Evaluating and Correcting Subsynchronous Vibration In Vertical Pumps

Case Study #8

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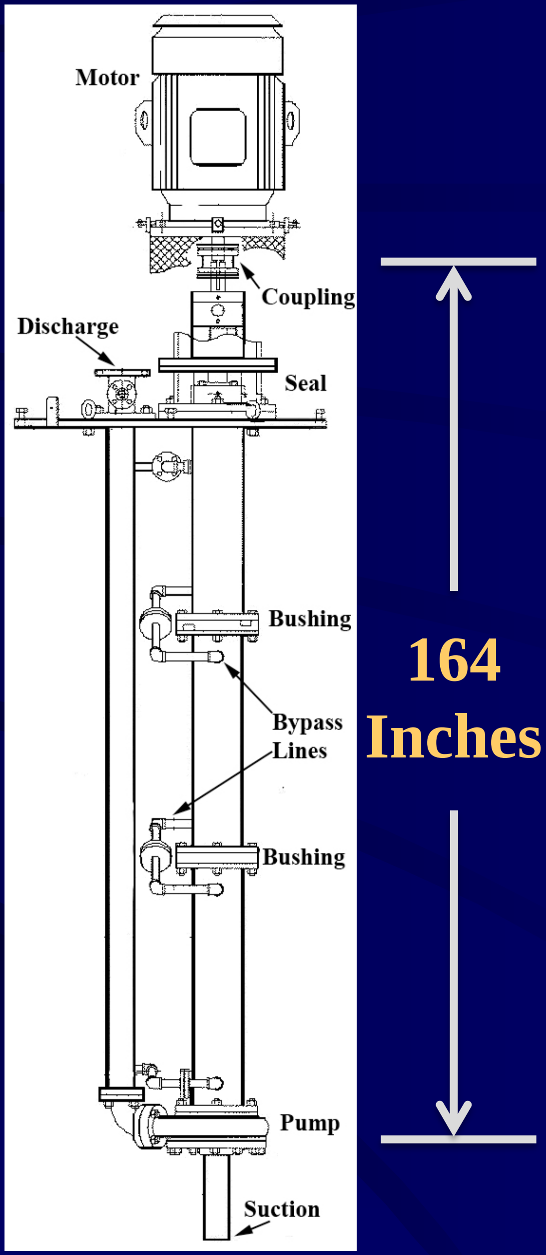
Case Study Overview

- New Vertical Pumps
- Liquid Sulfur Service
- Operating Speed – 3,575 RPM
- Primary Vibration Component at 1,750 CPM
- Shaft Whirling or Whipping Suspected
- Structural Resonance near ½ X
- Solution

Pump Layout


Motor
Coupling
Discharge
Seal
Bushing
Bypass
Lines
Bushing
Pump
Suction
164
Inches

Pump System

6 Vertical Pumps in 3 Separate Sumps

Single Stage 81 GPM 219 Ft Head 40 HP

Molten Sulfur at 300 °F

Pump and Shaft are Steam Jacketed

4 Radial Bearings/Bushings

Top Bearing is also Thrust Bearing

Line Shaft Bushings are Carbon Graphite

History

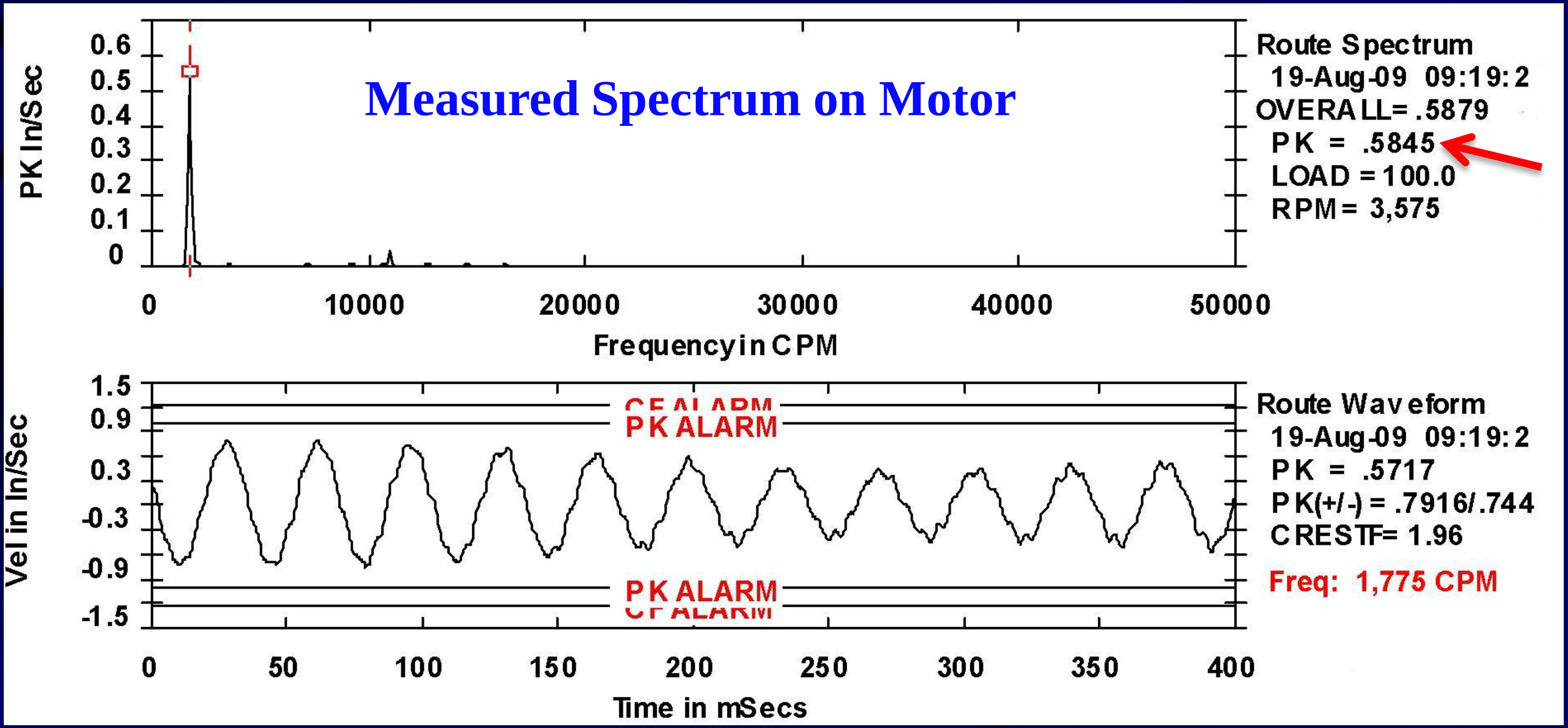
- Hard “Sulcrete” Buildup in Sumps
- New Pump Mounting System Devised
- Initial Base Impact Test Showed Structural Natural Frequency in Excess of 5,000 CPM
- **<u>Initial Vibration Readings:</u>**

➢ First Installation had 0.2 IPS at 1,710 CPM

➢ Second Installation had 0.65 IPS at 1,750 CPM

Vibration Measurements

- High Vibration on All Units
- Virtually no 1X (Running Speed) Vibration
- Most Vibration near ½X Running Speed



History

- Installed Impact Test Results on Motor

Bump Test Location	East - West Direction	North - South Direction
East Pump	**1,734 CPM**	**1,887 CPM**
West Pump	**1,657 CPM**	**1,887 CPM**

History

- Clearly There was a System Natural Frequency near Half of Operating Speed
- What was the “Forcing Function”?
- Sulfur “whirl” Considered

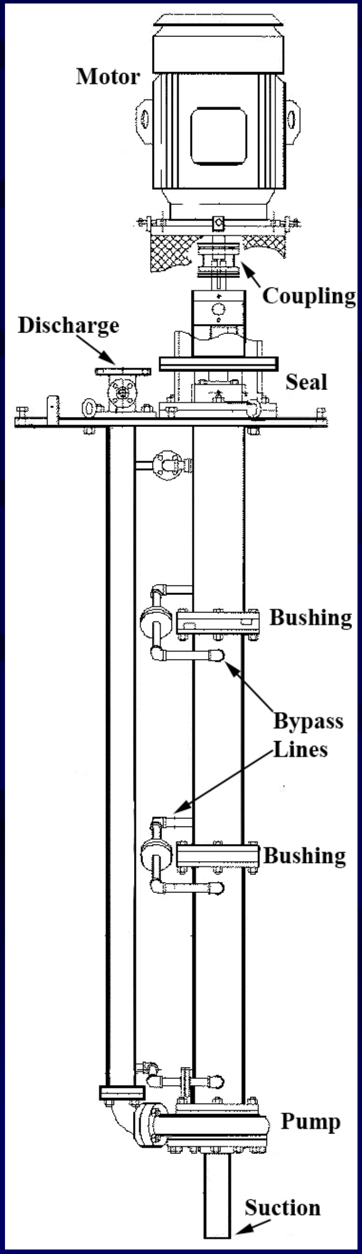
Initial Attempts

- Reduced Weight of Coupling
  - No Significant Effect
- Possibly Stiffen Structure?
  - Probably would be Ineffective – Not Done
- Rotordynamics Analysis
  - Selected Approach

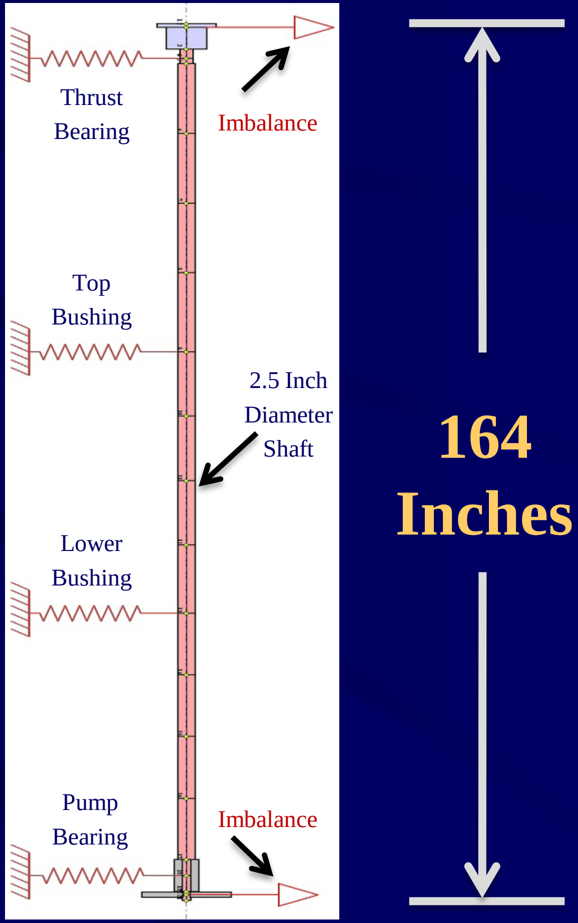
Rotordynamics Analysis

- Gather Data from Disassembled Unit
- Dimensions and Weights of all Rotating Parts
- Evaluate Bushing Dimensions
- Determine Properties of Liquid Sulfur
- Translate into Finite Element Model
- Match Model to Observed Vibrations
- Design New Components to Fix Problem

Actual System Compared to Model



FEA Model



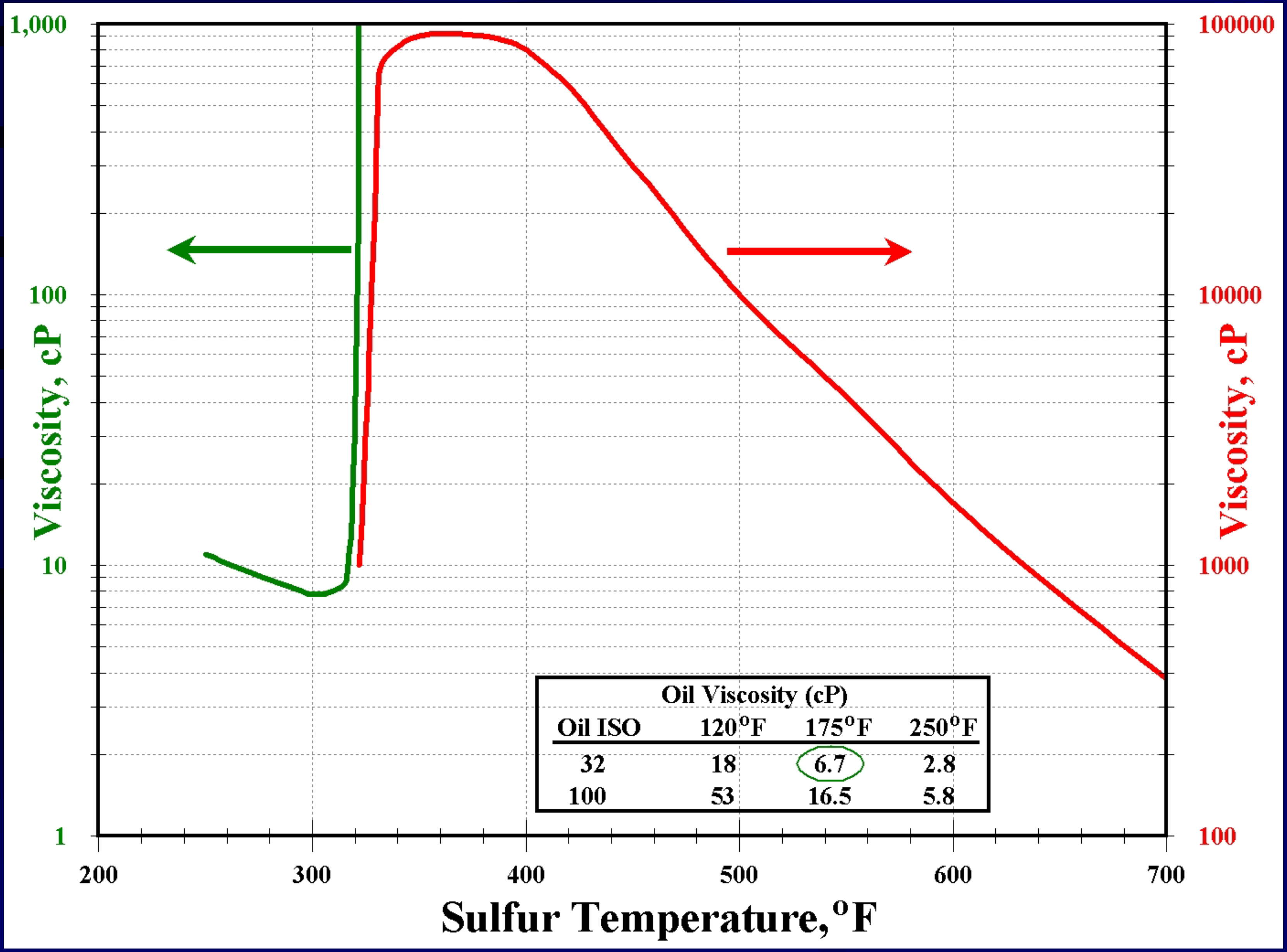
Center Two Rotating Sleeves

Properties of Molten Sulfur

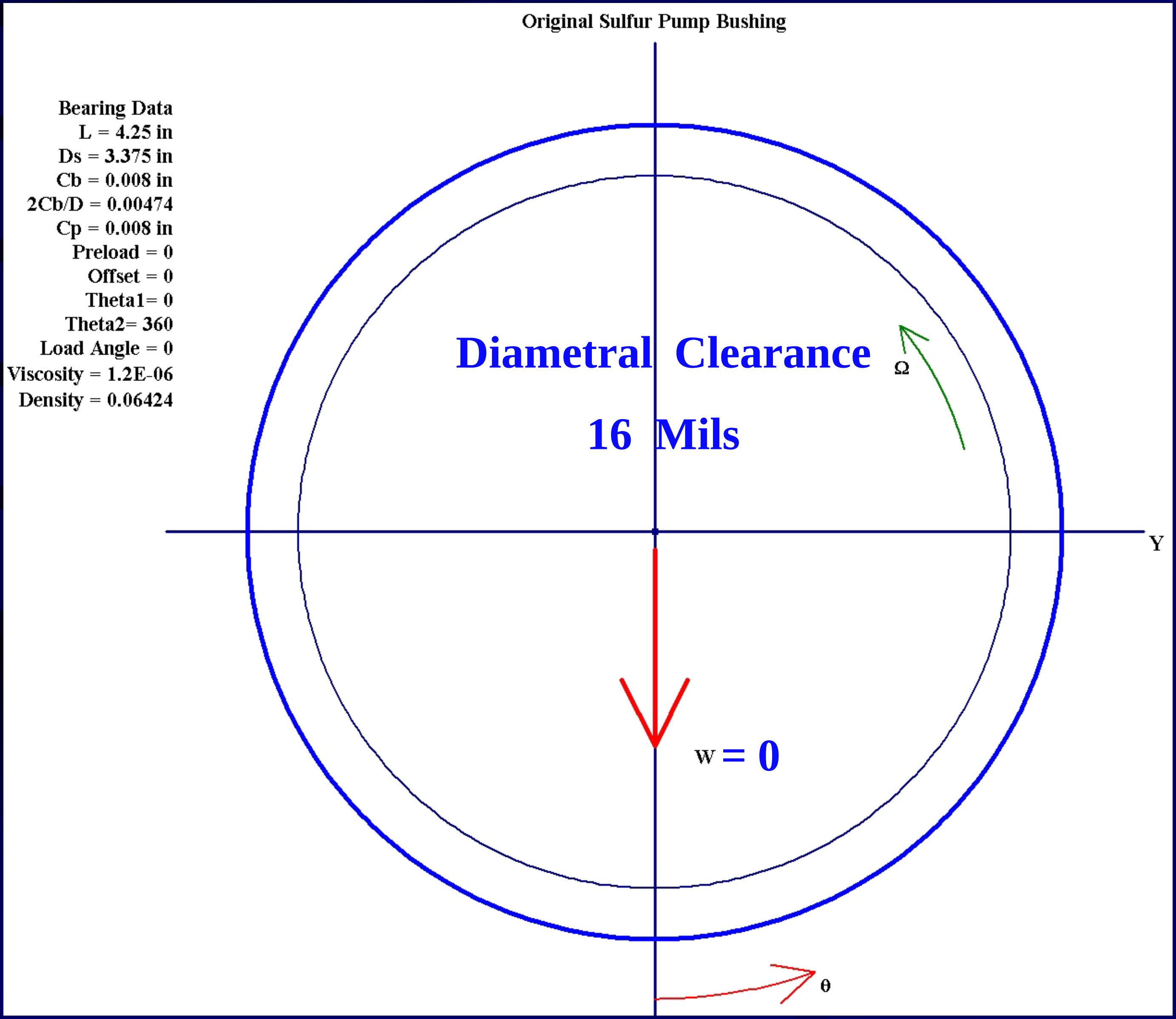
- Unusual Material
- Room Temperature Sulfur is a Crystalline Solid
- Fully Liquid at 235°F
- Forms Long-Chain Molecules – Gamma Sulfur
- Highly Non-Linear Viscosity
  - 7.8 cP at 300°F **93,000 cP at 350°F**
- Sump Temperature Control Very Important

Crystalline Solid Sulfur

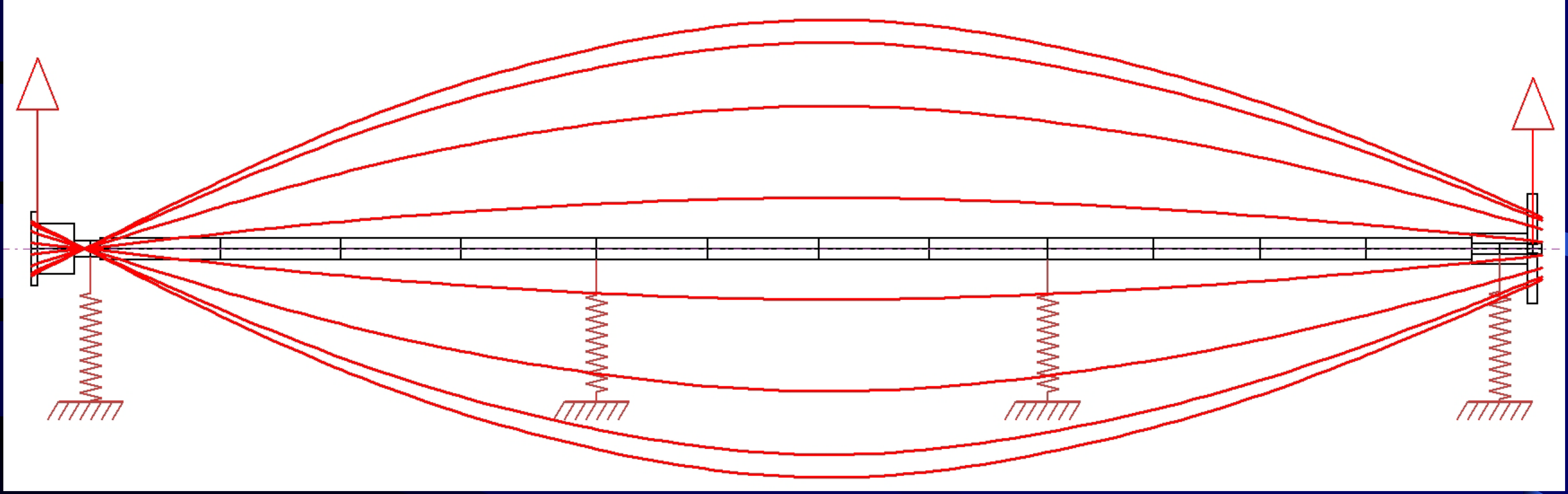
Sulfur Viscosity v. Temperature



Original Bushing Design

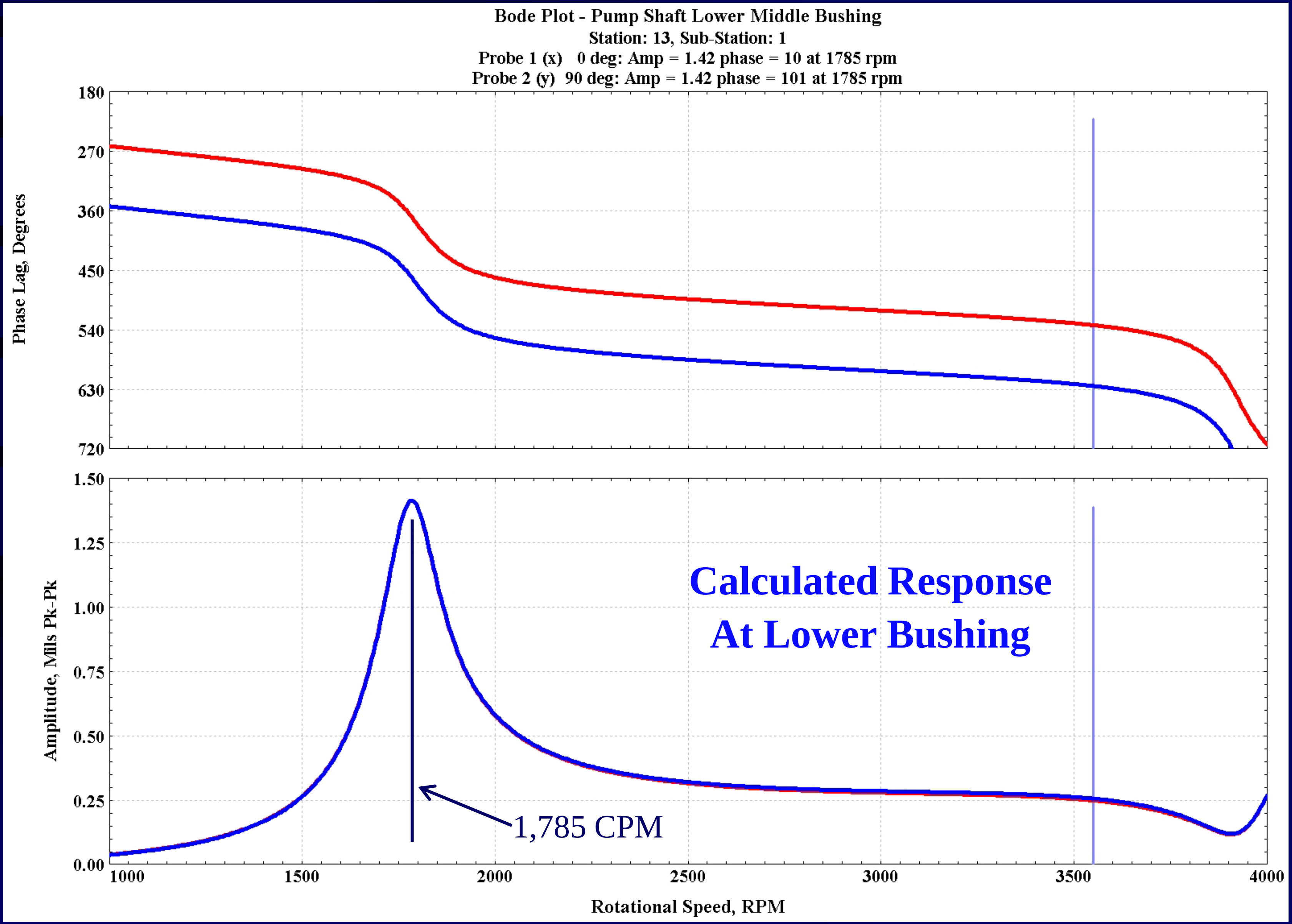


First Critical Speed Mode Shape

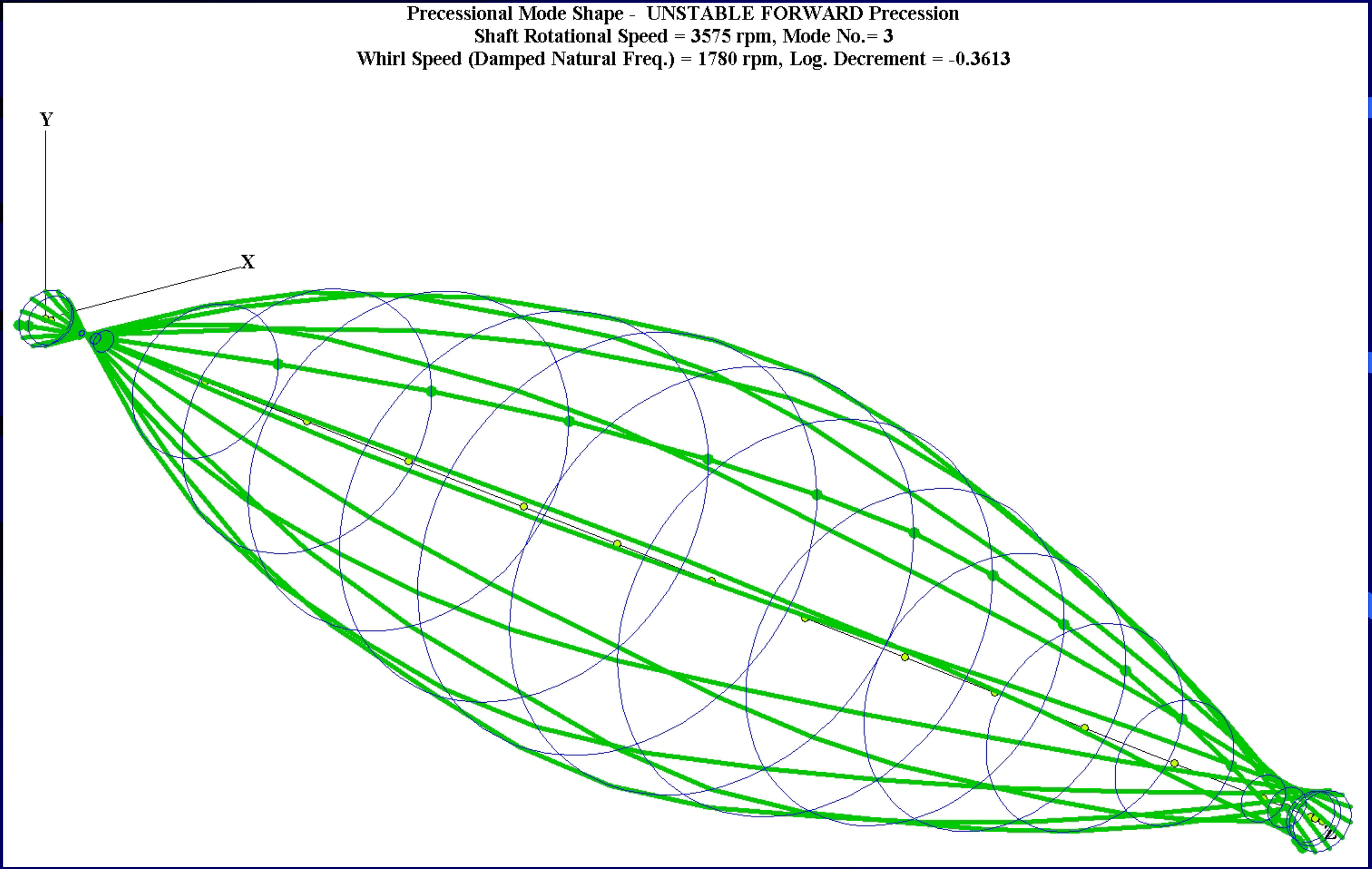


Calculated Frequency = 1,770 CPM
With Original Upper and Lower Bushings

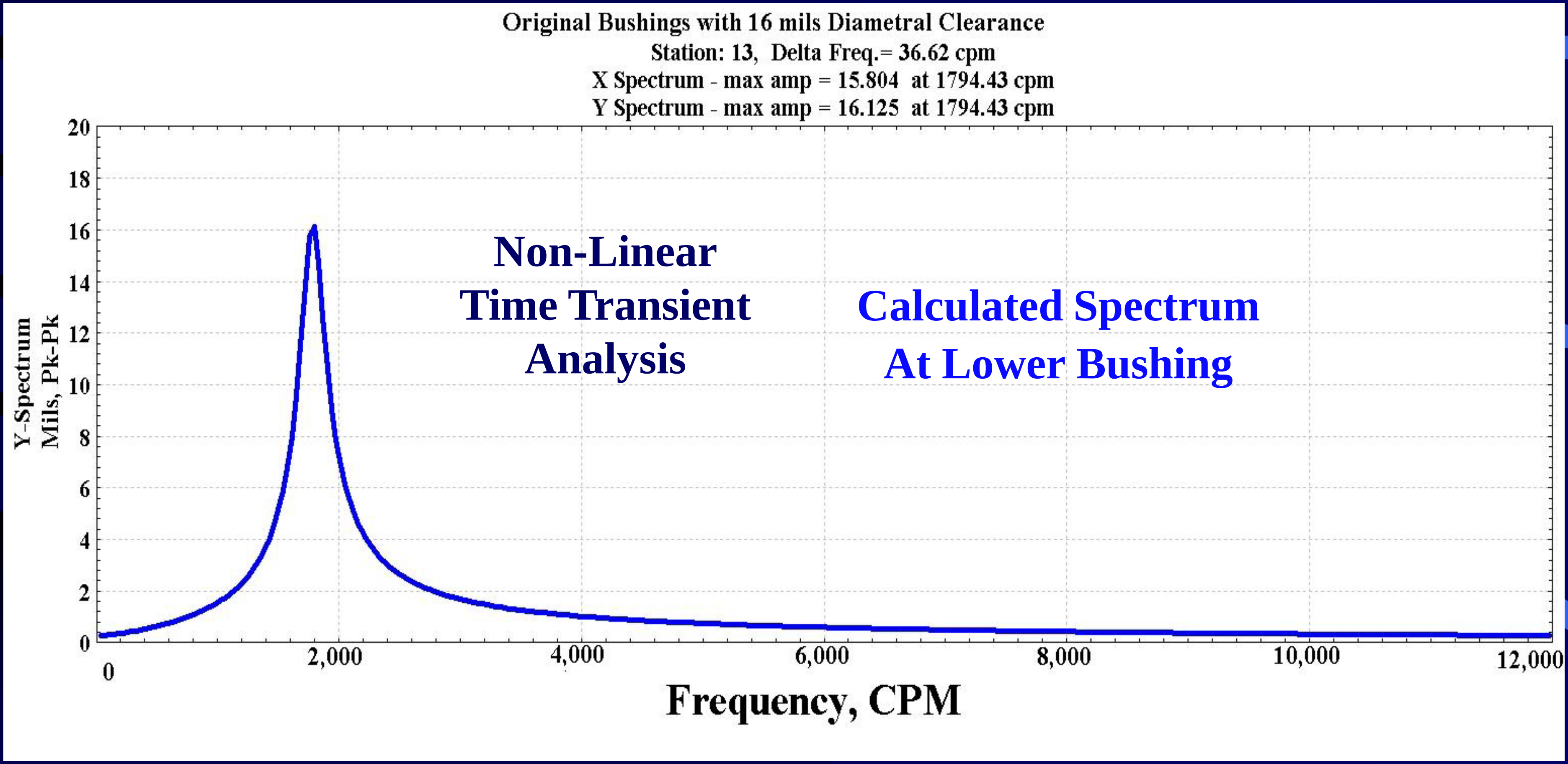
Original Unbalance Response



Stability with Original Bushings



Stability with Original Bushings



Evaluation

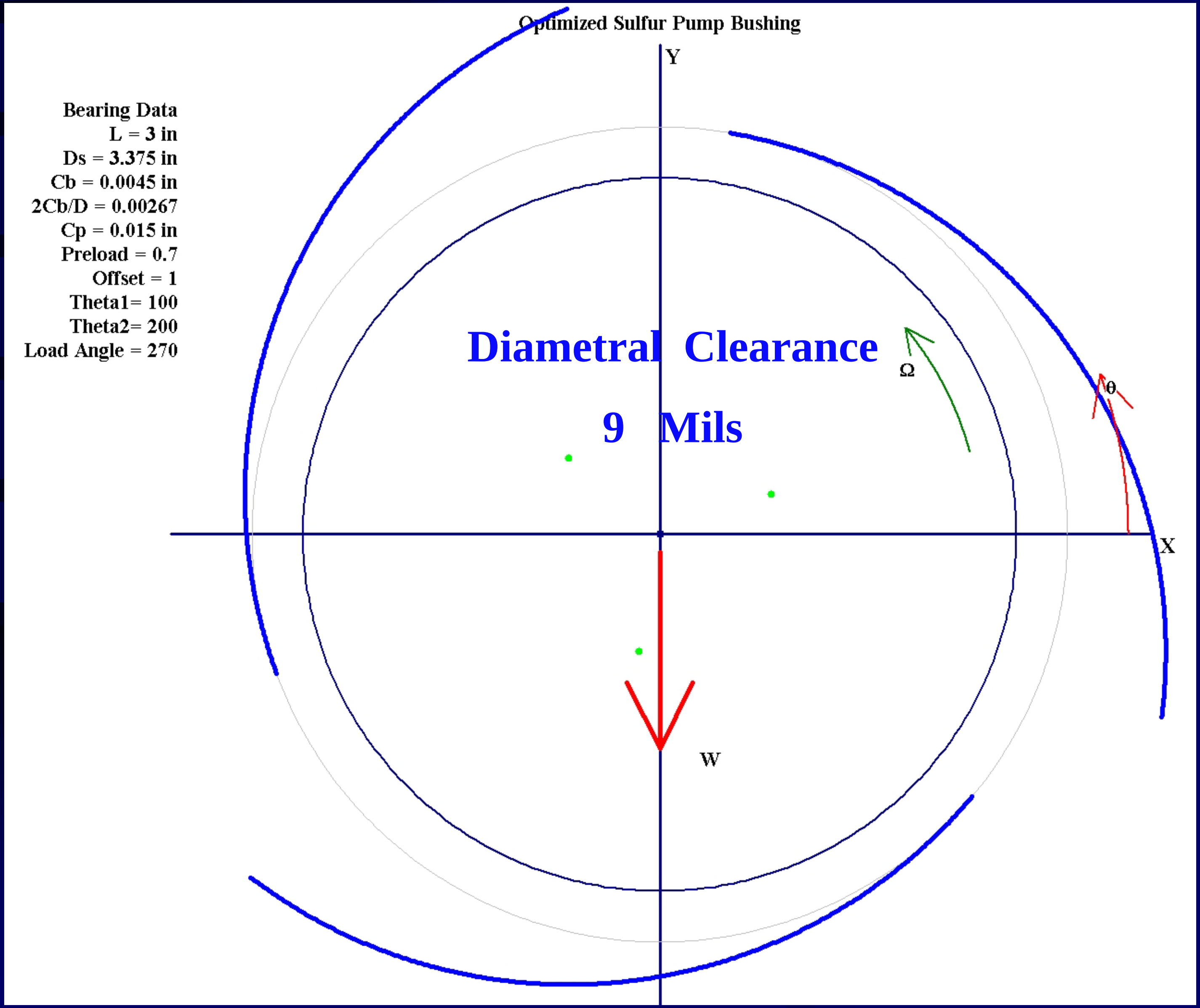
- Shaft Critical Speed at ½ Operating Speed
- Structural Resonance at ½ Operating Speed
- Inherently Unstable Plain Circular Bushings

- **Need To Control The Rotor Vibration**
- **Center Two Bushings Logical Items to Revise**

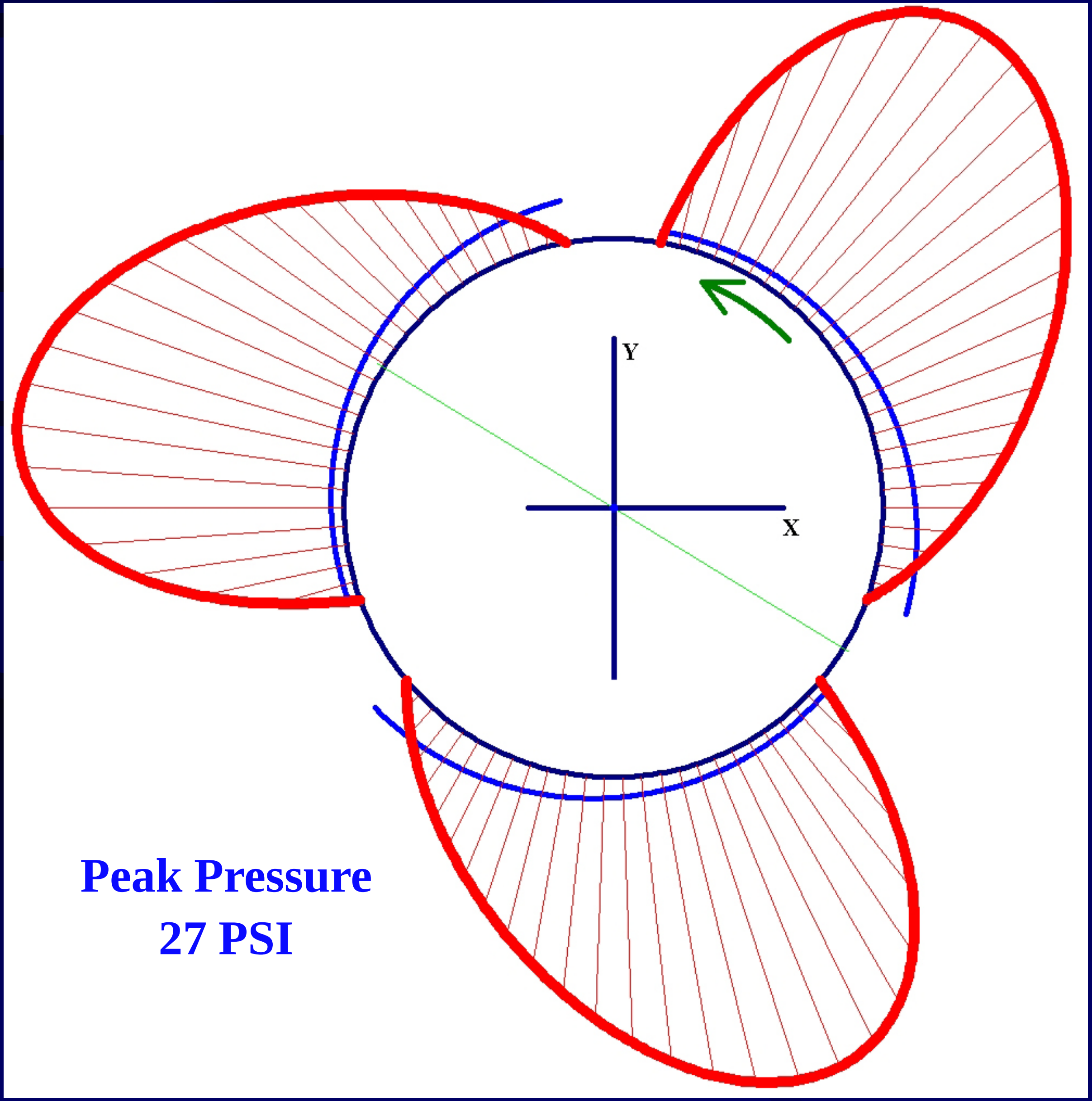
Solution Goals

- Design New Upper and Lower Bushings
  - Increase Direct Stiffness
  - Raise Critical Speed above Operating Speed
  - Eliminate Instability
  - Assure Low Operating Speed Vibration
  - Increase Reliability and Reduce Costs

Optimized Bushing Design



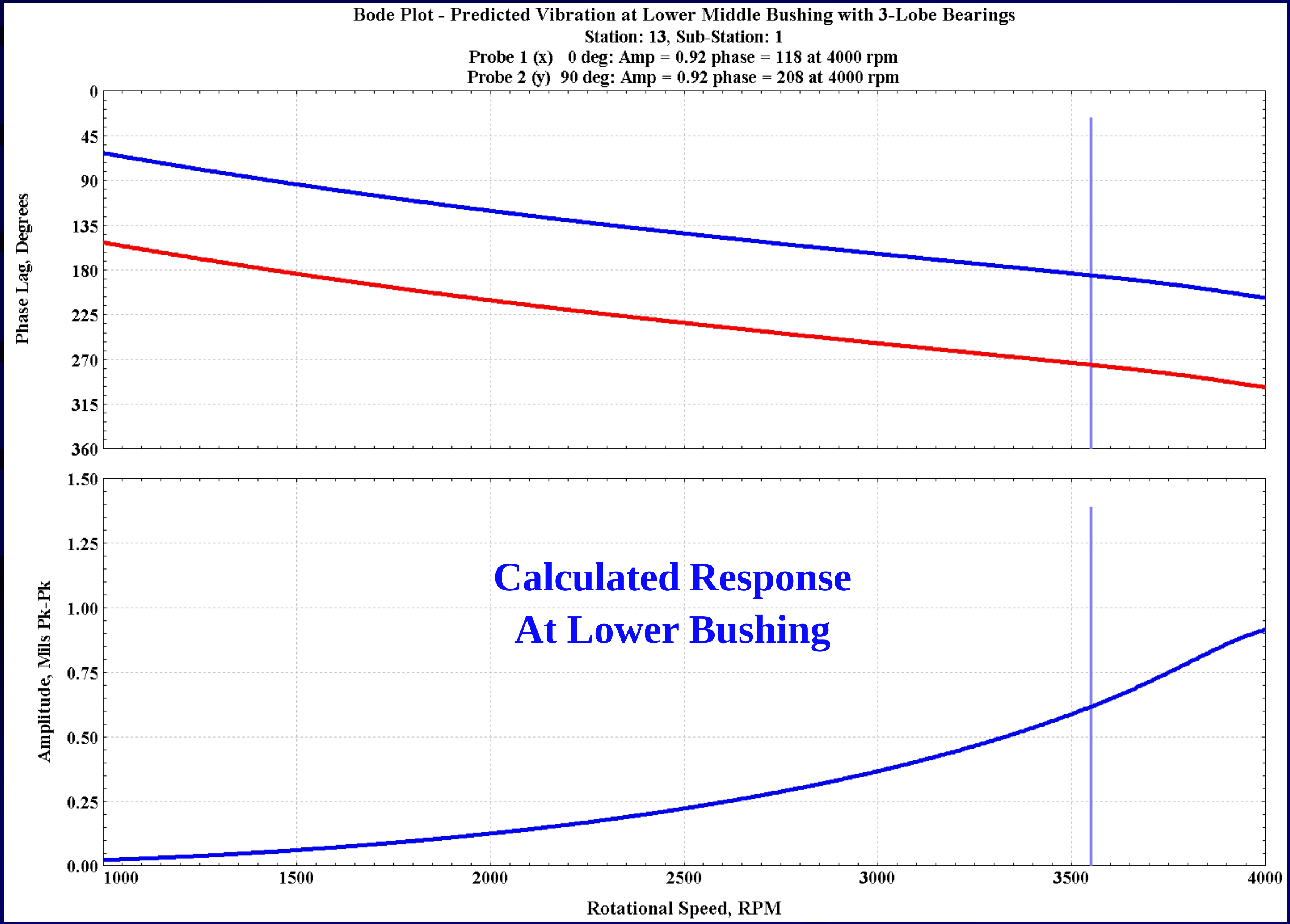
Optimized Bushing Pressure Profile



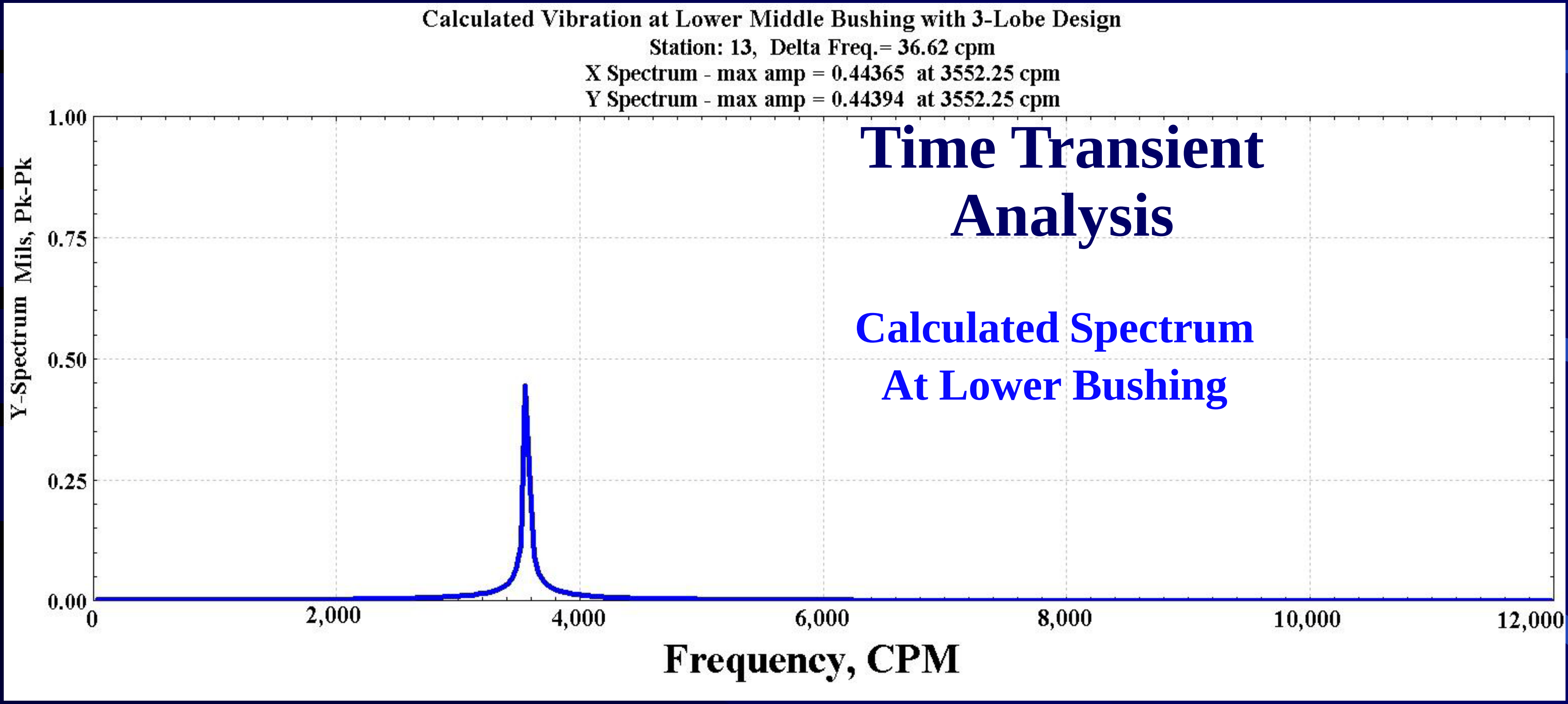
Bushing Stiffness and Damping Coefficient Comparison at 3,575 RPM

Bushing Type	Principal Stiffness, LB/IN	Principal Damping, LB-SEC/IN	Cross-Coupled Stiffness, LB/IN	Horsepower Loss
Plain Bushing	1,830	407	-69,400	0.65
3-Lobe Bushing	49,100 (26.8 Times Stiffer)	323	-20,700	0.38

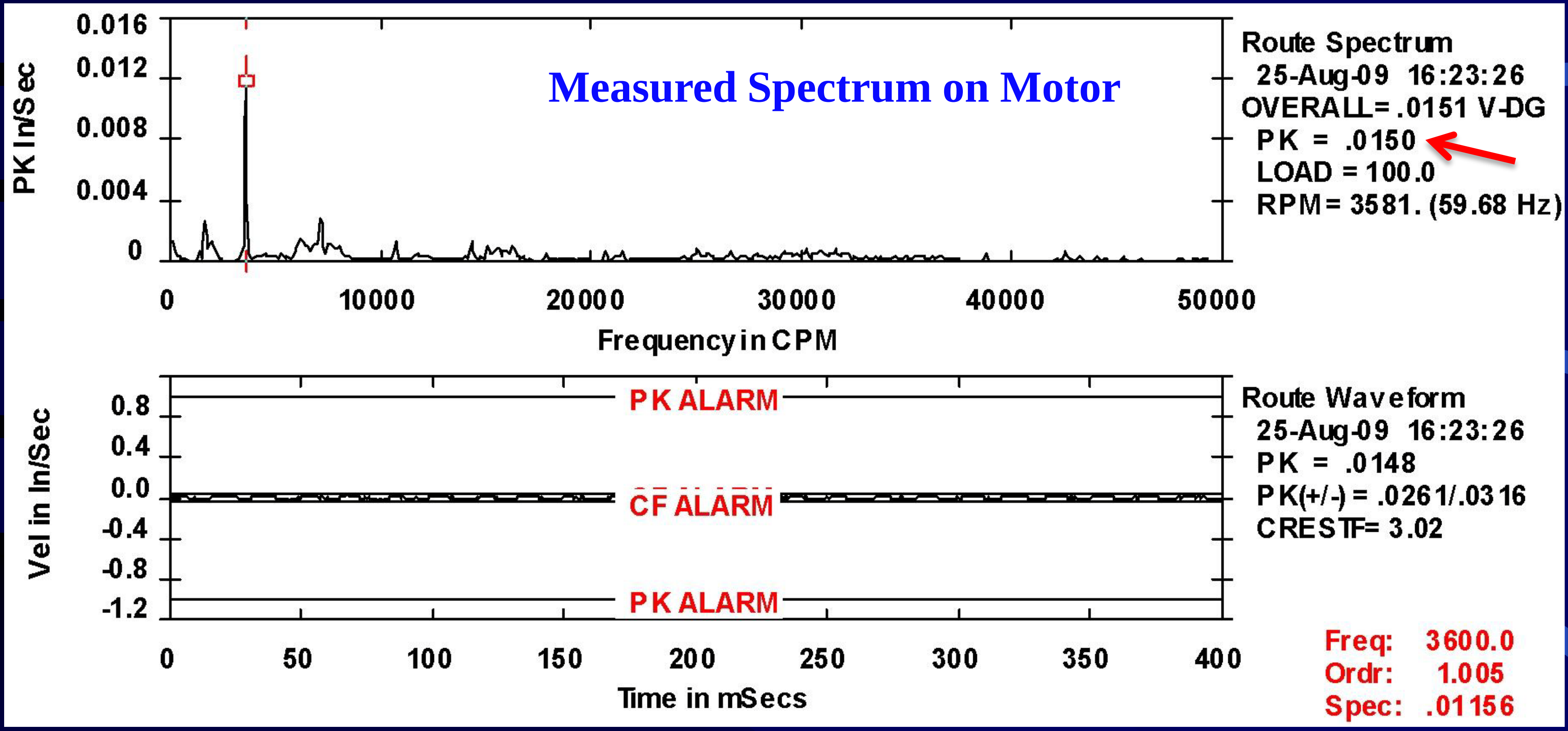
New Design Unbalance Response



Stability with New Design Bushings



Final Result



Conclusion

- Vibration Problem Eliminated
  - Replaced 2 Plain Bushings with Profile Design
    - ✓ Inexpensive
    - ✓ Available Locally
  - Eliminated Critical Speed
  - No Structural Modifications Necessary
  - Reliability Increased and Costs Reduced