

APPENDIX E

Finite Element Analysis Results

Appendix E: Finite Element Analysis

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Finite Element Analysis (FEA)

Considered WABTEC/SAB-WABCO Brake Disc

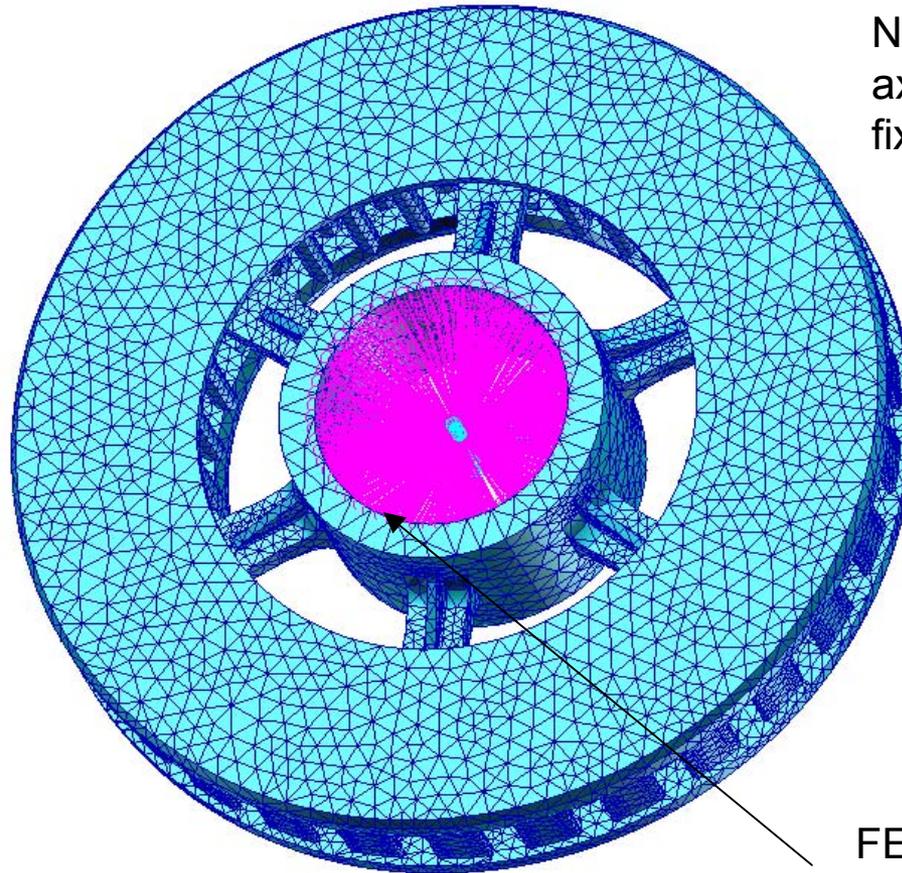
- Material Properties (Steel)
 - Modulus of Elasticity $E = 27.56 \times 10^6$ psi
 - Poisson's Ratio = 0.26
 - Density $\rho = 0.264$ lb/in³
- Finite Element Meshing
 - TET10 Midside Node Elements Used
 - 191700 Nodes In Model
- Considered Single, Unmounted Discs Only
 - No Compressive Stresses From Mounting Process Or Long-Term Use Accounted For

FEA

- Stress Analysis
 - Fixed Hub Mode
 - Free Mode
 - Heat Of Friction Plate $\sim \mu\text{strain/degree}$
 - Rotation Rate Strain
- Fundamental (Natural) Frequencies
 - Fixed Hub Results: First Fundamental Frequency - 206 Hz
 - Fixed Hub Results: Second Fundamental Frequency - 267 Hz
 - Free Hub Results: First Fundamental Frequency - 585 Hz

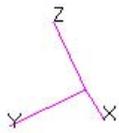
Natural Frequency and Spoke Strain Due to Mechanical Effects

FE Solid Model



Nodes on inner surface of axle hole constrained for fixed frequency analysis.

FE constraints to axle center.



Natural Frequency Analysis: ACELA Brake Rotor, Fixed Hub

Freq. (Hz)	Mode Shape
206	Disk rotates out-of-plane about hub
269	Disk translates out-of-plane about hub
645	Disk bends into saddle shape
799	Disk translates in-plane about hub

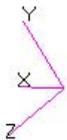
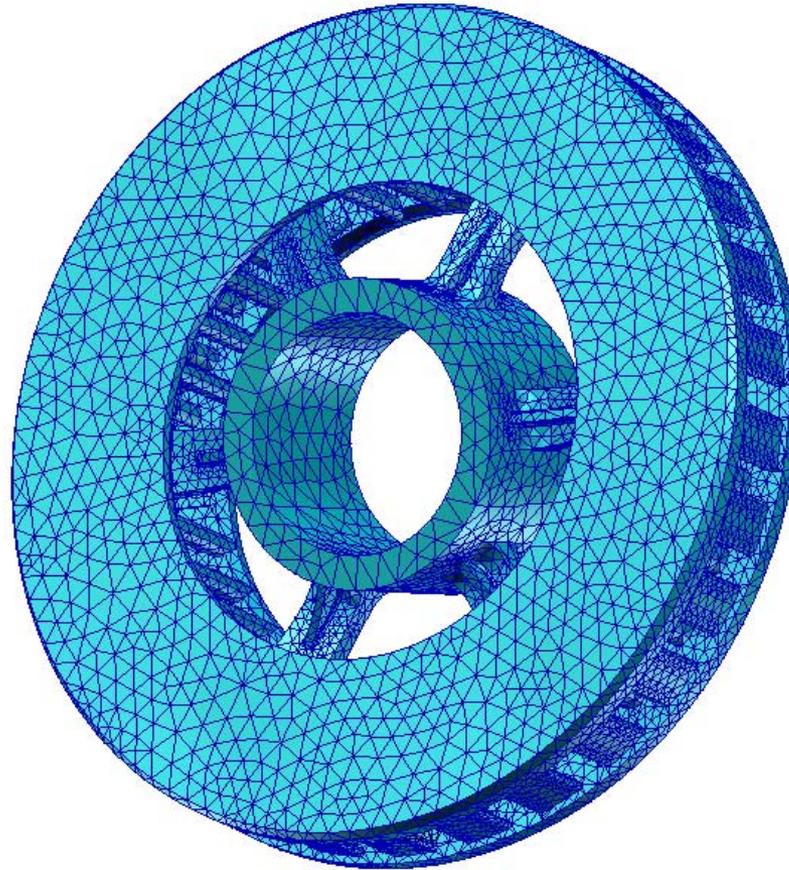
Note: For each of the above frequencies there were actually two modes at very slightly different frequencies, of identical shape but rotated with respect to each other.

FEA Modes of Vibration

1st Mode with Fixed Hub – 206 Hz

MSC.Patran 2005 09-May-05 10:16:53

Deform: fixed_model, A2:Mode 1 : Freq. = 206., Eigenvectors, Translational,

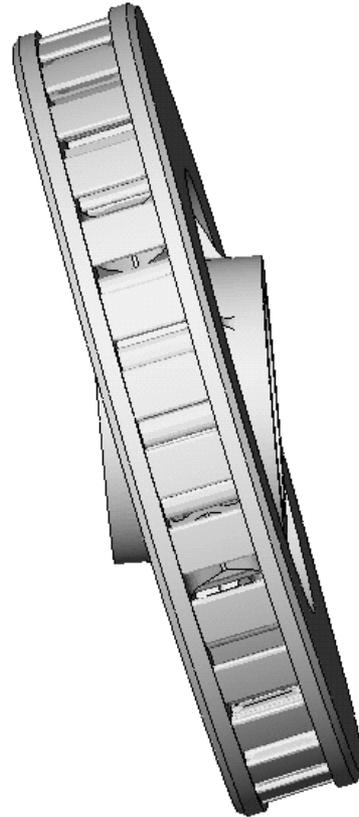


default_Deformation :
Max 2.26+000 @Nd 142861
Frame: 1
Scale = 1.00+000

FEA Modes of Vibration

1st Mode with Fixed Hub – 206 Hz

ACELA Brake Rotor ver 6 FULL - new spoke - FEA-test1 :: Frequency
Mode Shape : 1 Value = 206.05 Hz Deformation Scale 1 : 0.434447



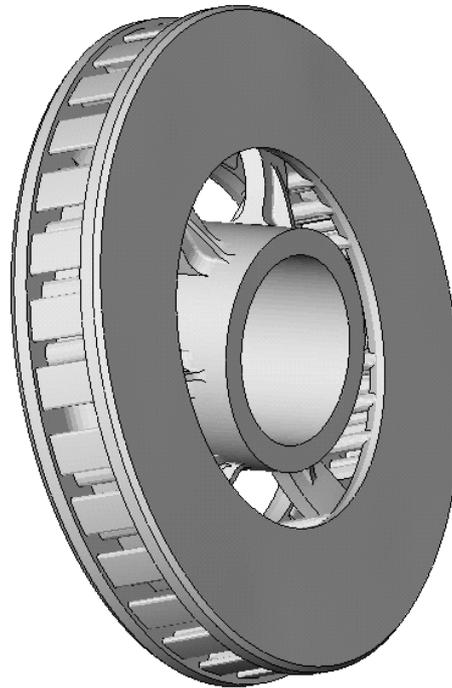
Out-of-
Plane
Bending
(BOP)
Mode

7

FEA Modes of Vibration

1st Mode with Fixed Hub – 206 Hz

ACELA Brake Rotor ver 6 FULL - new spoke - FEA-test1 :: Frequency
Mode Shape : 1 Value = 206.05 Hz Deformation Scale 1 : 0.434447

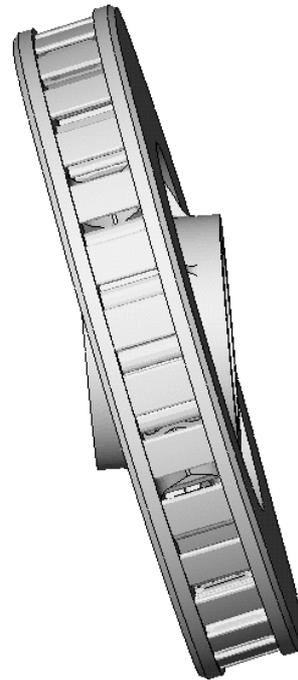


Out-of-
Plane
Bending
(BOP)
Mode

FEA Modes of Vibration

1st Mode with Fixed Hub – 206 Hz

ACELA Brake Rotor ver 6 FULL - new spoke - FEA-test1 :: Frequency
Mode Shape : 1 Value = 206.05 Hz Deformation Scale 1 : 0.434447



Out-of-
Plane
Bending
(BOP)
Mode



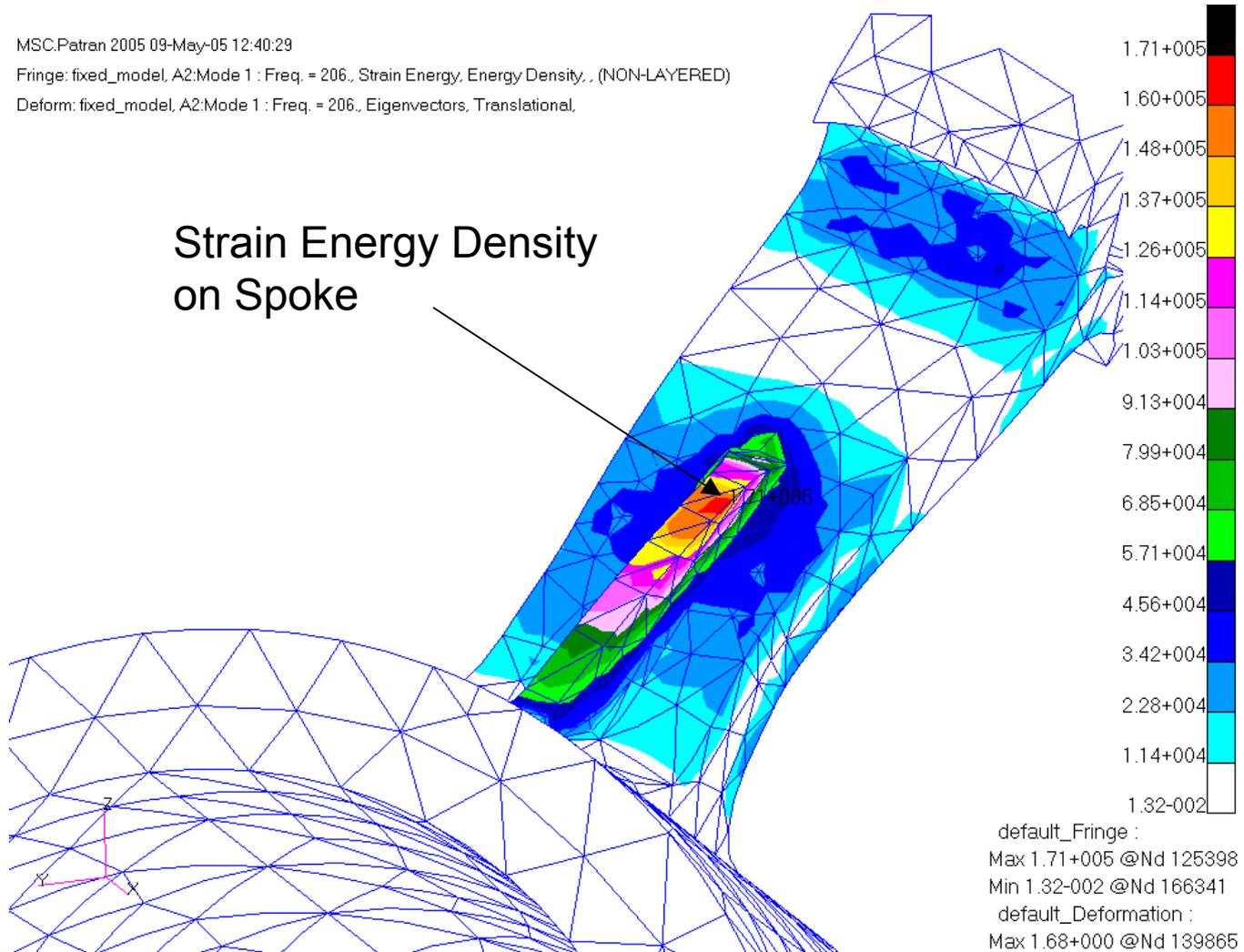
FE Results – Fixed Hub Analysis, 1st Mode: 206 Hz

MSC.Patran 2005 09-May-05 12:40:29

Fringe: fixed_model, A2:Mode 1 : Freq. = 206., Strain Energy, Energy Density, (NON-LAYERED)

Deform: fixed_model, A2:Mode 1 : Freq. = 206., Eigenvectors, Translational.

Strain Energy Density
on Spoke

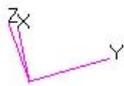
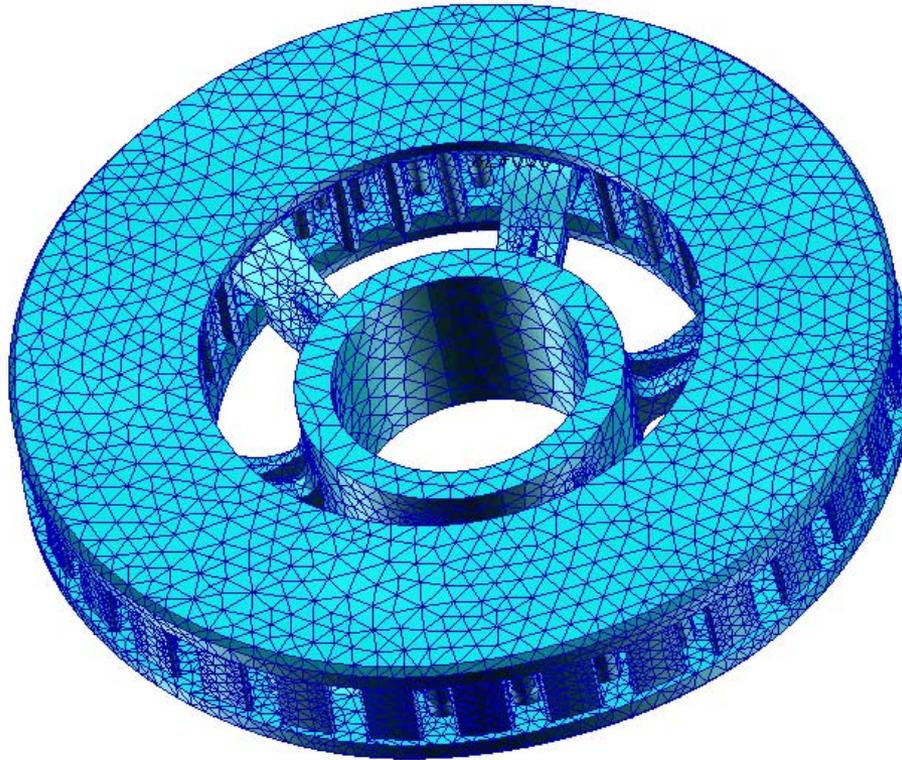


FEA Modes of Vibration

2nd Mode with Fixed Hub – 269 Hz

MSC.Patran 2005 15-Jun-05 10:33:43

Deform: fixed_model, A1:Mode 4 : Freq. = 268.69, Eigenvectors, Translational.



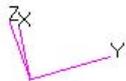
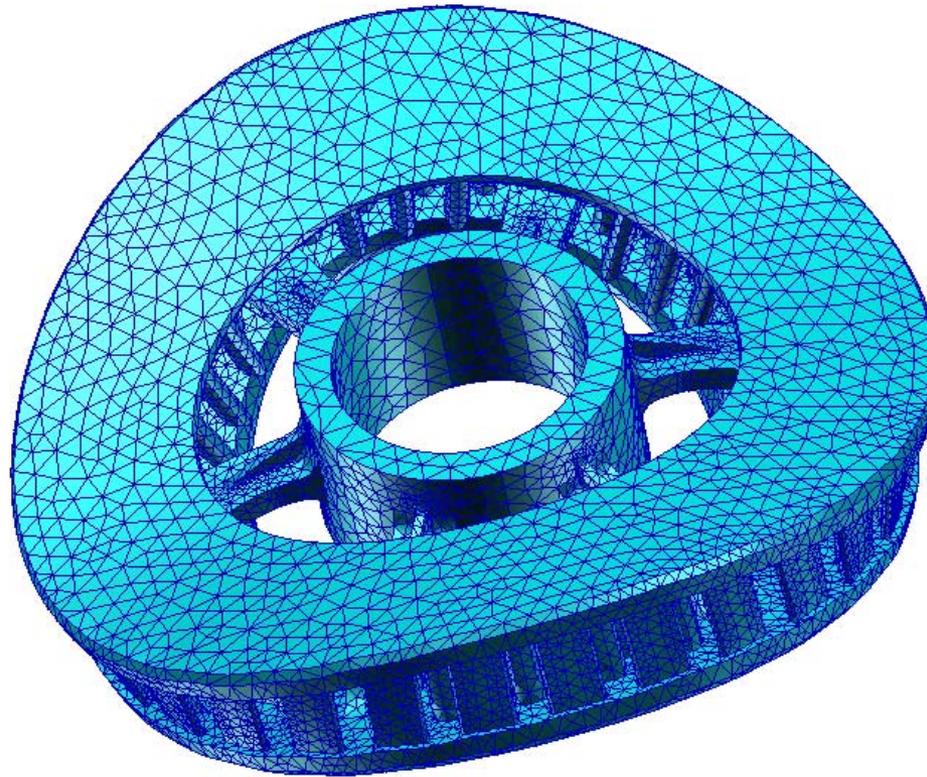
default_Deformation :
Max 1.32+000 @Nd 150305
Frame: 1
Scale = 1.00+000

FEA Modes of Vibration

3rd Mode with Fixed Hub – 645 Hz

MSC.Patran 2005 15-Jun-05 10:38:21

Deform: fixed_model, A1:Mode 6 : Freq. = 644.92, Eigenvectors, Translational,



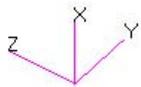
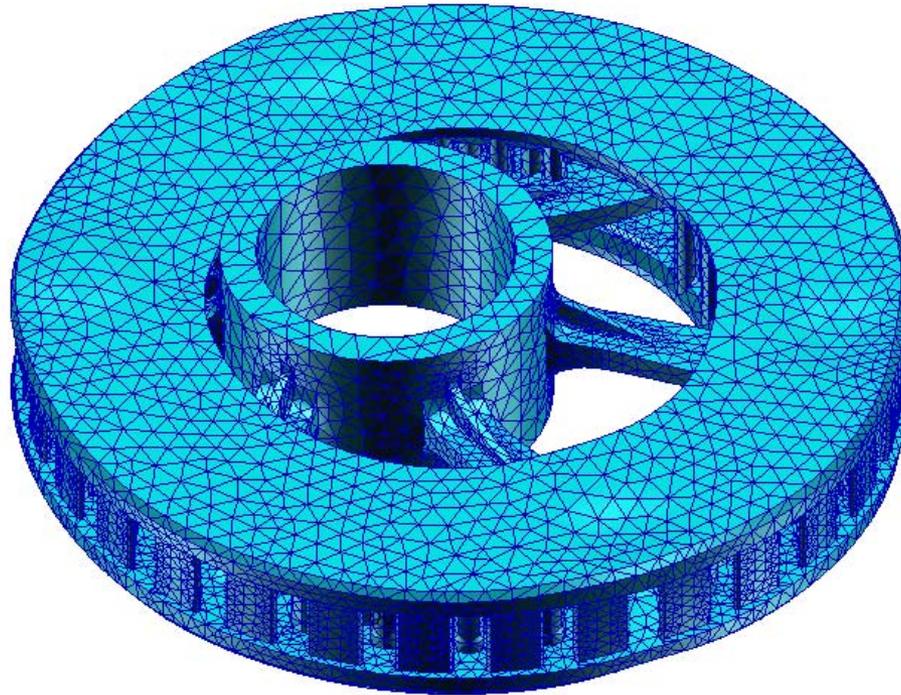
default_Deformation :
Max 2.45+000 @Nd 152820
Frame: 1
Scale = 1.00+000

FEA Modes of Vibration

4th Mode with Fixed Hub – 799 Hz

MSC.Patran 2005 15-Jun-05 10:40:41

Deform: fixed_model, A1:Mode 8 : Freq. = 799.36, Eigenvectors, Translational.



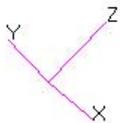
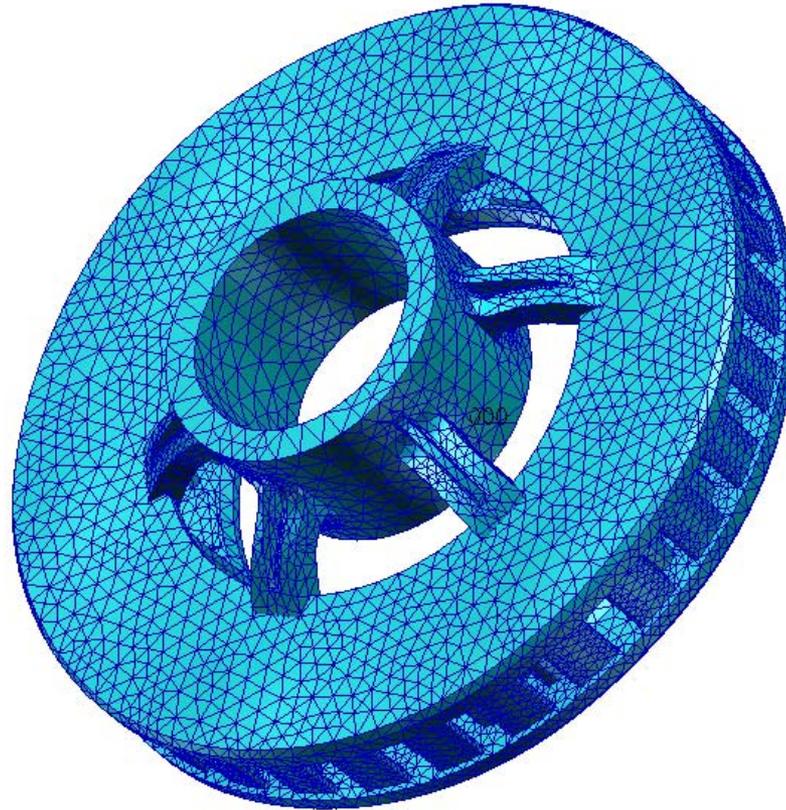
default_Deformation :
Max 1.38+000 @Nd 10595
Frame: 1
Scale = 1.00+000

FEA Modes of Vibration

1st Mode with Free Hub - 585 Hz

MSC.Patran 2005 09-May-05 10:20:45

Deform: free_model, A1:Mode 7 : Freq. = 585.78, Eigenvectors, Translational,



default_Deformation :
Max 2.34+000 @Nd 156964
Frame: 1
Scale = 1.00+000

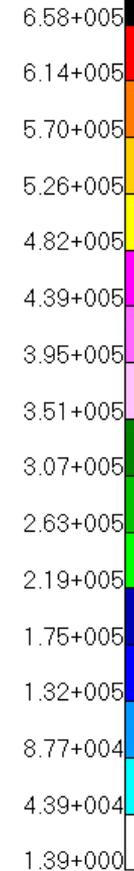
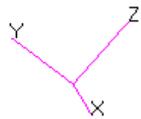
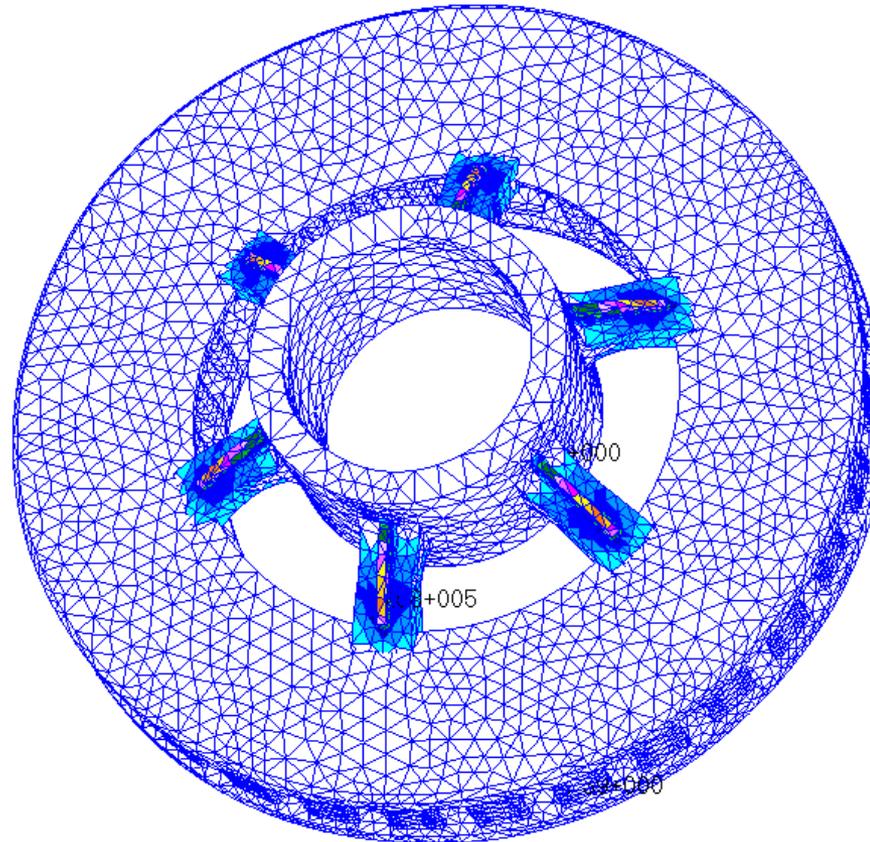
FEA Modes of Vibration

1st Mode with Free Hub - 585 Hz

MSC.Patran 2005 09-May-05 10:20:45

Fringe: free_model, A1:Mode 7 : Freq. = 585.78, Strain Energy, Energy Density, . (NON-LAYERED)

Deform: free_model, A1:Mode 7 : Freq. = 585.78, Eigenvectors, Translational,



default_Fringe :
Max 6.58+005 @Nd 161732
Min 1.39+000 @Nd 148610
default_Deformation :
Max 2.34+000 @Nd 156964
Frame: 12
Scale = 8.66-001

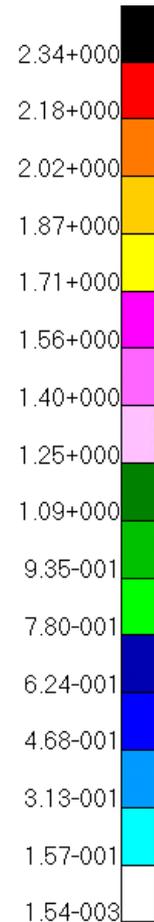
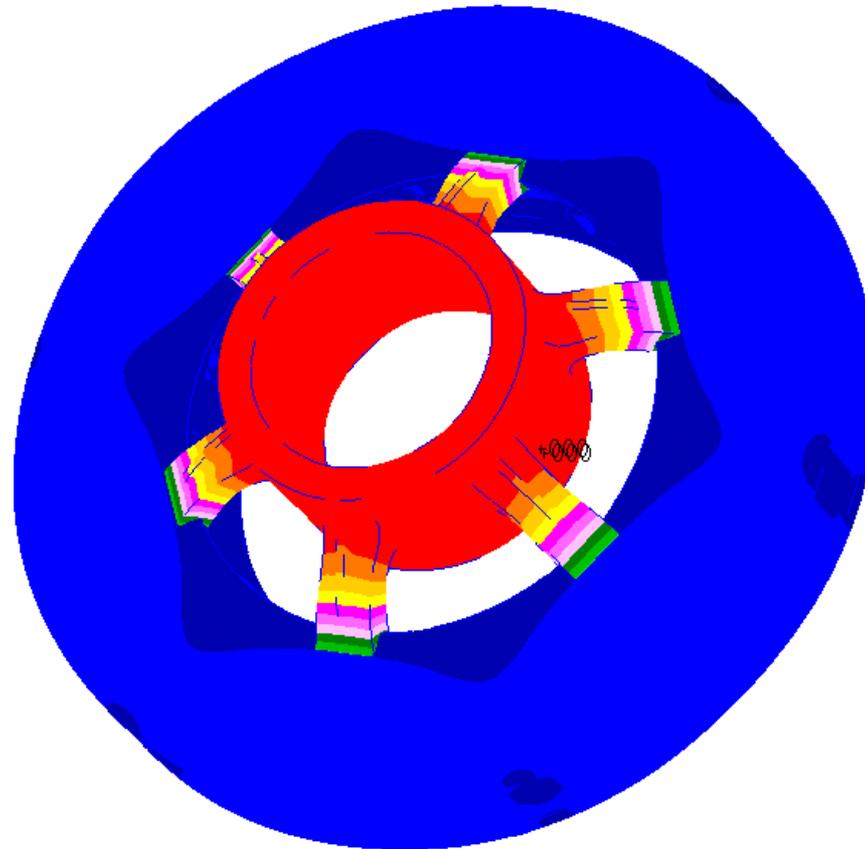
FEA Modes of Vibration

1st Mode with Free Hub - 585 Hz

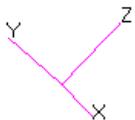
MSC.Patran 2005 09-May-05 10:20:45

Fringe: free_model, A1:Mode 7 : Freq. = 585.78, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Deform: free_model, A1:Mode 7 : Freq. = 585.78, Eigenvectors, Translational,



default_Fringe :
Max 2.34+000 @Nd 156964
Min 1.54-003 @Nd 34323
default_Deformation :
Max 2.34+000 @Nd 156964
Frame: 12
Scale = 8.66-001



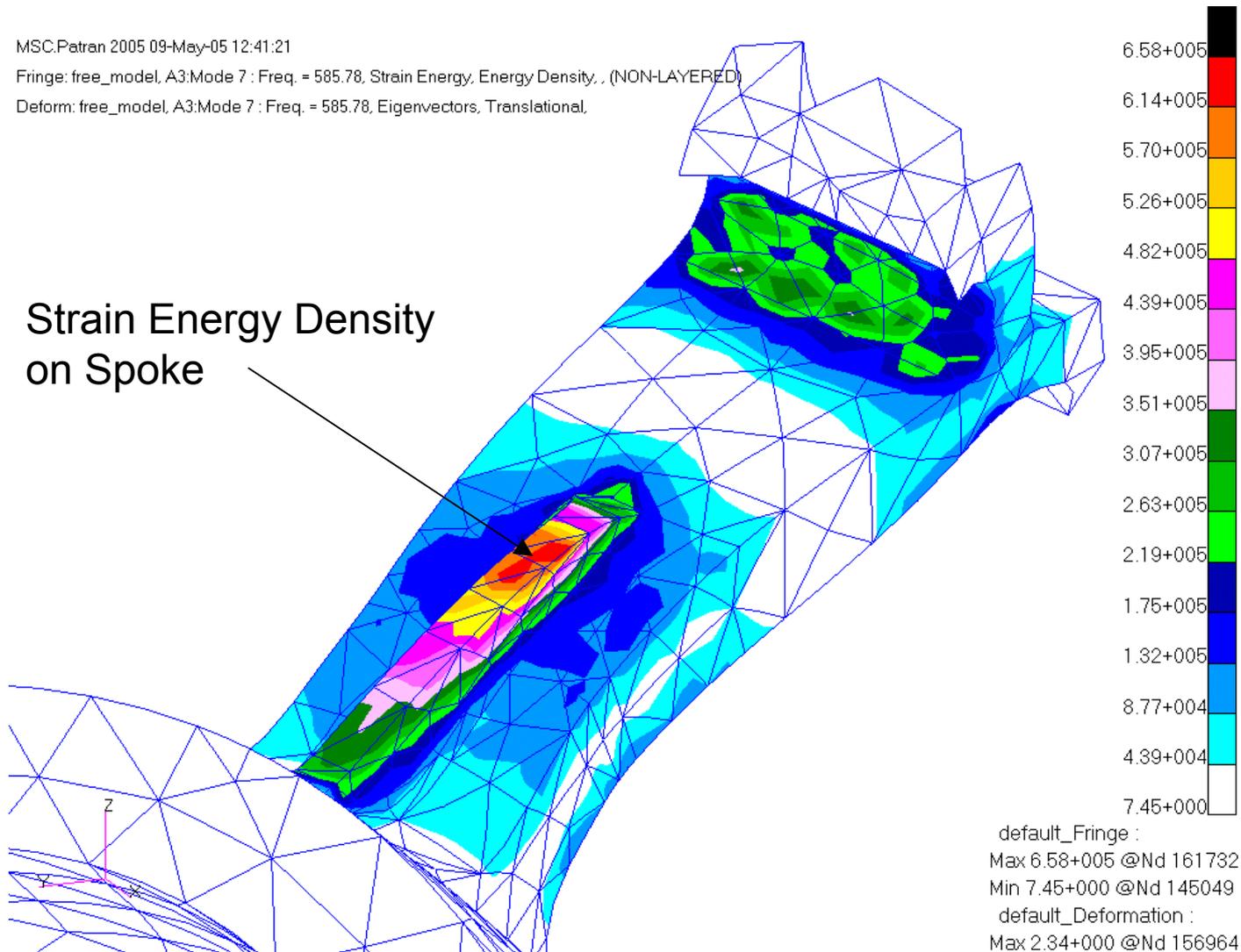
FE Results – Free Hub Analysis, 1st Mode: 585 Hz

MSC.Patran 2005 09-May-05 12:41:21

Fringe: free_model, A3:Mode 7 : Freq. = 585.78, Strain Energy, Energy Density, (NON-LAYERED)

Deform: free_model, A3:Mode 7 : Freq. = 585.78, Eigenvectors, Translational.

Strain Energy Density
on Spoke

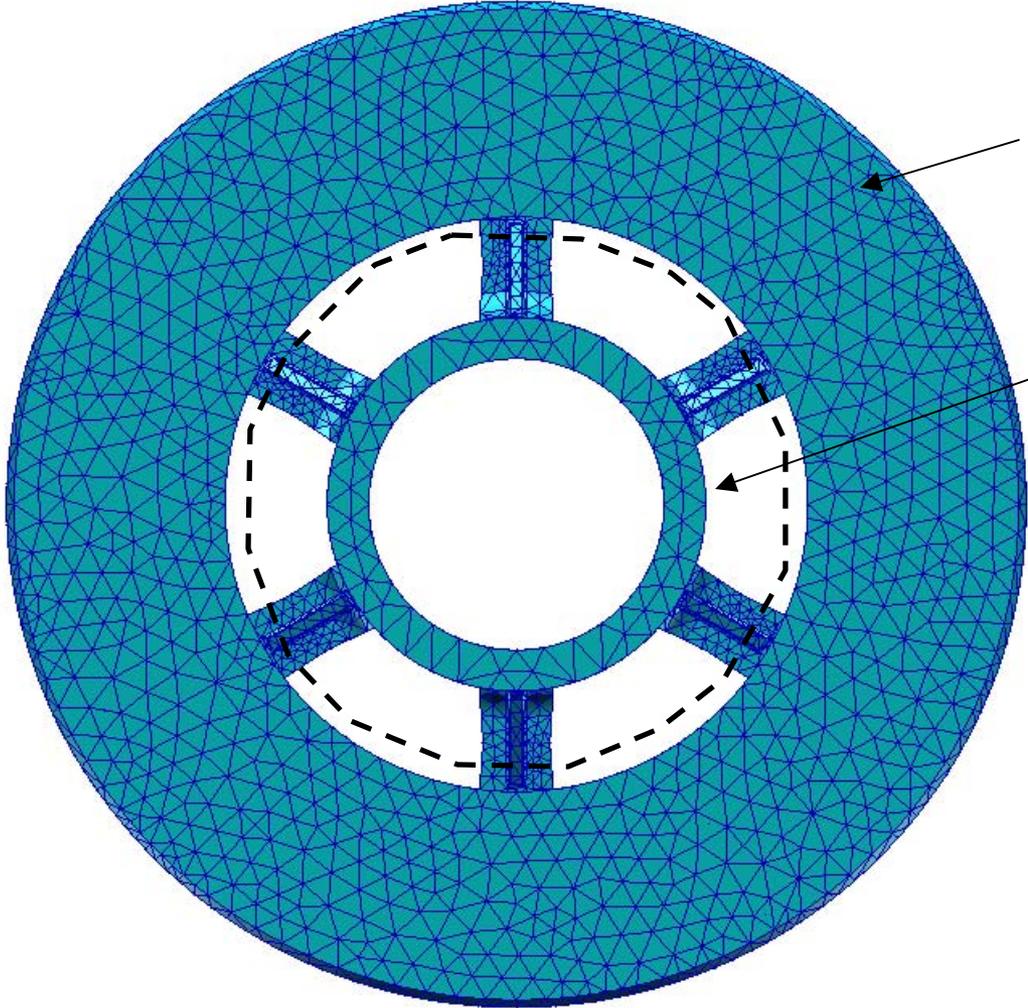


Spoke Strain Due to Thermal Effects

Thermal Stress Analysis

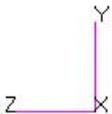
- Material Properties (Steel)
 - Modulus of Elasticity $E = 27.56 \times 10^6$ psi
 - Poisson's Ratio = 0.26
 - Density $\rho = 0.264$ lb/in³
- Temperatures
 - Assumed 70 °F (~Ambient Temperature) at Hub and 300 °F (Estimate of Temperature Resulting From Braking) at Braking Surface
- Mechanical Conditions
 - No External Loads or Rotation of the Disc

FEA: Thermal Conditions



Temperature of the
outer faces and
connectors = 300°F

Temperature of
inner hub and
spokes = 70°F

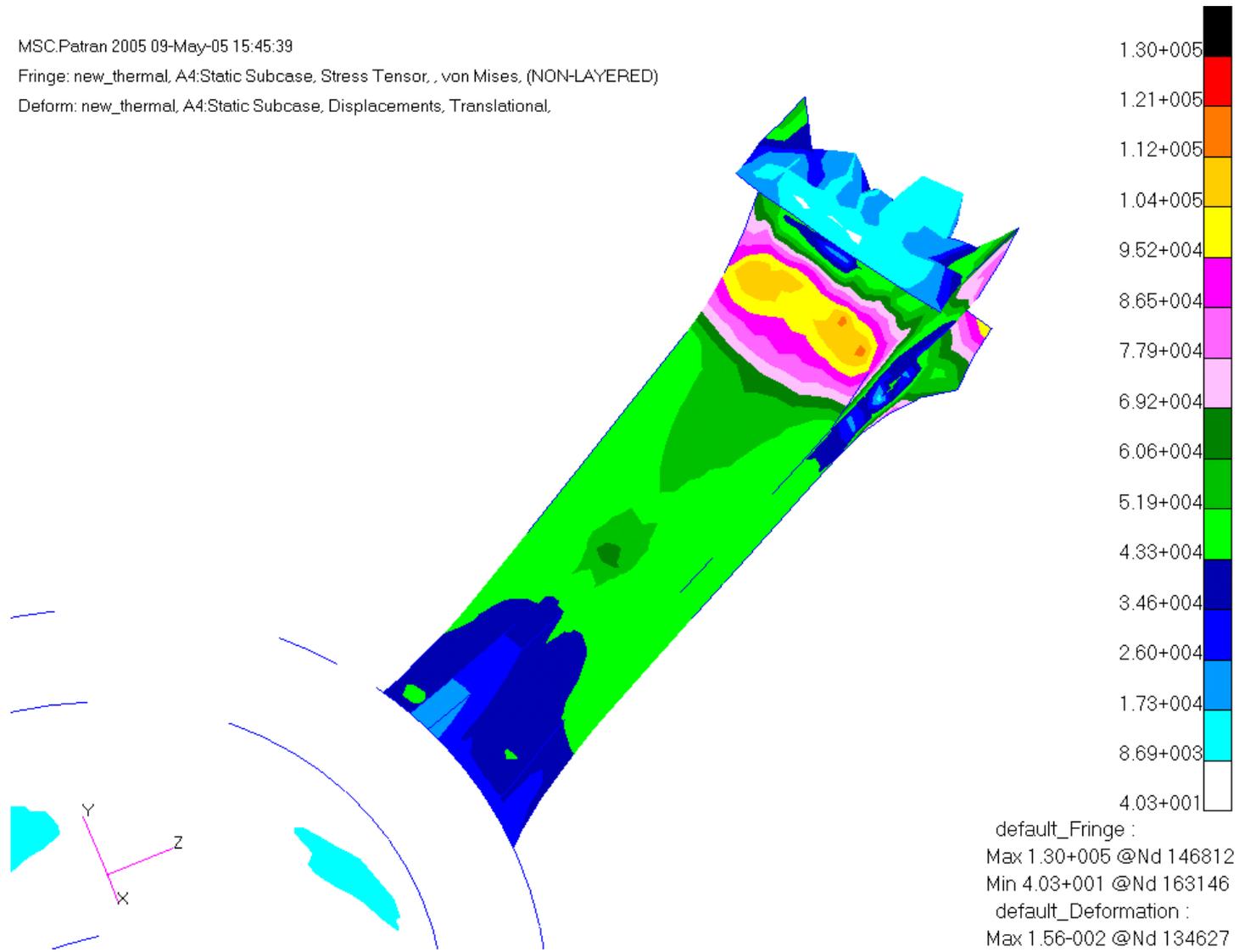


FEA: 300°F Thermal Spoke Stress (psi)

MSC.Patran 2005 09-May-05 15:45:39

Fringe: new_thermal, A4:Static Subcase, Stress Tensor, , von Mises, (NON-LAYERED)

Deform: new_thermal, A4:Static Subcase, Displacements, Translational,



FEA: Thermal Stress on Spoke

MSC.Patran 2005 09-May-05 11:40:28

Fringe: thermal, A1:Static Subcase, Stress Tensor, , von Mises, (NON-LAYERED)

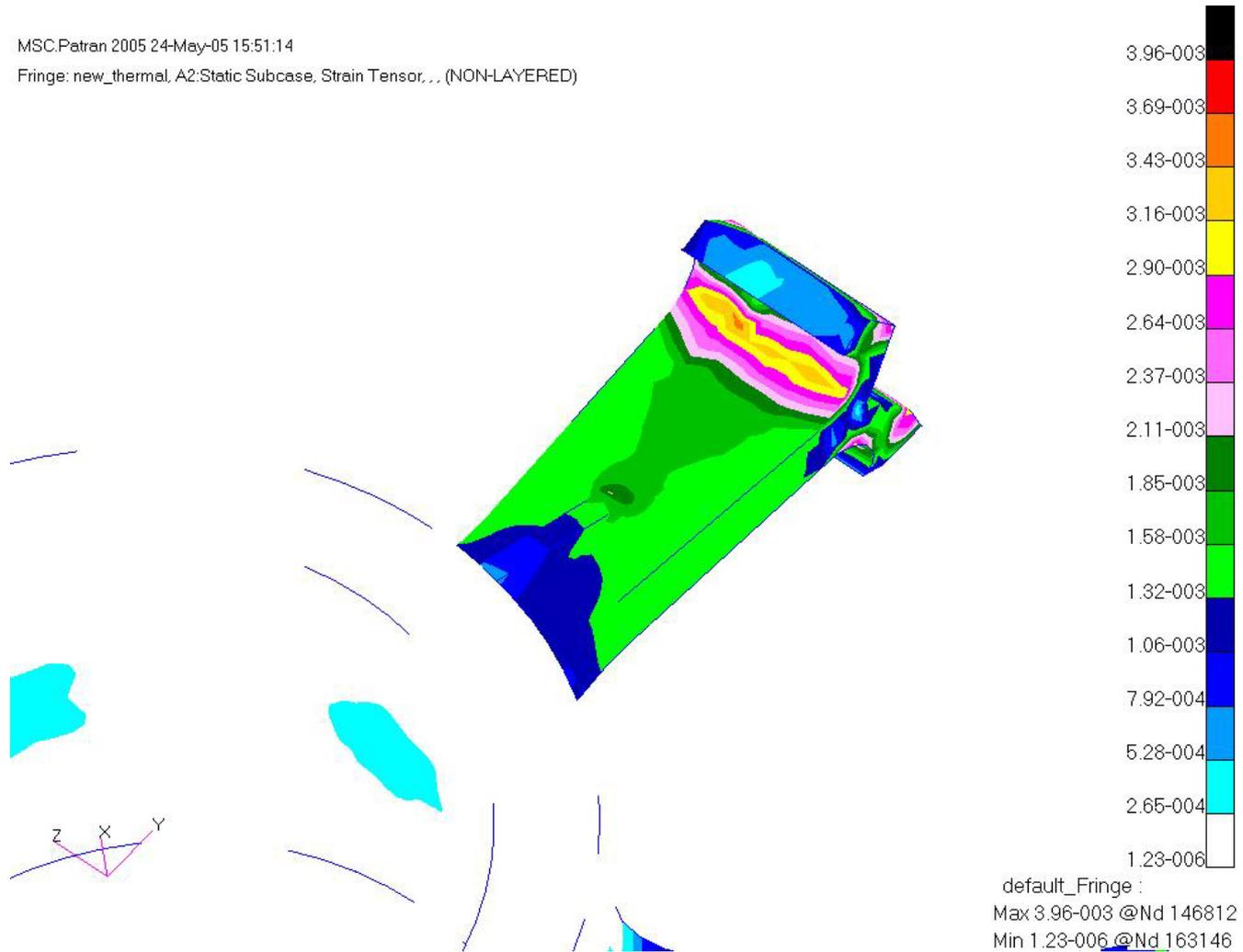


default_Fringe :
Max 1.09+004 @Nd 139856
Min 8.17+000 @Nd 163504

FEA: Spoke Strain Due to Thermal Effects

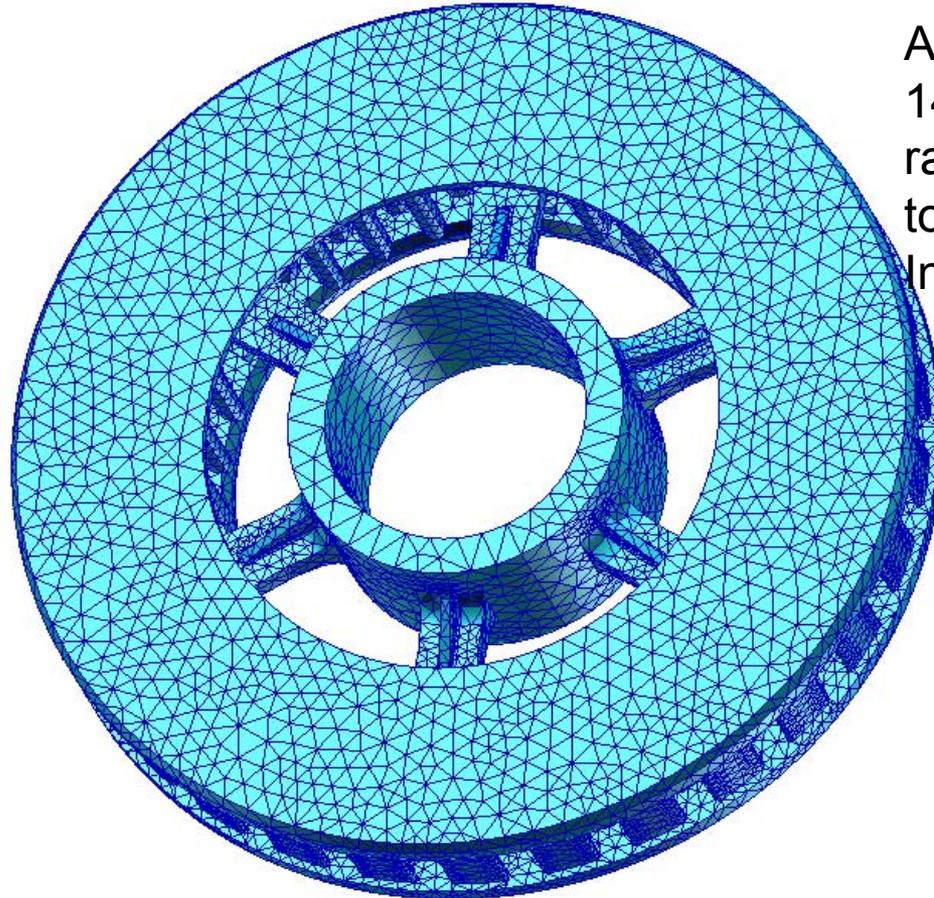
MSC.Patran 2005 24-May-05 15:51:14

Fringe: new_thermal, A2:Static Subcase, Strain Tensor, , (NON-LAYERED)

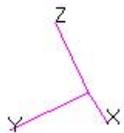


Spoke Strain Due to Rotational Effects

FEA: 1400 RPM Rotation



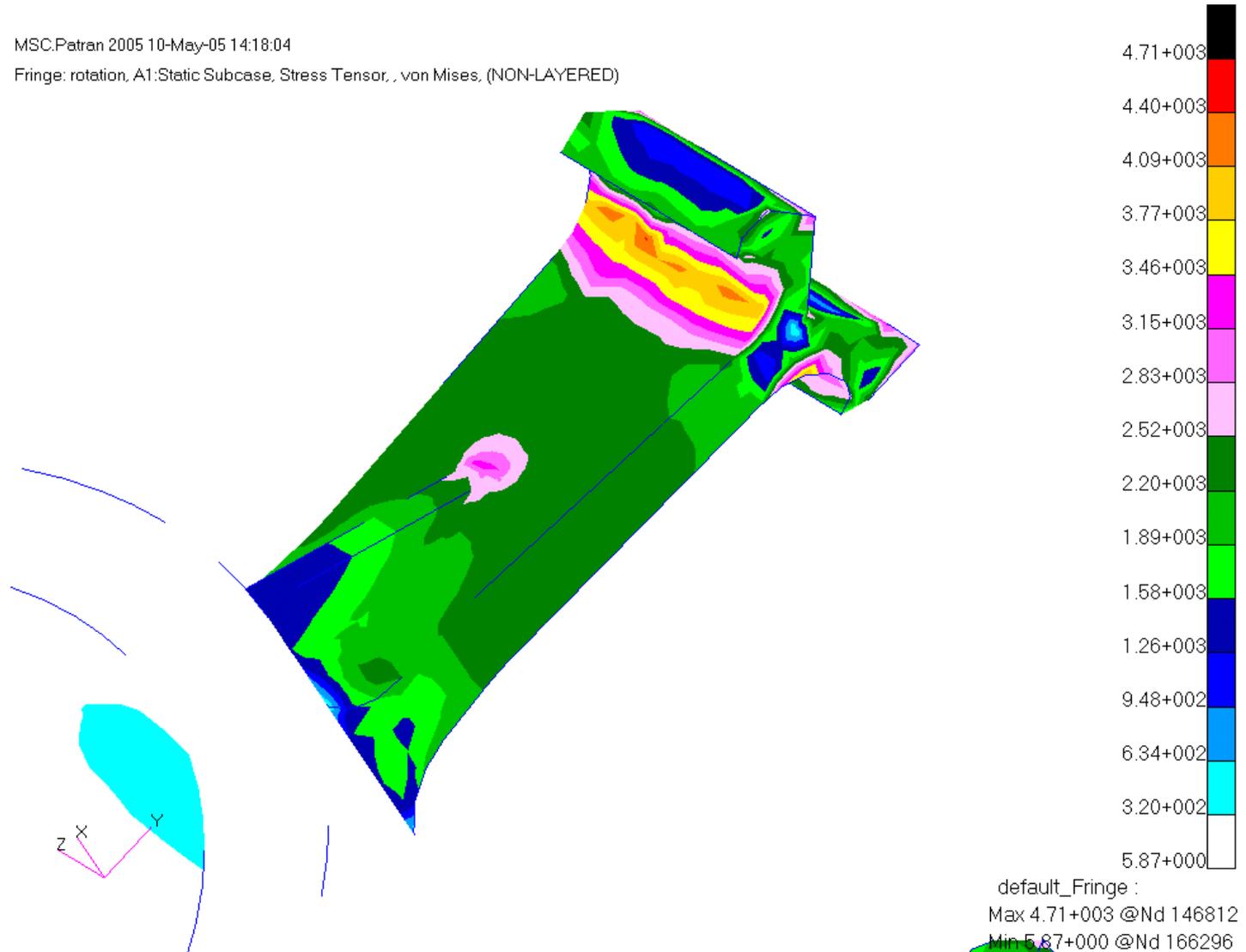
A rotation rate of 1400 RPM (146.6 rad/sec) is applied to the model as an Inertial Load.



FEA: 1400 RPM Rotation Stress on Spoke (psi)

MSC.Patran 2005 10-May-05 14:18:04

Fringe: rotation, A1:Static Subcase, Stress Tensor, , von Mises, (NON-LAYERED)



Conclusions

Finite Element Analysis Conclusions

- Predicts 206 Hz Out-Of-Plane Bending (BOP) Of Disc When The Hub Is Fixed
- Predicts A “Hot Spot” For Stress In BOP Mode At The General Location Of Observed Cracks
- Predicts Tensile Strain In Spokes Due To Temperature Rise In Friction Rings
- Predicts Low Strain In Spoke Due To Rotation