

Vertical Pump Motor Synchronous Vibration Case Study

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Abstract

A 4160V, 3600 RPM motor on an existing vertical pump suffered a major failure attributed to a lightning strike. After repair vibration levels were well above shutdown with the motor running at above 1 inch/second. Several inspections and re-assemblies were made with the same results. During each assembly the rotor was low speed balanced, and the assembled motor was balanced on a steel surface and rubber surface to less than 0.1 inch/second.

Further investigation of the vibration was pursued through the use of impact testing and finite element analysis. This testing and analysis revealed the existence of a natural frequency near running speed. Finite element analysis was used to make modifications to detune the system; however vibration levels did not change significantly.

Final solution of the vibration problem consisted of two plane balancing the motor on the pump head indicating that the standard shop approach to balancing the motor was ineffective. This paper discusses potential causes of the problem and makes recommendations for identifying and correcting the problem.

Problem History

- July 2004 – Motor failed due to lightning strike
- Until failure motor ran between 0.2-0.25 in/sec
- Sent to motor shop for rotor and stator repair
- After installation motor vibration was nearly 2.0 in/sec. All at 1x (synchronous).
- Motor returned to shop twice after this:
 - Rotor slow speed balance checked $<4W/N$
 - Assembled motor balanced on steel and rubber surfaces to less than 0.1 in/sec
- Vibration level could not be reduced below 1.0 in/sec.



Iso-butane vertical pump

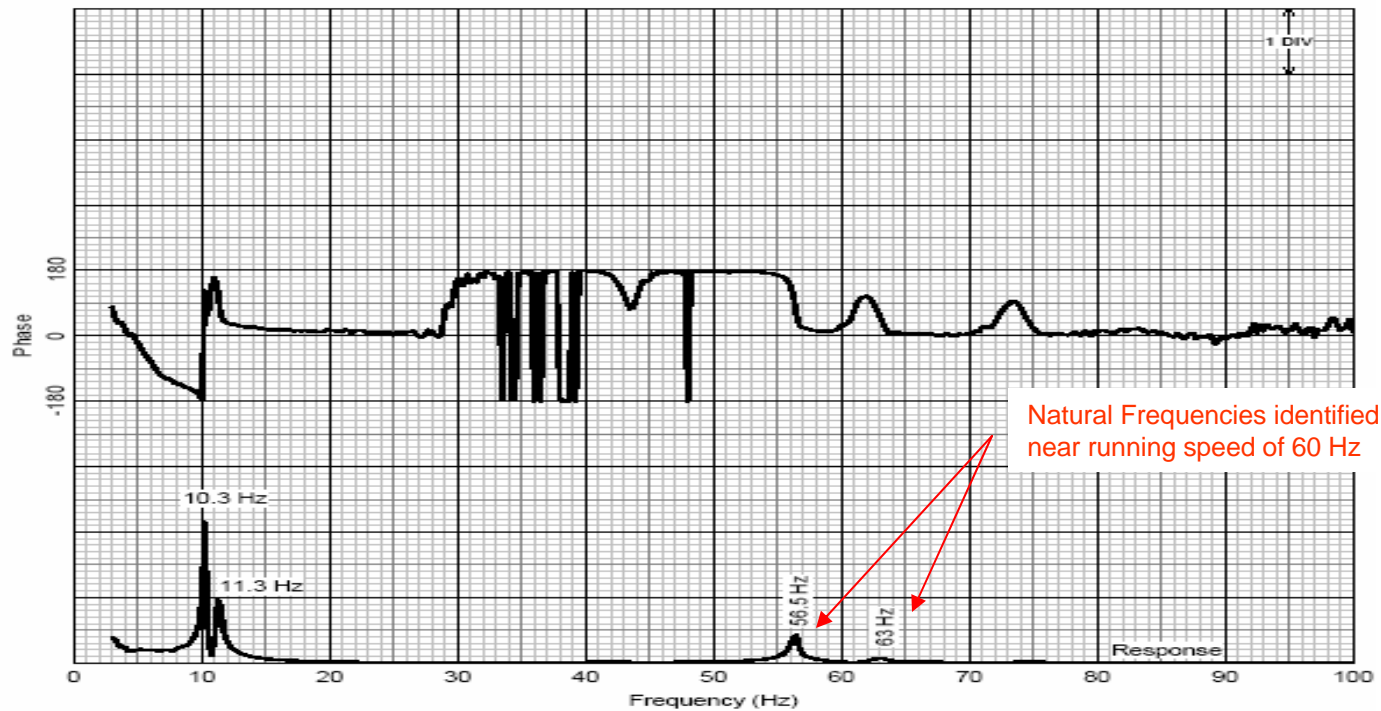
Motor Test with Pumphead

- Motor did not show signs of high vibration when tested alone at motor shop.
- Pumphead was brought to motor shop to evaluate motor vibration mounted on pumphead.
- Vibration of motor mounted on pumphead matched field observation of 1.0 in/sec.

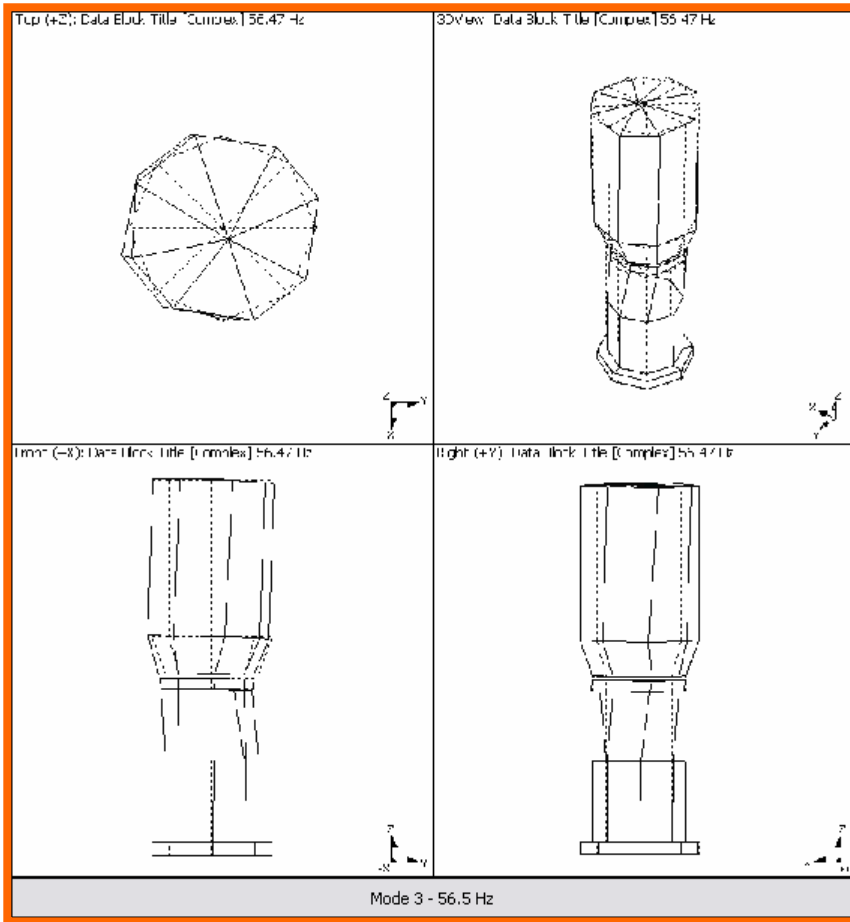


Impact Test

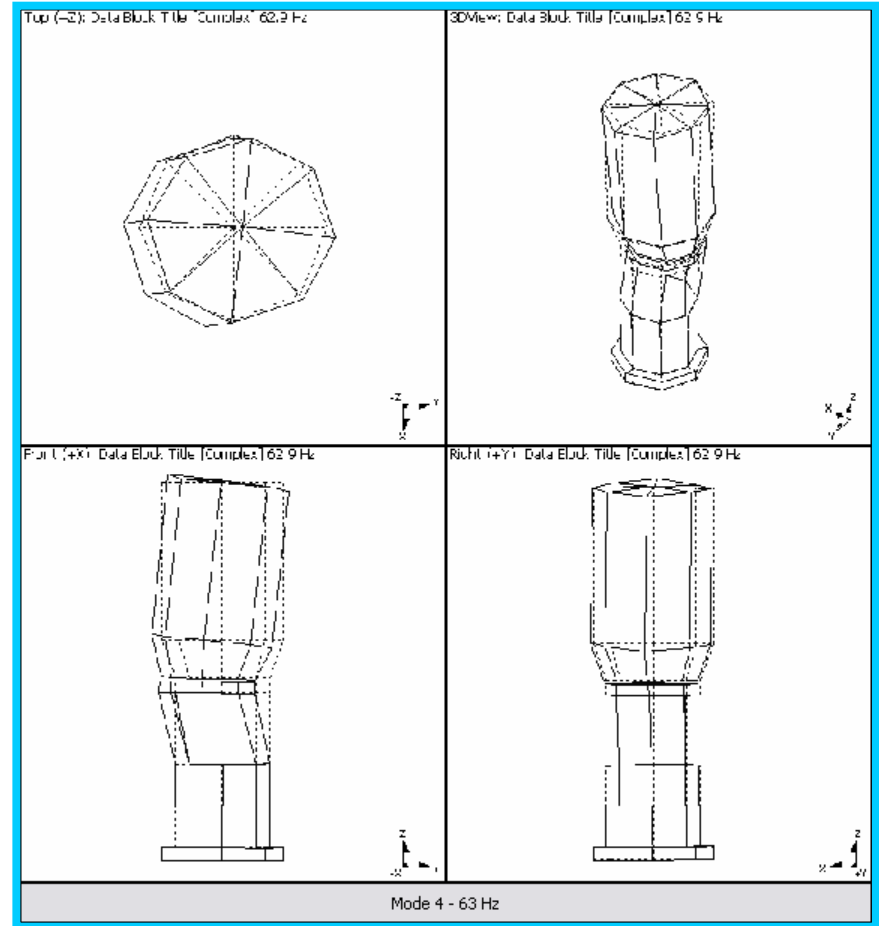
- Outside consultant brought in to assist with data gathering.



Impact Test Mode Shapes near Running Speed



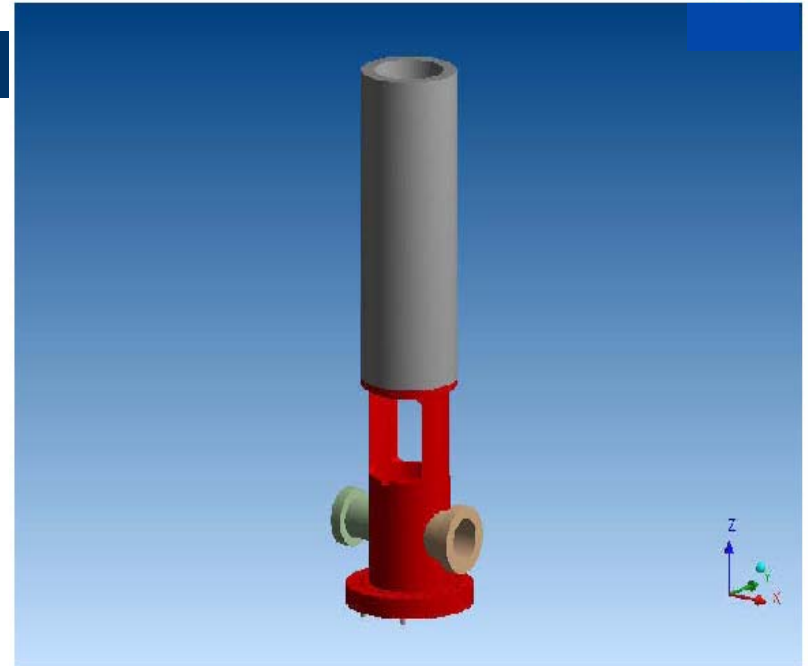
Torsional Mode 56.5 Hz



"Hula" Mode 63 Hz

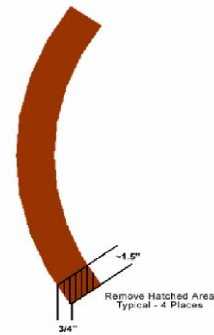
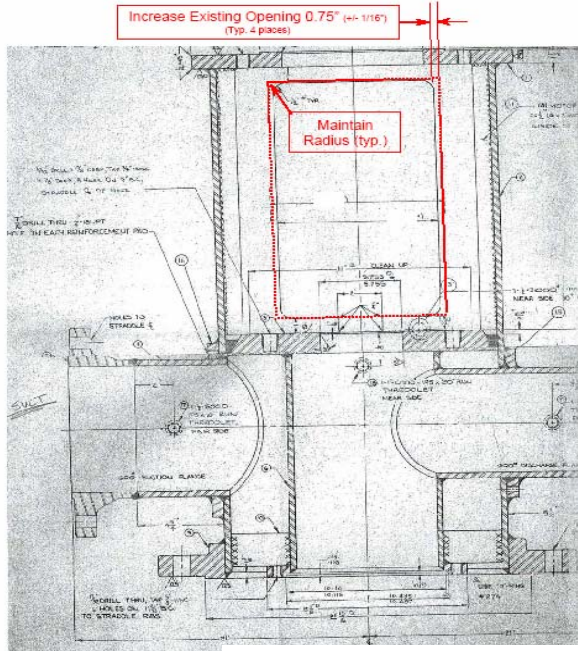
Rationale for Modifications

- Consultant recommended moving natural frequencies away from running speed by modifying pumphead structure.
- Consultant performed Finite Element Analysis (FEA) of motor pumphead system in order to determine most effective modifications.



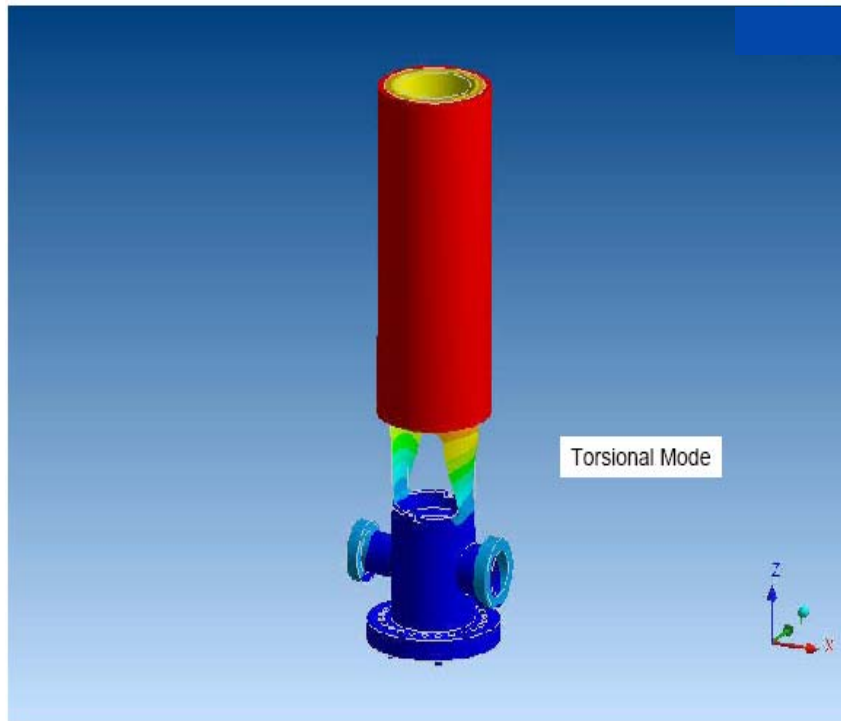
Motor-Pumphead FE Model

1st Modification – Enlarge Pump Window

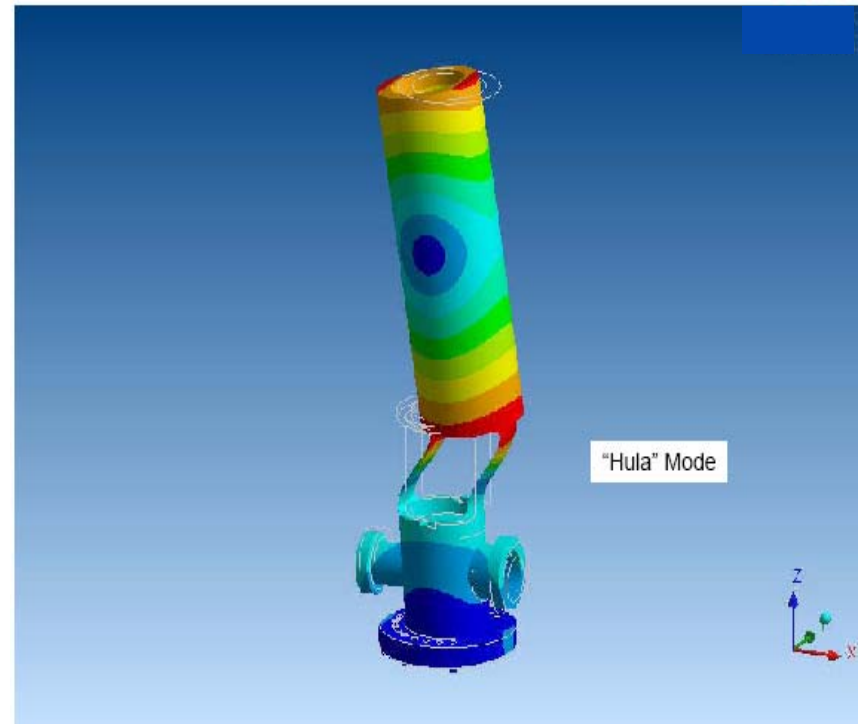


1st Modification – Enlarge Pump Window

FEA Predicted Natural Frequencies

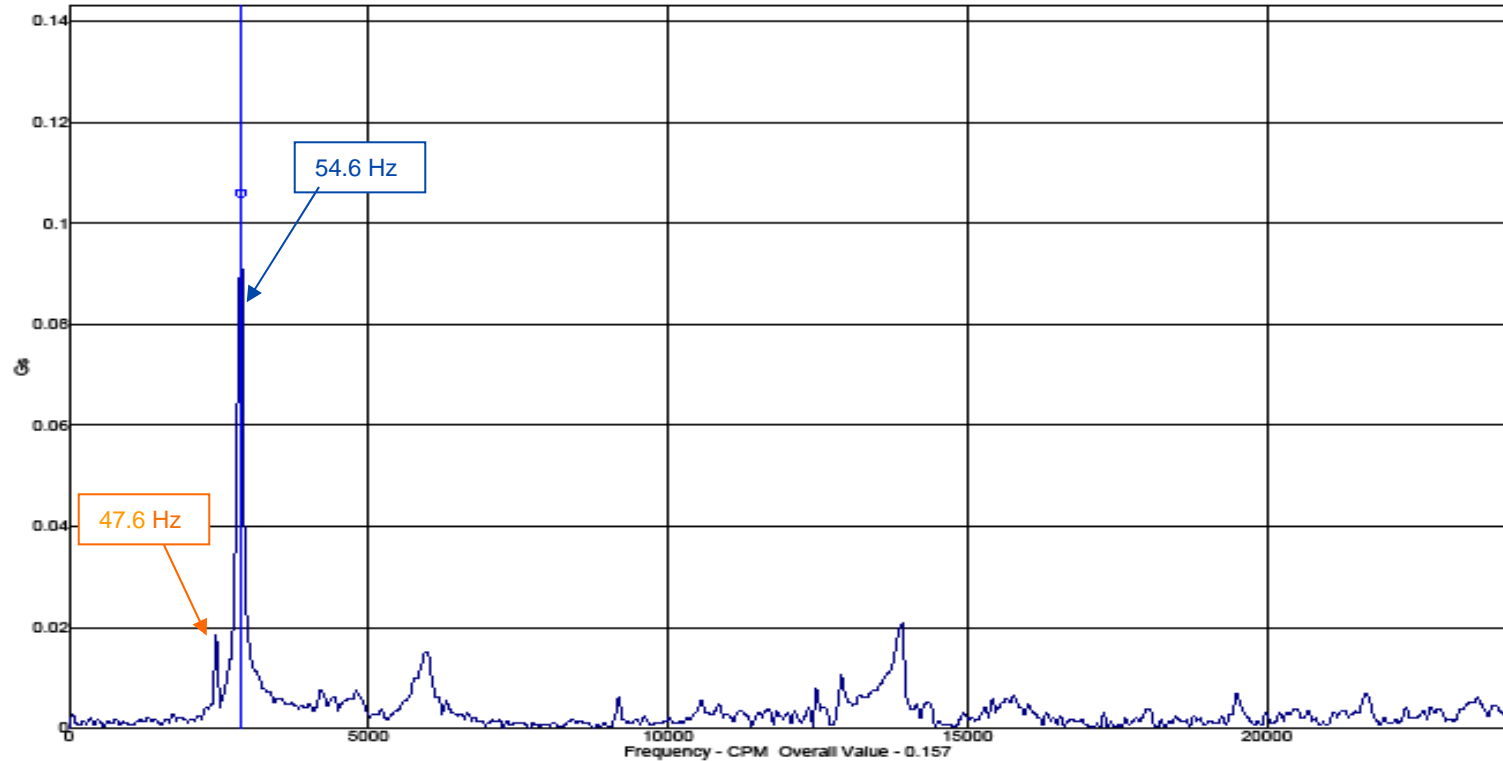


Torsional Mode 42 Hz



"Hula" Mode 52 Hz

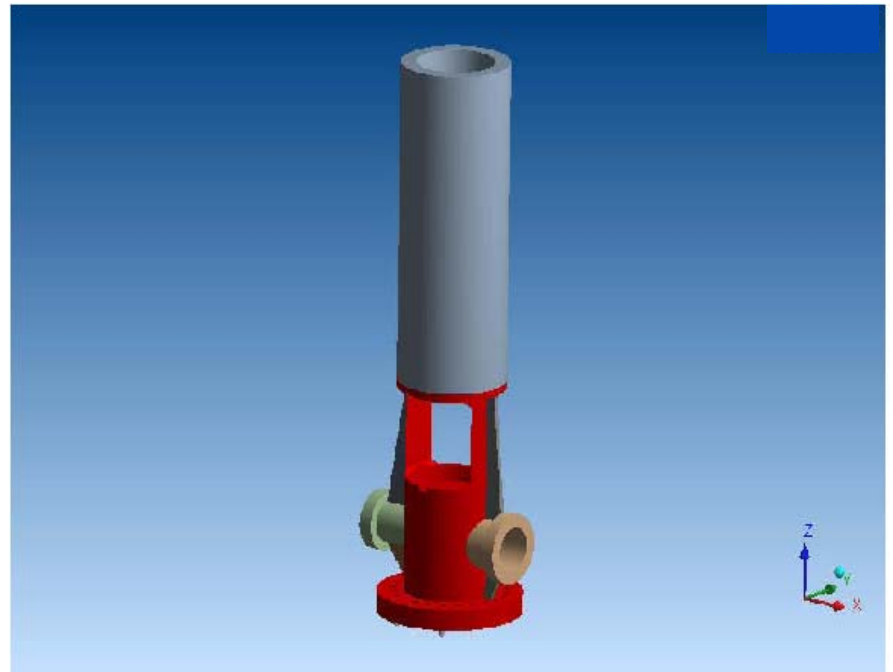
1st Modification – Bump Test Response



Natural Frequency Changes to Motor/Pump-head and Effect on Running Speed Overall Vibration

	Modification Description	Torsional Mode (Hz)	1 st "Hula" Mode (Hz)	Overall Vibration (in/sec pk)
Original	None	56.5	62.8	~1.0
First Modification	Increase window size of pump-head	47.6	54.6	~0.76

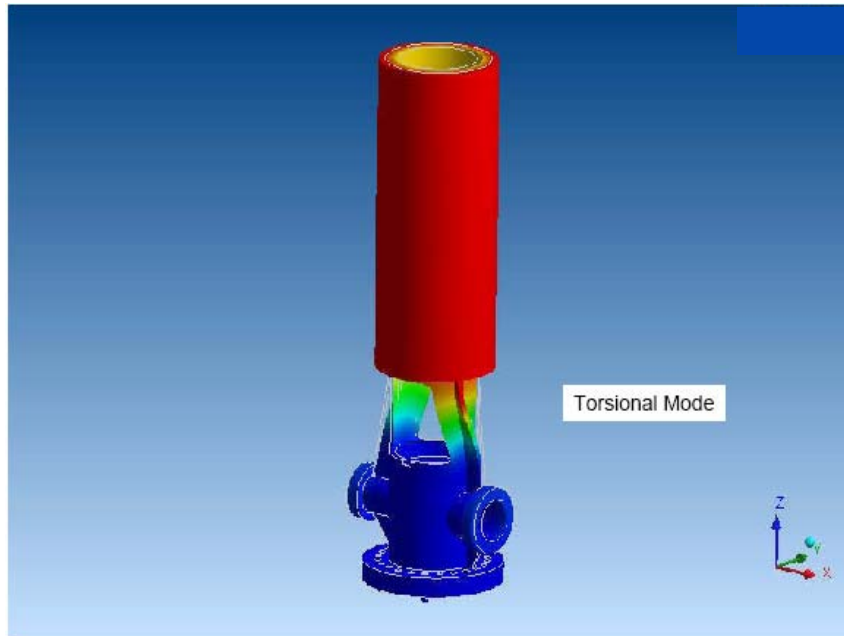
2nd Modification – Stiffening Gussets



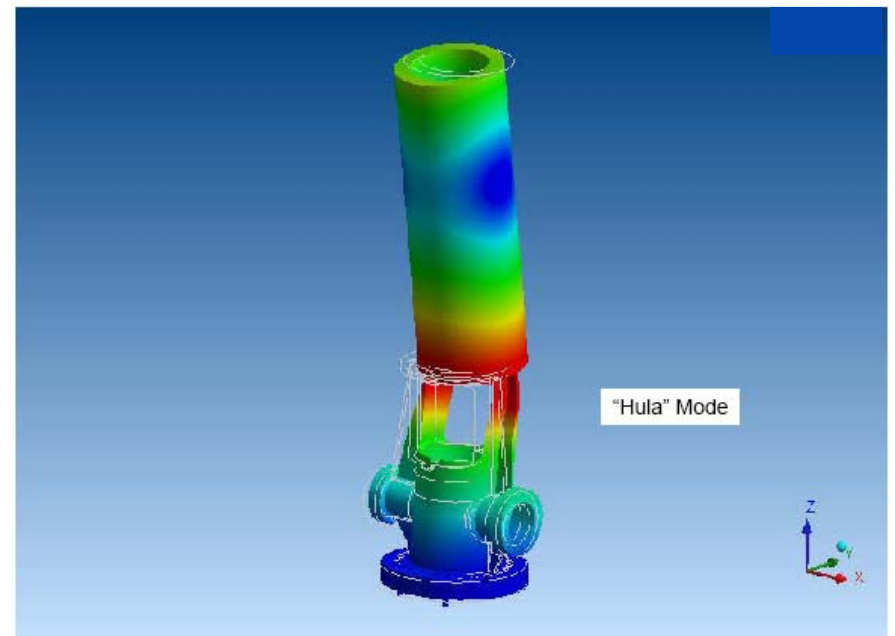
Motor-Pumphead FE Model
w/ gussets

2nd Modification – Stiffening Gussets

FEA Predicted Natural Frequencies

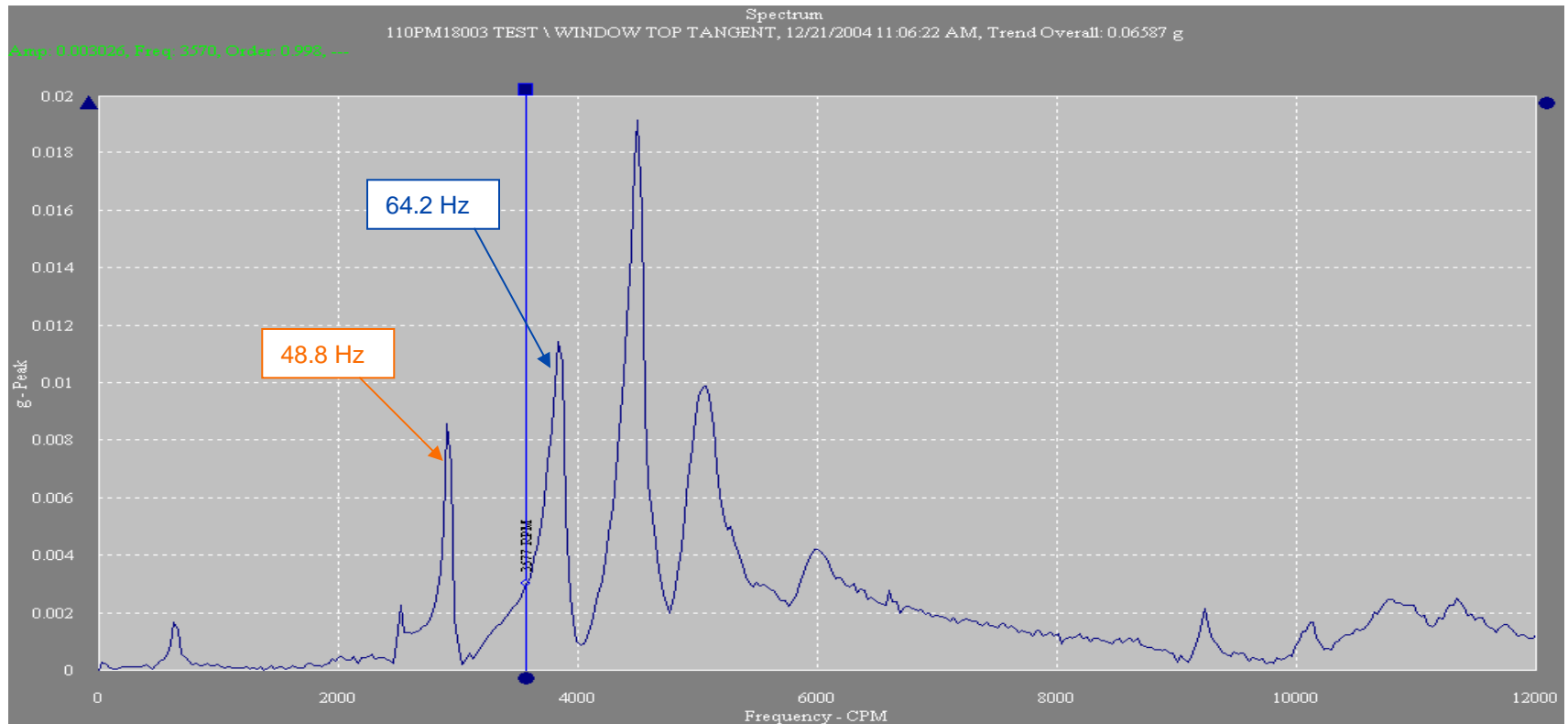


Torsional Mode 44 Hz



"Hula" Mode 85 Hz

2nd Modification – Stiffening Gussets



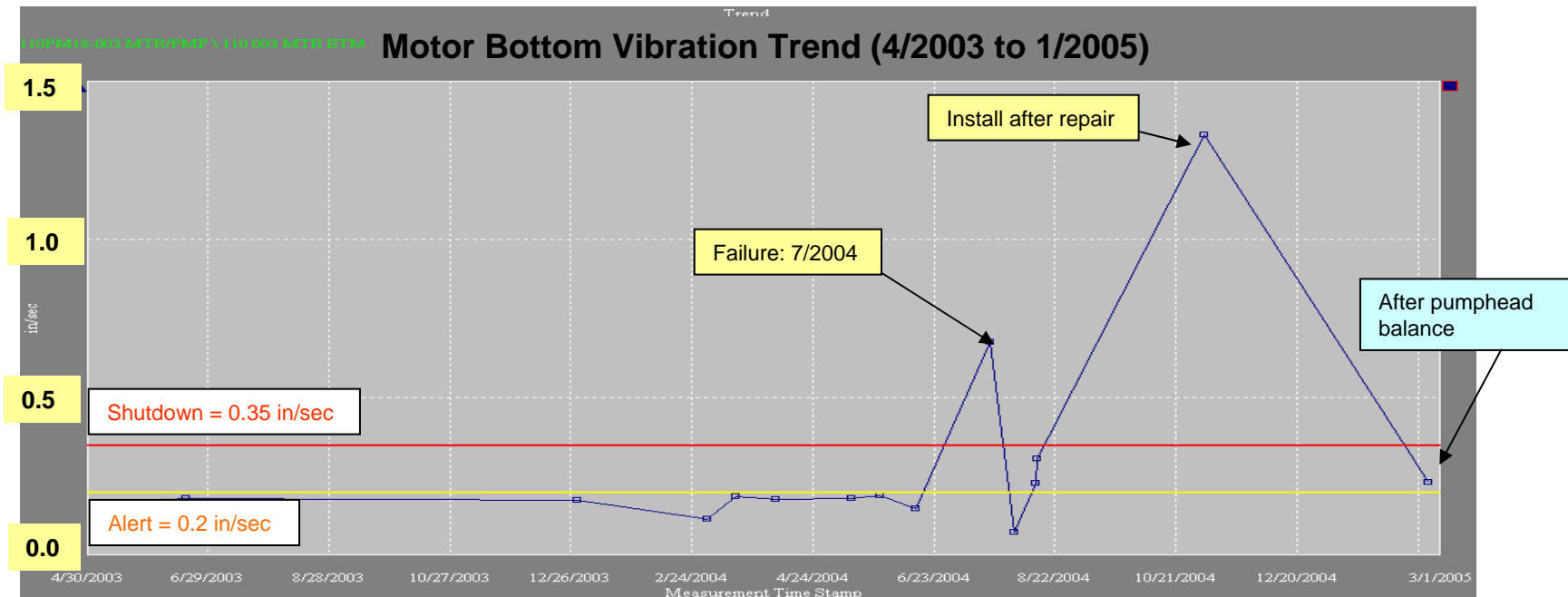
Natural Frequency Changes to Motor/Pump-head and Effect on Running Speed Overall Vibration				
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Original	None	56.5	62.8	~1.0
First Modification	Increase window size of pump-head	47.6	54.6	~0.76
Second Modification	Add stiffening gussets to pump-head	48.8	64.2	~1.01

Balancing Solution

- Detuning effort was not successful and consultant recommended new pumphead design.
- Since this motor had been running for many years with no natural frequency issues and sister pump of same design did not exhibit such behavior decision was made to attempt balancing motor on pumphead.
- Motor shop two-plane balanced motor to 0.1 in/sec. Top and bottom of motor were nearly 180° out-of-phase.
- Motor and pumphead were installed in the field and ran at 0.25 in/sec.

Balancing Solution

- Balancing on pumphead had not been attempted before because:
 - Balancing of the motor on rubber and steel to less than 0.1 in/sec was thought to be sufficient. After first repair attempt this criterion was lowered to less than 0.05 in/sec on this motor.
 - Balancing of the motor on pumphead could require that motor be matched to the pumphead.

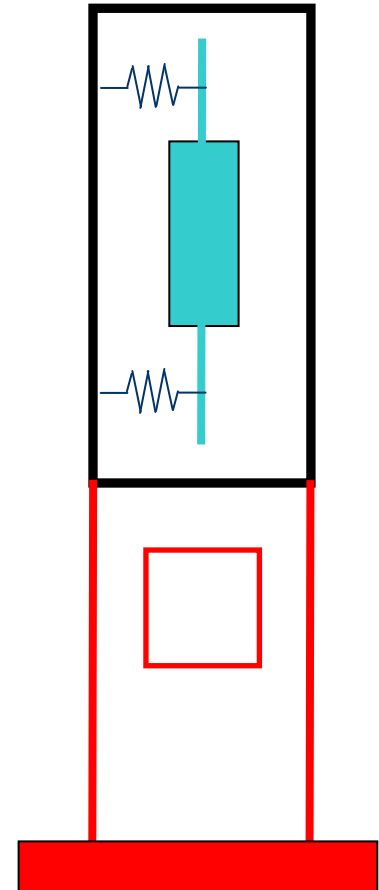


Why did Structural Modification not work?

- Natural frequency may not be root cause. This rotor and sister rotor never experienced problems before.
- This problem has been observed on other repairs and on some new motors (3600 RPM and 4160 V motors).
 - a) Pumphead was swapped for totally different design pumphead and high vibration persisted.
 - b) All exhibited 180° out-of-phase vibration between top and bottom of motor. All appeared balanced on rubber and steel.
 - c) Two-plane balancing on pumphead was difficult on some motors due to instability of balance vectors.
 - d) Balancing on pumphead was effective temporarily but very sensitive to coupling run-out and thermal sensitivity of rotor.

Why did Structural Modification not work?

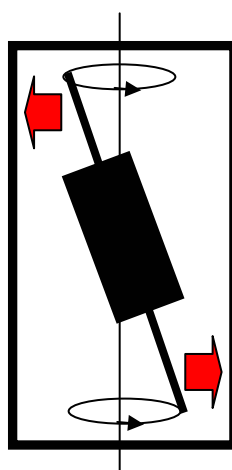
- FEA model did not include rotor generated forces, rotor stiffness and rotor support stiffnesses.



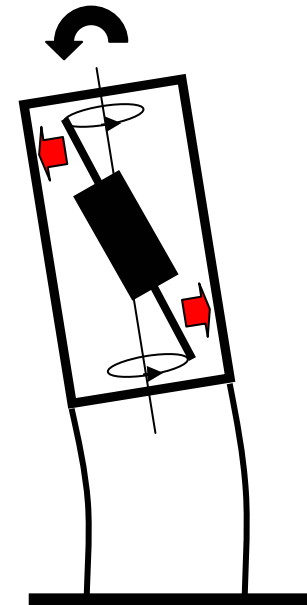
Why did standard balance procedure not work?

Need to couple balance suggests possible 2nd critical near running speed or very high couple unbalance.

- Rotor balance is a slow speed balance. Did not correct for couple unbalance present at 3600 RPM.
- Couple unbalance of 2000 lb rotor in 7500 lb stator did not produce significant vibration of assembled motor on rubber and steel.
- Motor rotor couple unbalance caused deflection of flexible pumphead.

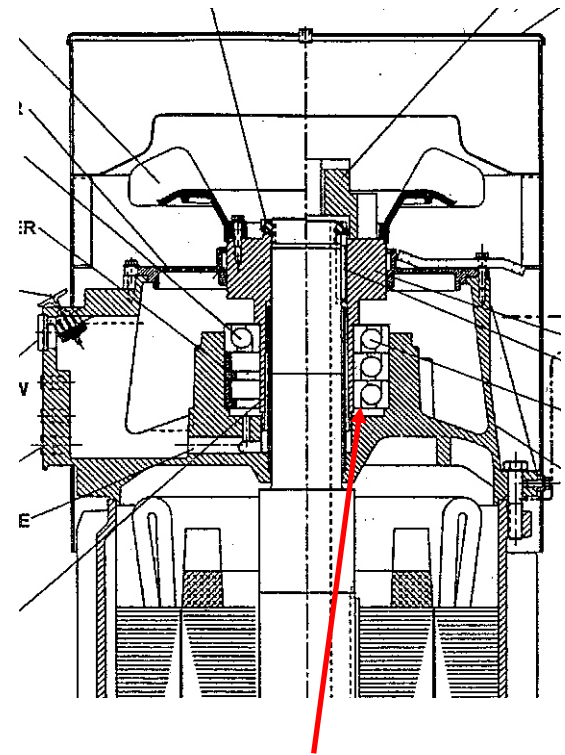


Conical Mode
(2nd Critical)



Possible Causes

- All these motor applications had high thrust bearing design consisting of 3 angular contact bearings (2 down, 1 up).
- Lack of precision of fits at upper thrust bearing could create high unbalance due to eccentricity.
- Insufficient down thrust causing improper loading of bearing and affecting stiffness.
- Other motor shop experience suggests significant attention needs to be paid to thrust bearing area during assembly with 3600 RPM high thrust motors.



High Thrust Bearing

Recommendations/Comments

- 1) Consider check balancing of 3600 RPM, 4160 V vertical high thrust motors on pumphead.
- 2) Close inspection of thrust bearing fits.
- 3) On some of the new motors that exhibited this problem it was found that installing a wavy washer above the bottom bearing stabilized the vibration.