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GEORGE R. BROWN CONVENTION CENTER

High Vibration Analysis of Eddy Current Drum Coupled Motor to a Vertical Centrifugal Pump – Solution Based on EMA, ODS and FEA

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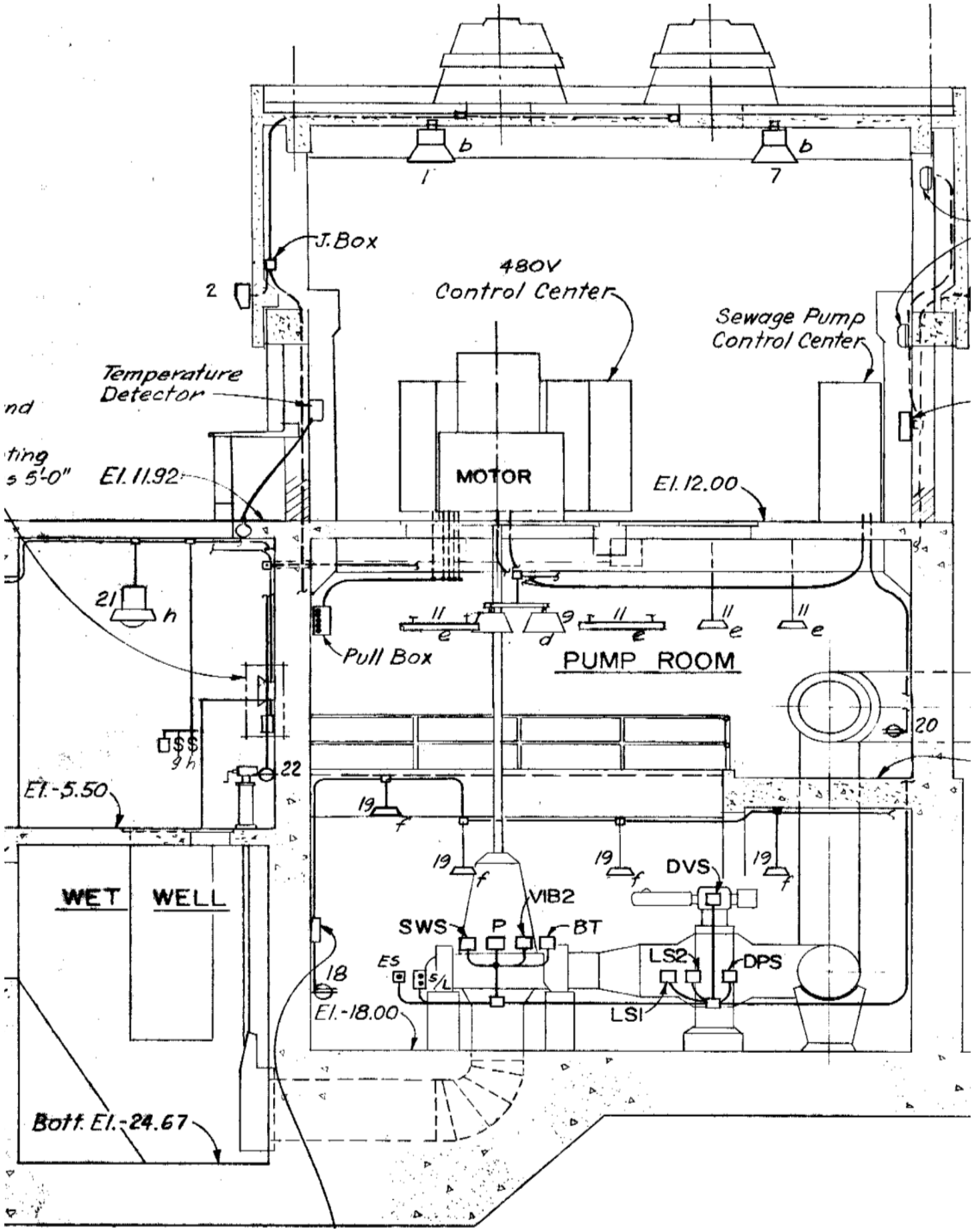
Biography – Juan D. Gamarra

- Mechanical Solutions, Inc. – Assistant Manager of Turbomachinery Testing – Senior Staff Engineer
- Focus on new rotating machinery development projects, as well as resolving difficult field machinery problems.
- B.S. & M.S., Mechanical Eng., Stevens Institute of Technology
- Co-Author of "Effect of Component Interference Fit and Fluid Density on the Lateral and Torsional Natural Frequencies of Pump and Turbomachinery Rotor Systems" - Proceedings of the Twenty-Ninth Pump Symposium
- Co-Author of "Drive Shaft Failure Analysis on a Multistage Vertical Turbine Pump in River Water Supply Service in a Nickel and Cobalt Mine in Madagascar" - Based on ODS and FEA - Proceedings of the Thirtieth Pump Symposium

Problem Statement

- The 35-year old pump station moves up to 43 MGD of raw wastewater to the city's treatment facility via two 1,500-hp high-capacity pumps for wet weather flows. After the motors were refurbished in 2011, excessive motor vibration occurred at certain pump speeds, thereby restricting the pumping system's ability to handle various flow ranges.
- After multiple field balances to the motors and coupling drums, the City of Tampa set out to fix the vibration issue, instead of putting on a "Band-Aid" (field balancing) every time the vibration levels exceeded their limits.
- Prior to any finite element analysis (FEA), cladding and extra bracing were added to supporting I-beam structure to reduce vibration. This only made matters worse.
- The goal became to use FEA to identify and implement a practical fix that worked over the pump operating speed range.

Outline Drawing



Motor

HP:	1000 or 1500
Volts:	4160
Phase:	3
Hertz:	60
RPM:	294 or 592
AMPS:	137 or 187
Weight:	44,000 lbs

Pump

Type:	Centrifugal
Application:	Gray Water
Speed Range:	228 to 590 RPM

* Eddy current coupling allows the constant dual speed motor to operate at pump range shown.

Photos

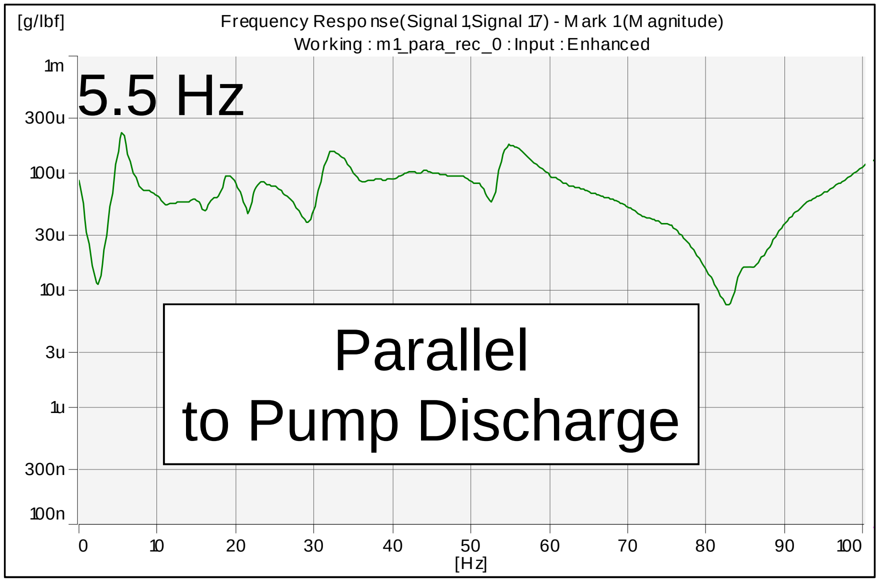
Top: Support added at motor base

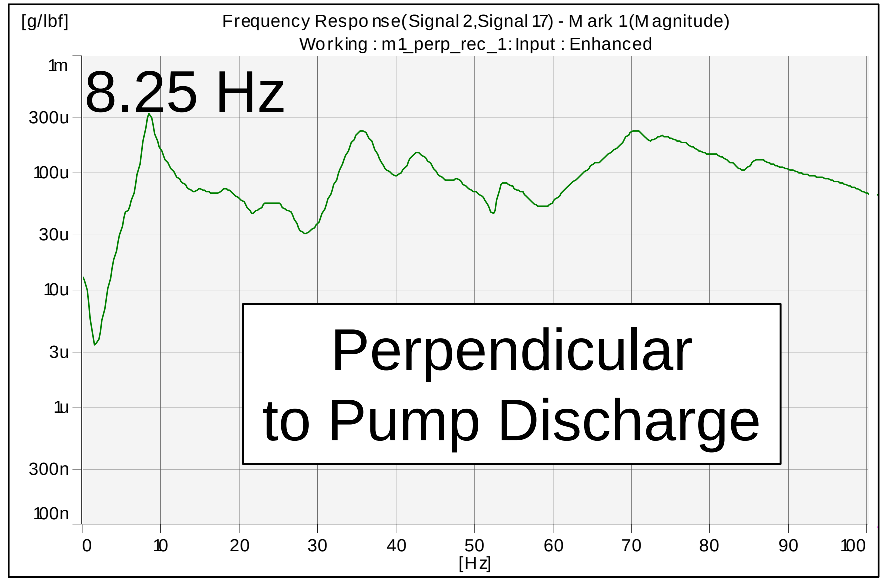
Left: Motor to Junction Box Connection Weld Crack

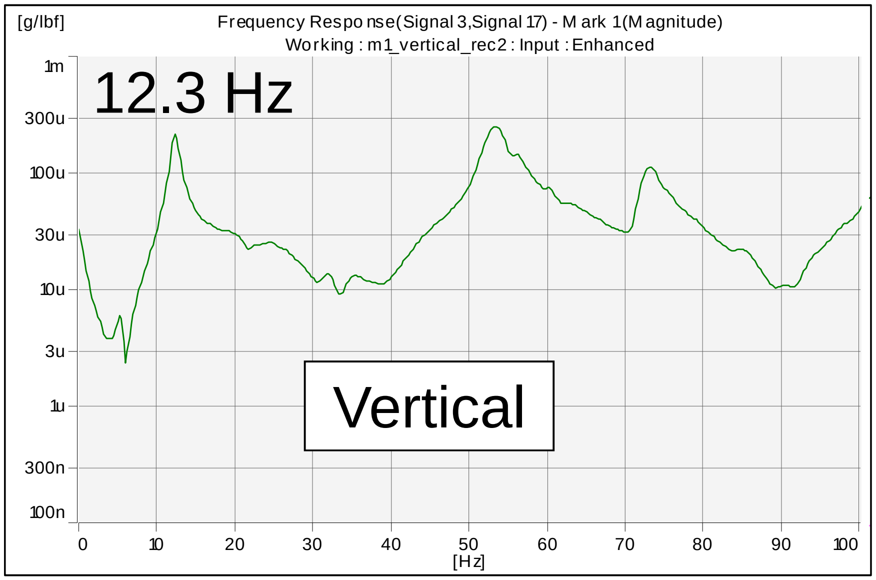
Analysis Method and Steps Taken

- Experimental Modal Analysis (EMA) data was collected to find natural frequencies of the different system components.
- RF telemetry strain gauges measuring torque were installed on the driveshaft of one pump.
- Time-transient vibration testing results on the motor, pump, and drive shaft were collected using accelerometers and proximity probes.
- An Operating Deflection Shape (ODS) test was performed to reveal dynamic behavior of the entire system.
- A test-calibrated FEA-based solution design approach was used to develop a fix with a high degree of confidence of success.

Experimental Modal Analysis (EMA)

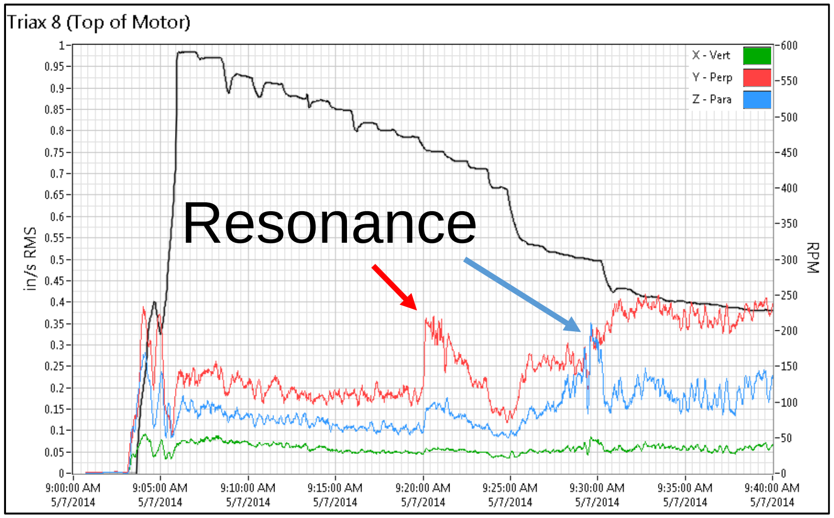


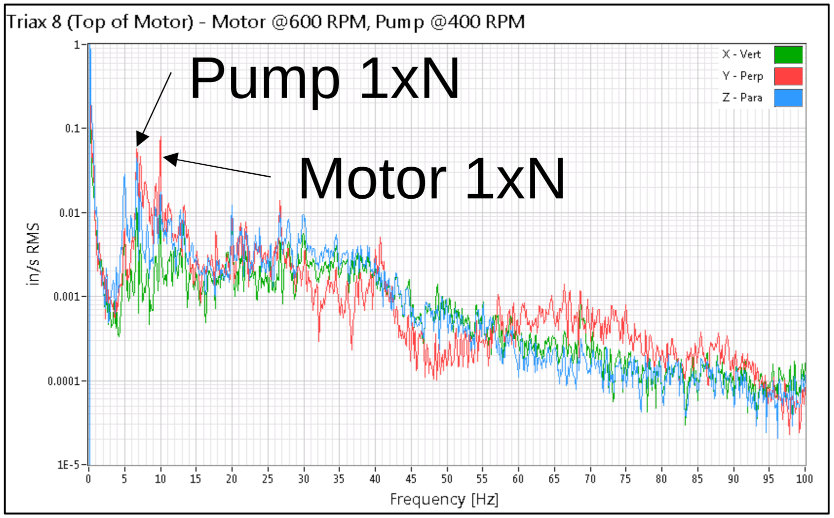


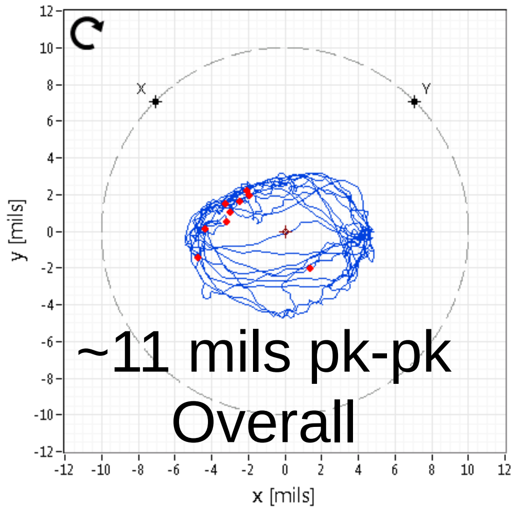


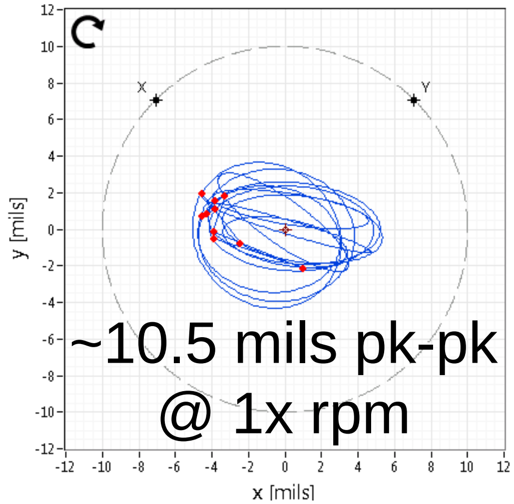
*Directions struck at the top of the motor with a modally tuned impact hammer. FRFs are of accelerometers located near and inline with impacts.

Condition Monitoring Plots





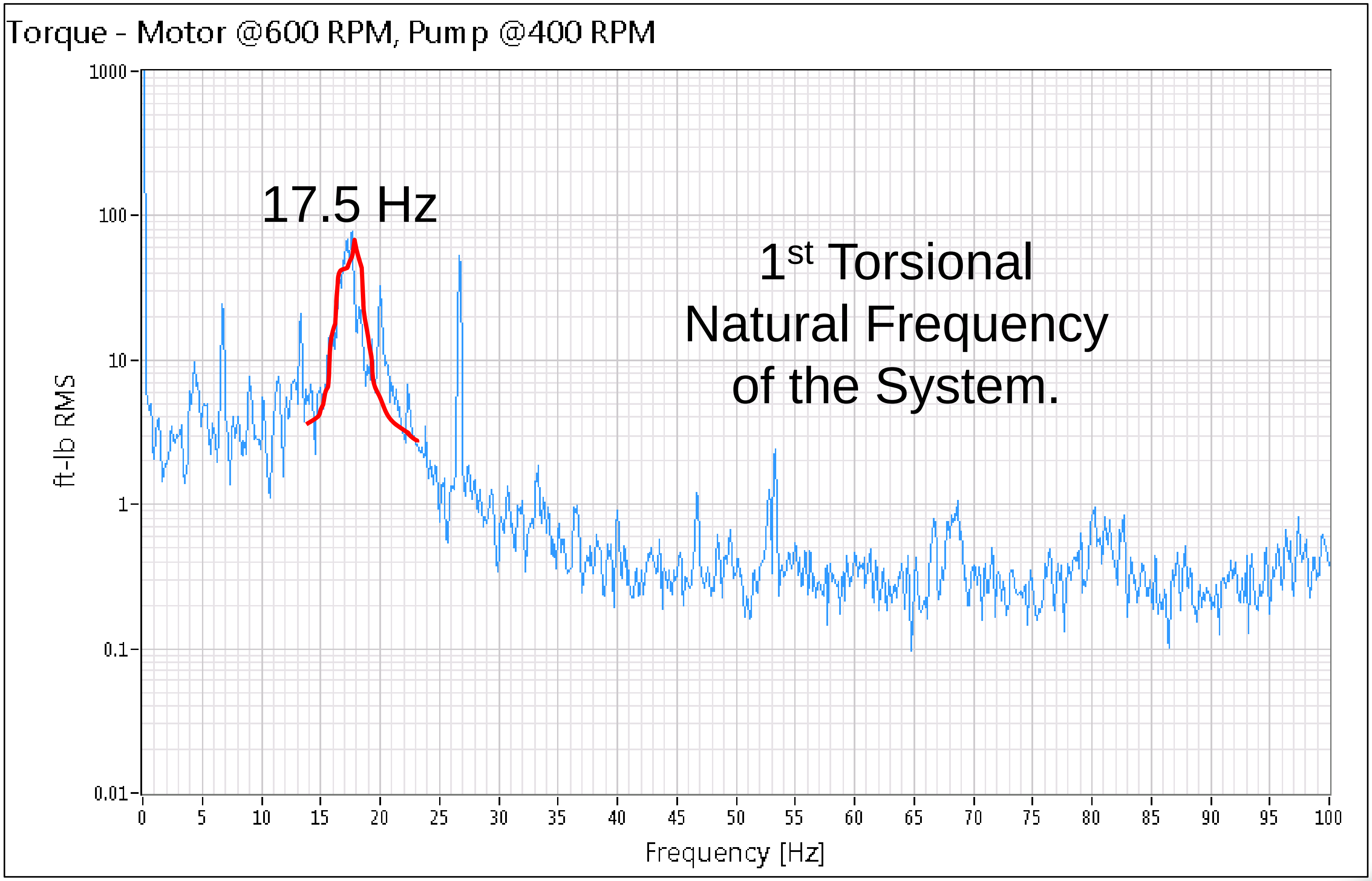




305 RPM (5.1 Hz)
450 RPM (7.5 Hz)

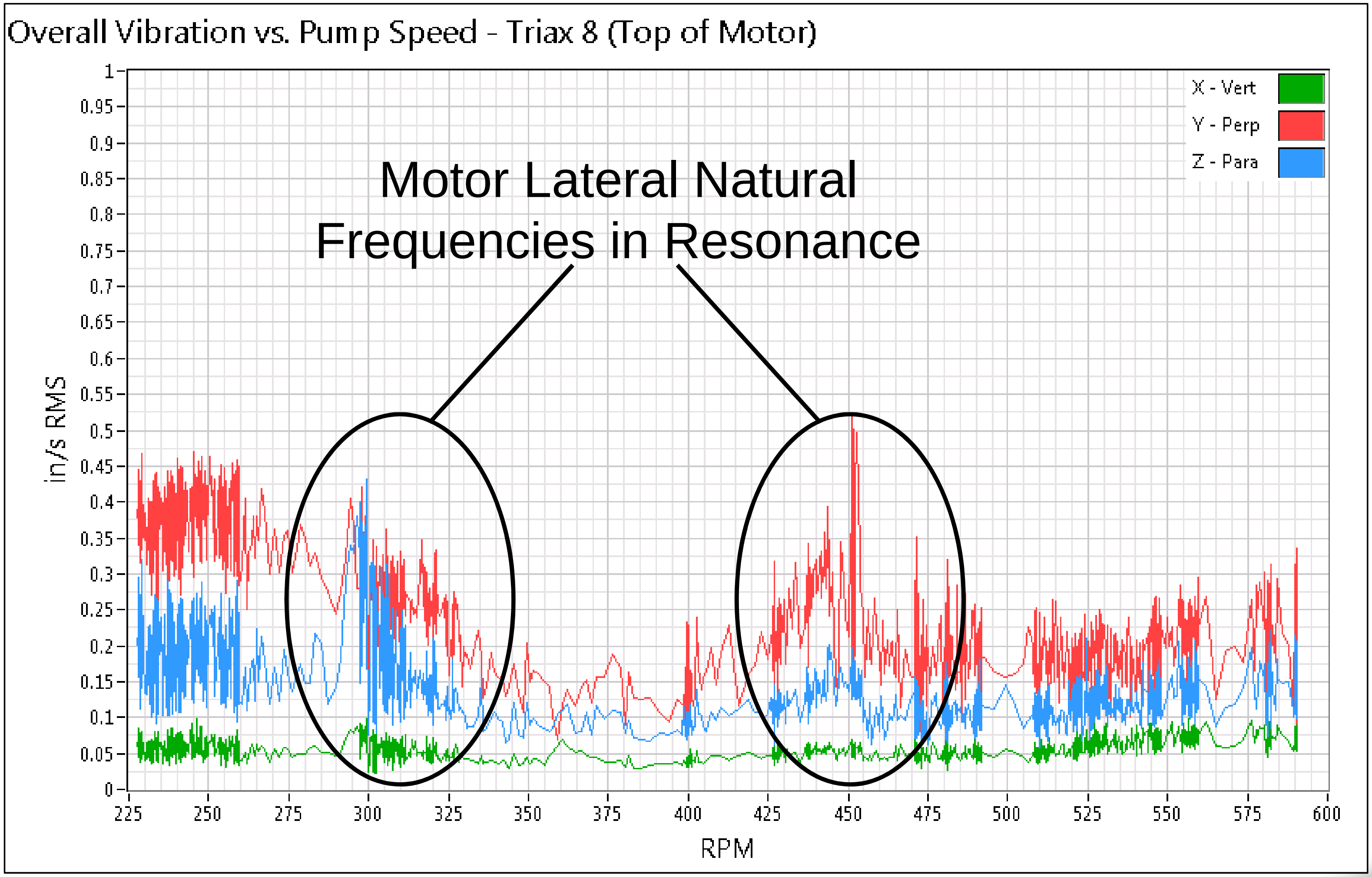
The radial proximity probes were located at the motor output shaft near the coupling.

FFT Spectra of Torque Strain Gauge



Since the torsional natural frequency was calculated to be 17.5 Hz, it was ruled out as a possible source of the elevated vibration.

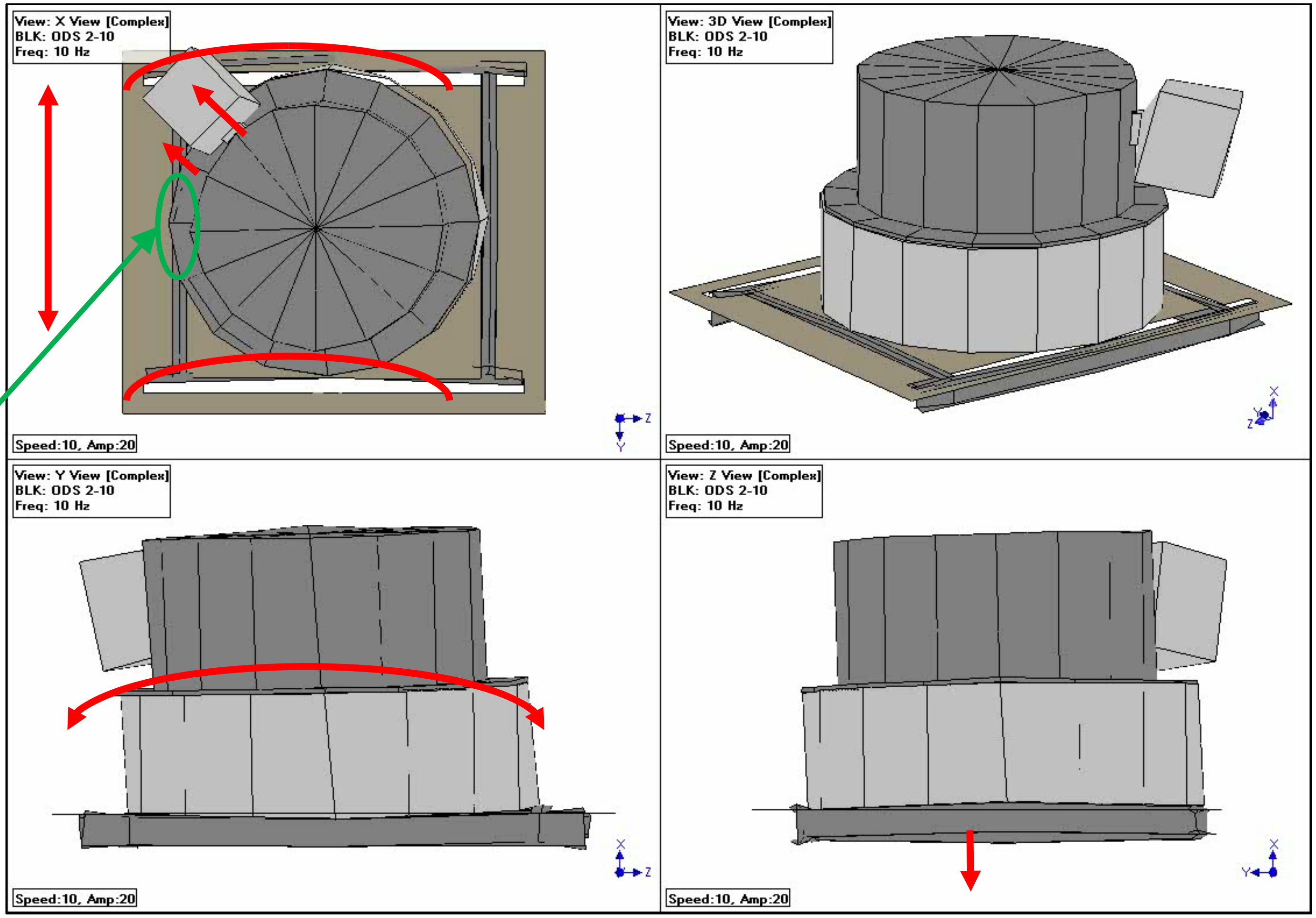
Top of the Motor Vibration vs. Speed



This speed vs. vibration trend plot shows that as the speed approaches the natural frequencies, the vibration gradually increases and vice versa.

Computer Model Using ME'scopeVES Software Plotting ODS Test Results

Bolted Connection Loose

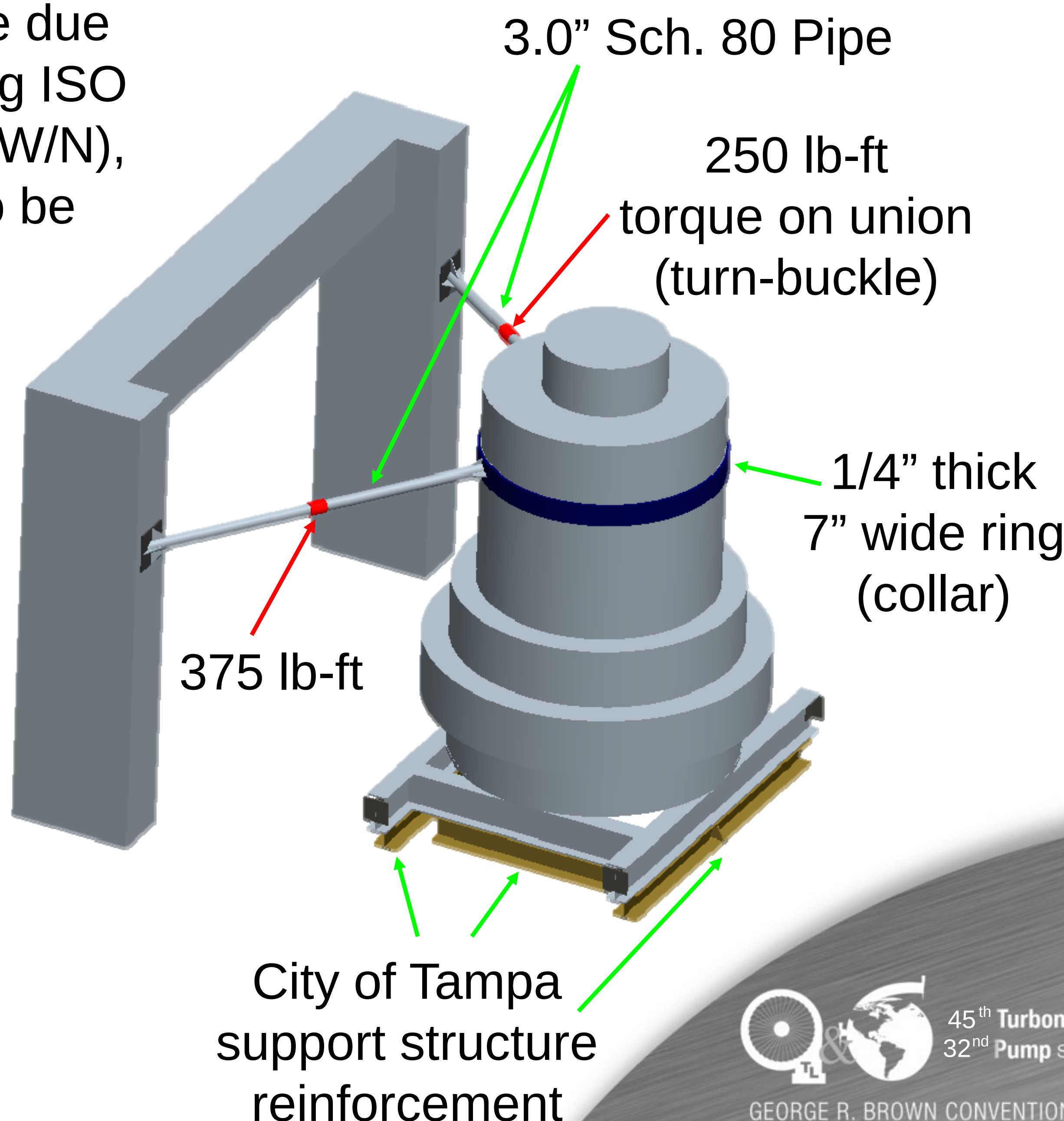


The ODS animation at 10 Hz indicated a strong motion of the motor swaying and jumping. It also indicated a loose connection between the junction box and motor.

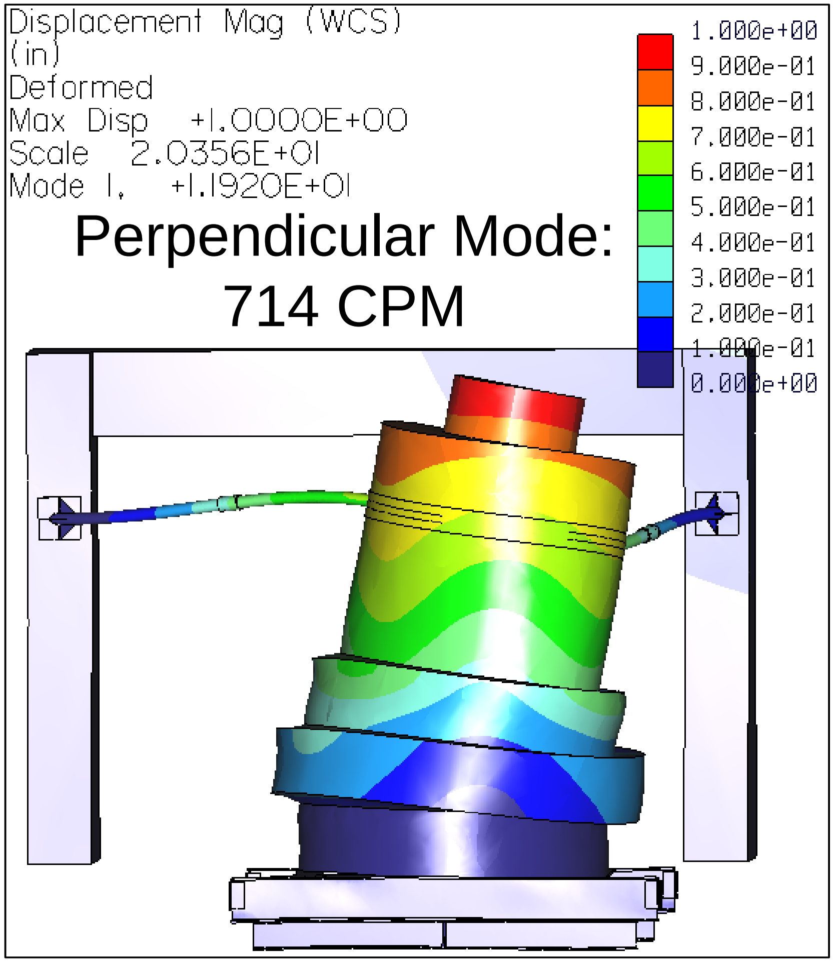
Modifications

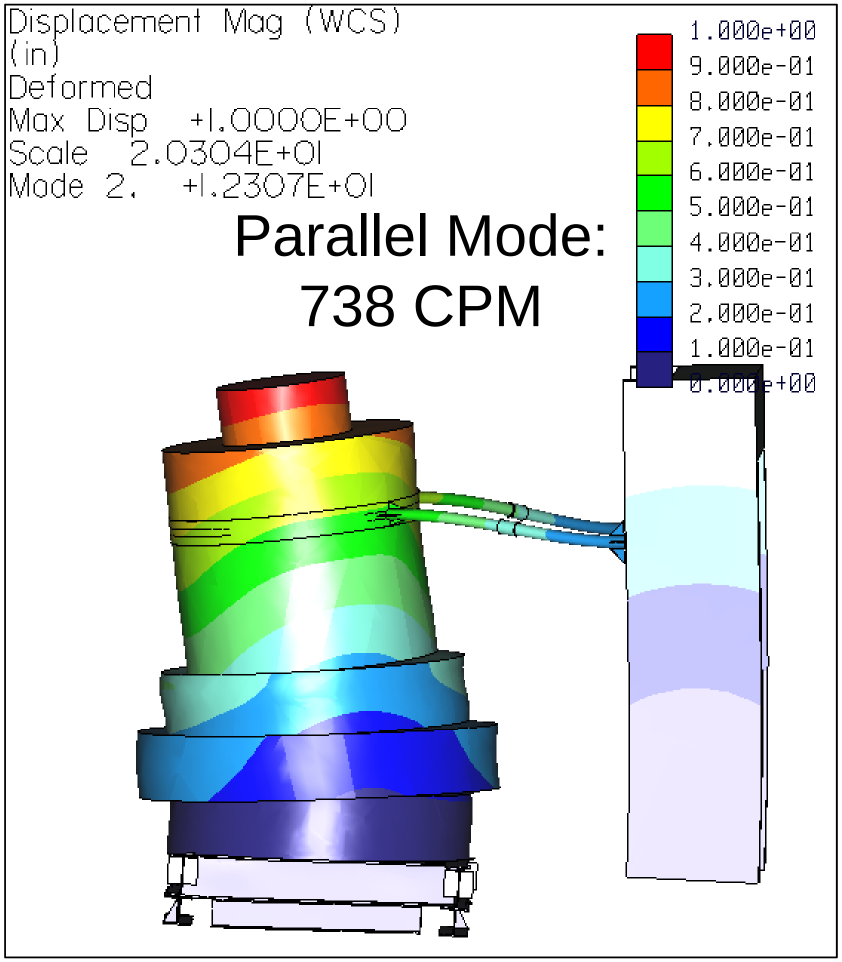
Based on the motor rotor weight and speed, the radial force due to residual imbalance using ISO G2.5 or four times API (16W/N), the radial dynamic force to be supported was calculated.

The struts were to be anchored at the existing concrete supports and welded to a fabricated ring around the motor. Turn-buckle pre-load "in compression" (pushing the bracket and the ring outwards) was produced by the torque applied at the coupling.



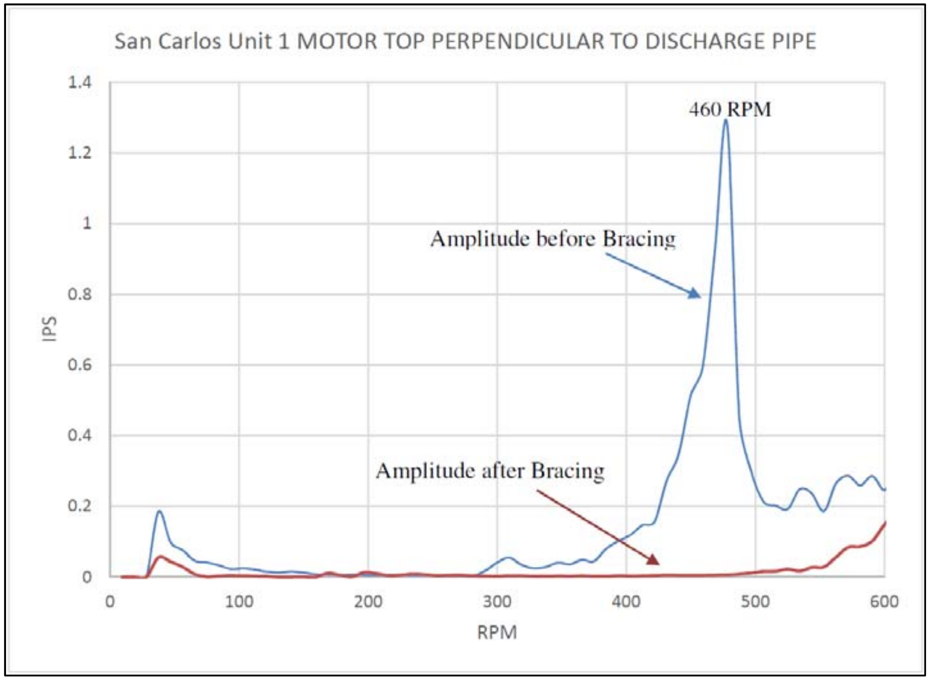
Finite Element Analysis

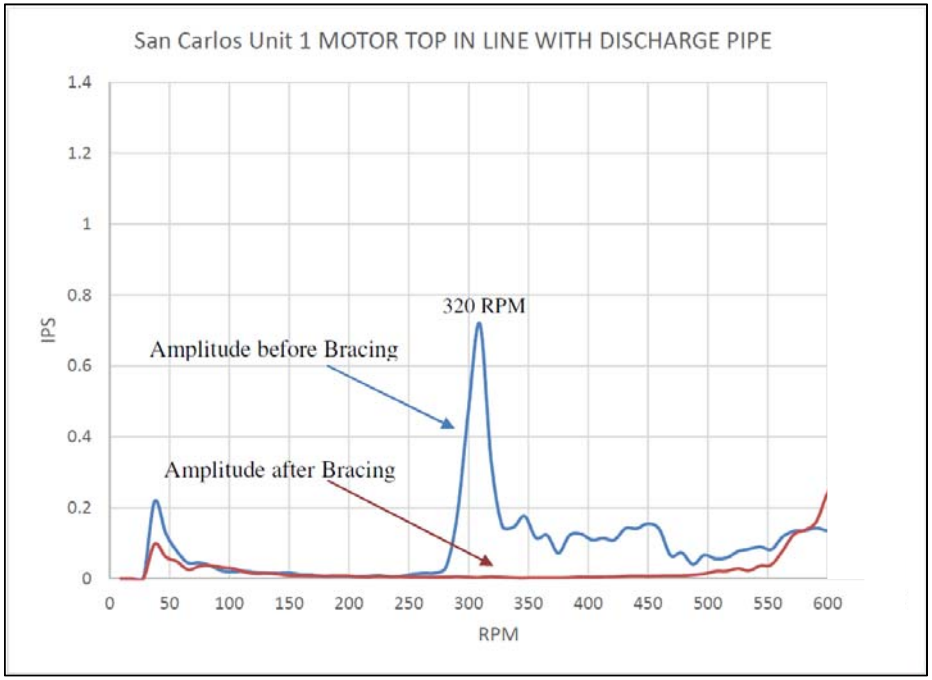




The lowest predicted FEA separation margin from the full motor speed of 600 rpm (10 Hz) was approximately 19%. This indicated the suggested modifications would increase the motor natural frequencies enough to prevent resonance.

Vibration Response Before and After Modifications





Wall Anchor

Turn-Buckle

Blue: Before
Red: After

Conclusions / Observations

1. The testing performed showed that the rocking structural natural frequencies of the motor were 5.0 Hz and 7.5 Hz in the parallel and perpendicular to the discharge pipe direction, respectively.
2. These natural frequencies were in resonance when the pump operated at speeds of 300 cpm and 450 cpm. There was no separation margin since the pumps operated from a minimum of 228 cpm to a maximum of 590 cpm. Both of these natural frequencies were determined to be in resonance with the running speed forcing function.
3. The vibration levels were not greatly excited due to the currently well-balanced rotor. From experience, this vibration would be amplified in the future as the imbalance load increases.

Recommendations/ Results

1. Test results were used to calibrate an FEA model to determine the effectiveness of various methods to increase the structural stiffness of the top of the motor in order to shift the problematic natural frequencies up to a safer separation margin of 15% above the running speed frequency.
2. Results of the analysis predicted that the addition of two steel struts (turn-buckles), going from a steel ring at the top of the motor to mounting plates on the concrete pillars, would shift the structural natural frequency above the acceptable 15% separation margin from the pump running speed.
3. Independent verification of the modifications by the City of Tampa before and after their installation showed a clear decrease in vibration throughout the pump operating speed range. The recommended fix worked as intended.

Note: The City of Tampa decided to weld the struts to motor, eliminating the need for a steel ring around the top of the motor.