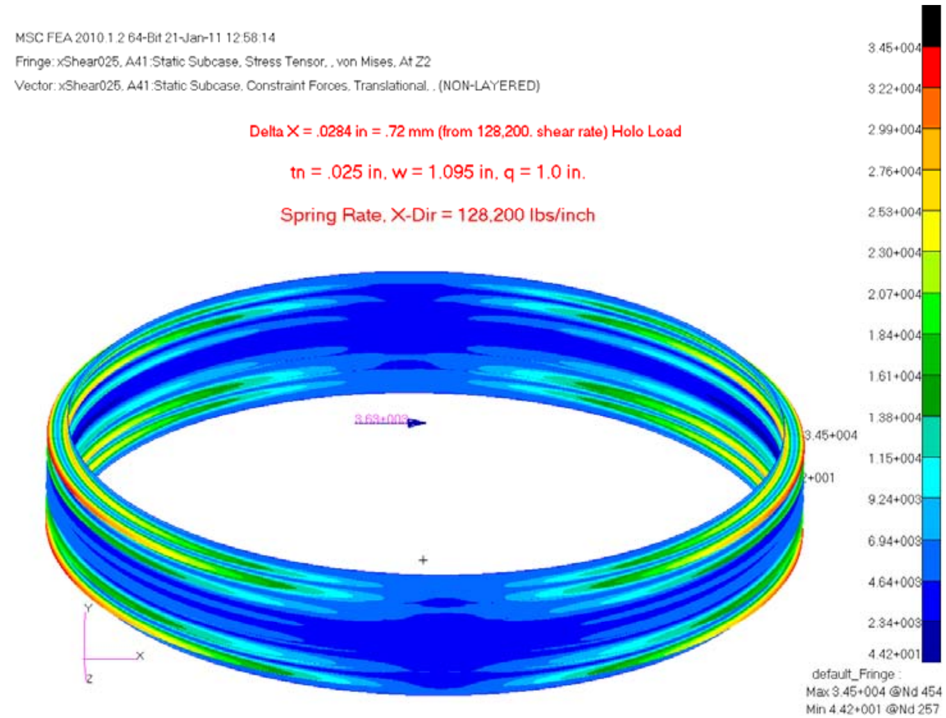
Fringe: XShear020, A42:Static Subcase, Stress Tensor, , von Mises, At Z2
Vector: XShear020, A42:Static Subcase, Constraint Forces, Translational, , (NON-LAYERED)
Delta X = .0374 in = .95 mm (from 71,120. shear rate) Halo Loads
tn = .02 in, w = 1.095 in, q= 1.0 in.
Spring Rate, X-Dir = 71,200. lbs/inch
3.85+004
default_Fringe :
Max 3.85+004 @Nd 454
Min 2.17+002 @Nd 24893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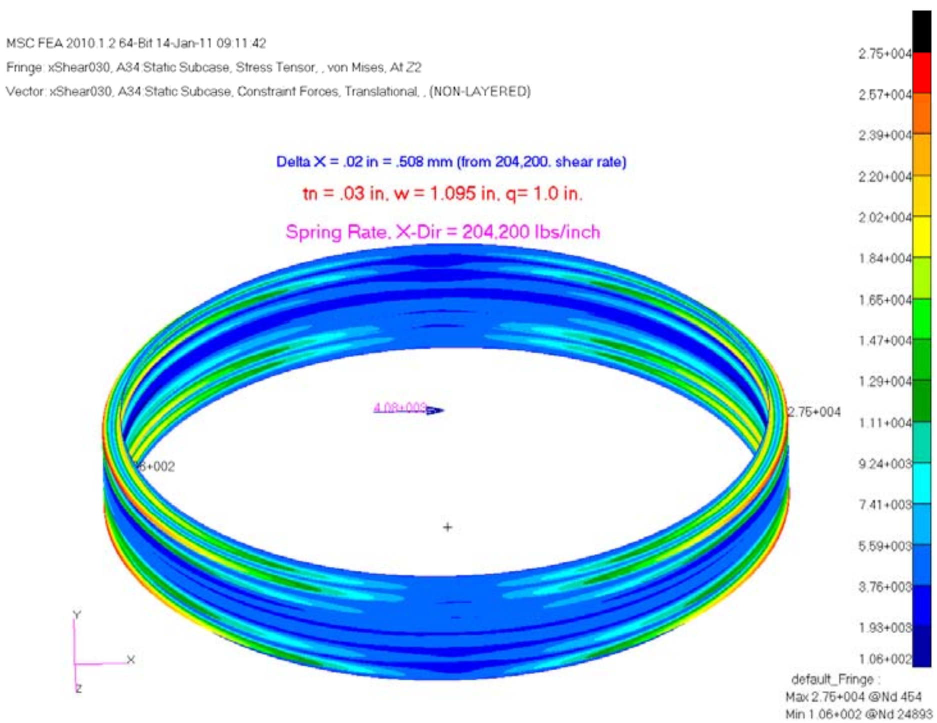
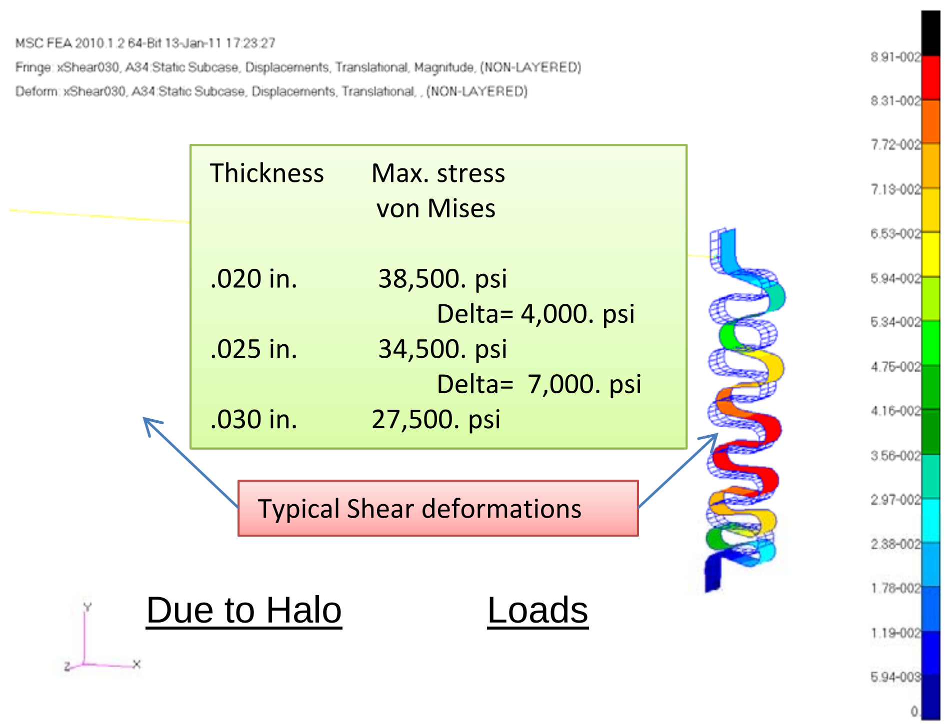
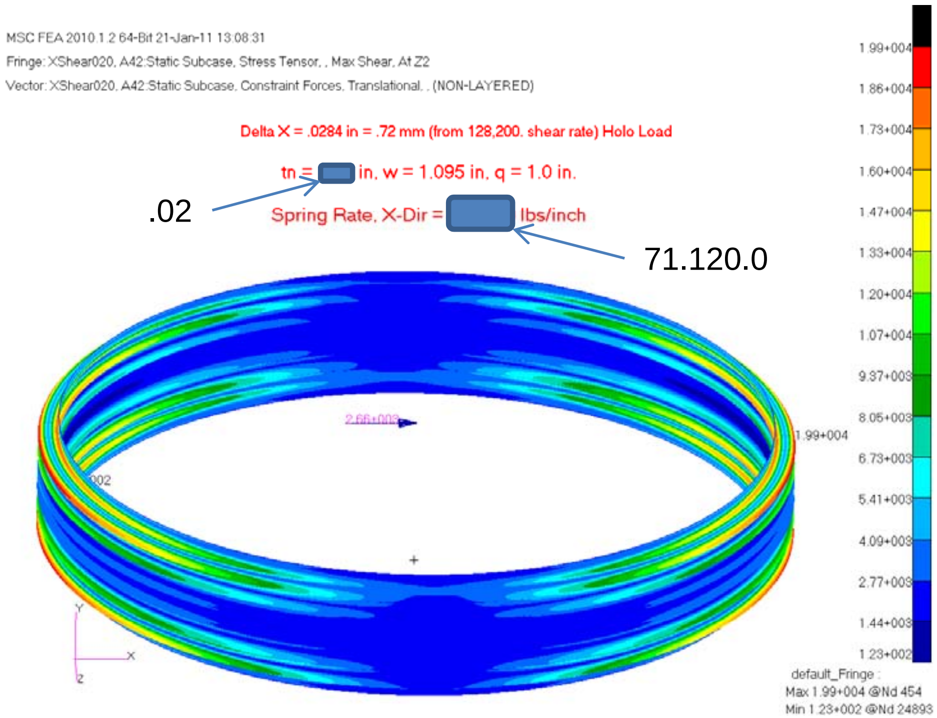
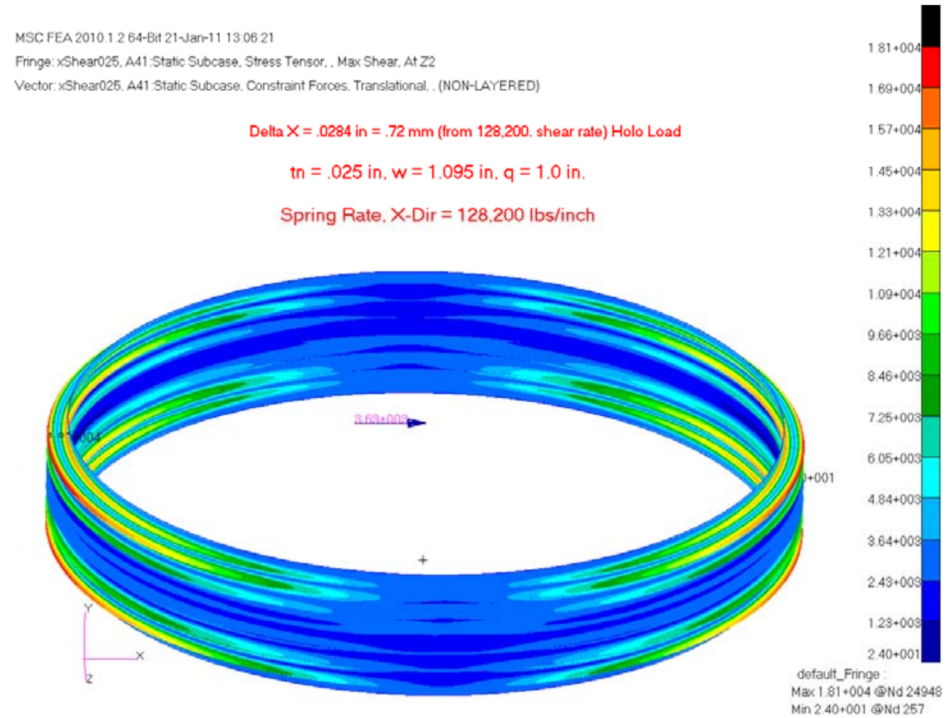
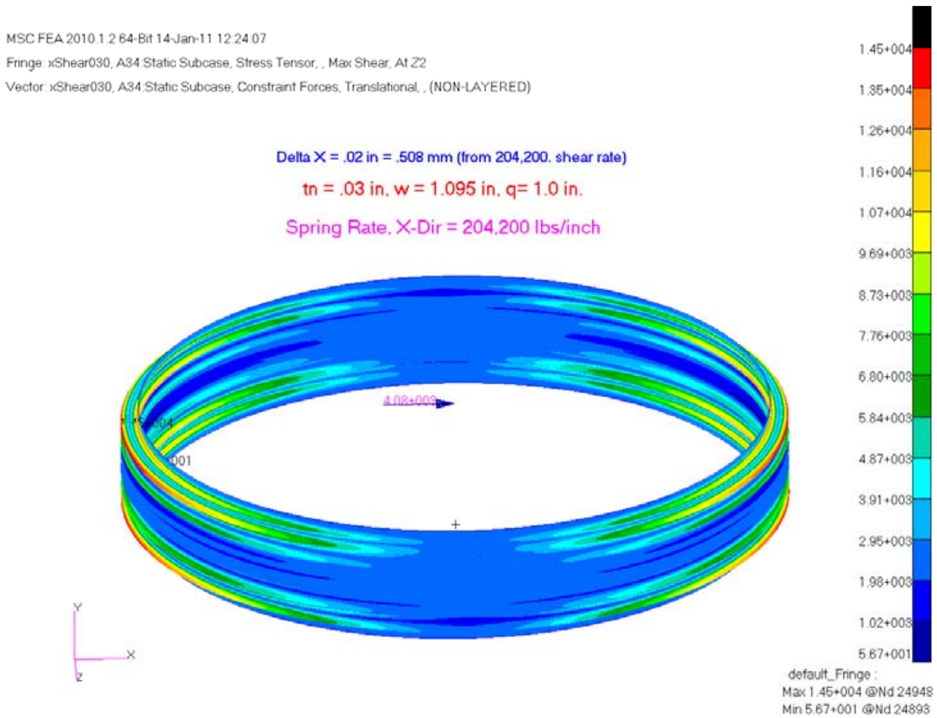
Fringe: xShear025, A41:Static Subcase, Stress Tensor, , von Mises, At Z2
Vector: xShear025, A41:Static Subcase, Constraint Forces, Translational, , (NON-LAYERED)
Delta X = .0284 in = .72 mm (from 128,200. shear rate) Holo Load
tn = .025 in, w = 1.095 in, q = 1.0 in.
Spring Rate, X-Dir = 128,200 lbs/inch
3.45+004
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
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



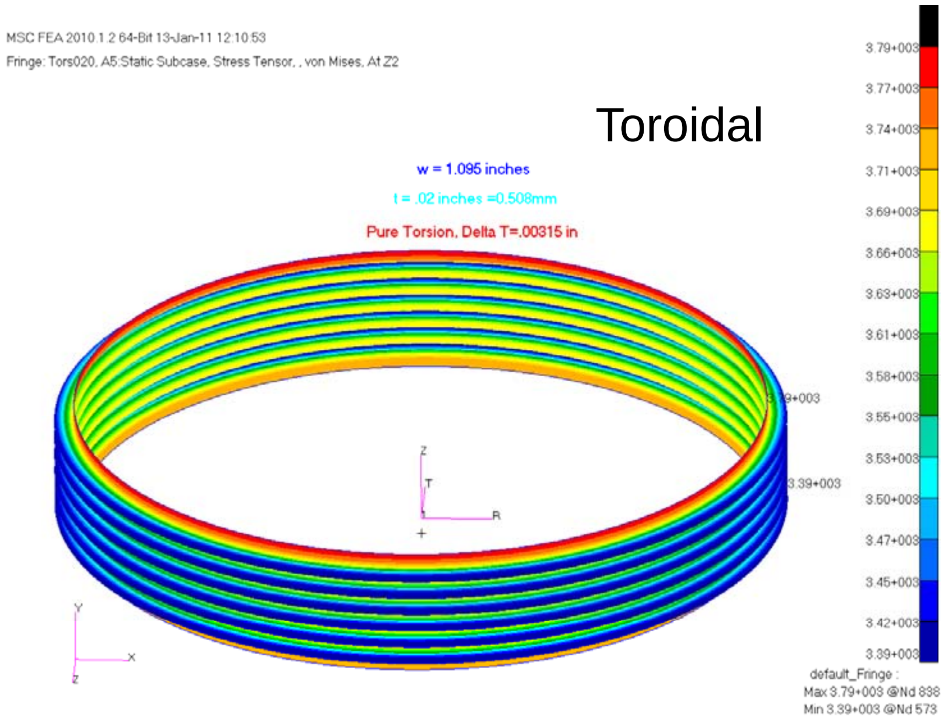


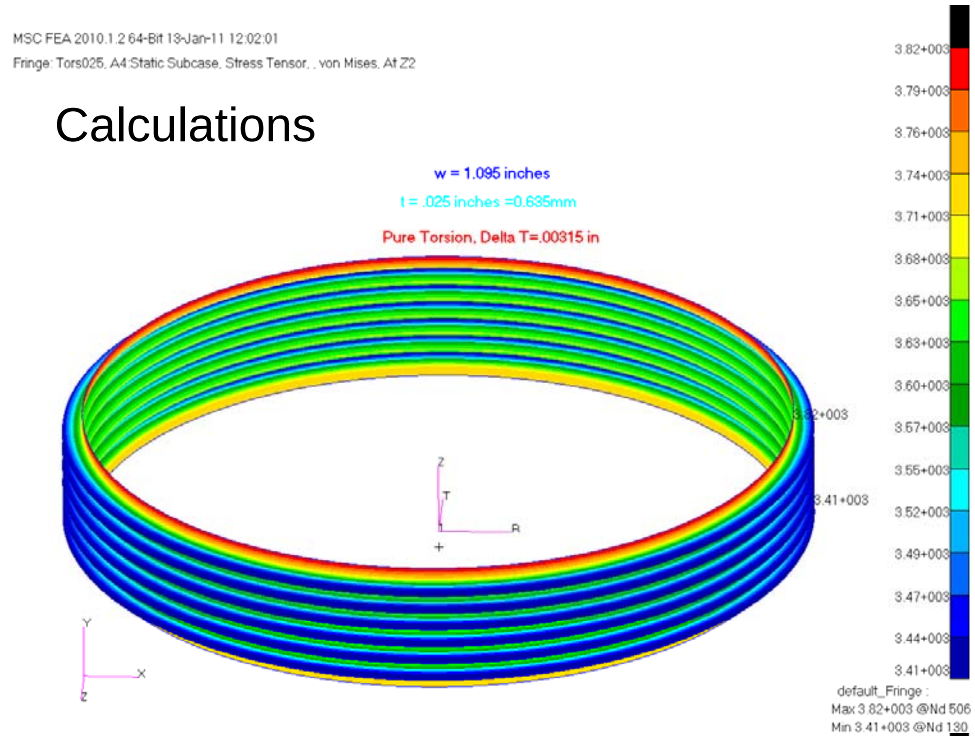


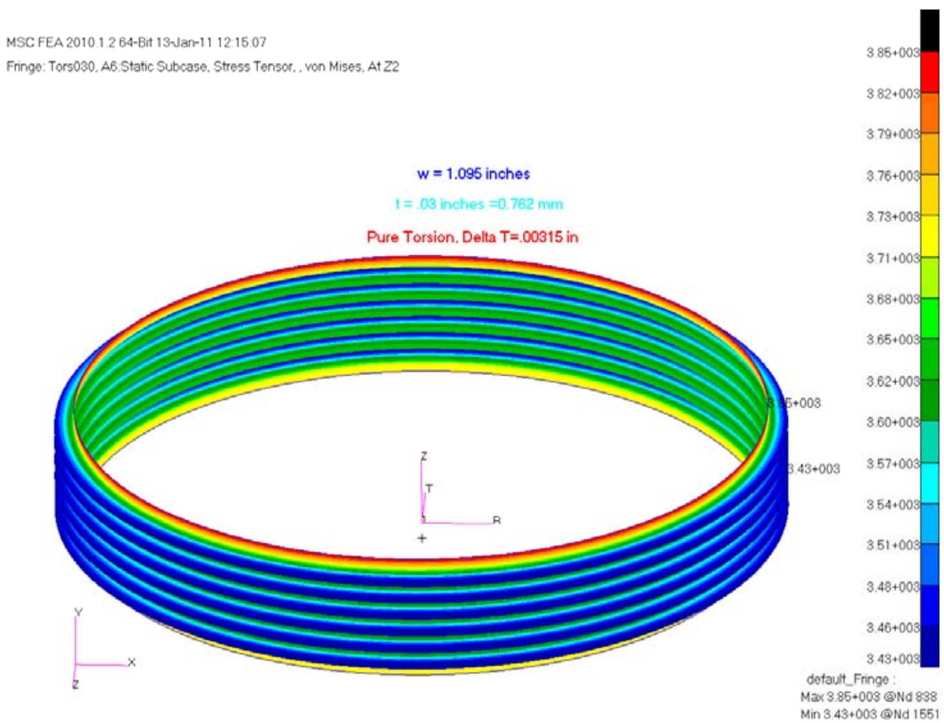
<u>Halo Loads</u> <u>Shear Stresses</u>

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







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Vector: Tors030, A6:Static Subcase, Constraint Forces, Translational, , (NON-LAYERED)

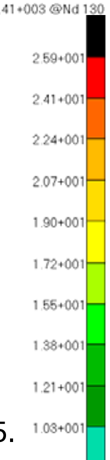
Example for torque calculation

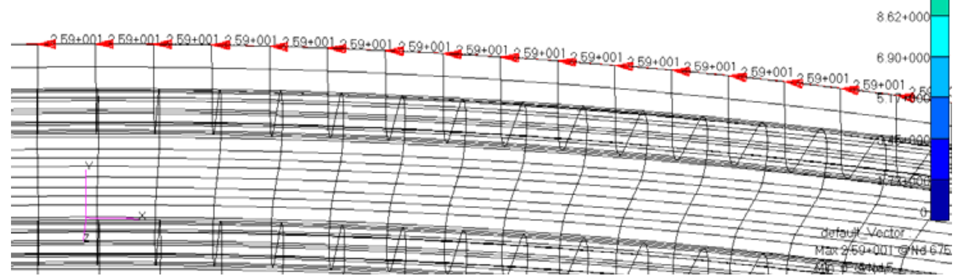
w = 1.095 inches

t = .03 inches =0.762 mm

Pure Torsion, Delta T=.00315 in

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

APPENDIX B

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

Executive Summary

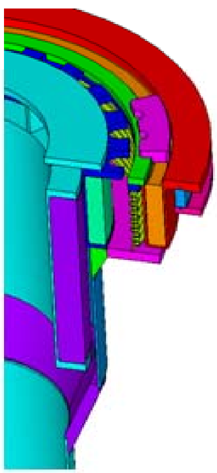
There are two bellows used on the centerstack, The upper and lower bellows. These form the vacuum connection between the centerstack casing and the insulated ceramic electrical break that allows the CHI system to impose a voltage difference between the inside and outside of the vessel internals. the 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.

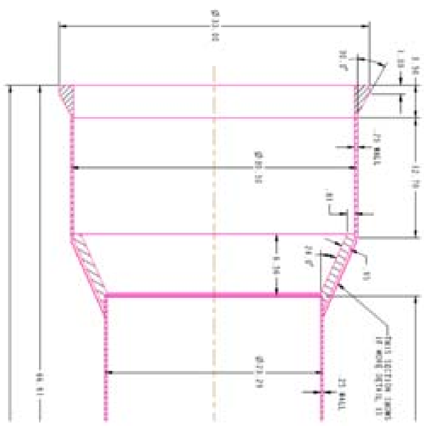
Purpose

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.

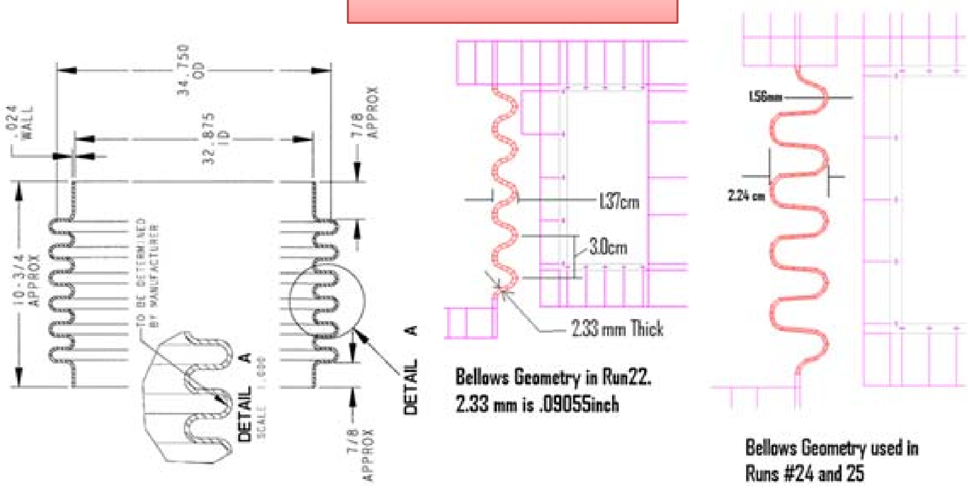
Additionally, this calculation will consider and qualify the stresses in the ceramic break and Viton seal. The ceramic break and Viton seal are considered in the global analysis calculation # NSTX CALC 10-01-02, and the inner PF coil calculations #NSTX CALC 133-01-00. Local and detailed stresses in the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



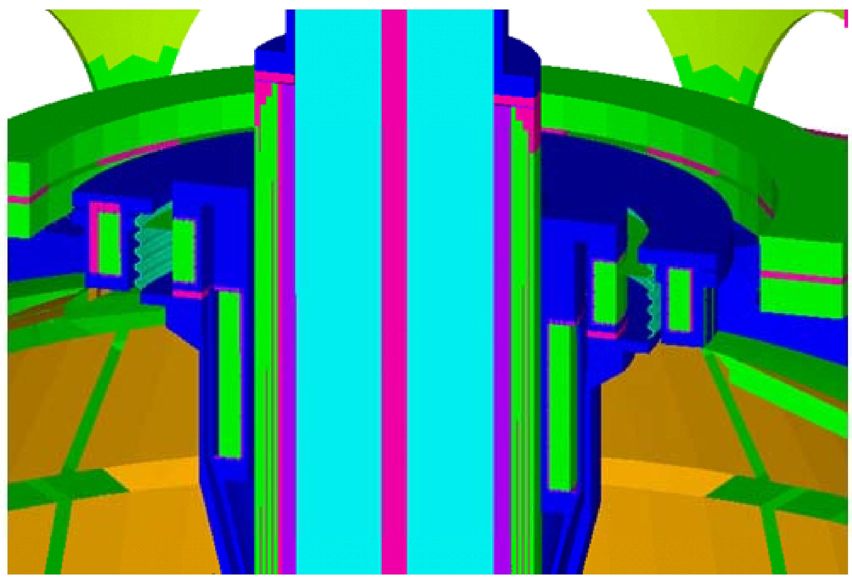


Note: This data was presented under the present calculation number and it was considered preliminary. It is included here simply because it describes the flow process for the required load considerations.

APPENDIX B

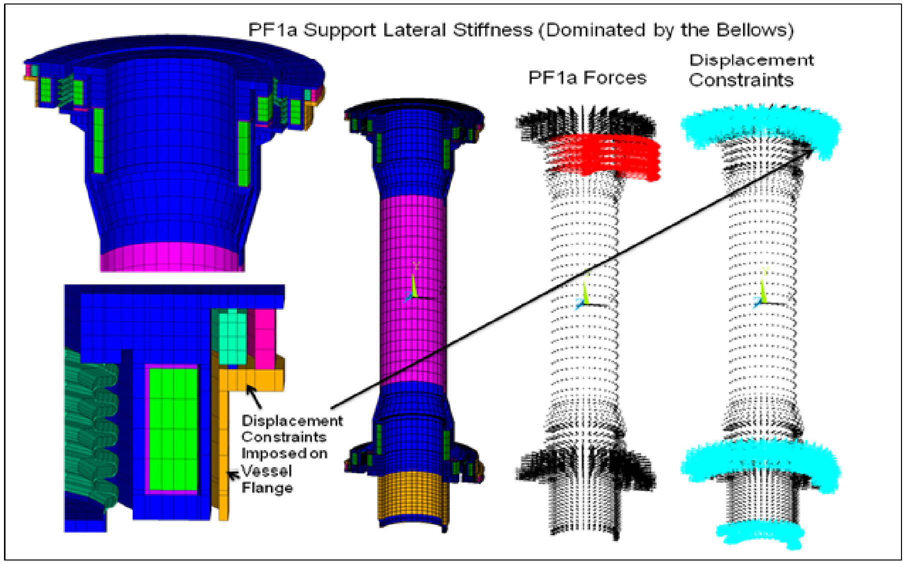


Upper Bellows geometry in the Global Model, NSTX CALC 10-01-02



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

APPENDIX B



Vertical Expansion of the Centerstac Casing

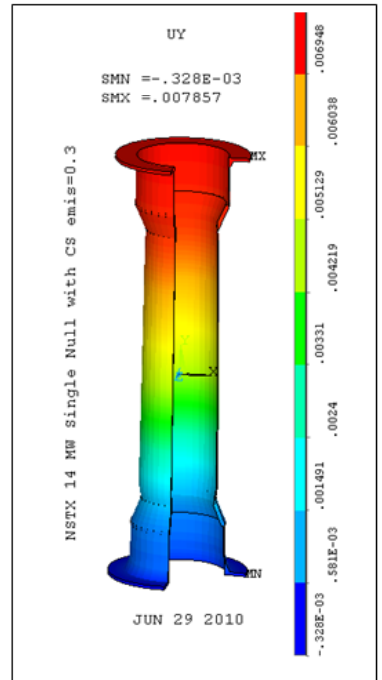
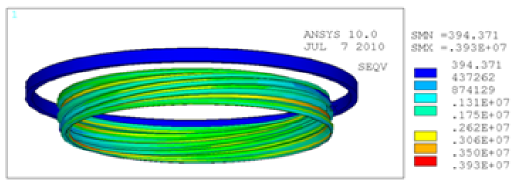


Figure Vertical Displacement of the Centerstack Casing for the calculated operating heat loads from Calculation# NSTX CALC-11-01-00

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

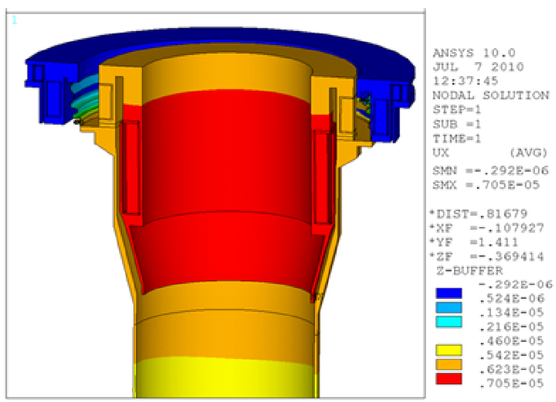
3000N total applied as nodal forces

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

>>>>>

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

PF1a is stable



Final_ EJMA.ppt

EJMA vs. NASTRAN Calculations
Used to check the Finite Element simulation

	EJMA -Stress		NASTRAN -Stress		Shear rate	Torque
	psi		psi		lbs/in	in-lbs
Thickness	Pressure	Axial	Pressure	Axial		
.020 in	15,200.0	25,600.0	15,600	23.300.0	71,120.0	98,211.0
					2800#/mm	
.025 in	9,736.0	31,990.6	9,640.0	28,800.0	128,200.0	122,800.0
					5040#/mm	
.030 in	6,762.0	38,386.0	6,970.0	34,400.0	204,200.0	147,400.0
			8,190.0		8,040#/mm	
	Note:	w= 1.095 for all calculations				
		q=1.0 inches		Torsional delta = .00315in = .8e-4m		
		1.0 mm= .0394 in				

Results From Pressure and Axial Loads only

	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)

Equations are from Section 4.13 of the EJMA manual

Slides #3 and #4 present calculation for , t = .02, w = 1.095, q = 1.0 inches
Slides #5 and #6 present calculation for , t = .025, w = 1.095, q = 1.0 inches
Slides #7 and #8 present calculation for , t = .03, w = 1.095, q = 1.0 inches

Slides #9 to #11 present data for various coefficients which are used in the above calculations.

EJMA Calculations for t=.02 , w=1.095, q= 1.0 inches

	A	B	C	D	E	F	G	H	I
2			EJMA Calculations for t=.02 , w=1.095, q= 1.0 inches						
3									
4									
5		Db		38	in	Inside diameter			
6									
7		Dm= Db+w+nt		39.115	in	Mean diameter			
8									
9		tp=t(Db/Dm)^-2		0.01971	in				
10		tp^2		0.00039					
11		Cp		0.68		from curves, Figure 4.16 EJMA			
12									
13		n		1		material plies of thickness "t"			
14		t		0.02	in				
15		w		1.095	in				
16		w^3		1.31293					
17									
18		q		1	in				
19		P		14.5	psi				
20									
21		S3=Pw/2ntp				Meridional Membrane due to pressure			
22							Eq. 4-30		
23			S3	268.56	psi				
24									
25		P/2		7.25					
26									
27		(w/tp)^2		3085.52					
28									
29		S4=P/2n(w/tp)^2Cp				Meridional Bending due to pressure			
30							Eq.4-31		
31			S4	15211.6	psi				
32									
33		Eb		2.9E+07	psi	Elastic modulus			
34									
35		e=X/N		0.0525	in	Per convolution			
36		X		0.315	in				
37		N		6		Number of convolutions			
38		Cf		1.65		from curve, Figure 4.17 EJMA			
39									
40		S5=Eb(tp)^2(e))/2(w)^3*Cf				Meridional membrane due to deflection			
41							Eq. 4-32		
42			S5	136.55	psi				
43									

$S_6=5(Eb)(tp)e/3(w^2)C_d$ Meridional Bending due to deflection

Eq.4-33

S_6	25594.13	psi

C_d 1.63 from curve, Figure 4-18

Spring Rate

$f_{iu}=1.7\ ((DmEb(tp^3)n)/(w^3)Cf))$ Bellows Theoretical Axial Spring Rate

Eq.4-37

tp^3	7.7E-06
DmEb	1.1E+09
DmEb*(tp	8689.44
w^3Cf	2.16634

f_{iu}	6818.9	lbs/in

Note: Per convolution

K_{total}	1136.48	lbs/in

For N=6 (total convolutions) in series

6818.9	3409.45	1704.73	1136.48
6818.9			
6818.9	3409.45		
6818.9			
6818.9	3409.45		
6818.9			

Required Parameters for all Curve Constants

1.82rm/(Dmtp)^-2	0.518	
rm	0.25	in
2rm/w	0.457	

Fatigue Life Calculations

$St = 0.7\ (S3 + S4) + (S5 + S6)$ See Figure 4-20

St=	36566.8	psi

EJMA Calculations for t=.025 , w=1.095, q= 1.0 inches

Db		38	in	Inside diameter
Dm= Db+w+nt		39.12	in	Mean diameter
tp=t(Db/Dm)^-2		0.02464	in	
tp^2		0.00061		
Cp		0.68		from curves, Figure 4.16 EJMA
n		1		material plies of thickness "t"
t		0.025	in	
w		1.095	in	
w^3		1.31293		
q		1	in	
P		14.5	psi	
S3=Pw/2ntp				Meridional Membrane due to pressure
				Eq. 4-30
	S3	322.20	psi	
P/2		7.25		
(w/tp)^2		1974.98		
S4=P/2n(w/tp)^2Cp				Meridional Bending due to pressure
				Eq.4-31
	S4	9736.67	psi	
Eb		2.9E+07	psi	Elastic modulus
e=X/N		0.0525	in	Per convolution
X		0.315	in	
N		6		Number of convolutions
Cf		1.65		from curve, Figure 4.17 EJMA
S5=Eb(tp)^2(e))/2(w)^3*Cf				Meridional membrane due to deflection
				Eq. 4-32
	S5	213.34	psi	

$S_6 = 5(Eb)(tp)e/3(w^2)C_d$ — Meridional Bending due to deflection

Eq.4-33

S_6	31990.62	psi

C_d 1.63 from curve, Figure 4-18

Spring Rate

$f_{iu} = 1.7\ ((DmEb(tp^3)n)/(w^3)Cf))$ — Bellows Theoretical Axial Spring Rate

Eq.4-37

tp^3	1.5E-05
DmEb	1.1E+09
DmEb*(tp^	16970.5
w^3Cf	2.16634

f_{iu}	13317.3	lbs/in

Note: Per convolution

Ktotal	2219.55	lbs/in

For N=6 (total convolutions) in series

13317.3	6658.66	3329.33	2219.55
13317.3			
13317.3	6658.66		
13317.3			
13317.3	6658.66		
13317.3			

Required Parameters for all Curve Constants

1.82rm/(Dmtp)^-2		0.463
rm	0.25	in
2rm/w		0.457

Fatigue Life Calculations

$$S_f = 0.7\ (S3 + S4) + (S5 + S6)$$

See Figure 4-20

$S_{f=}$	39245.2	psi

EJMA Calculations for t=.03 , w=1.095, q= 1.0 inches

Db	38	in	Inside diameter
Dm= Db+w+nt	39.125	in	Mean diameter
tp=t(Db/Dm)^-2	0.02957	in	
tp^2	0.00087		
Cp	0.68		from curves, Figure 4.16 EJMA
n	1		material plies of thickness "t"
t	0.03	in	
w	1.095	in	
w^3	1.31293		
q	1	in	
P	14.5	psi	
S3=Pw/2ntp			Meridional Membrane due to pressure
			Eq. 4-30
S3	268.56	psi	
P/2	7.25		
(w/tp)^2	1371.69		
S4=P/2n(w/tp)^2Cp			Meridional Bending due to pressure
			Eq.4-31
S4	6762.44	psi	
Eb	2.9E+07	psi	Elastic modulus
e=X/N	0.0525	in	Per convolution
X	0.315	in	
N	6		Number of convolutions
Cf	1.65		from curve, Figure 4.17 EJMA
S5=Eb(tp)^2(e))/2(w)^3*Cf			Meridional membrane due to deflection
			Eq. 4-32
S5	307.17	psi	

$S_6 = 5(E_b)(t_p)e/3(w^2)C_d$ — Meridional Bending due to deflection

Eq.4-33

S_6	38386.29	psi

C_d 1.63 from curve, Figure 4-18

Spring Rate

$f_{iu} = 1.7\ ((D_m E_b (t_p^3) n)/(w^3) C_f))$ — Bellows Theoretical Axial Spring Rate

Eq.4-37

tp^3	2.6E-05
DmEb	1.1E+09
DmEb*(tp^	29323.1
w^3Cf	2.16634

f_{iu}	23010.8	lbs/in

Note: Per convolution

K_{total}	3835.14	lbs/in

For N=6 (total convolutions) in series

23010.8	11505.4	5752.71	3835.14
23010.8			
23010.8	11505.4		
23010.8			
23010.8	11505.4		
23010.8			

Required Parameters for all Curve Constants

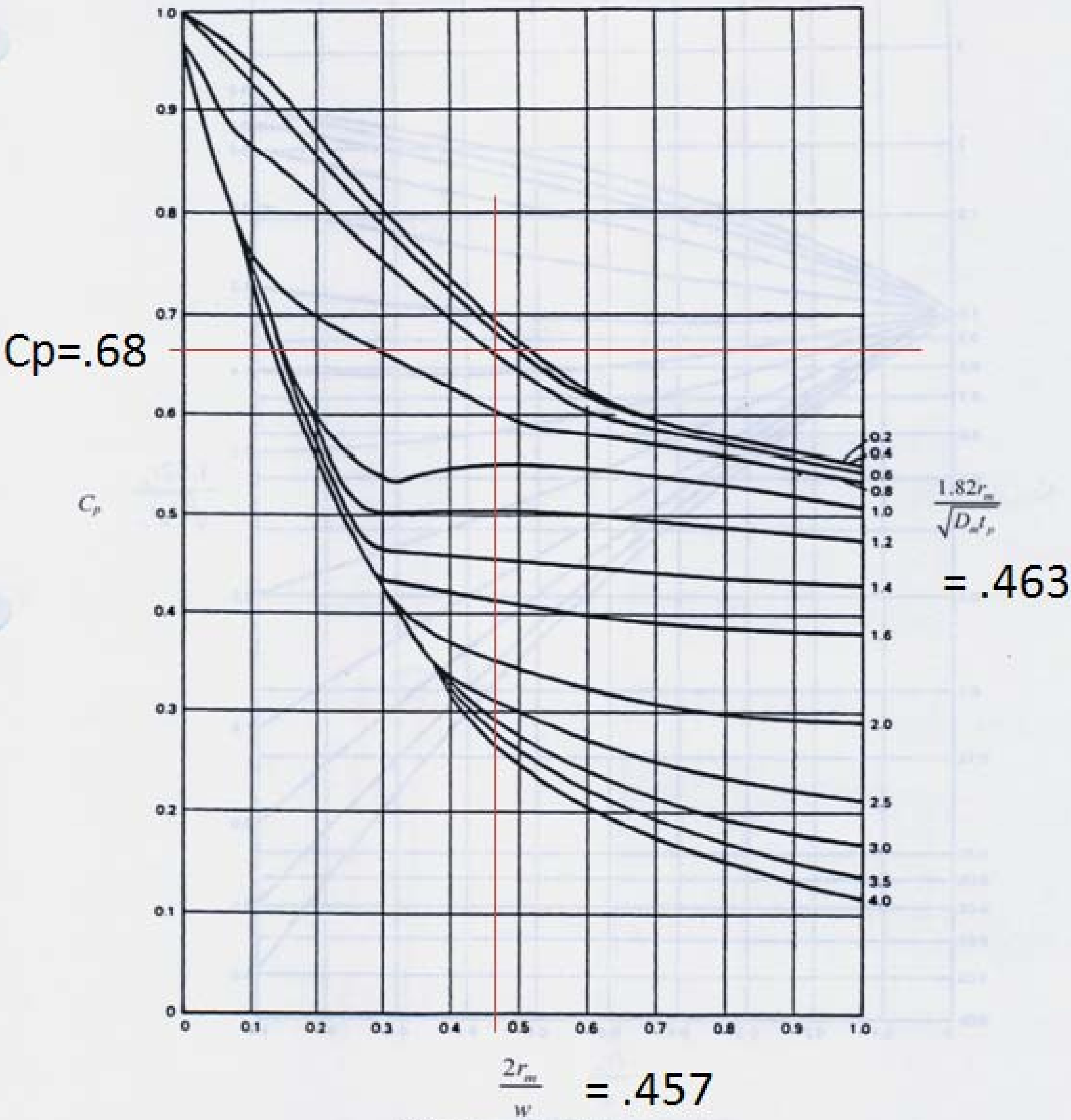
1.82rm/(Dmtp)^-2		0.423
rm	0.25	in
2rm/w		0.457

Fatigue Life Calculations

$$S_f = 0.7\ (S_3 + S_4) + (S_5 + S_6)$$

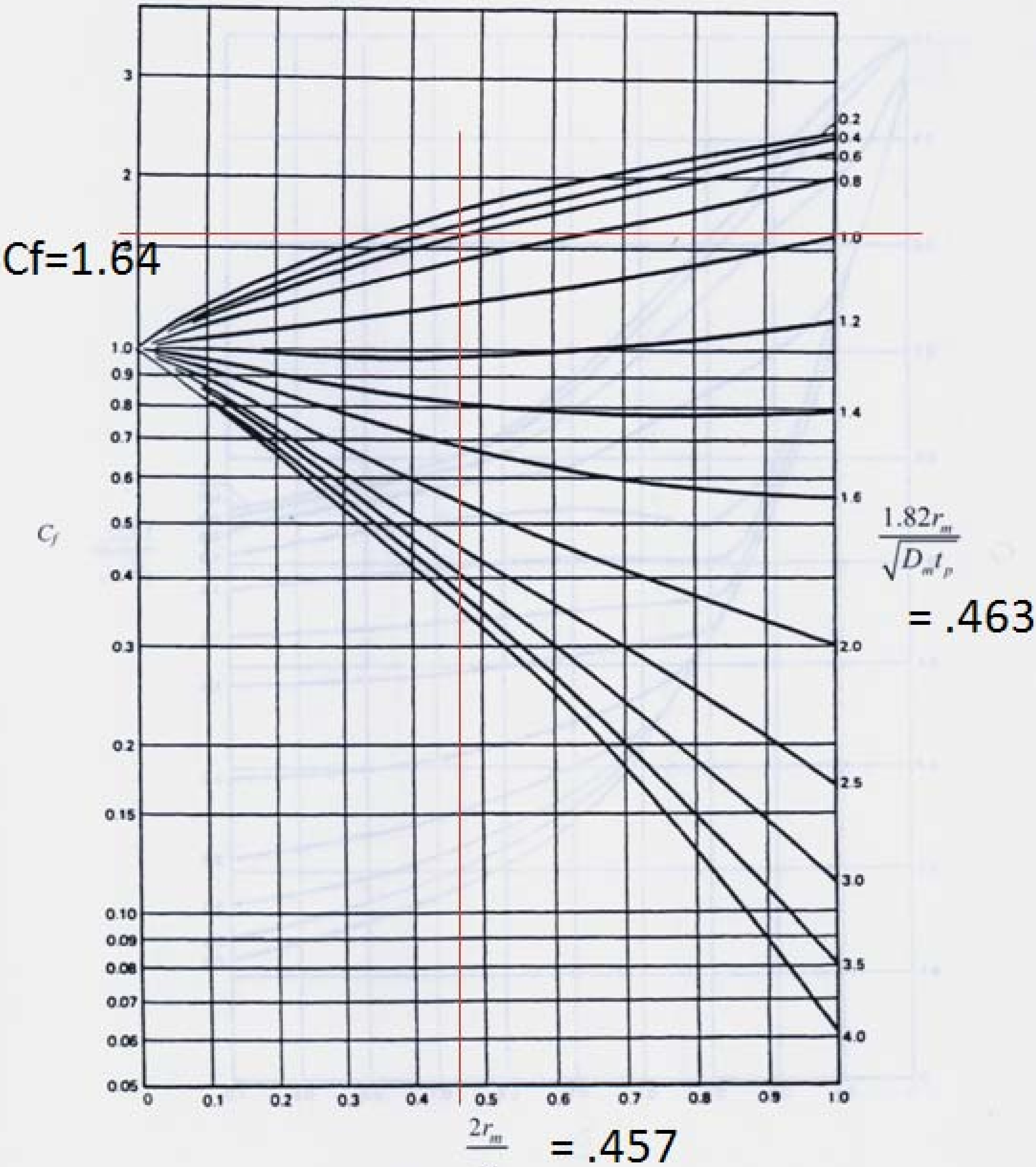
See Figure 4-20

$S_{f=}$	43615.2	psi



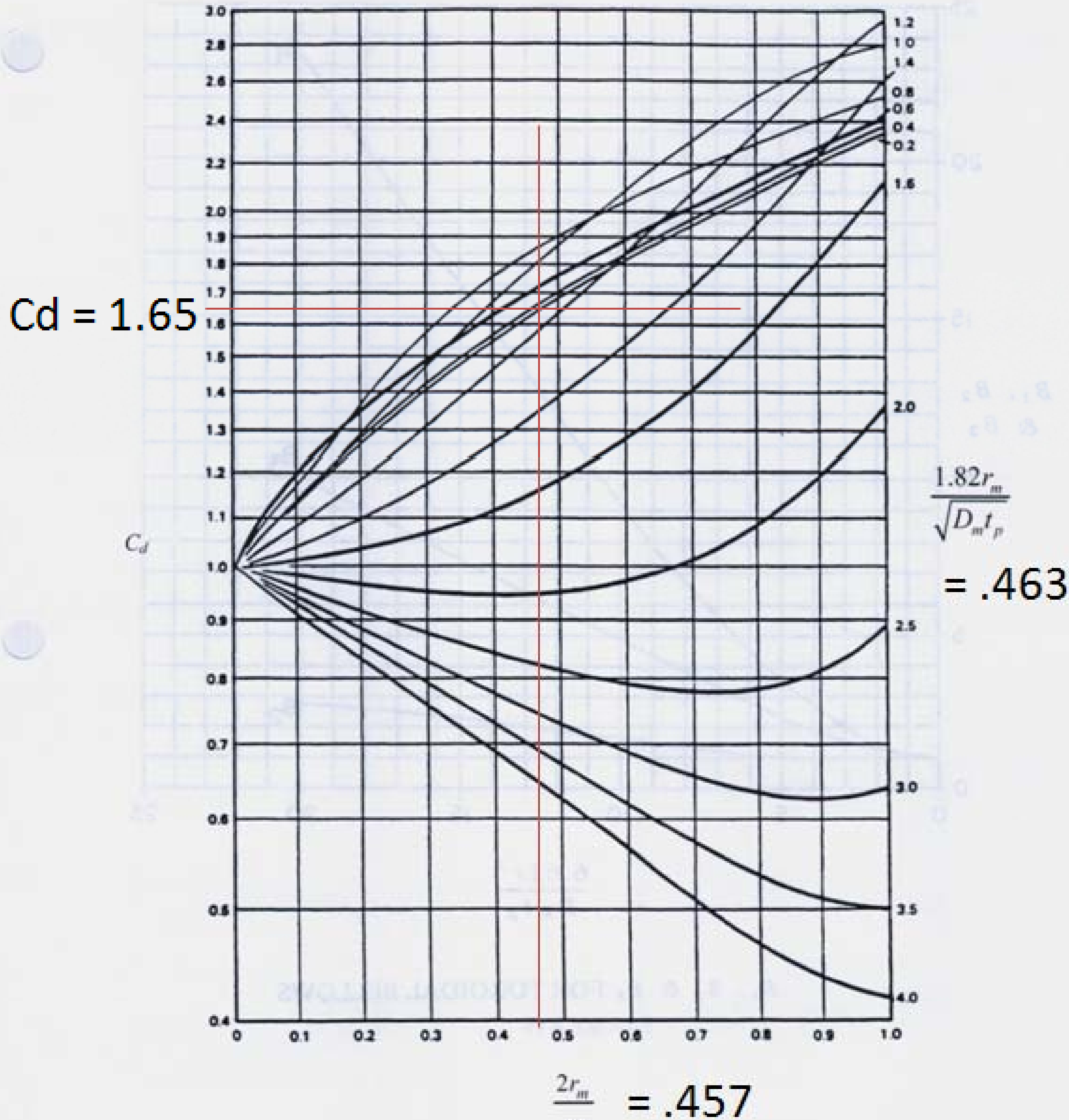
C_p for Convoluted Bellows

FIGURE 4.16



C_f for Convoluted Bellows

FIGURE 4.17



C_d for Convoluted Bellows

FIGURE 4.18

EJMA Fatigue Life estimate for combined Axial and Pressure loads only

These curves are intended to predict average fatigue life at temperatures below 800°F for austenitic stainless steel bellows which have not been heat treated and have not more than 5 plies. They are considered valid primarily in the range of 10^3 to 10^5 cycles, due to the limited data available for the very low and very high cyclic ranges.

The equations are of the form provided in Design of Pressure Vessels for Low Fatigue by B.F. Langer, ASME paper 61-WA-18. The constants were modified to reflect the experience of EJMA members for bellows fatigue life.

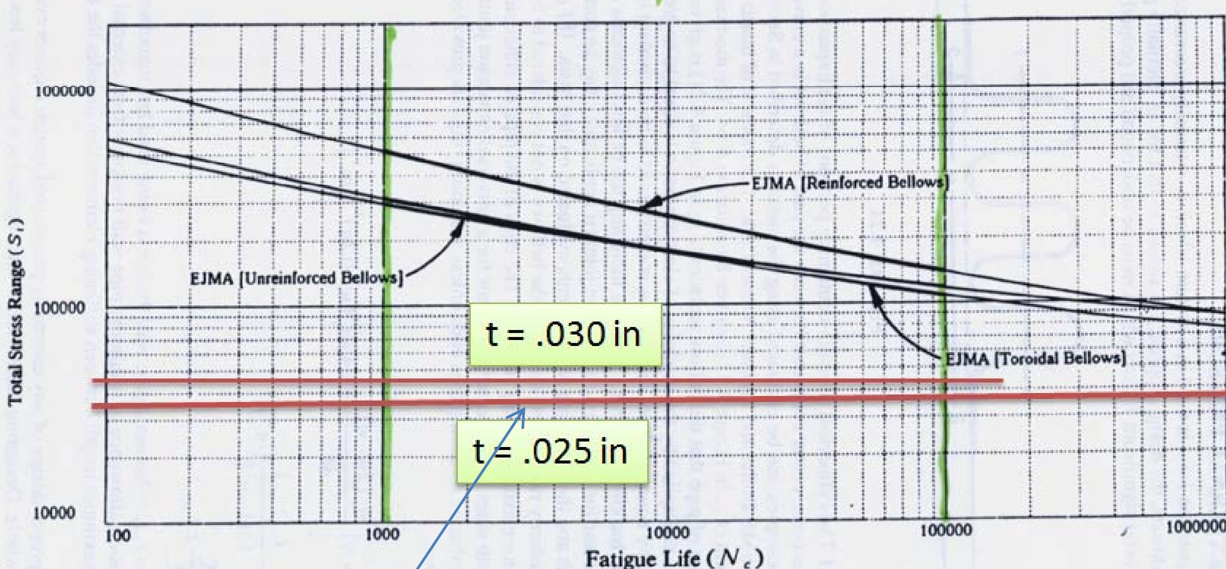


FIGURE 4.20

UNREINFORCED

$$N_c = \left(\frac{1.86 \times 10^6}{S_t - 54000}\right)^{3.4}$$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6)$$

REINFORCED

$$N_c = \left(\frac{5.18 \times 10^6}{S_t - 41800}\right)^{2.9}$$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6)$$

TOROIDAL

$$N_c = \left(\frac{2.30 \times 10^6}{S_t - 41800}\right)^{3.25}$$

$$S_t = 3S_3 + S_5 + S_6$$

See slide #2 for "St" values

Final_ EJMA.ppt

EJMA vs. NASTRAN Calculations
Used to check the Finite Element simulation

	EJMA -Stress		NASTRAN -Stress		Shear rate	Torque
	psi		psi		lbs/in	in-lbs
Thickness	Pressure	Axial	Pressure	Axial		
.020 in	15,200.0	25,600.0	15,600	23.300.0	71,120.0	98,211.0
					2800#/mm	
.025 in	9,736.0	31,990.6	9,640.0	28,800.0	128,200.0	122,800.0
					5040#/mm	
.030 in	6,762.0	38,386.0	6,970.0	34,400.0	204,200.0	147,400.0
			8,190.0		8,040#/mm	
	Note:	w= 1.095 for all calculations				
		q=1.0 inches		Torsional delta = .00315in = .8e-4m		
		1.0 mm= .0394 in				

Results From Pressure and Axial Loads only

	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)

Equations are from Section 4.13 of the EJMA manual

Slides #3 and #4 present calculation for , t = .02, w = 1.095, q = 1.0 inches
Slides #5 and #6 present calculation for , t = .025, w = 1.095, q = 1.0 inches
Slides #7 and #8 present calculation for , t = .03, w = 1.095, q = 1.0 inches

Slides #9 to #11 present data for various coefficients which are used in the above calculations.

EJMA Calculations for t=.02 , w=1.095, q= 1.0 inches

Db		38	in	Inside diameter	
Dm= Db+w+nt		39.115	in	Mean diameter	
tp=t(Db/Dm)^-2		0.01971	in		
tp^2		0.00039			
Cp		0.68		from curves, Figure 4.16 EJMA	
n		1		material plies of thickness "t"	
t		0.02	in		
w		1.095	in		
w^3		1.31293			
q		1	in		
P		14.5	psi		
S3=Pw/2ntp				Meridional Membrane due to pressure	
					Eq. 4-30
	S3	268.56	psi		
P/2		7.25			
(w/tp)^2		3085.52			
S4=P/2n(w/tp)^2Cp				Meridional Bending due to pressure	
					Eq.4-31
	S4	15211.6	psi		
Eb		2.9E+07	psi	Elastic modulus	
e=X/N		0.0525	in	Per convolution	
X		0.315	in		
N		6		Number of convolutions	
Cf		1.65		from curve, Figure 4.17 EJMA	
S5=Eb(tp)^2(e))/2(w)^3*Cf				Meridional membrane due to deflection	
					Eq. 4-32
	S5	136.55	psi		

S_6=5(Eb)(tp)e/3(w^2)C_d — Meridional Bending due to deflection

Eq.4-33

S_6	25594.13	psi

C_d 1.63 from curve, Figure 4-18

Spring Rate

f_{iu}=1.7 ((DmEb(tp^3)n)/(w^3)Cf)) — Bellows Theoretical Axial Spring Rate

Eq.4-37

tp^3	7.7E-06
DmEb	1.1E+09
DmEb*(tp	8689.44
w^3Cf	2.16634

f_{iu}	6818.9	lbs/in

Note: Per convolution

Ktotal	1136.48	lbs/in

For N=6 (total convolutions) in series

6818.9	3409.45	1704.73	1136.48
6818.9			
6818.9	3409.45		
6818.9			
6818.9	3409.45		
6818.9			

Required Parameters for all Curve Constants

1.82rm/(Dmtp)^-2	0.518	
rm	0.25	in
2rm/w	0.457	

Fatigue Life Calculations

$$S_t = 0.7\,(S_3 + S_4) + (S_5 + S_6)$$

See Figure 4-20

St=	36566.8	psi

EJMA Calculations for t=.025 , w=1.095, q= 1.0 inches

Db		38	in	Inside diameter
Dm= Db+w+nt		39.12	in	Mean diameter
tp=t(Db/Dm)^-2		0.02464	in	
tp^2		0.00061		
C_p		0.68		from curves, Figure 4.16 EJMA
n		1		material plies of thickness "t"
t		0.025	in	
w		1.095	in	
w^3		1.31293		
q		1	in	
P		14.5	psi	
S_3=Pw/2ntp				Meridional Membrane due to pressure
				Eq. 4-30
	S_3	322.20	psi	
P/2		7.25		
(w/tp)^2		1974.98		
S_4=P/2n(w/tp)^2C_p				Meridional Bending due to pressure
				Eq.4-31
	S_4	9736.67	psi	
E_b		2.9E+07	psi	Elastic modulus
e=X/N		0.0525	in	Per convolution
X		0.315	in	
N		6		Number of convolutions
C_f		1.65		from curve, Figure 4.17 EJMA
S_5=Eb(tp)^2(e))/2(w)^3*C_f				Meridional membrane due to deflection
				Eq. 4-32
	S_5	213.34	psi	

$S_6 = 5(E_b)(t_p)e/3(w^2)C_d$ — Meridional Bending due to deflection

Eq.4-33

S_6	31990.62	psi

C_d 1.63 from curve, Figure 4-18

Spring Rate

$f_{iu} = 1.7\ ((D_mE_b(t_p\text{^}3)n)/(w\text{^}3)C_f))$ — Bellows Theoretical Axial Spring Rate

Eq.4-37

tp^3	1.5E-05
DmEb	1.1E+09
DmEb*(tp^	16970.5
w^3Cf	2.16634

f_{iu}	13317.3	lbs/in

Note: Per convolution

Ktotal	2219.55	lbs/in

For N=6 (total convolutions) in series

13317.3	6658.66	3329.33	2219.55
13317.3			
13317.3	6658.66		
13317.3			
13317.3	6658.66		
13317.3			

Required Parameters for all Curve Constants

1.82rm/(Dmtp)^-2		0.463	
rm	0.25	in	
2rm/w		0.457	

Fatigue Life Calculations

$S_f = 0.7\ (S3 + S4) + (S5 + S6)$ See Figure 4-20

$S_{f=}$	39245.2	psi

EJMA Calculations for t=.03 , w=1.095, q= 1.0 inches

2						
3						
4						
5	Db		38	in	Inside diameter	
6						
7	Dm= Db+w+nt		39.125	in	Mean diameter	
8						
9	tp=t(Db/Dm)^-2		0.02957	in		
10	tp^2		0.00087			
11	Cp		0.68		from curves, Figure 4.16 EJMA	
12						
13	n		1		material plies of thickness "t"	
14	t		0.03	in		
15	w		1.095	in		
16	w^3		1.31293			
17						
18	q		1	in		
19	P		14.5	psi		
20						
21	S3=Pw/2ntp				Meridional Membrane due to pressure	
22						Eq. 4-30
23		S3	268.56	psi		
24						
25	P/2		7.25			
26						
27	(w/tp)^2		1371.69			
28						
29	S4=P/2n(w/tp)^2Cp				Meridional Bending due to pressure	
30						Eq.4-31
31		S4	6762.44	psi		
32						
33	Eb		2.9E+07	psi	Elastic modulus	
34						
35	e=X/N		0.0525	in	Per convolution	
36	X		0.315	in		
37	N		6		Number of convolutions	
38	Cf		1.65		from curve, Figure 4.17 EJMA	
39						
40	S5=Eb(tp)^2(e))/2(w)^3*Cf				Meridional membrane due to deflection	
41						Eq. 4-32
42		S5	307.17	psi		
43						

$S_6 = 5(E_b)(t_p)e/3(w^2)C_d$ — Meridional Bending due to deflection

Eq.4-33

S_6	38386.29	psi

C_d 1.63 from curve, Figure 4-18

Spring Rate

$f_{iu} = 1.7\ ((D_m E_b (t_p^3) n)/(w^3) C_f))$ — Bellows Theoretical Axial Spring Rate

Eq.4-37

tp^3	2.6E-05
DmEb	1.1E+09
DmEb*(tp^	29323.1
w^3Cf	2.16634

f_{iu}	23010.8	lbs/in

Note: Per convolution

K_{total}	3835.14	lbs/in

For N=6 (total convolutions) in series

23010.8	11505.4	5752.71	3835.14
23010.8			
23010.8	11505.4		
23010.8			
23010.8	11505.4		
23010.8			

Required Parameters for all Curve Constants

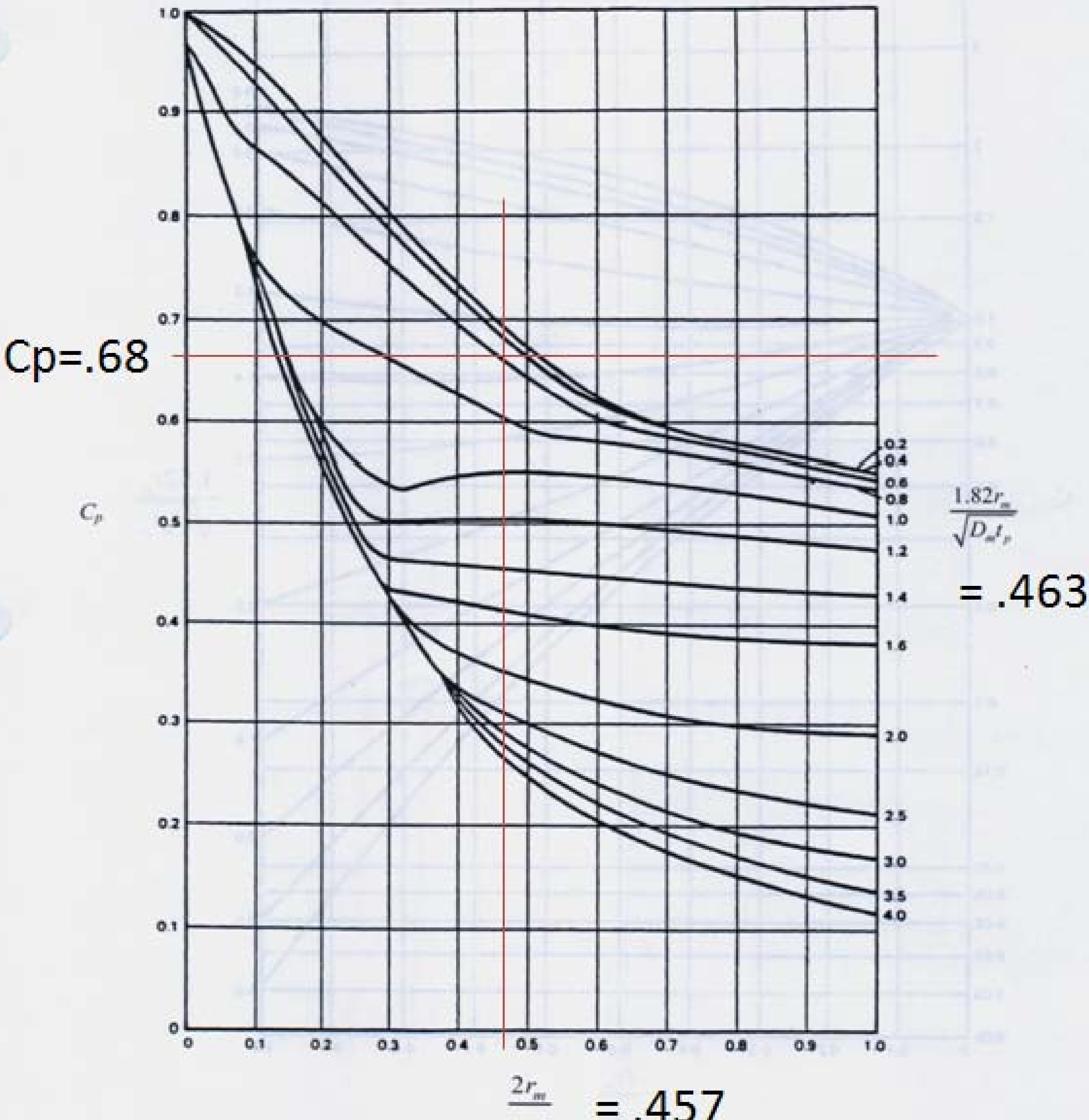
1.82rm/(Dmtp)^-2		0.423
rm	0.25	in
2rm/w		0.457

Fatigue Life Calculations

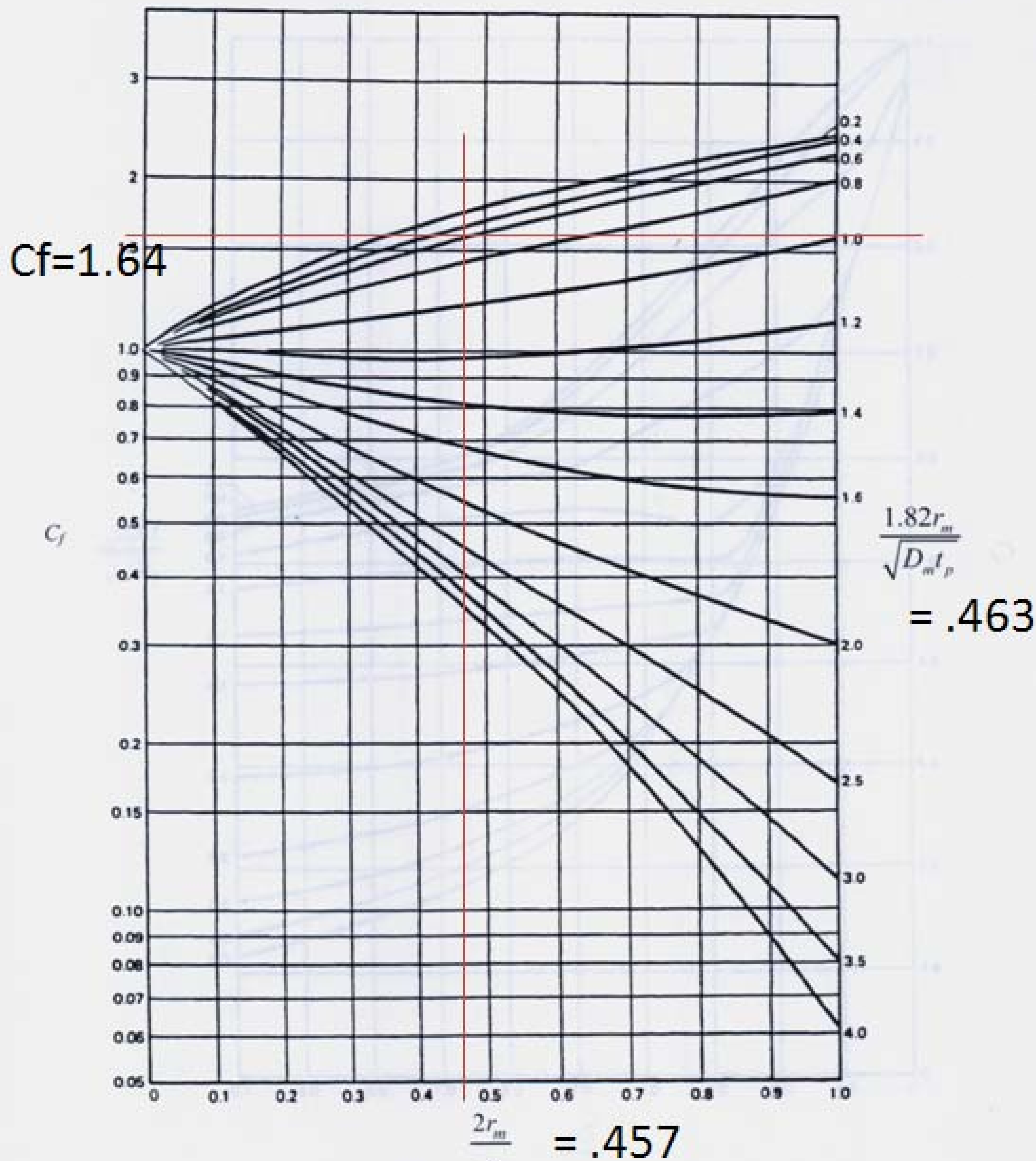
$$S_f = 0.7\ (S_3 + S_4) + (S_5 + S_6)$$

See Figure 4-20

$S_{f=}$	43615.2	psi

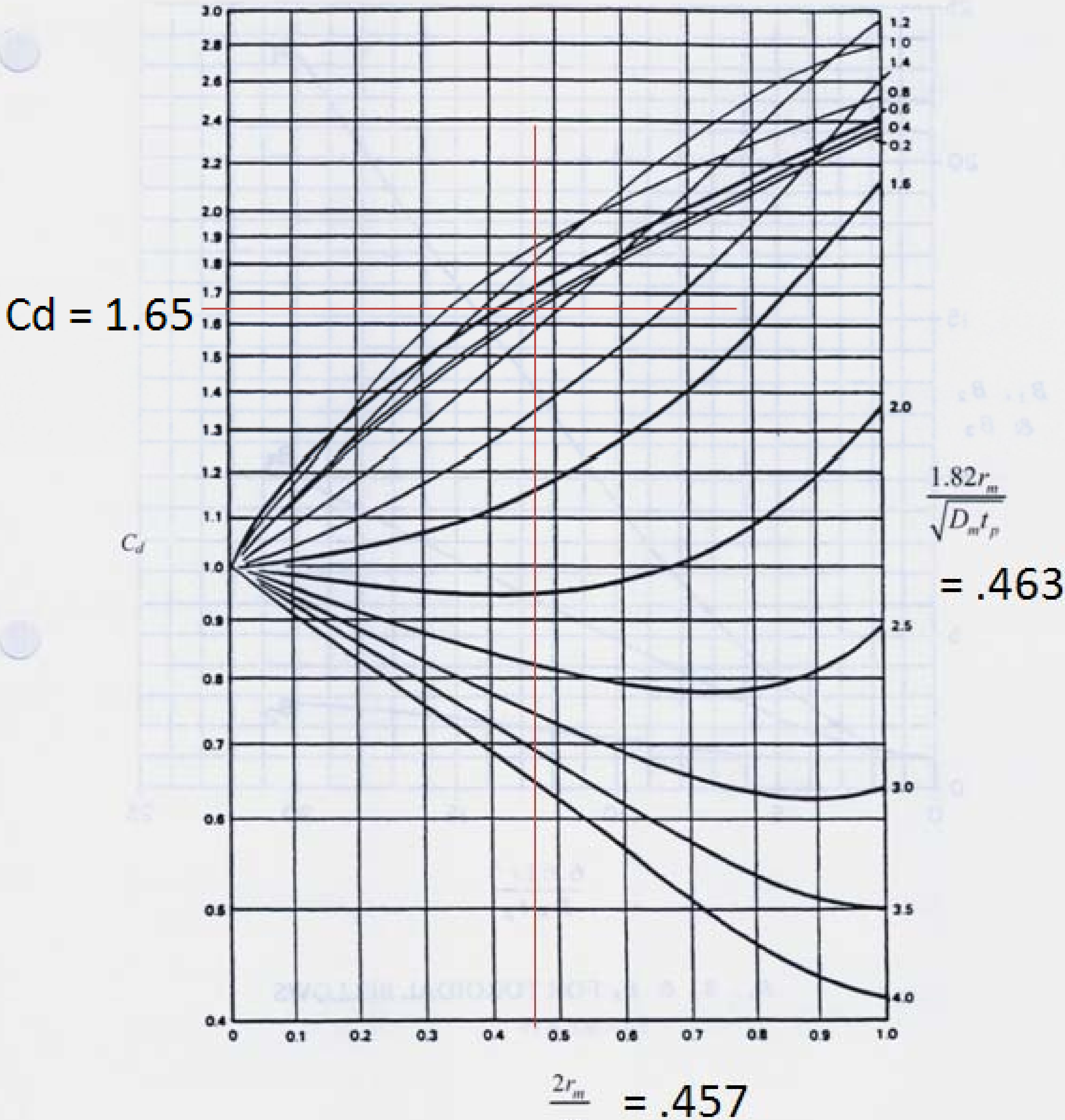


C_p for Convoluted Bellows
FIGURE 4.16



C_f for Convoluted Bellows

FIGURE 4.17



C_d for Convoluted Bellows

FIGURE 4.18

EJMA Fatigue Life estimate for combined Axial and Pressure loads only

These curves are intended to predict average fatigue life at temperatures below 800°F for austenitic stainless steel bellows which have not been heat treated and have not more than 5 plies. They are considered valid primarily in the range of 10^3 to 10^5 cycles, due to the limited data available for the very low and very high cyclic ranges.

The equations are of the form provided in Design of Pressure Vessels for Low Fatigue by B.F. Langer, ASME paper 61-WA-18. The constants were modified to reflect the experience of EJMA members for bellows fatigue life.

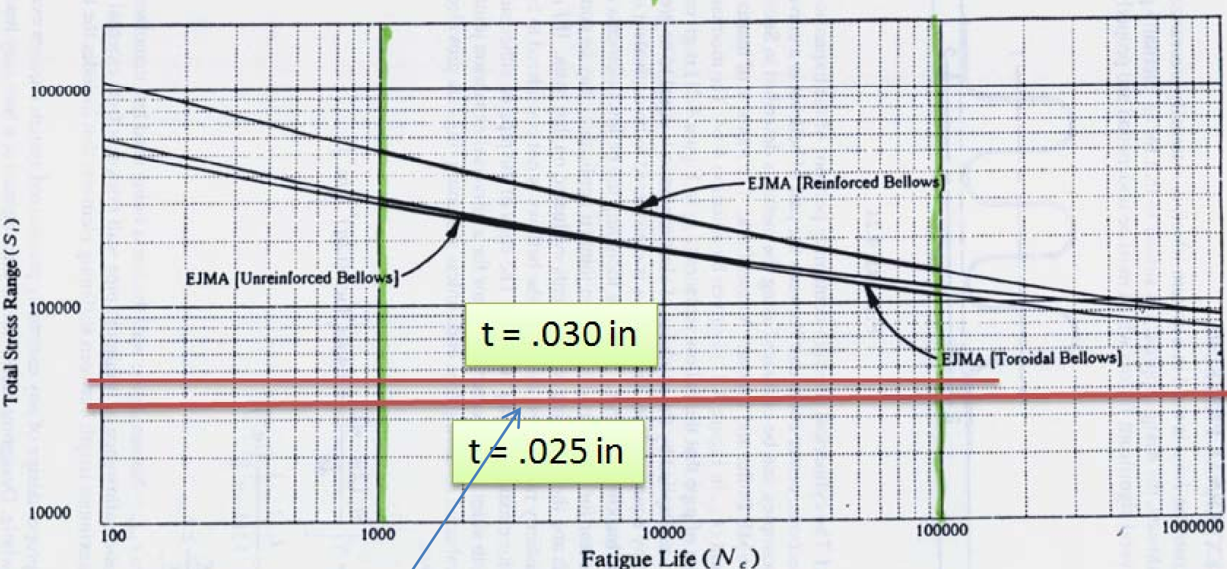


FIGURE 4.20

UNREINFORCED

$$N_c = \left(\frac{1.86 \times 10^6}{S_t - 54000}\right)^{3.4}$$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6)$$

REINFORCED

$$N_c = \left(\frac{5.18 \times 10^6}{S_t - 41800}\right)^{2.9}$$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6)$$

TOROIDAL

$$N_c = \left(\frac{2.30 \times 10^6}{S_t - 41800}\right)^{3.25}$$

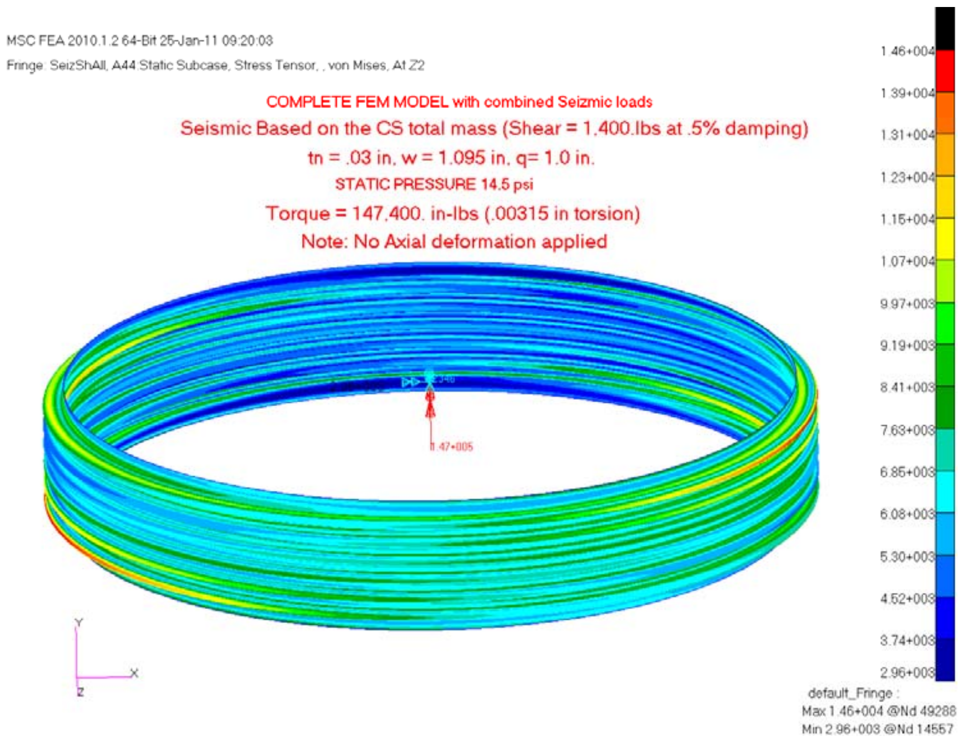
$$S_t = 3S_3 + S_5 + S_6$$

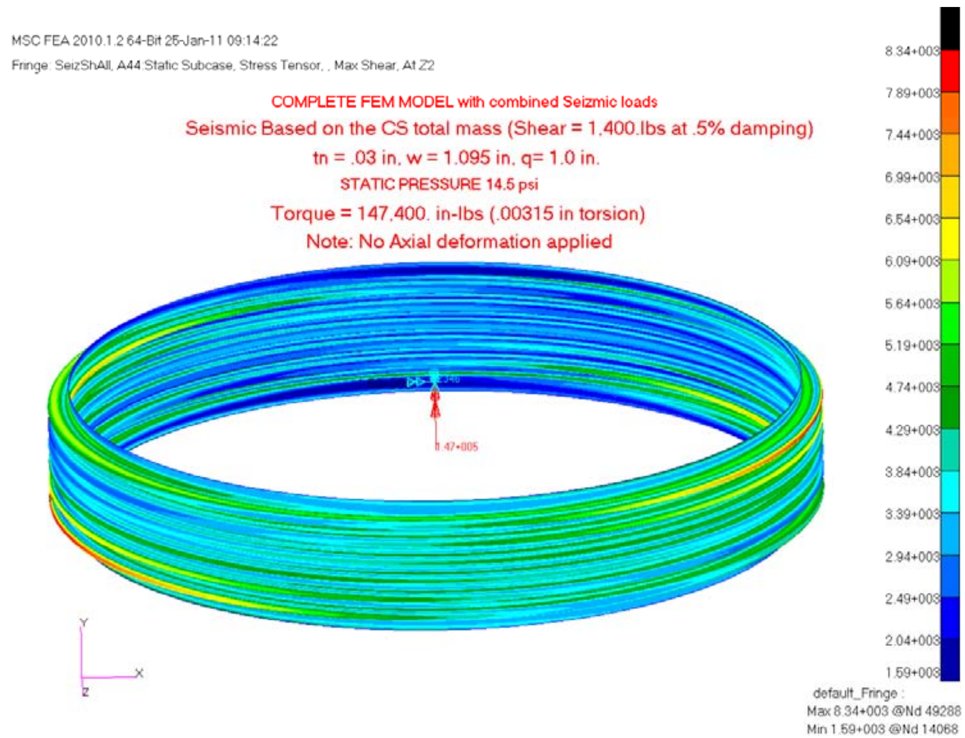
See slide #2 for "St" values

Seismic data included
No Axial deformation

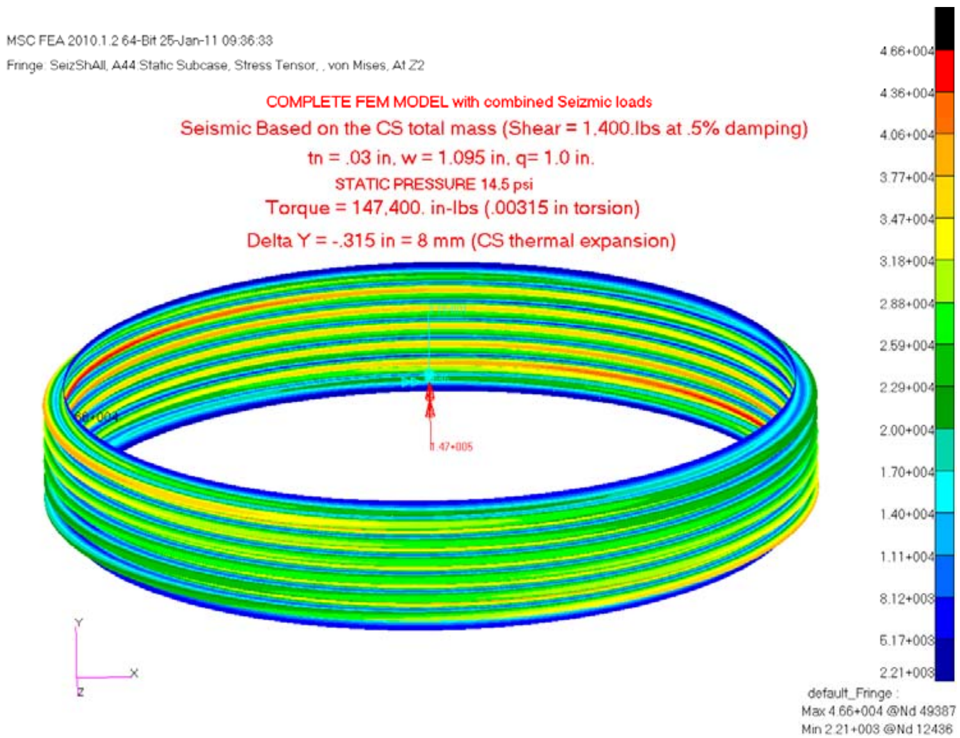
Static Calculations

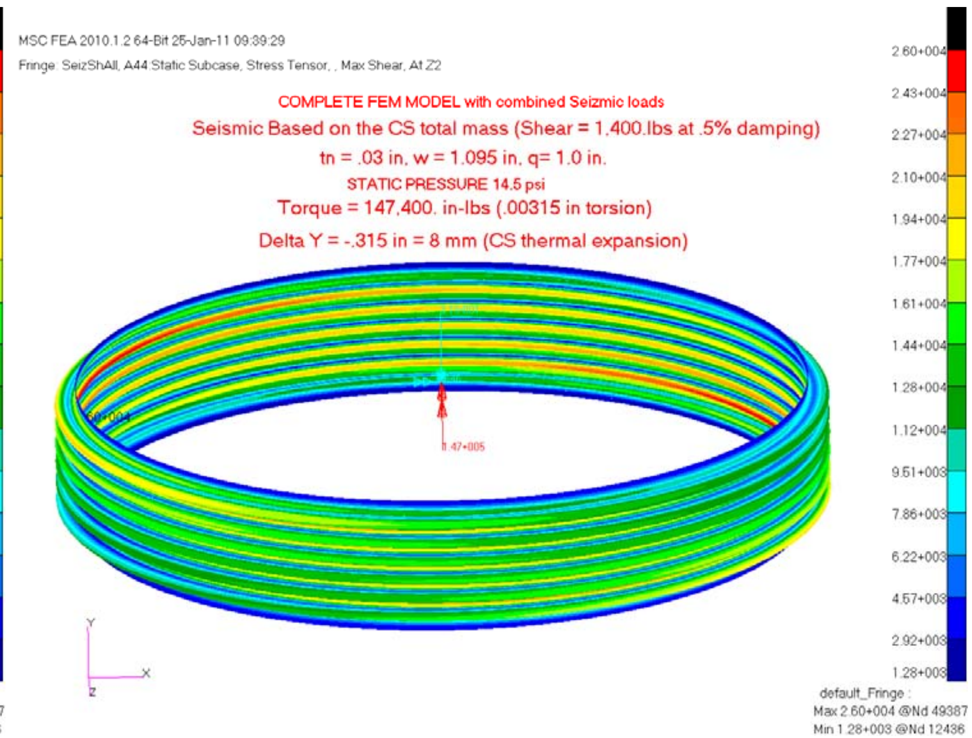
P. Rogoff
1/25/2011





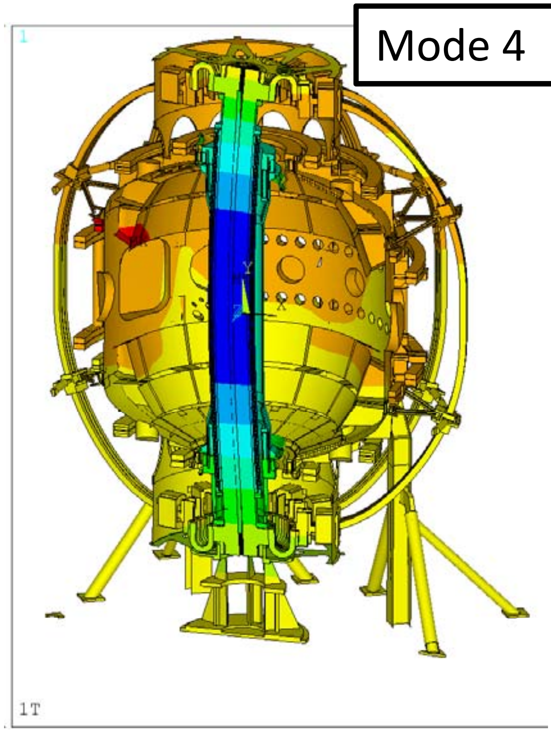
Seismic Data Including
Axial deformation due to the Cs thermal expansion



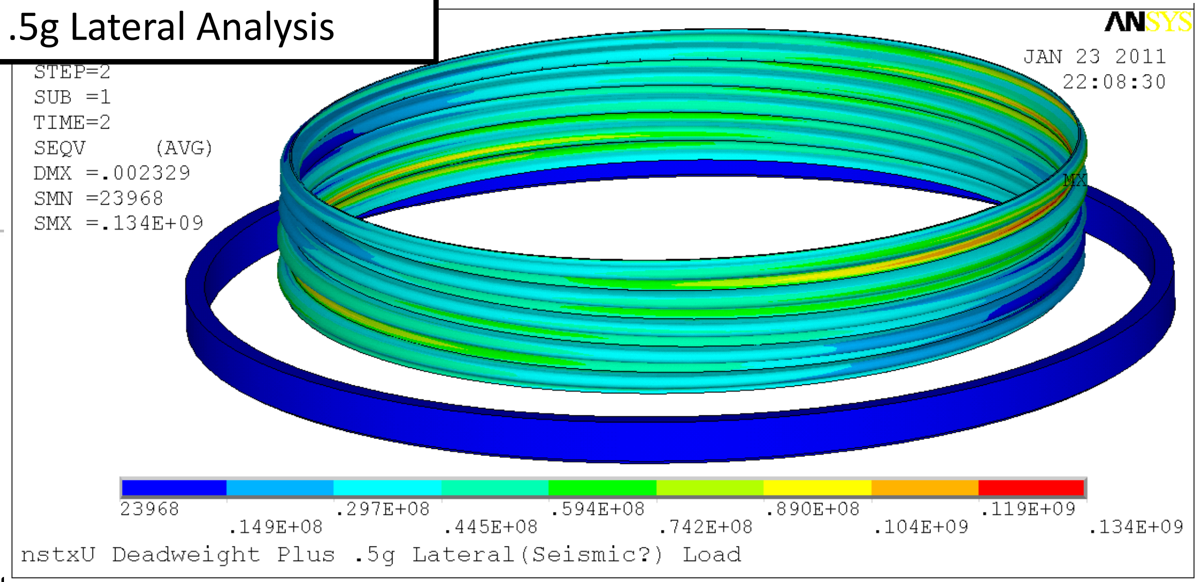


The next slide shows Seismic results which were obtained from the
the complete NSTX update structure simulation with ANSYS 12.1. This
work was completed by P. Titus and it is also available under a different
calculation report. (See, NSTXU-CALC-10-01-02)
These calculations were completed using the standard seismic scenario
for the TFTR facilities with .05% damping.
Both calculations show maximum stress results well within the material
Yield allowable for the Inconel bellows.

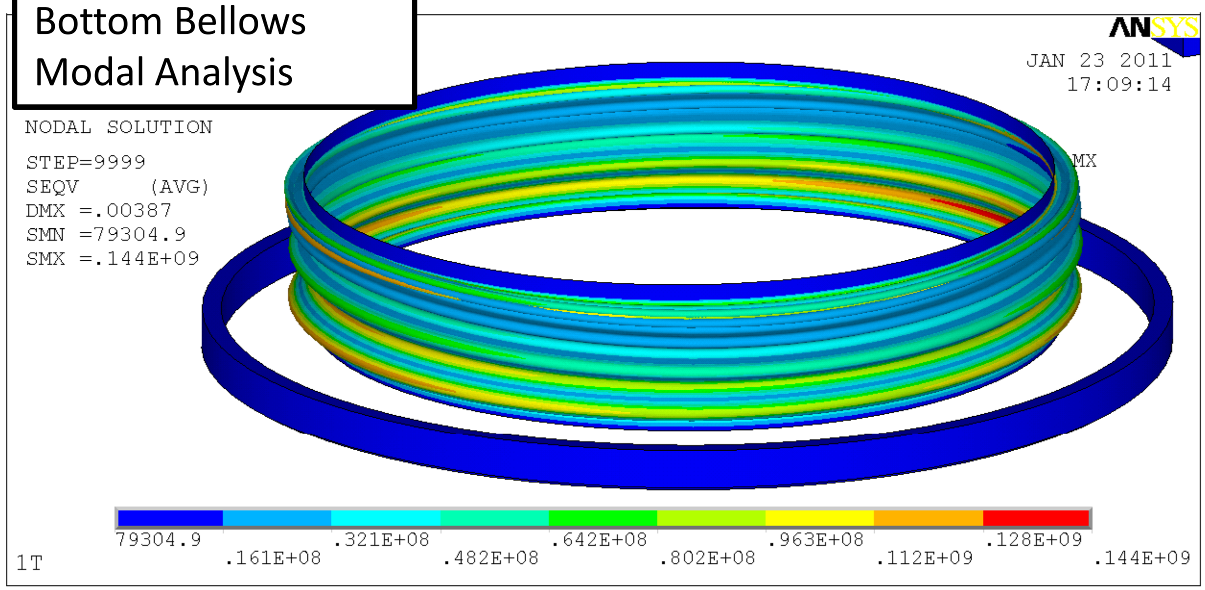
Mode 4



Bottom Bellows Static .5g Lateral Analysis



Bottom Bellows Modal Analysis

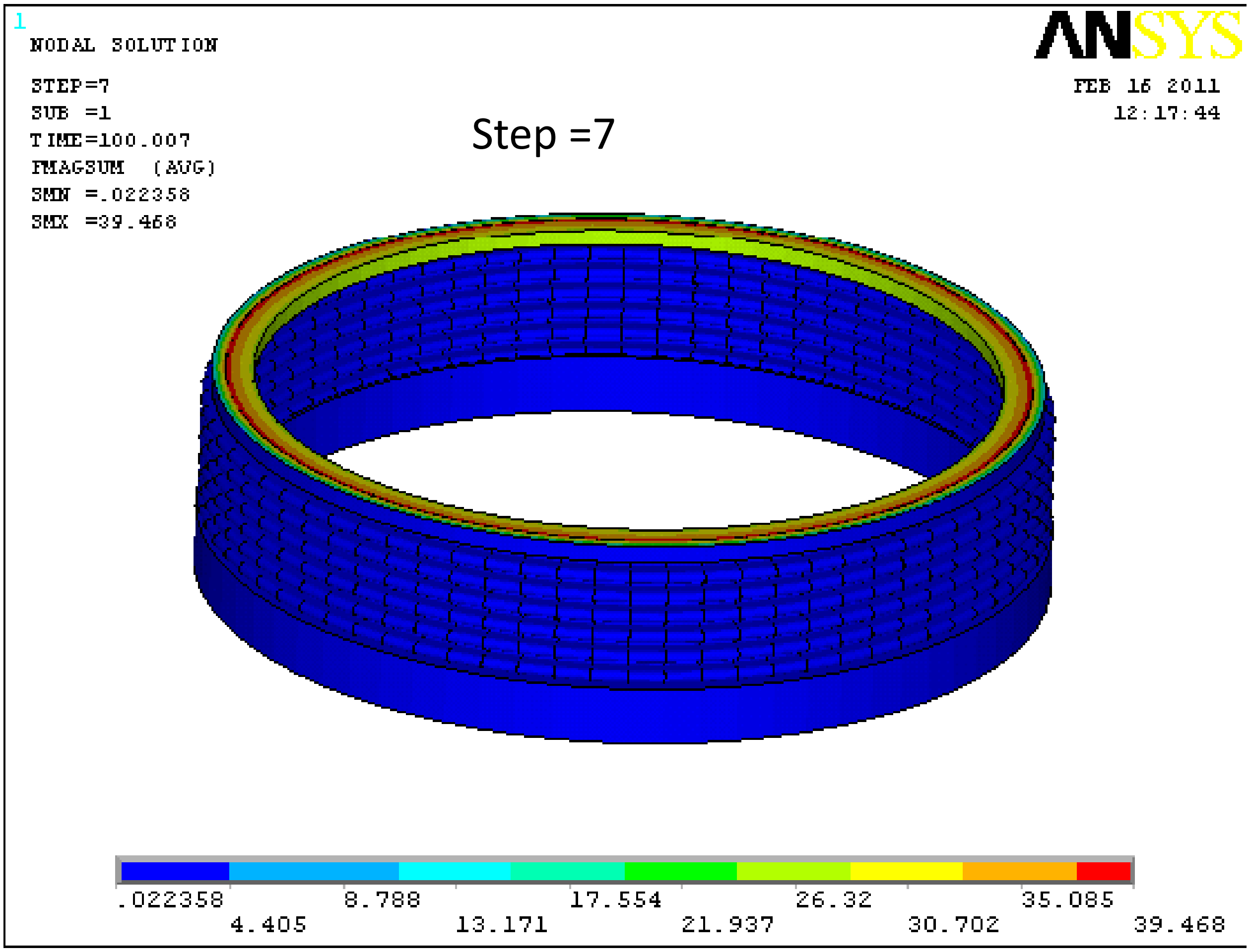


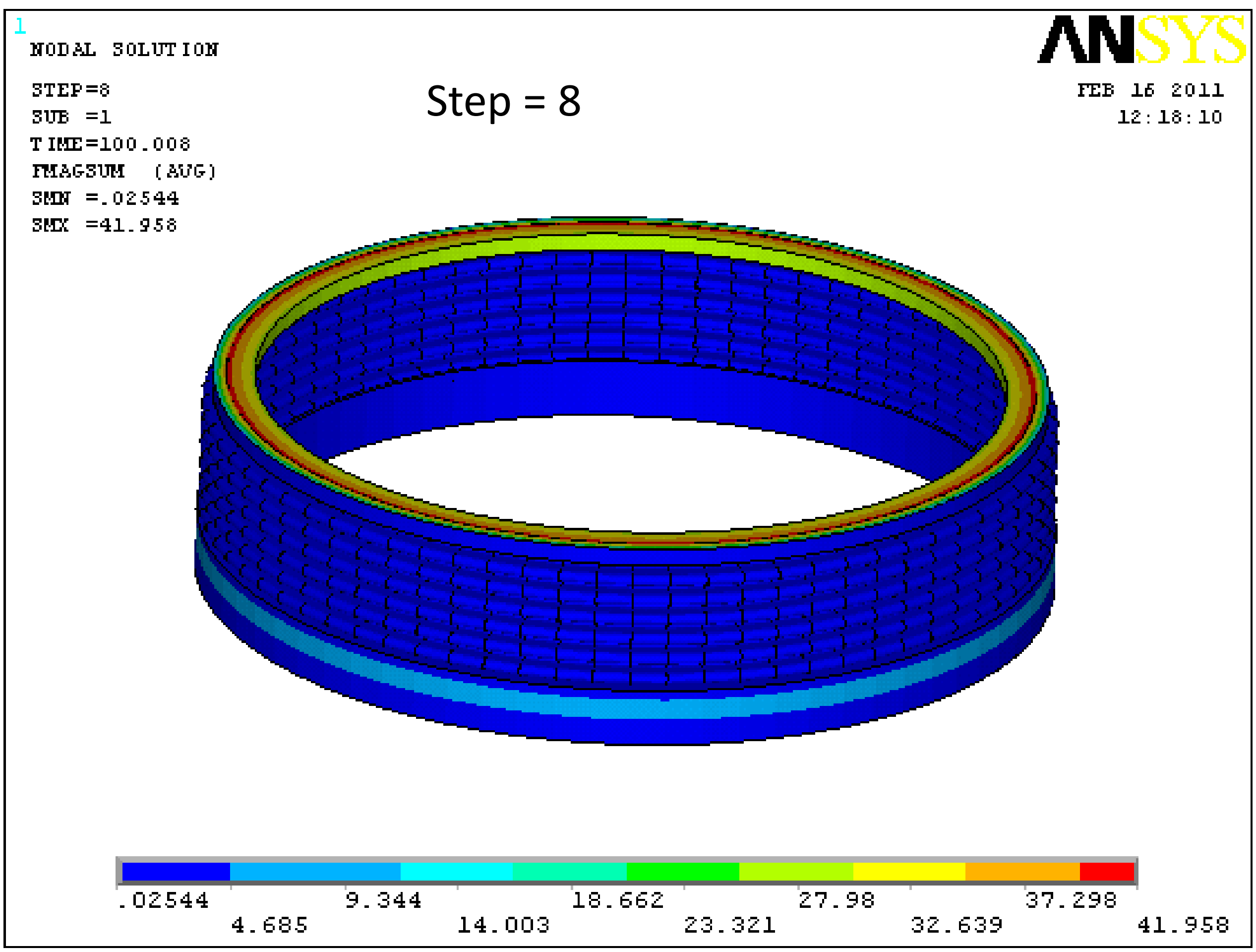
LOWER BELLOWS MAGNETIC DISRUPTION CHECK

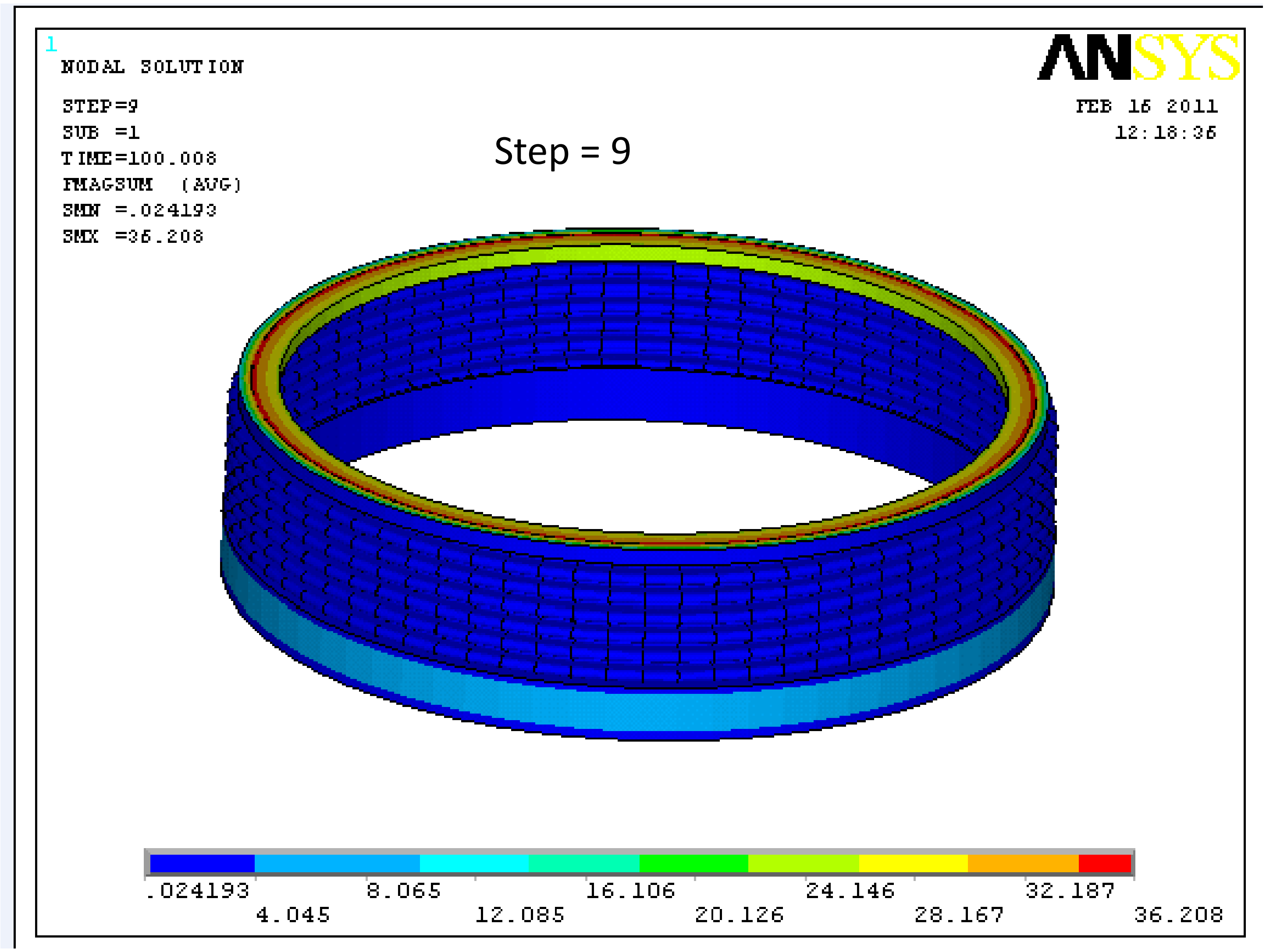
These calculations were performed using a sequence of ANSYS prep7 runs:

* Using “BellDisrupt02.txt” “elect2.db” was created and saved with data for 40 time steps for restart in the next phase of the process. This data is then used in the “Static01.txt” to create the “struct2PR.db” for further static processing.

<u>Note:</u> All the necessary data is located at:
asalehz-64pc,G:\ANSYS_PR\BellowsEM1


1
NODAL SOLUTION
STEP=7
SUB =1
TIME=100.007
FMAGSUM (AVG)
SMN =.022358
SMX =39.468
Step =7
ANSYS
FEB 16 2011
12:17:44
.022358
4.405
8.788
13.171
17.554
21.937
26.32
30.702
35.085
39.468


1
NODAL SOLUTION
STEP=8
SUB =1
TIME=100.008
FMAGSUM (AVG)
SMN =.02544
SMX =41.958
Step = 8
ANSYS
FEB 16 2011
12:18:10
.02544
4.685
9.344
14.003
18.662
23.321
27.98
32.639
37.298
41.958


1
NODAL SOLUTION
STEP=9
SUB =1
TIME=100.008
FMAGSUM (AVG)
SMN =.024193
SMX =36.208
FEB 16 2011
12:18:36
Step = 9
.024193
4.045
8.065
12.085
16.106
20.126
24.146
28.167
32.187
36.208

Displacements and VonMises stresses

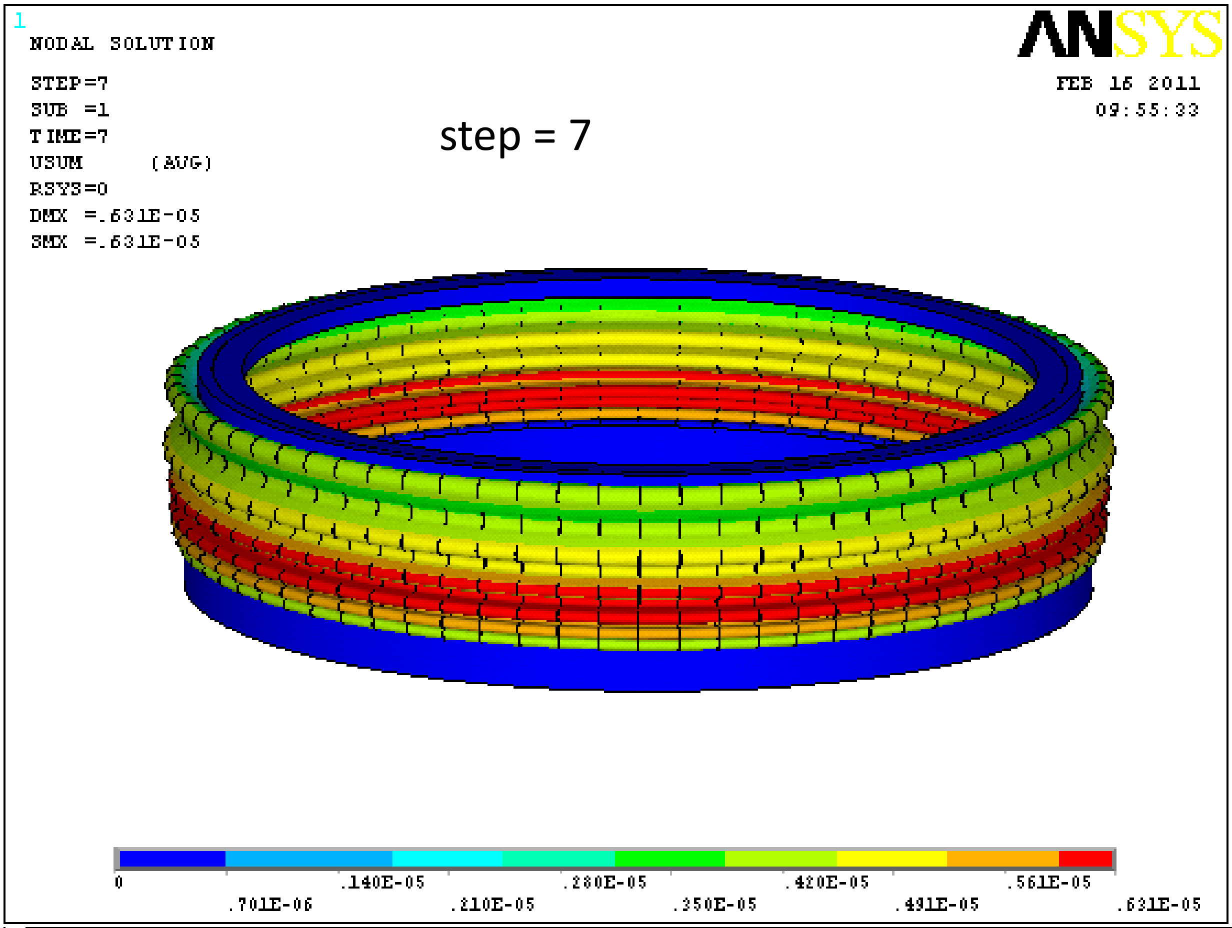
From “struct2PR.db”
Input data “Static01.txt”

Due to the disruption magnetic forces at the lower bellows. General input data provided by A. Brooks and P. Titus in ANSYS Prep7 format.

Maximum displacements and stresses are calculated at iteration “step = 8”, i.e., stress = 3.37 MPa (about 500. psi), therefore, adding small increase to the Inconel bellows.

Steps #7 and #9 are shown in order to help verify the maximum load and reaction conditions.

Conclusion: Stresses due to the magnetic disruption at the lower bellows are insignificant.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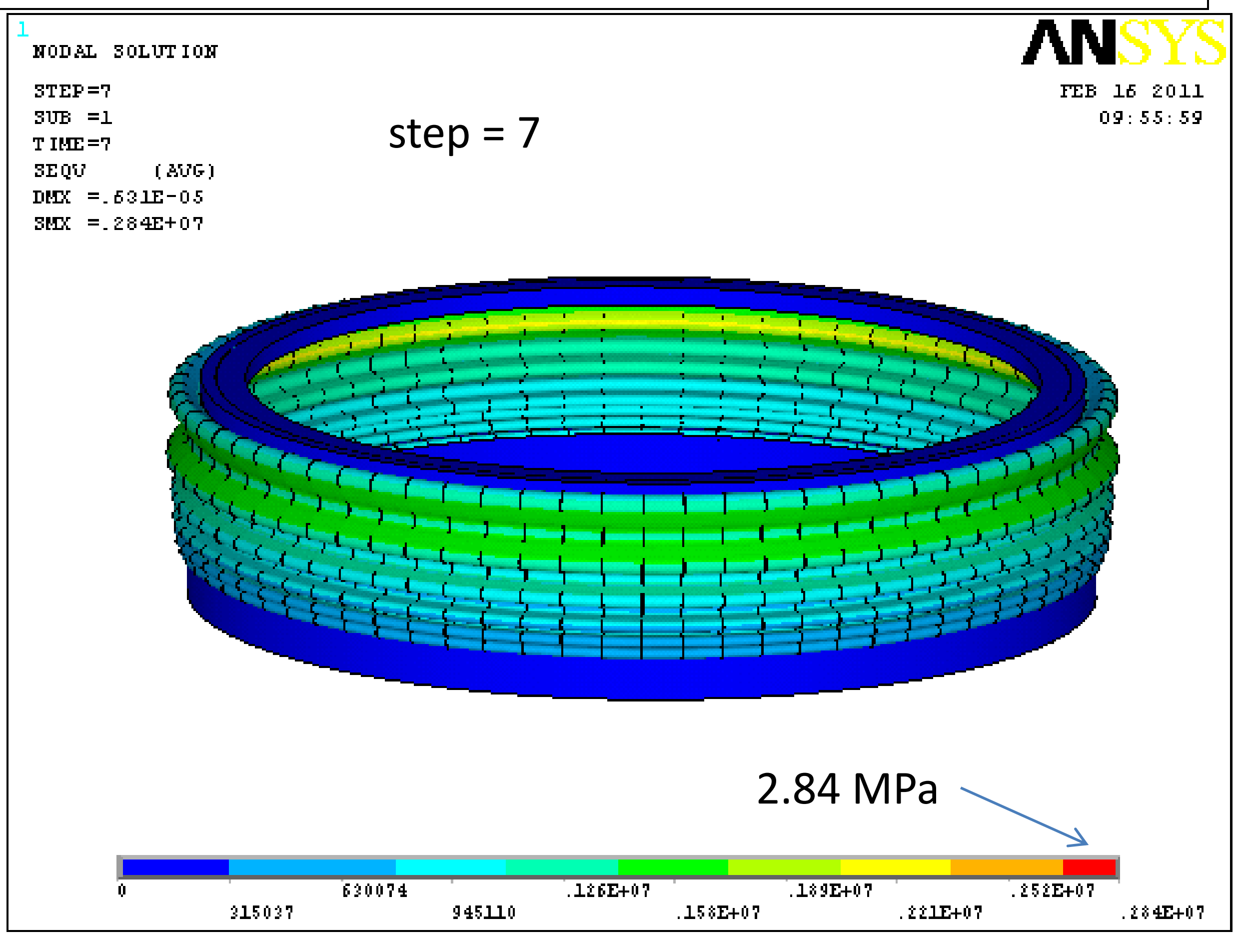
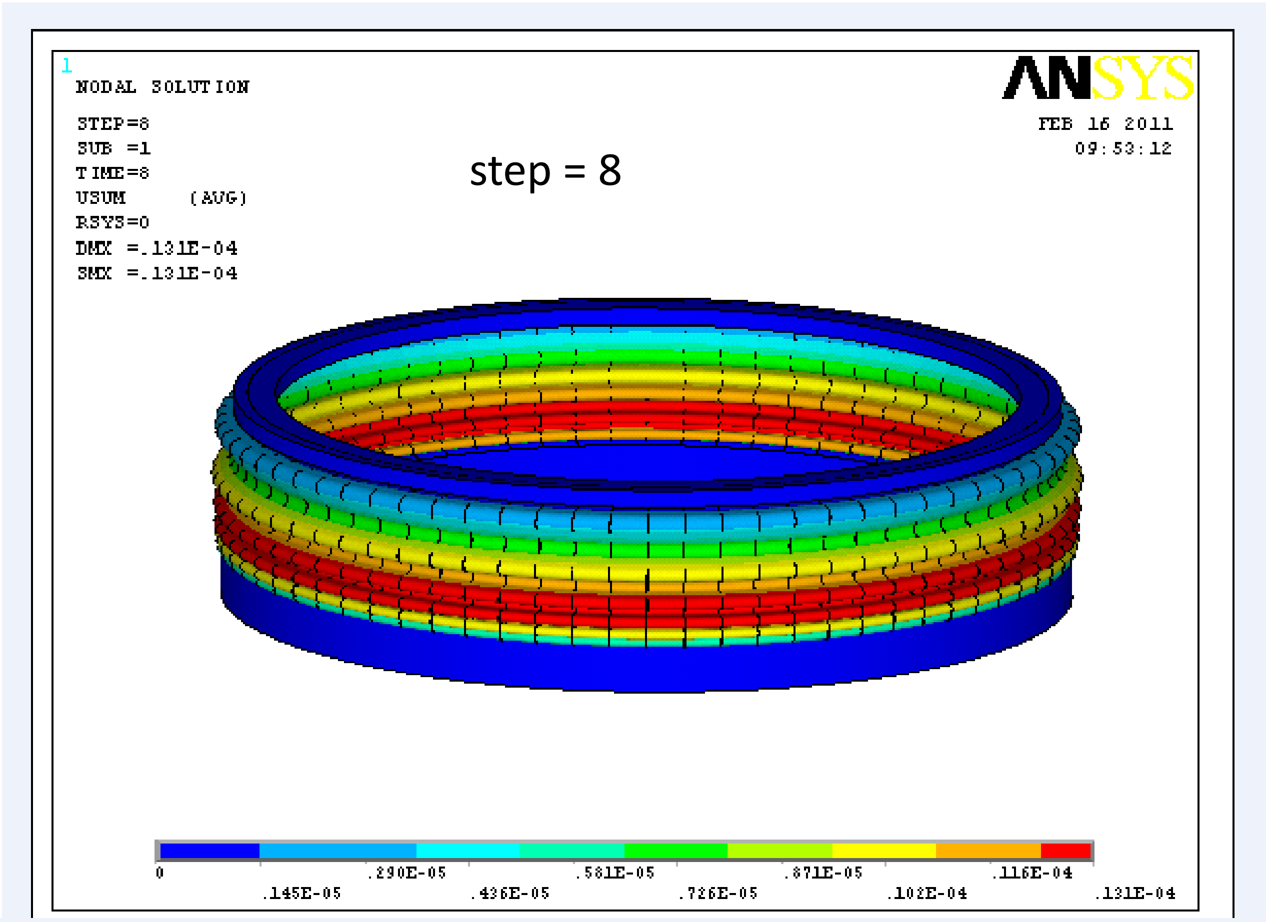
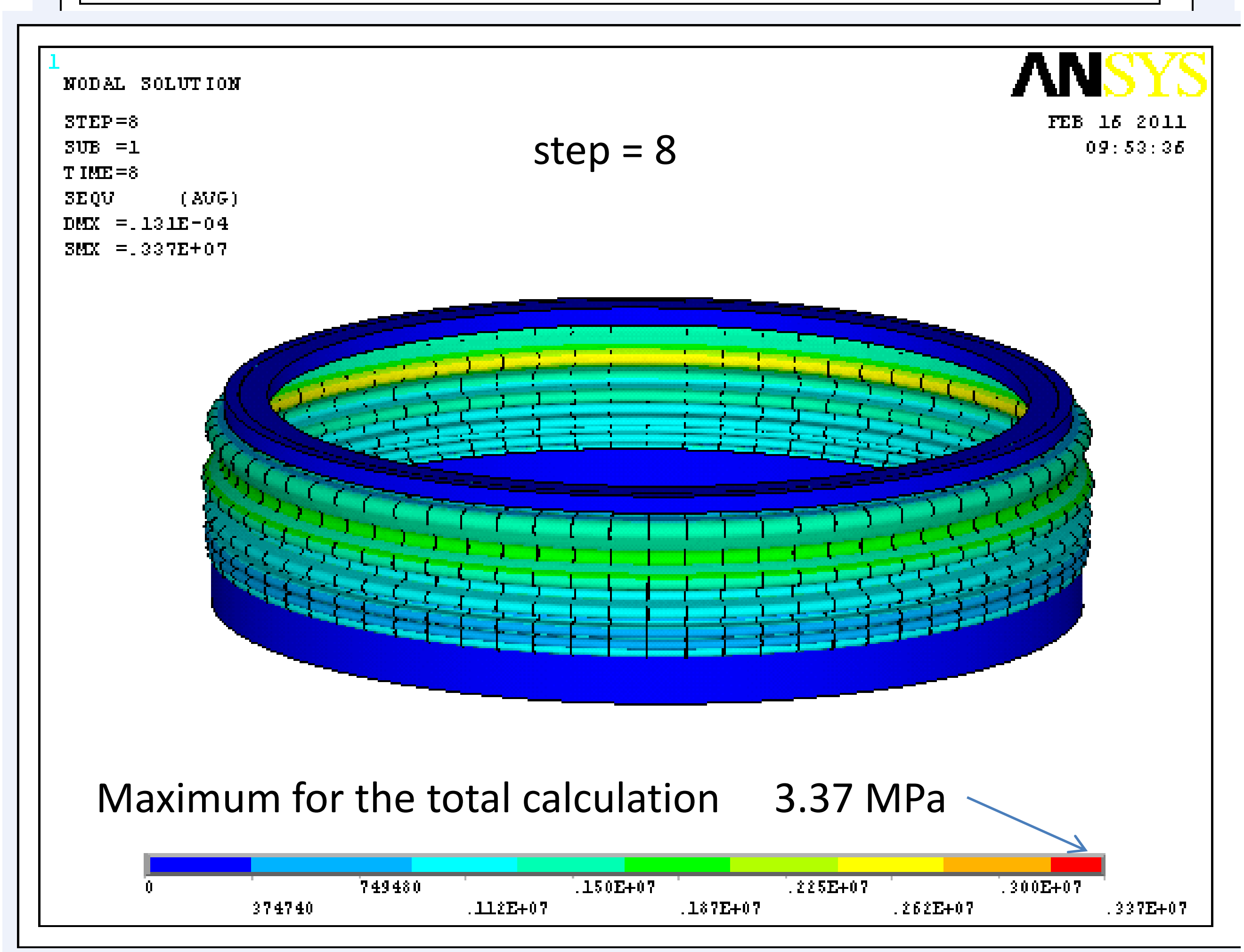
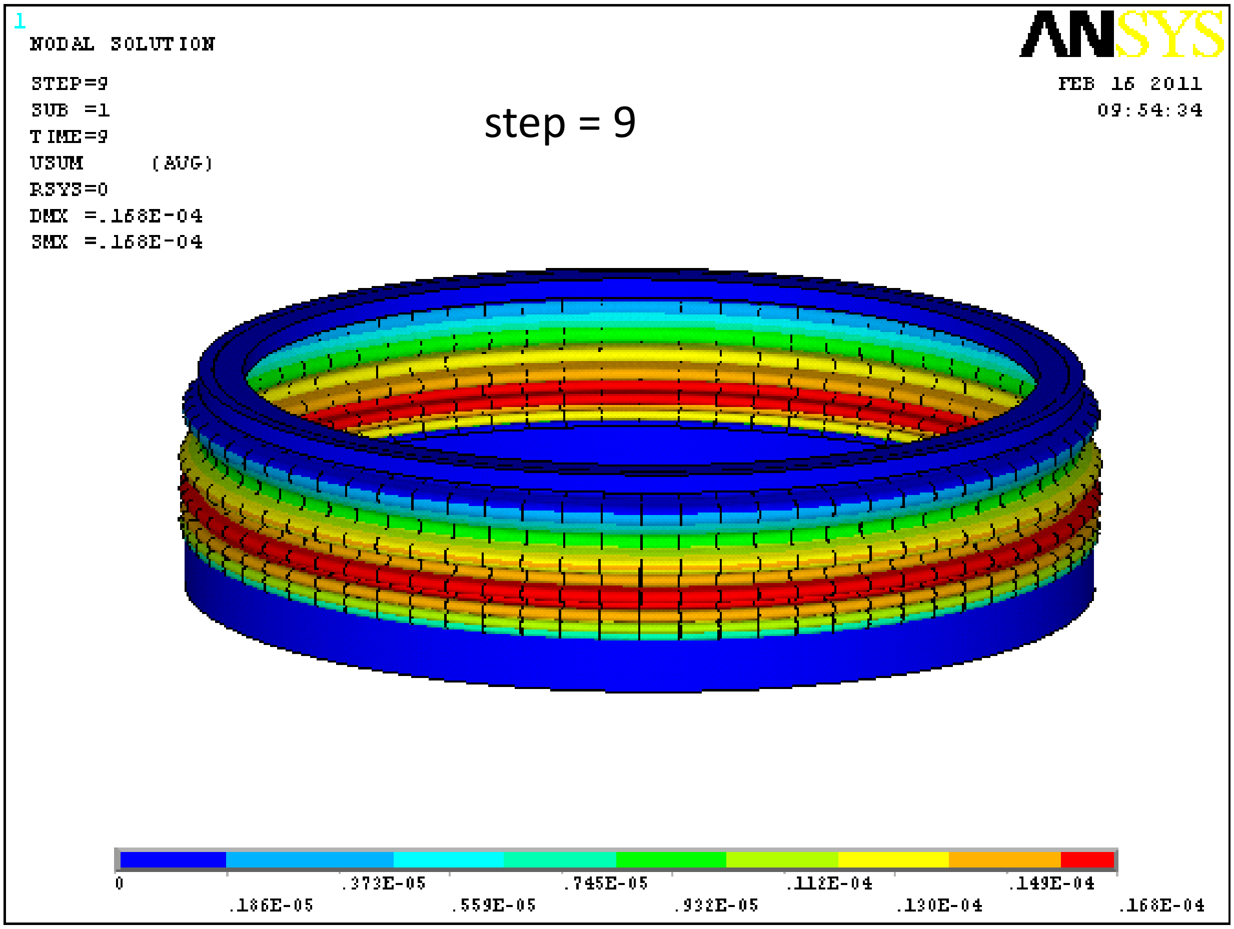
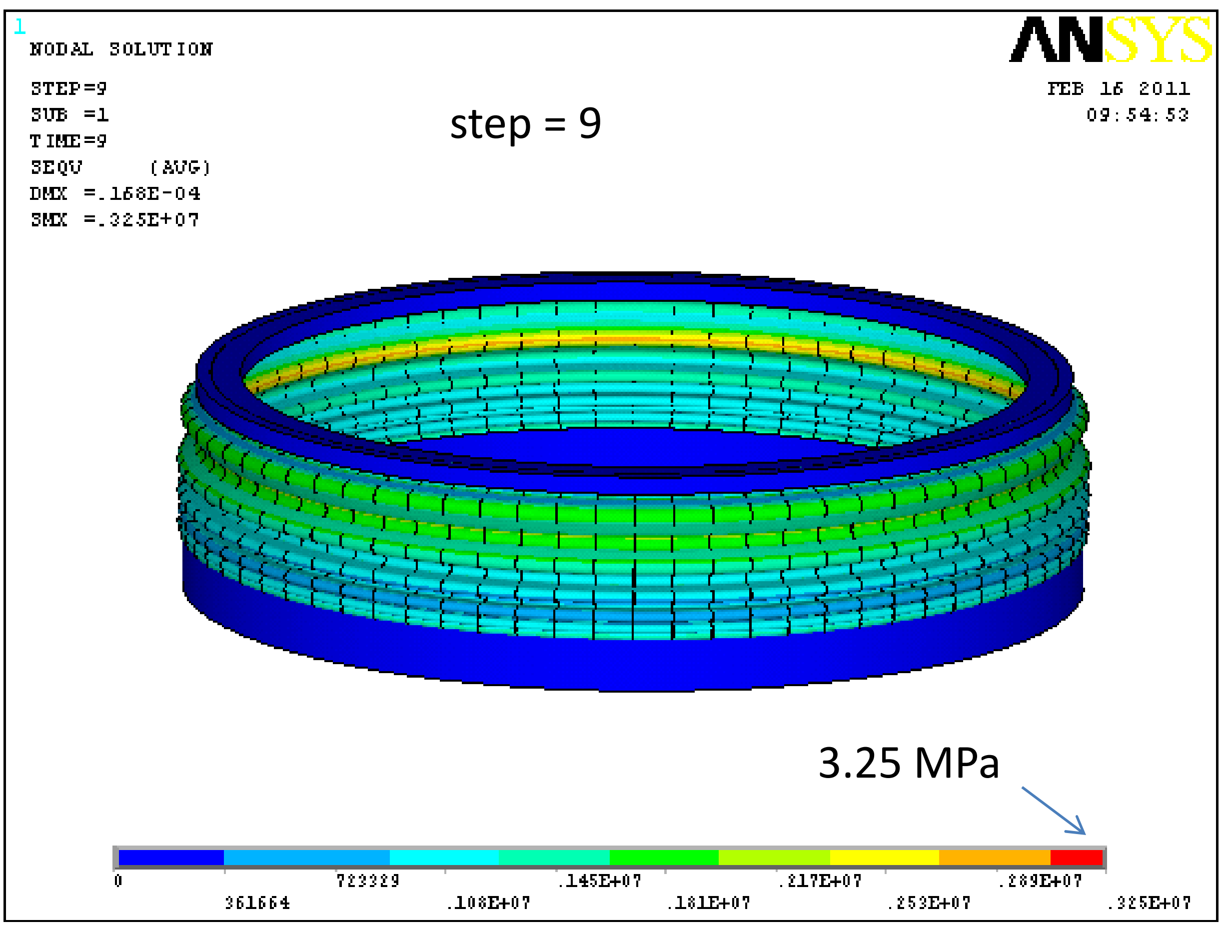
NODAL SOLUTION
STEP=7
SUB =1
TIME=7
USUM (AVG)
RSYS=0
DMX =.631E-05
SMX =.631E-05
ANSYS
FEB 16 2011
09:55:33
step = 7
0
.701E-06
.140E-05
.210E-05
.280E-05
.350E-05
.420E-05
.491E-05
.561E-05
.631E-05


1
NODAL SOLUTION
STEP=7
SUB =1
TIME=7
SEQV (AVG)
DMX =.631E-05
SMX =.284E+07
ANSYS
FEB 16 2011
09:55:59
step = 7
2.84 MPa
0
315037
630074
945110
.126E+07
.158E+07
.189E+07
.221E+07
.252E+07
.284E+07


NODAL SOLUTION
STEP=8
SUB =1
TIME=8
USUM (AVG)
RSYS=0
DMX =.131E-04
SMX =.131E-04
ANSYS
FEB 16 2011
09:53:12
step = 8
0
.145E-05
.290E-05
.436E-05
.581E-05
.726E-05
.871E-05
.102E-04
.116E-04
.131E-04


NODAL SOLUTION
STEP=8
SUB =1
TIME=8
SEQV (AVG)
DMX =.131E-04
SMX =.337E+07
ANSYS
FEB 16 2011
09:53:36
step = 8
Maximum for the total calculation 3.37 MPa
0
374740
749480
.112E+07
.150E+07
.187E+07
.225E+07
.262E+07
.300E+07
.337E+07


1
NODAL SOLUTION
STEP=9
SUB =1
TIME=9
USUM (AVG)
RSYS=0
DMX =.168E-04
SMX =.168E-04
step = 9
ANSYS
FEB 16 2011
09:54:34
0
.186E-05
.373E-05
.559E-05
.745E-05
.932E-05
.112E-04
.130E-04
.149E-04
.168E-04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STEP=9
SUB =1
TIME=9
SEQV (AVG)
DMX =.168E-04
SMX =.325E+07
step = 9
ANSYS
FEB 16 2011
09:54:53
3.25 MPa
0
361664
723329
.108E+07
.145E+07
.181E+07
.217E+07
.253E+07
.289E+07
.325E+07

NSTX CSU BELLOWS FIRST 10 MODE SHAPES

- Total weight = 18.1 lbs
- Bellows in fixed mode.

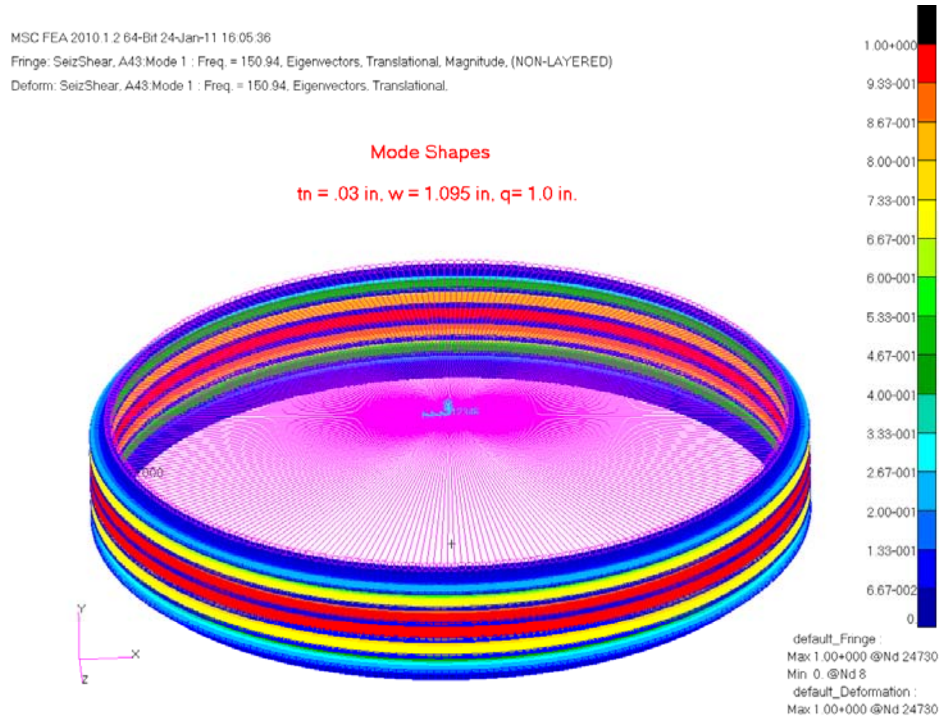
0 SUBCASE 1

R E A L   E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	8.994094E+05	9.483720E+02	1.509381E+02	1.000000E+00	8.994094E+05
2	2	2.629203E+06	1.621482E+03	2.580668E+02	1.000000E+00	2.629203E+06
3	3	2.629204E+06	1.621482E+03	2.580669E+02	1.000000E+00	2.629204E+06
4	4	2.969075E+06	1.723100E+03	2.742400E+02	1.000000E+00	2.969075E+06
5	5	2.969114E+06	1.723112E+03	2.742417E+02	1.000000E+00	2.969114E+06
6	6	3.471941E+06	1.863315E+03	2.965557E+02	1.000000E+00	3.471941E+06
7	7	3.471943E+06	1.863315E+03	2.965558E+02	1.000000E+00	3.471943E+06
8	8	3.523462E+06	1.877089E+03	2.987479E+02	1.000000E+00	3.523462E+06
9	9	4.063636E+06	2.015846E+03	3.208319E+02	1.000000E+00	4.063636E+06
10	10	4.063637E+06	2.015846E+03	3.208319E+02	1.000000E+00	4.063637E+06

1 MSC.NASTRAN JOB CREATED ON 17-NOV-10 AT 11:54:20 JANUARY 24, 2011 MSC.NASTRAN 6/19/08 PAGE

P.Rogoff
1/24/2011


MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:05:36
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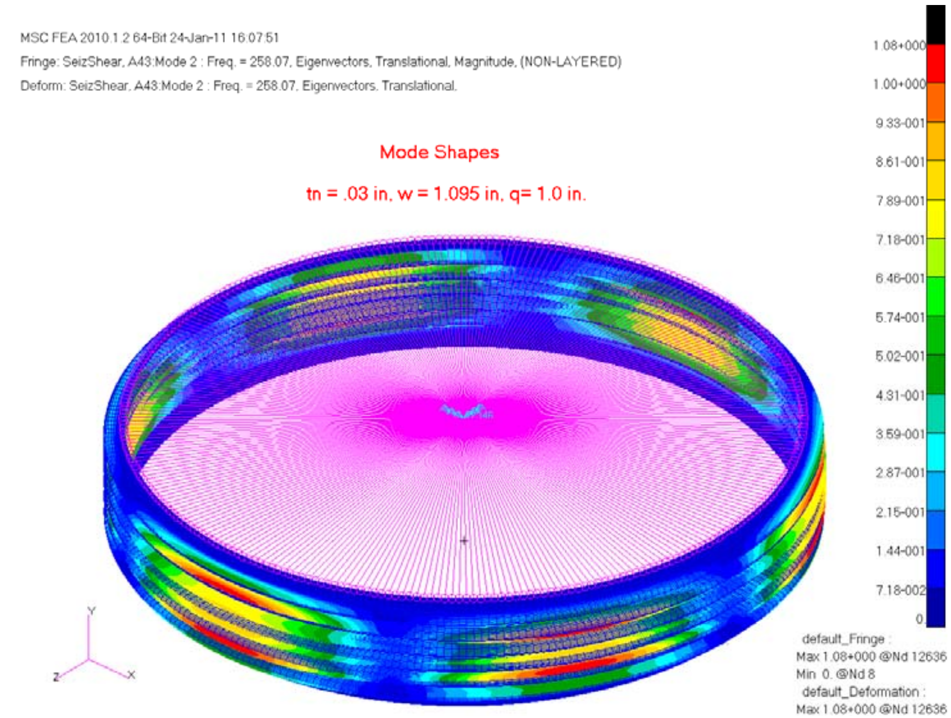
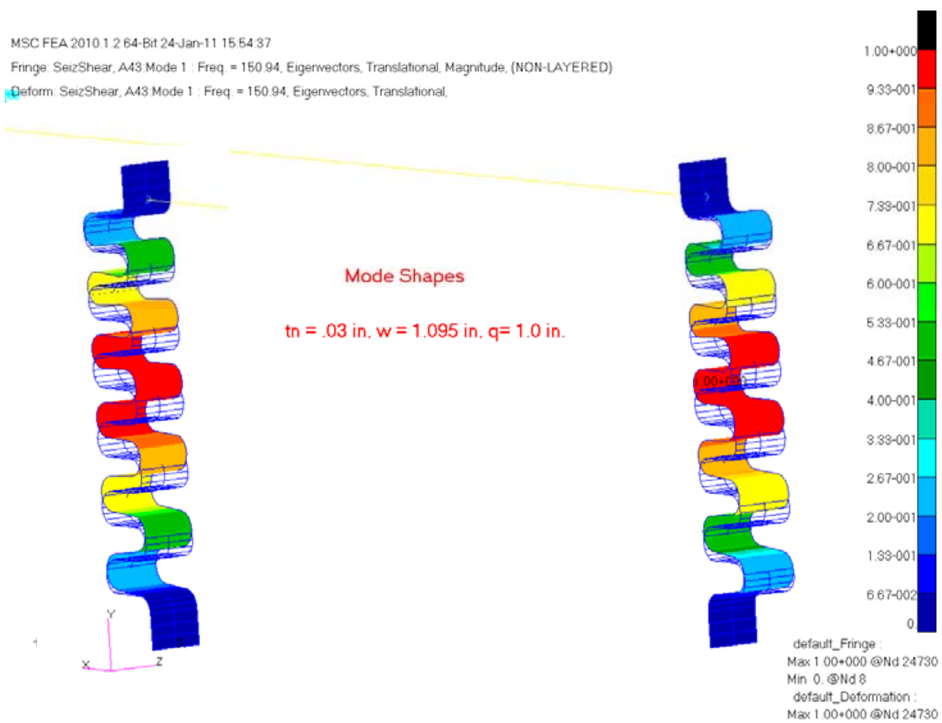
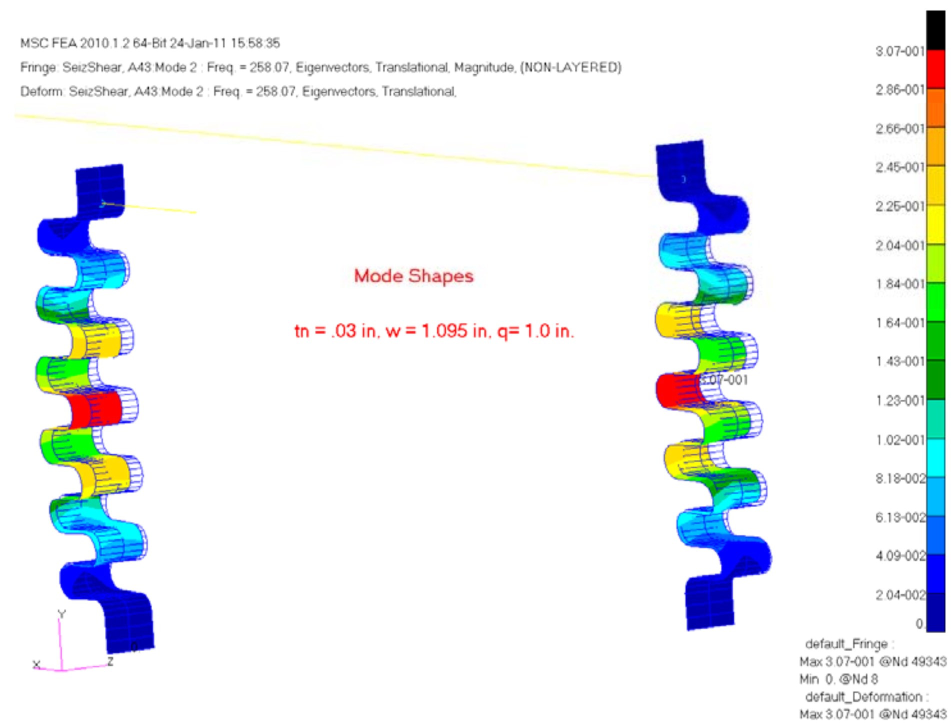
Deform: SeizShear, A43:Mode 1 : Freq. = 150.94, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 24730
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 24730
Y
X
Z


MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:07:51
Fringe: SeizShear, A43:Mode 2 : Freq. = 258.07, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SeizShear, A43:Mode 2 : Freq. = 258.07, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.08+000
1.00+000
9.33-001
8.61-001
7.89-001
7.18-001
6.46-001
5.74-001
5.02-001
4.31-001
3.59-001
2.87-001
2.15-001
1.44-001
7.18-002
0
default_Fringe :
Max 1.08+000 @Nd 12636
Min 0. @Nd 8
default_Deformation :
Max 1.08+000 @Nd 12636
Y
Z
X


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:54:37
Fringe: SeizShear, A43:Mode 1 : Freq. = 150.94, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SeizShear, A43:Mode 1 : Freq. = 150.94, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 24730
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 24730
Y
X
Z


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:58:35
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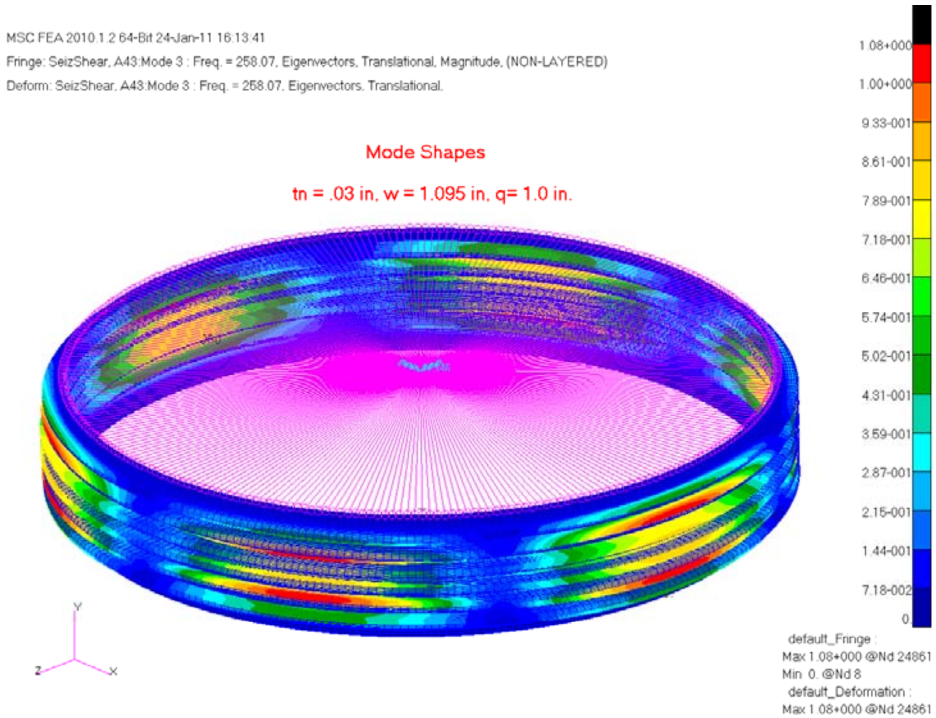
Deform: SeizShear, A43:Mode 2 : Freq. = 258.07, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
3.07-001
2.86-001
2.66-001
2.45-001
2.25-001
2.04-001
1.84-001
1.64-001
1.43-001
1.23-001
1.02-001
8.18-002
6.13-002
4.09-002
2.04-002
0
default_Fringe :
Max 3.07-001 @Nd 49343
Min 0. @Nd 8
default_Deformation :
Max 3.07-001 @Nd 49343
Y
X
Z


MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:13:41
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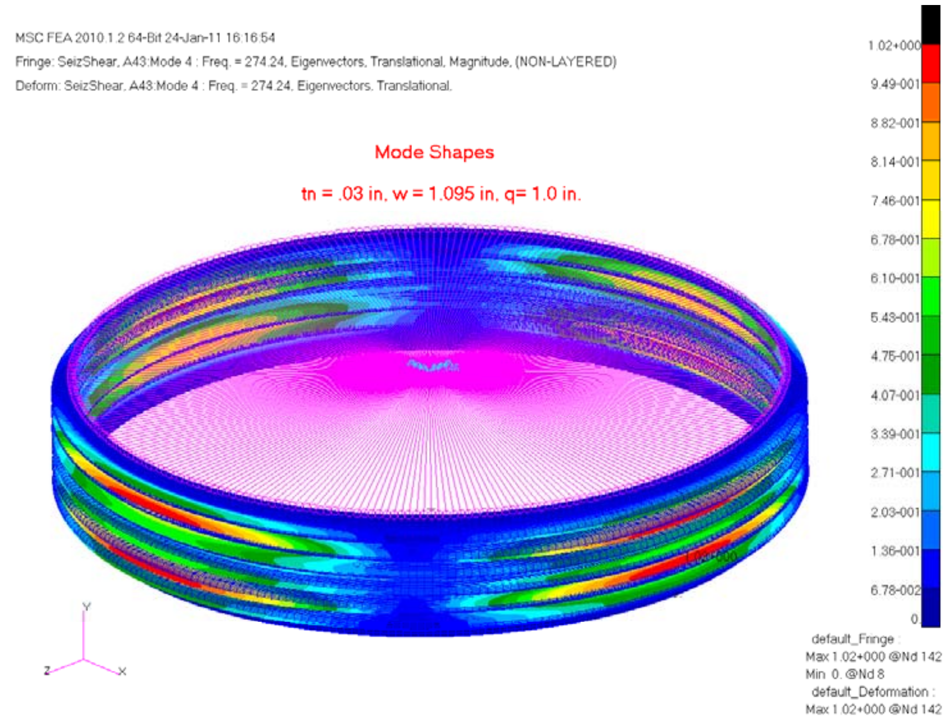
Deform: SeizShear, A43:Mode 3 : Freq. = 258.07, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.08+000
1.00+000
9.33-001
8.61-001
7.89-001
7.18-001
6.46-001
5.74-001
5.02-001
4.31-001
3.59-001
2.87-001
2.15-001
1.44-001
7.18-002
0
default_Fringe :
Max 1.08+000 @Nd 24861
Min 0. @Nd 8
default_Deformation :
Max 1.08+000 @Nd 24861
Y
Z
X


MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:16:54
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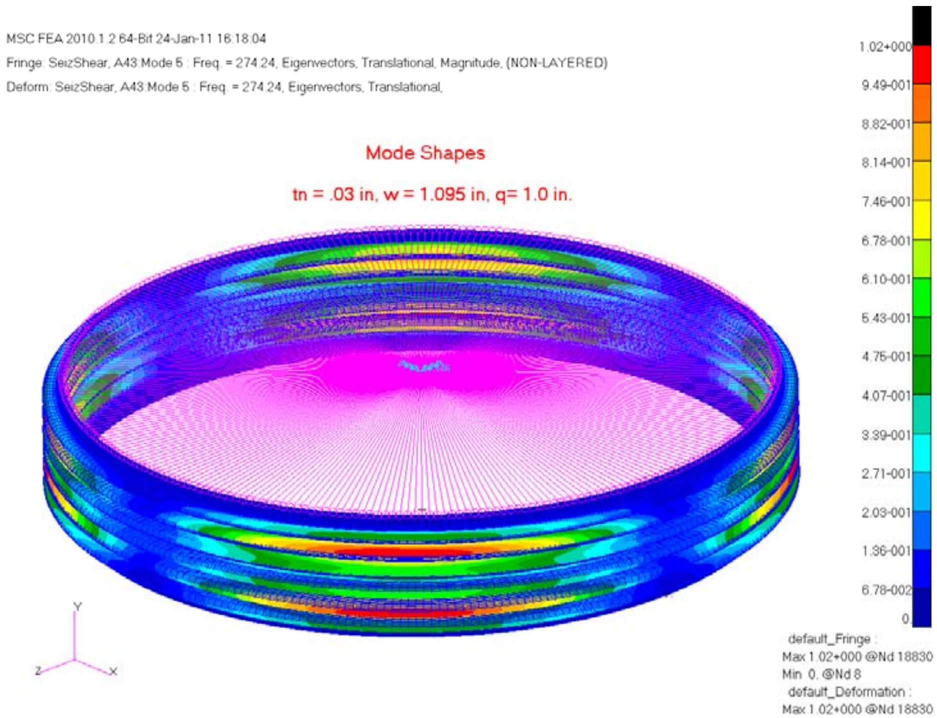
Deform: SeizShear, A43:Mode 4 : Freq. = 274.24, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.02+000
9.49-001
8.82-001
8.14-001
7.46-001
6.78-001
6.10-001
5.43-001
4.75-001
4.07-001
3.39-001
2.71-001
2.03-001
1.36-001
6.78-002
0
default_Fringe :
Max 1.02+000 @Nd 142
Min 0. @Nd 8
default_Deformation :
Max 1.02+000 @Nd 142
Y
Z
X


MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:18:04
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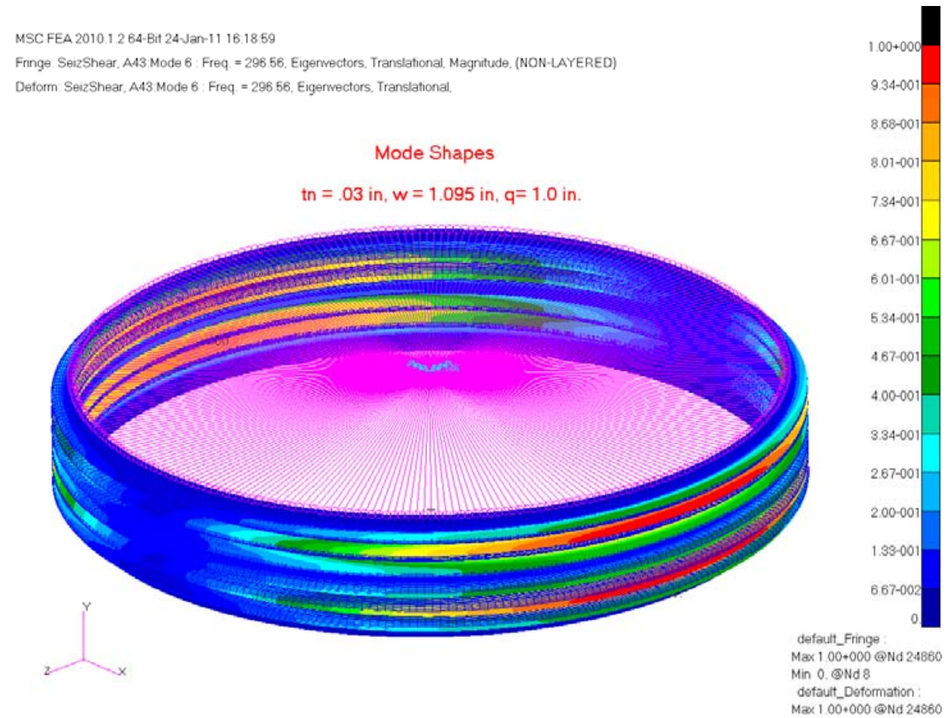
Deform: SeizShear, A43:Mode 5 : Freq. = 274.24, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.02+000
9.49-001
8.82-001
8.14-001
7.46-001
6.78-001
6.10-001
5.43-001
4.75-001
4.07-001
3.39-001
2.71-001
2.03-001
1.36-001
6.78-002
0
default_Fringe :
Max 1.02+000 @Nd 18830
Min 0. @Nd 8
default_Deformation :
Max 1.02+000 @Nd 18830
Y
Z
X


MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:18:59
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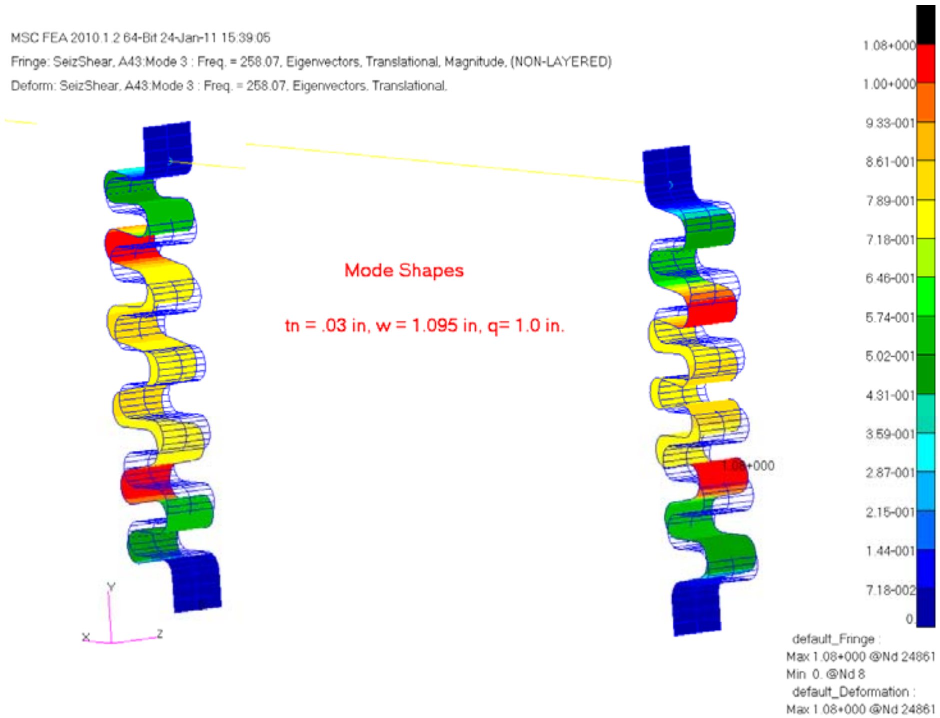
Deform: SeizShear, A43:Mode 6 : Freq. = 296.56, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.34-001
8.68-001
8.01-001
7.34-001
6.67-001
6.01-001
5.34-001
4.67-001
4.00-001
3.34-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 24860
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 24860
Y
Z
X


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:39:05
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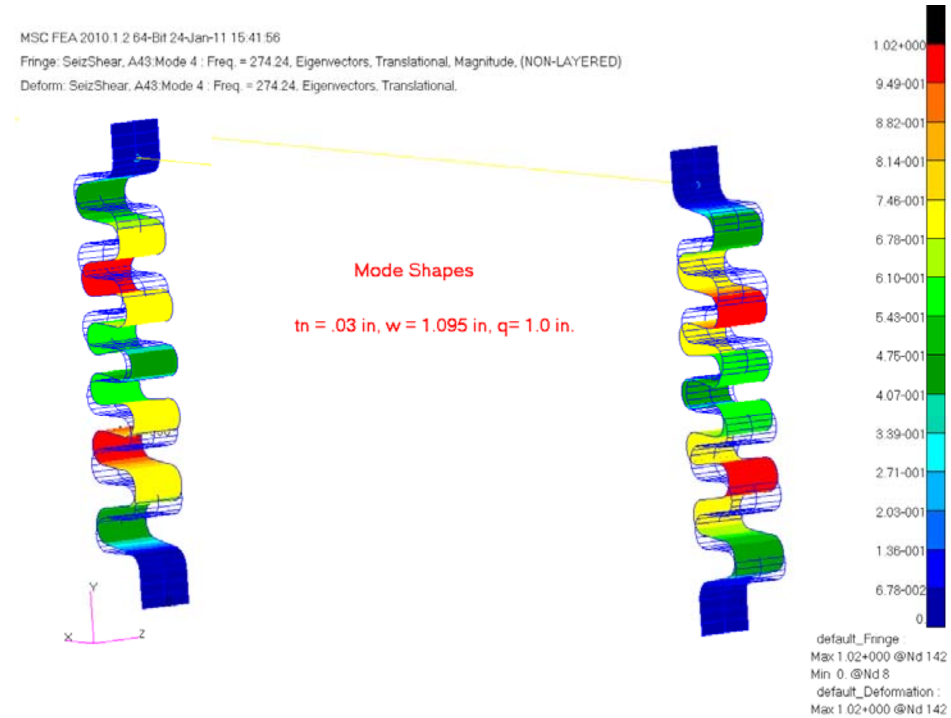
Deform: SeizShear, A43:Mode 3 : Freq. = 258.07, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.08+000
1.00+000
9.33-001
8.61-001
7.89-001
7.18-001
6.46-001
5.74-001
5.02-001
4.31-001
3.59-001
2.87-001
2.15-001
1.44-001
7.18-002
0
default_Fringe :
Max 1.08+000 @Nd 24861
Min 0. @Nd 8
default_Deformation :
Max 1.08+000 @Nd 24861


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:41:56
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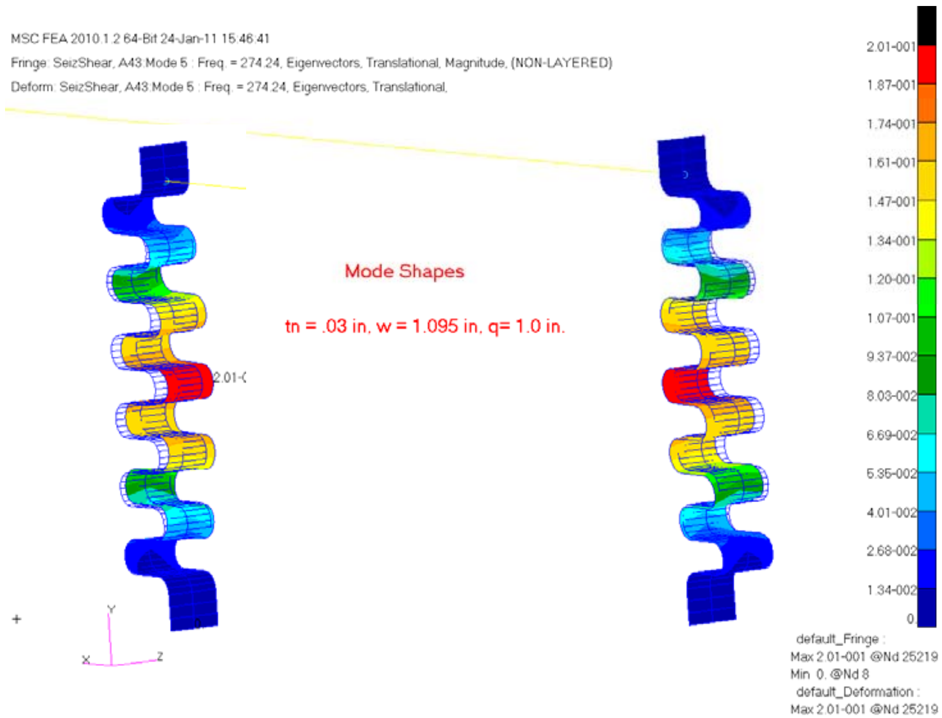
Deform: SeizShear, A43:Mode 4 : Freq. = 274.24, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.02+000
9.49-001
8.82-001
8.14-001
7.46-001
6.78-001
6.10-001
5.43-001
4.75-001
4.07-001
3.39-001
2.71-001
2.03-001
1.36-001
6.78-002
0
default_Fringe :
Max 1.02+000 @Nd 142
Min 0. @Nd 8
default_Deformation :
Max 1.02+000 @Nd 142


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:46:41
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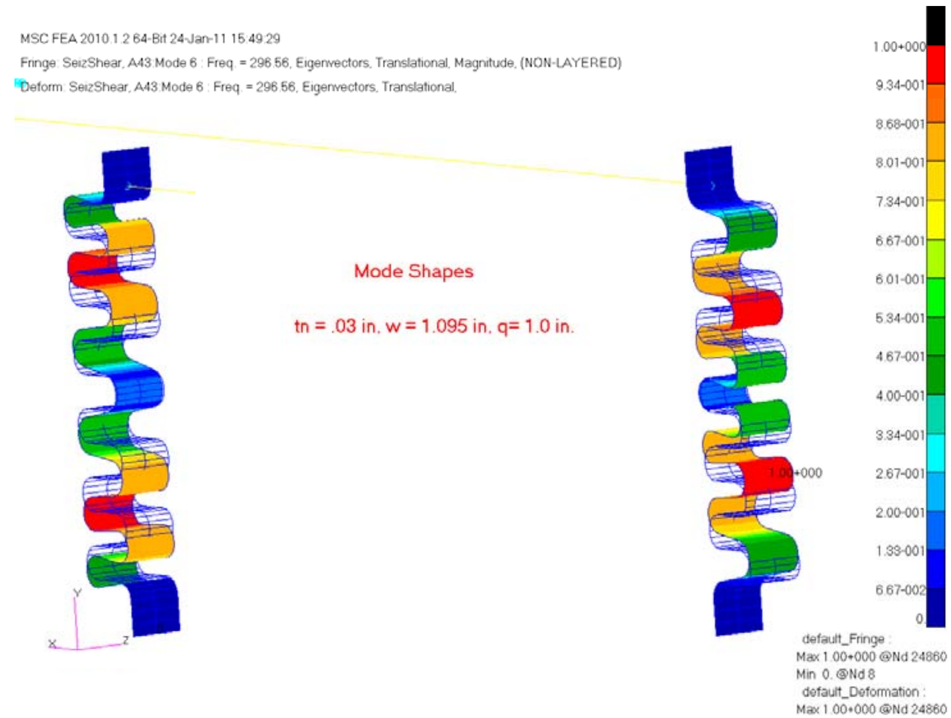
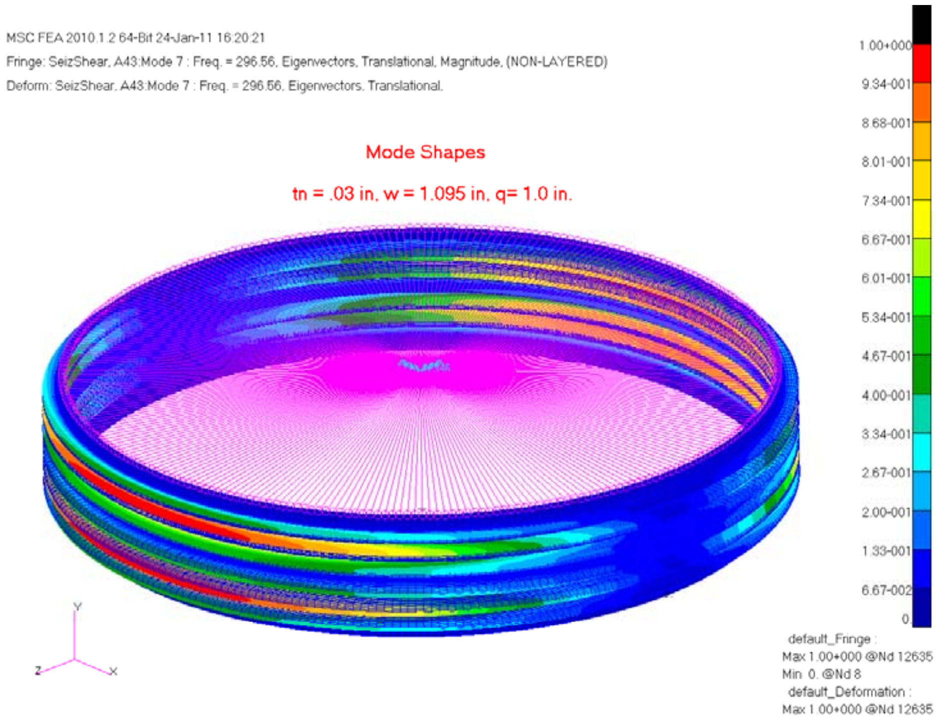
Deform: SeizShear, A43:Mode 5 : Freq. = 274.24, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
2.01-001
1.87-001
1.74-001
1.61-001
1.47-001
1.34-001
1.20-001
1.07-001
9.37-002
8.03-002
6.69-002
5.35-002
4.01-002
2.68-002
1.34-002
0
default_Fringe :
Max 2.01-001 @Nd 25219
Min 0. @Nd 8
default_Deformation :
Max 2.01-001 @Nd 25219


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:49:29
Fringe: SeizShear, A43:Mode 6 : Freq. = 296.56, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SeizShear, A43:Mode 6 : Freq. = 296.56, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.34-001
8.68-001
8.01-001
7.34-001
6.67-001
6.01-001
5.34-001
4.67-001
4.00-001
3.34-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 24860
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 24860



MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:20:21
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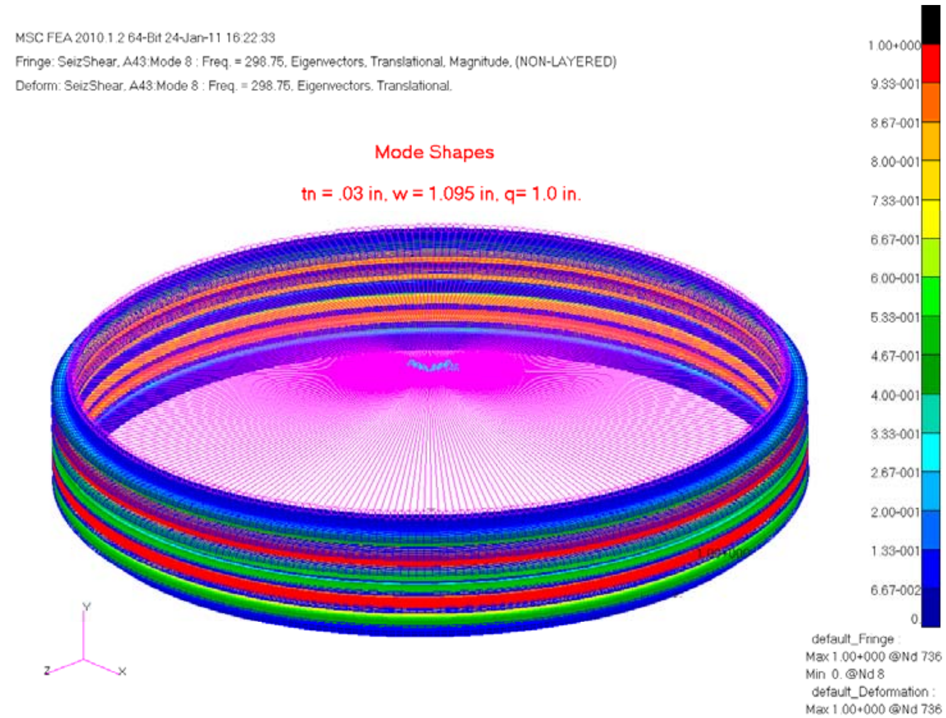
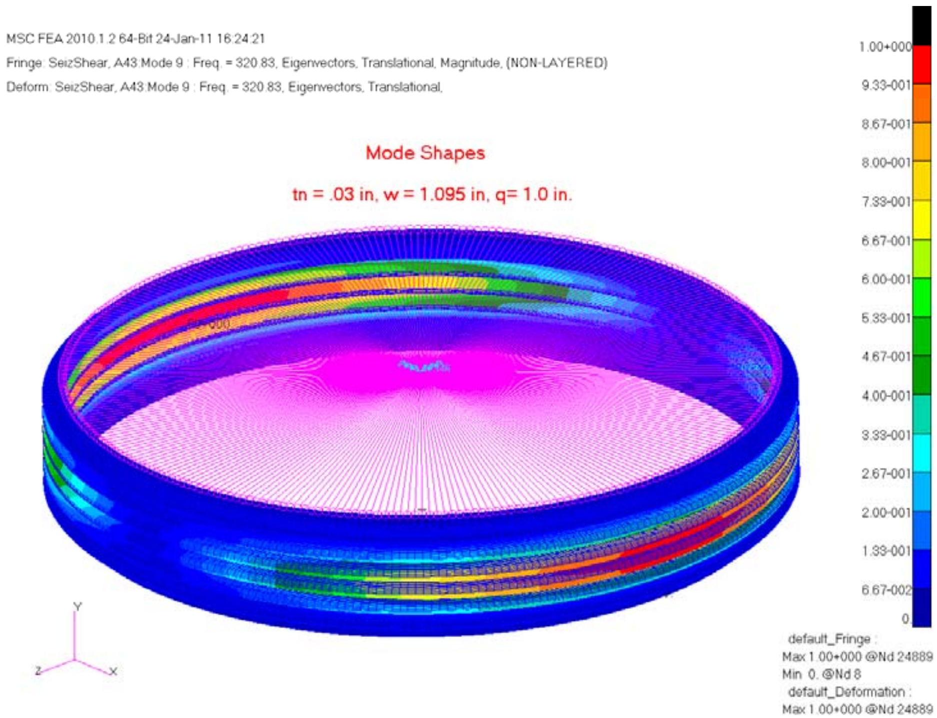
Deform: SeizShear, A43:Mode 7 : Freq. = 296.56, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.34-001
8.68-001
8.01-001
7.34-001
6.67-001
6.01-001
5.34-001
4.67-001
4.00-001
3.34-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 12635
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 12635
Y
Z
X



MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:22:33
Fringe: SeizShear, A43:Mode 8 : Freq. = 298.75, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SeizShear, A43:Mode 8 : Freq. = 298.75, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 736
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 736
Y
Z
X



MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:24:21
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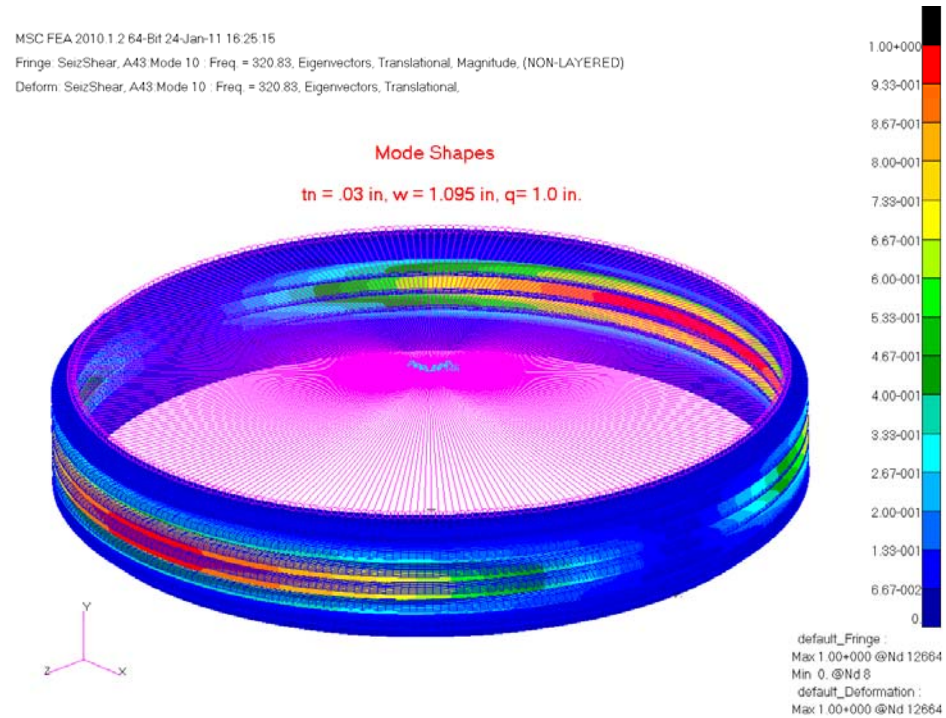
Deform: SeizShear, A43:Mode 9 : Freq. = 320.83, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 24889
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 24889
Y
Z
X



MSC FEA 2010.1.2 64-Bit 24-Jan-11 16:25:15
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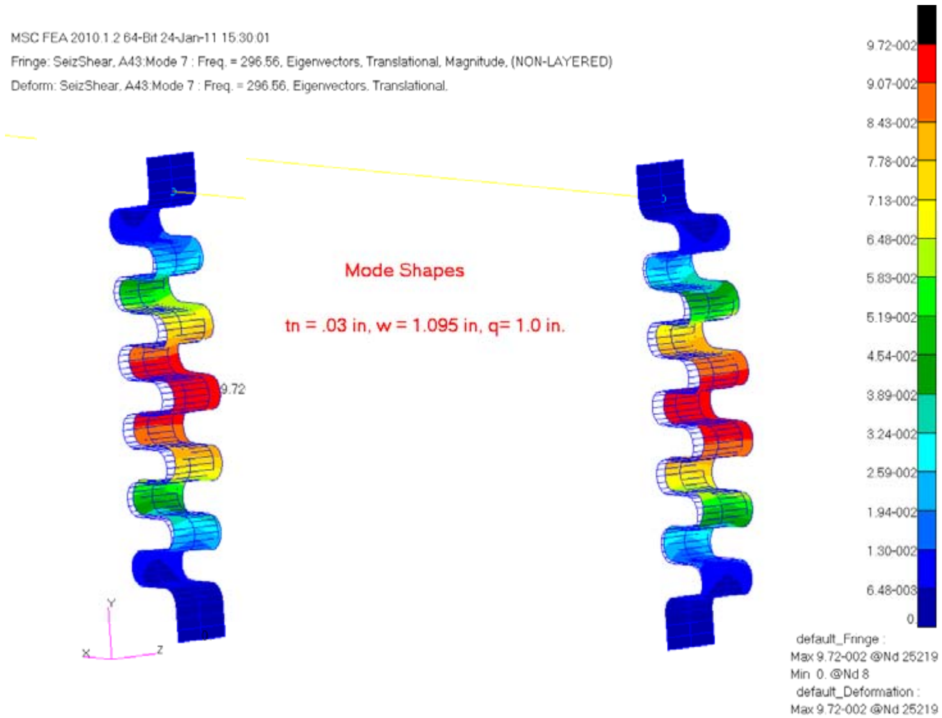
Deform: SeizShear, A43:Mode 10 : Freq. = 320.83, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 12664
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 12664
Y
Z
X


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:30:01
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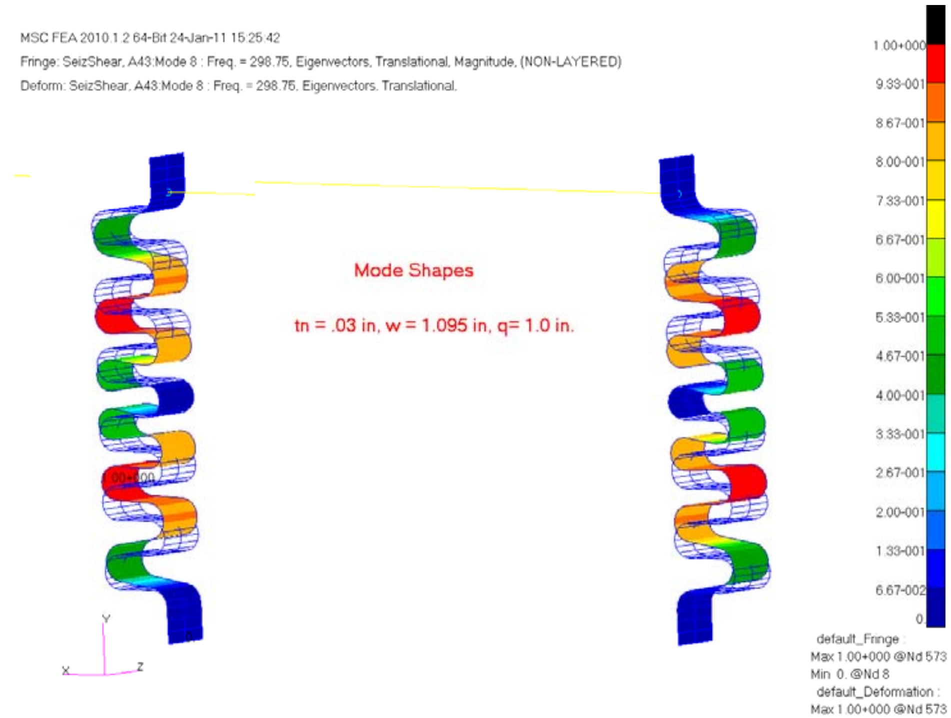
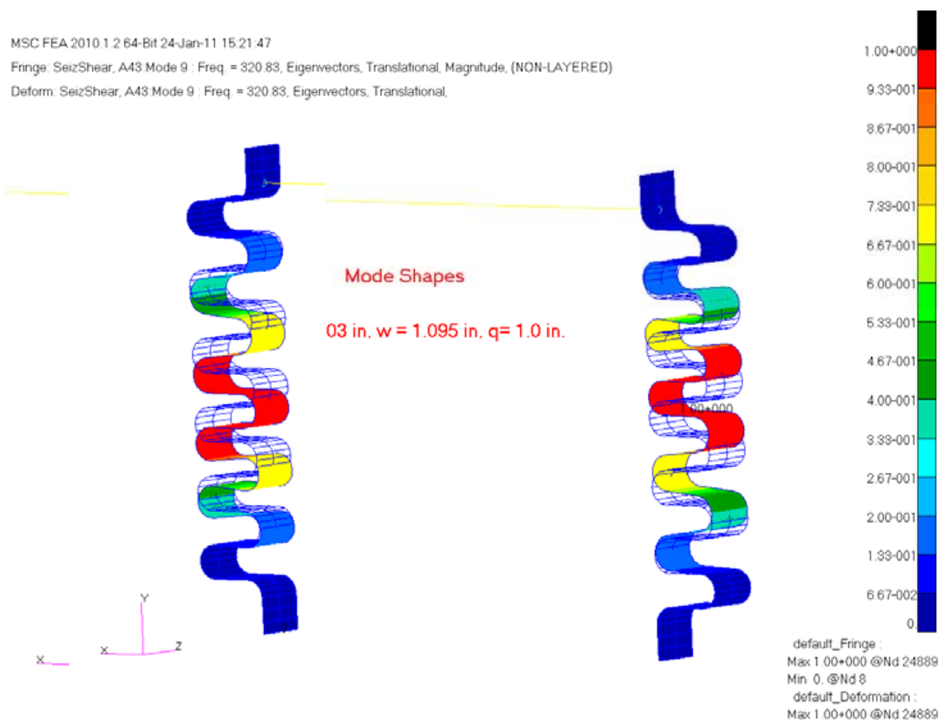
Deform: SeizShear, A43:Mode 7 : Freq. = 296.56, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
9.72
9.72-002
9.07-002
8.43-002
7.78-002
7.13-002
6.48-002
5.83-002
5.19-002
4.54-002
3.89-002
3.24-002
2.59-002
1.94-002
1.30-002
6.48-003
0
default_Fringe :
Max 9.72-002 @Nd 25219
Min 0. @Nd 8
default_Deformation :
Max 9.72-002 @Nd 25219


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:25:42
Fringe: SeizShear, A43:Mode 8 : Freq. = 298.75, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SeizShear, A43:Mode 8 : Freq. = 298.75, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 573
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 573


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:21:47
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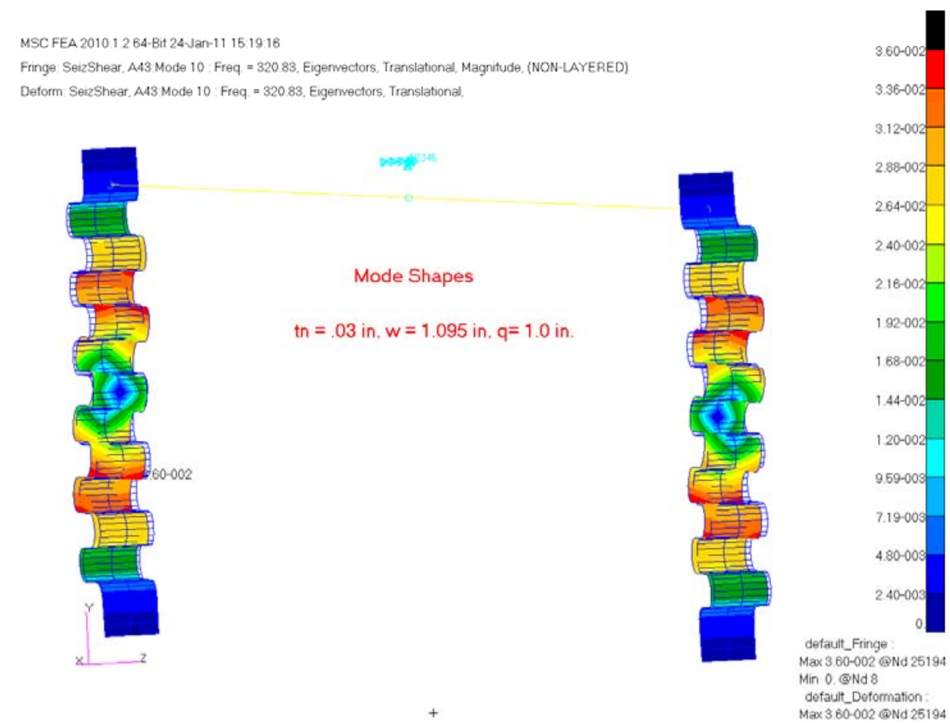
Deform: SeizShear, A43:Mode 9 : Freq. = 320.83, Eigenvectors, Translational,
Mode Shapes
03 in, w = 1.095 in, q= 1.0 in.
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 24889
Min 0. @Nd 8
default_Deformation :
Max 1.00+000 @Nd 24889


MSC FEA 2010.1.2 64-Bit 24-Jan-11 15:19:16
Fringe: SeizShear, A43:Mode 10 : Freq. = 320.83, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SeizShear, A43:Mode 10 : Freq. = 320.83, Eigenvectors, Translational,
Mode Shapes
tn = .03 in, w = 1.095 in, q= 1.0 in.
3.60-002
3.36-002
3.12-002
2.88-002
2.64-002
2.40-002
2.16-002
1.92-002
1.68-002
1.44-002
1.20-002
9.59-003
7.19-003
4.80-003
2.40-003
0
default_Fringe :
Max 3.60-002 @Nd 25194
Min 0. @Nd 8
default_Deformation :
Max 3.60-002 @Nd 25194

STANDARD ROUND EXPANSION JOINT SPECIFICATION SHEET

Customer:			Date:	Page:
Project:			Prepared By:	
Item or Tag Number:				
Quantity:				
Size:				
Style or Type (single, universal, hinged, gimbal, etc.)				
End Connections		Thickness/Flange Rating		
		Material		
*Pressure		Design		
		Operating		
		Test		
*Temperature		Design		
		Operating		
		Installation		
Media		Media		
		Flow Velocity		
		Flow Direction		
Movements and Life Cycle	Installation	Axial Extension		
		Axial Compression		
		Lateral		
		Angular		
		Number of Cycles		
	Design	Axial Extension		
		Axial Compression		
		Lateral		
		Angular		
		Number of Cycles		
	Operation	Axial Extension		
		Axial Compression		
		Lateral		
		Angular		
		Number of Cycles		
Materials		Bellows		
		Liner		
		Cover		
Dimensions		Overall Length		
		Maximum O.D.		
		Minimum I.D.		
Spring Rates		Maximum Axial Spring Rate		
		Maximum Lateral Spring Rate		
		Maximum Angular Spring Rate		
Quality Assurance Required Code		Bellows Long. Seam Weld		
		Bellows Attachments Weld		
		Piping		
Applicable Codes and Standards B31.1, B31.3, Section 8 Division 1				