Diagnosing and Correcting a Damaging Below-Ground Column Natural Frequency in a Vertical Pump Using Field Testing and FEA

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- **Co-Author Pump Vibration Chapter, McGraw-Hill Pump Handbook**

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- **Co-Author Pump Vibration Chapter, McGraw-Hill Pump Handbook**

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Case Study

By:

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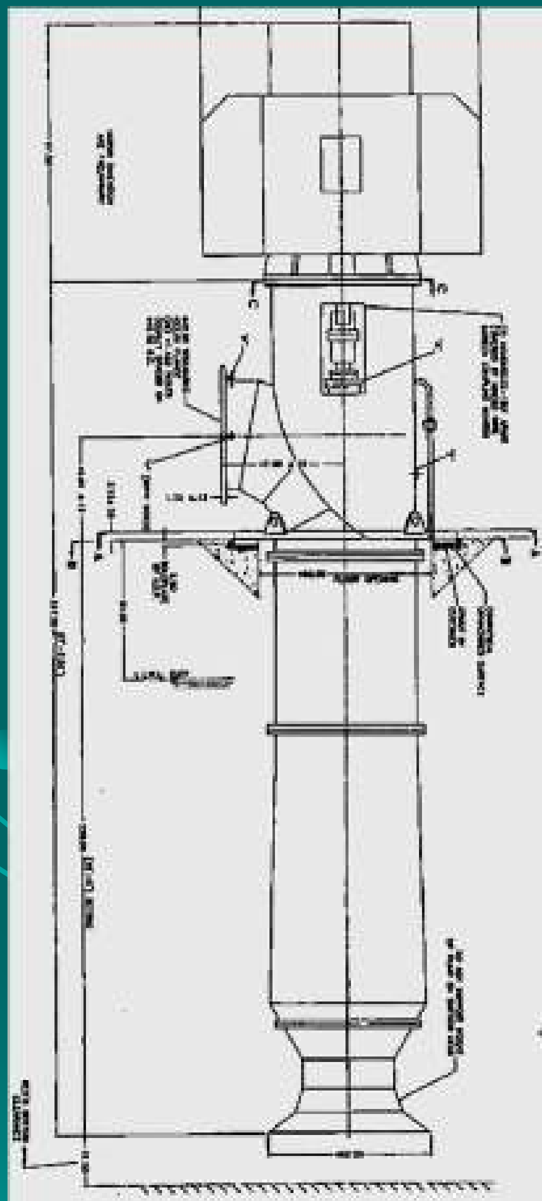
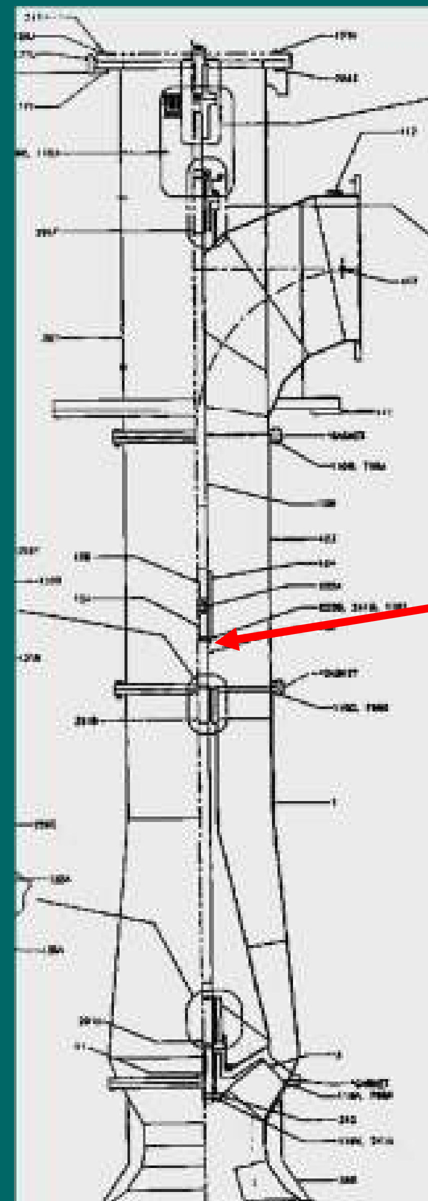
Background

- Two single-stage Circulation Pumps (VTP) installed in 2001 in a 480 MW coal-fired plant in OK, USA.
- The pumps were driven by 1,500 HP induction motors (23,550 lbm) at 510 rpm (8.50 Hz).
- The rated capacity: 66,000 GPM and 70 ft of TDH.

Background





Shaft
Failure

Background

- In 2008, acceptable vibration (0.10 in/s pk) in two orthogonal directions was measured at the top of the motor. The amplitude increased gradually over the next 2.5 years. Within this period, the pump shaft failed in December 2009 (5.5 inch diameter at the upper end of the pump shaft coupling). Before the failure, the vibration was approximately 0.20 in/s pk. In addition, there were only a few of the upper column flange bolts remaining in place, and there was minor rubbing detected at the tip of the impeller vanes. During this period, when the pump was sent out for repair, the soleplate was replaced.
- After the pump was re-installed in March 2010, the vibration was around 0.20 in/s pk, then it started to increase quickly reaching the alarm level of 0.40 in/s pk in the mid-2010.

Background

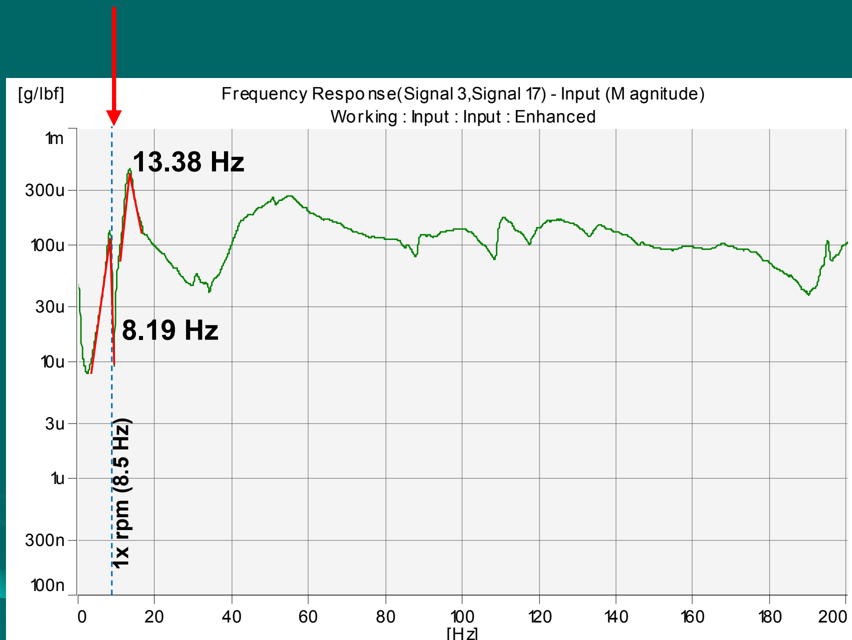
- In order to achieve an adequate level at the mounting flange of the motor (April 2011), variable thickness shims were required between the discharge head and the soleplate to reduce the vibration.
- Vibration was also susceptible to the discharge pressure. By throttling the valve, the response in vibration amplitude was favorable (lower).

Vibration Testing, Analysis, and Solution Methods

- Experimental Modal Analysis (EMA) test to determine the natural frequencies of the pump structure.
- Operating Deflection Shape (ODS) testing during steady operation.
- Finite Element Analysis (FEA) calibrated to the installed field data to test practical fixes.

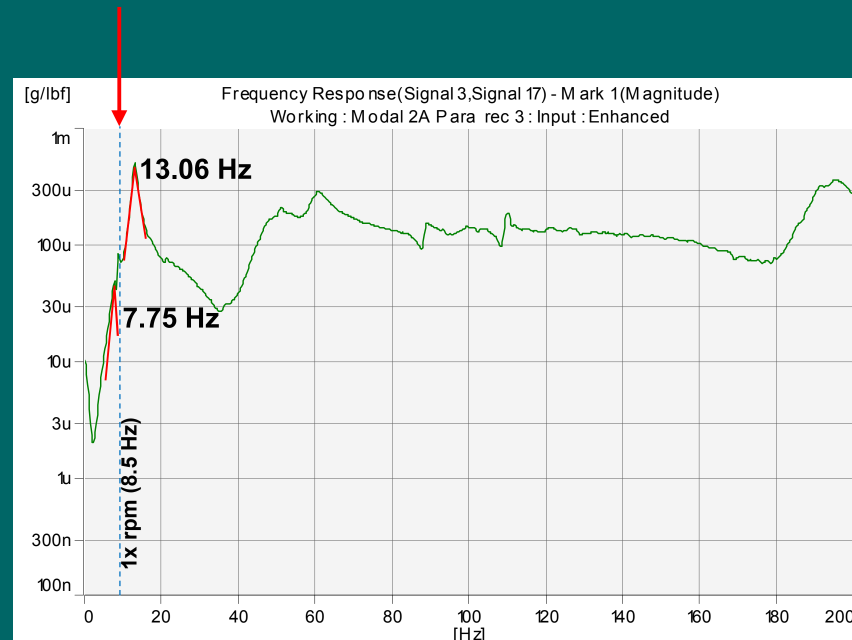
Experimental Modal Analysis (EMA) Test Results

Running speed (8.50 Hz)



Motor Top Perpendicular

Running speed (8.50 Hz)

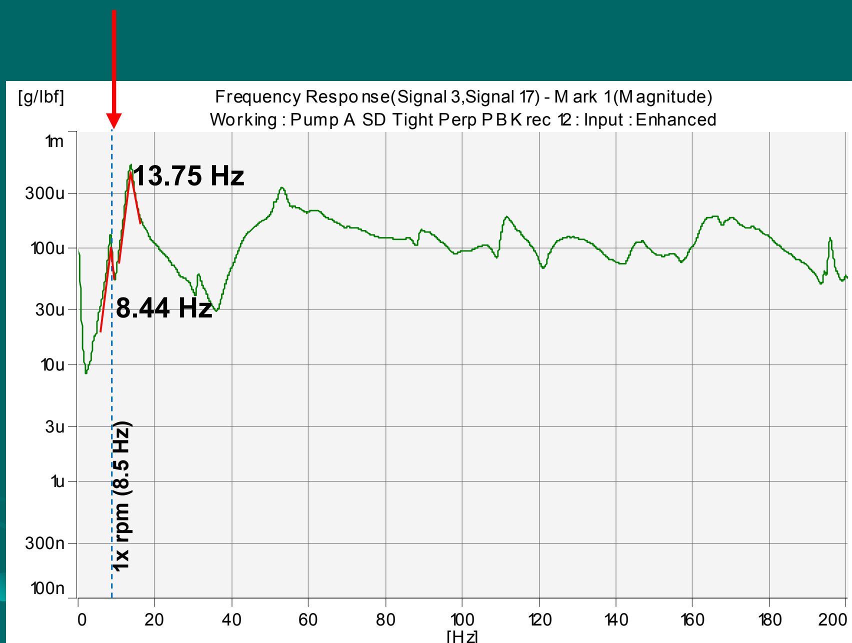


Motor Top Parallel

Pump A While Operating (Loose Pump)

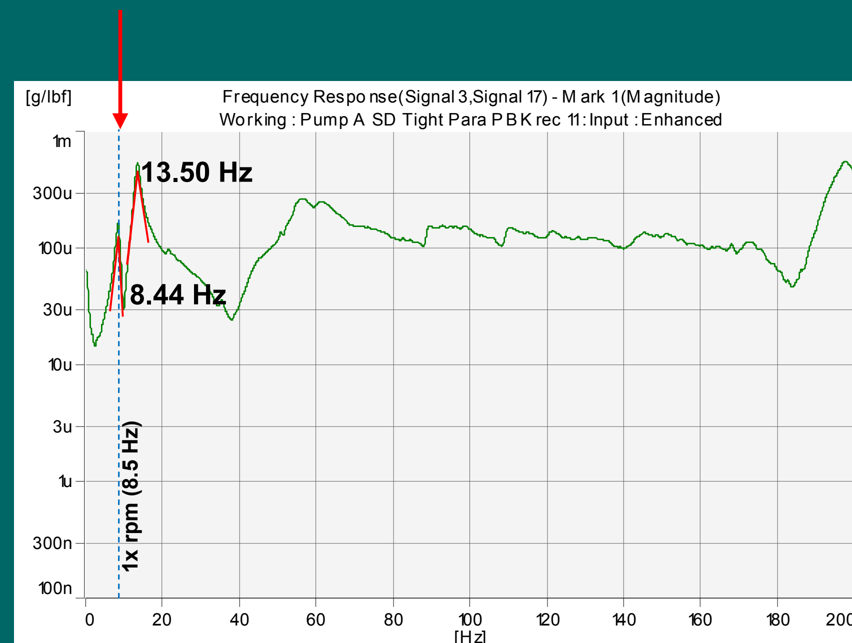
Experimental Modal Analysis (EMA) Test Results

Running speed (8.50 Hz)



Motor Top Perpendicular

Running speed (8.50 Hz)



Motor Top Parallel

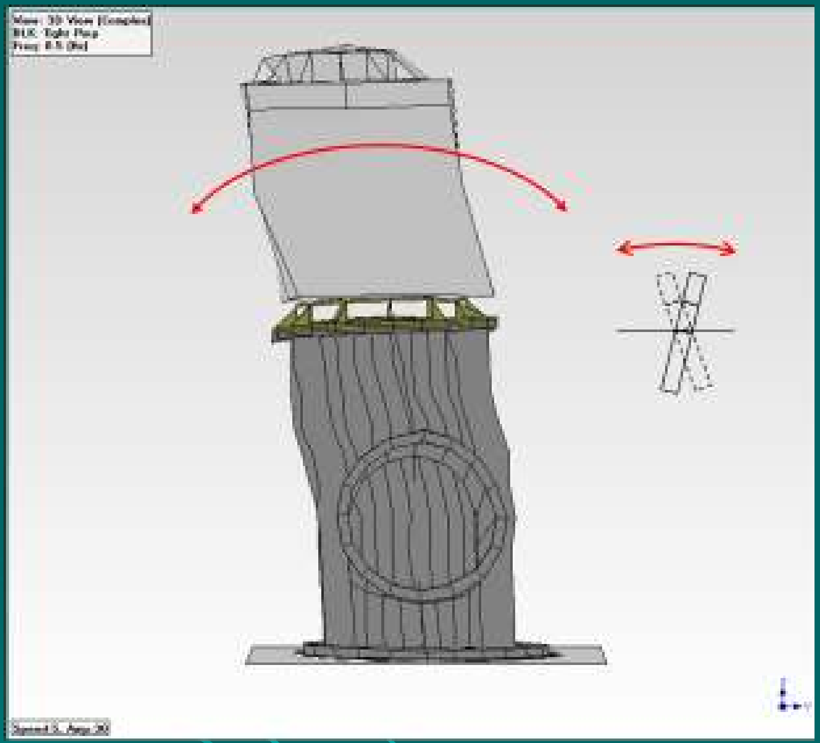
Pump A While Shut-down (Tight Pump)

Experimental Modal Analysis (EMA) Test Results

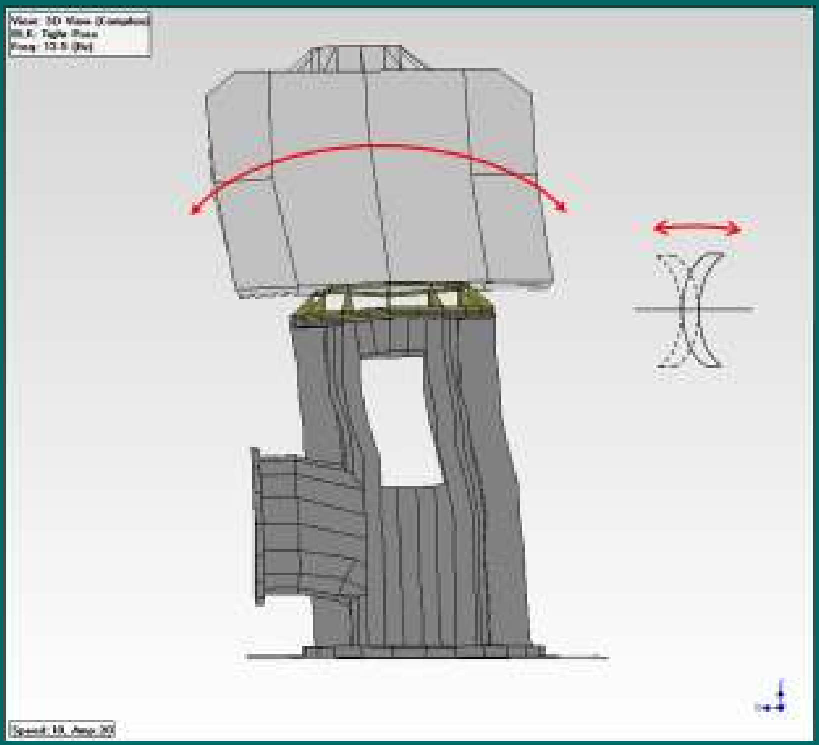
Structural Natural Frequency Summary Table

CWP Pump A	Structural Natural Frequencies (Hz)				Mode Shape
Condition	Perpendicular Direction	Separation Margin (%)	Parallel Direction	Separation Margin (%)	
Discharge Head Loose During Operation	8.19	-3.7%	7.75	-8.8%	Trunion Mode
	13.38	57.4%	13.06	53.6%	"C" Shape Mode
Discharge Head Loose During Shut-down	8.13	-4.4%	8.13	-4.4%	Trunion Mode
	13.44	58.1%	13.31	56.6%	"C" Shape Mode
Discharge Head Tightened During Shut-down	8.44	-0.7%	8.44	-0.7%	Trunion Mode
	13.75	61.8%	13.50	58.8%	"C" Shape Mode

Experimental Modal Analysis (EMA) Test Results

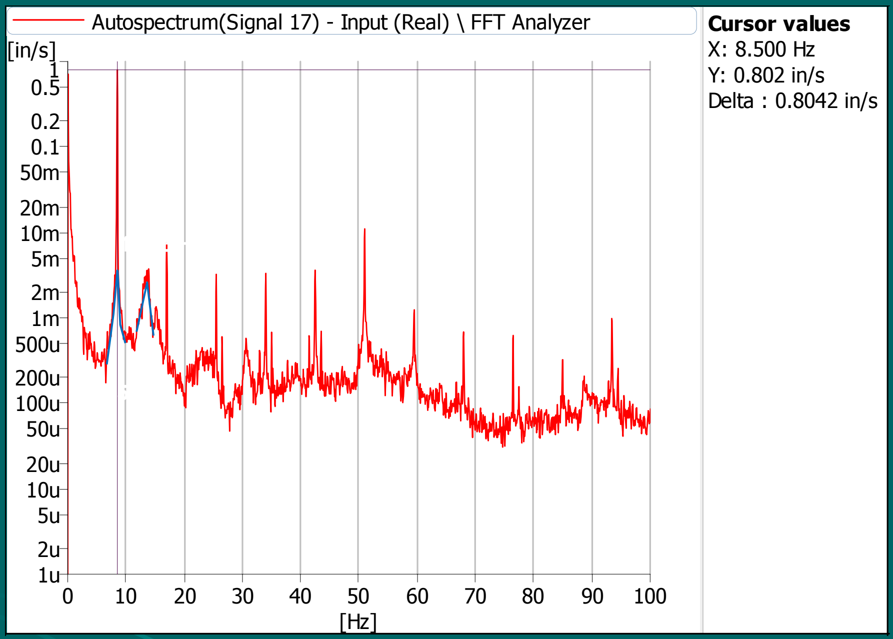


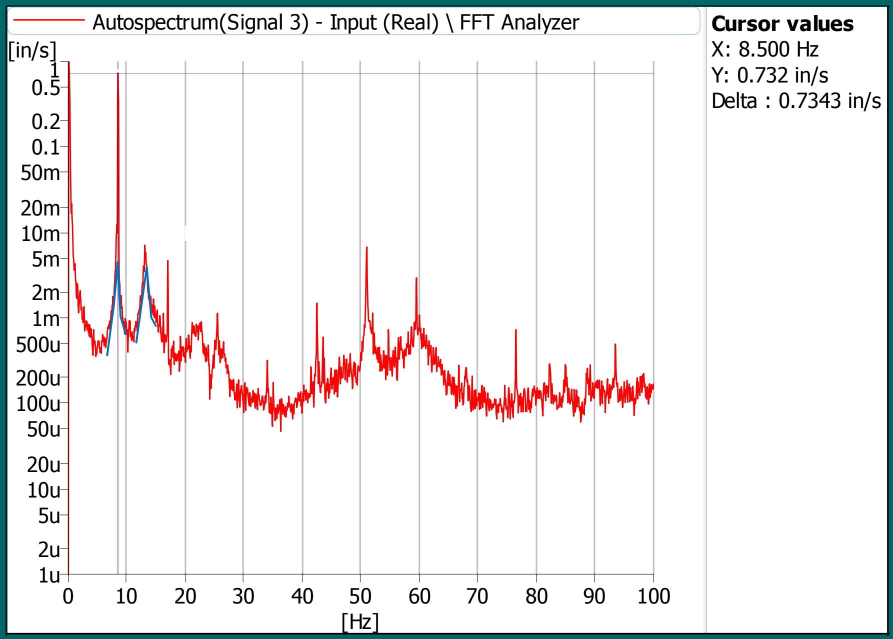
Trunion mode at 8.44 Hz in the perpendicular direction



Global “C” shape mode at 13.50 Hz in the parallel direction

Vibration Test Results





Motor Top Perpendicular
Overall: 1.13 in/s pk

Motor Top Parallel
Overall: 1.04 in/s pk

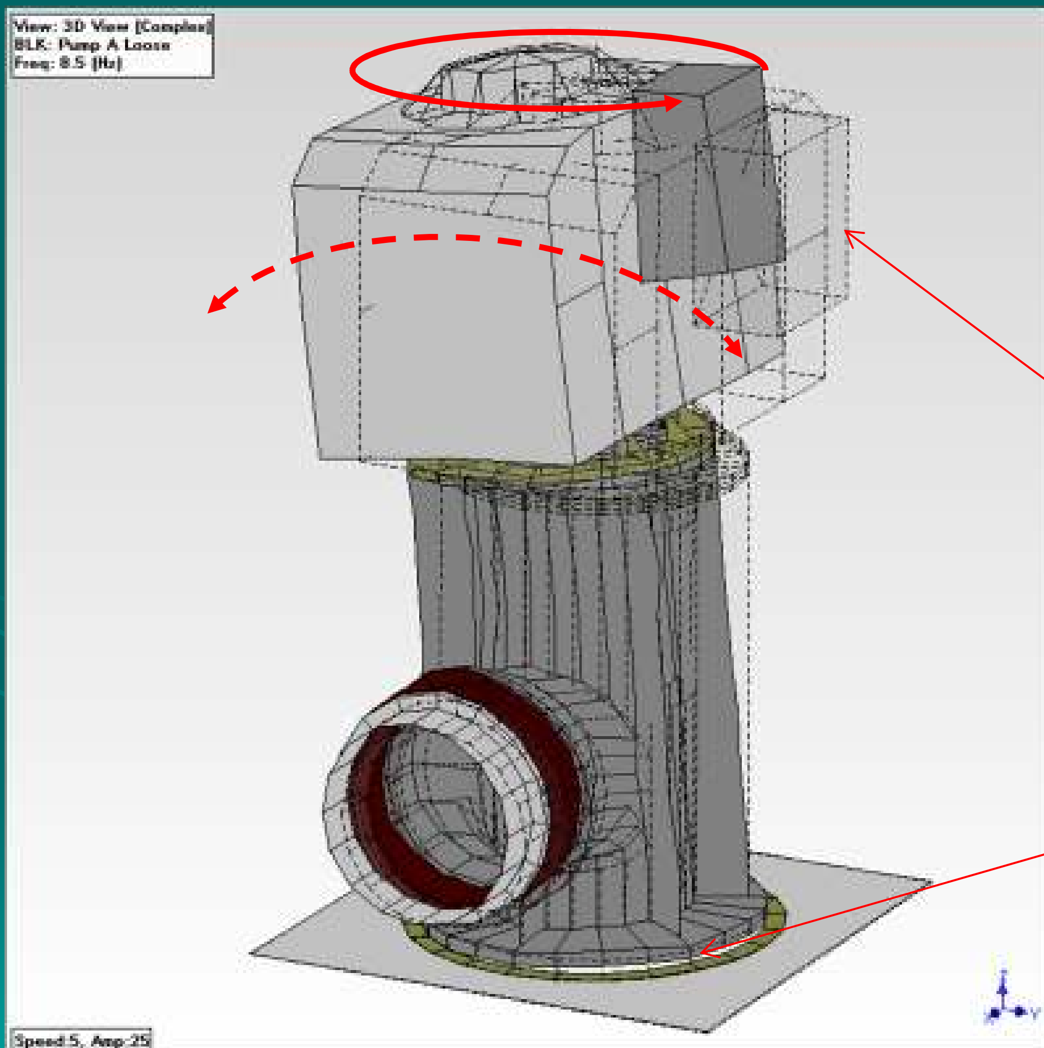
Pump A While Pump was Tightened to the Soleplate

Experimental Modal Analysis (EMA) Test Results

Vibration Amplitude Summary Table

Unit	Condition	Location / Direction	Vibration Amplitude (in/s pk)			
			Perpendicular		Parallel	
			1x rpm	Overall	1x rpm	Overall
CWP Pump A	Discharge Head Loose	Top of the Motor	0.766	0.767	0.470	0.471
		Top of the Discharge Head	0.337	0.338	0.326	0.327
	Discharge Head Tightened	Top of the Motor	1.131	1.134	1.032	1.035
		Top of the Discharge Head	0.488	0.525	0.448	0.451

Operating Deflection Shape (ODS) Testing



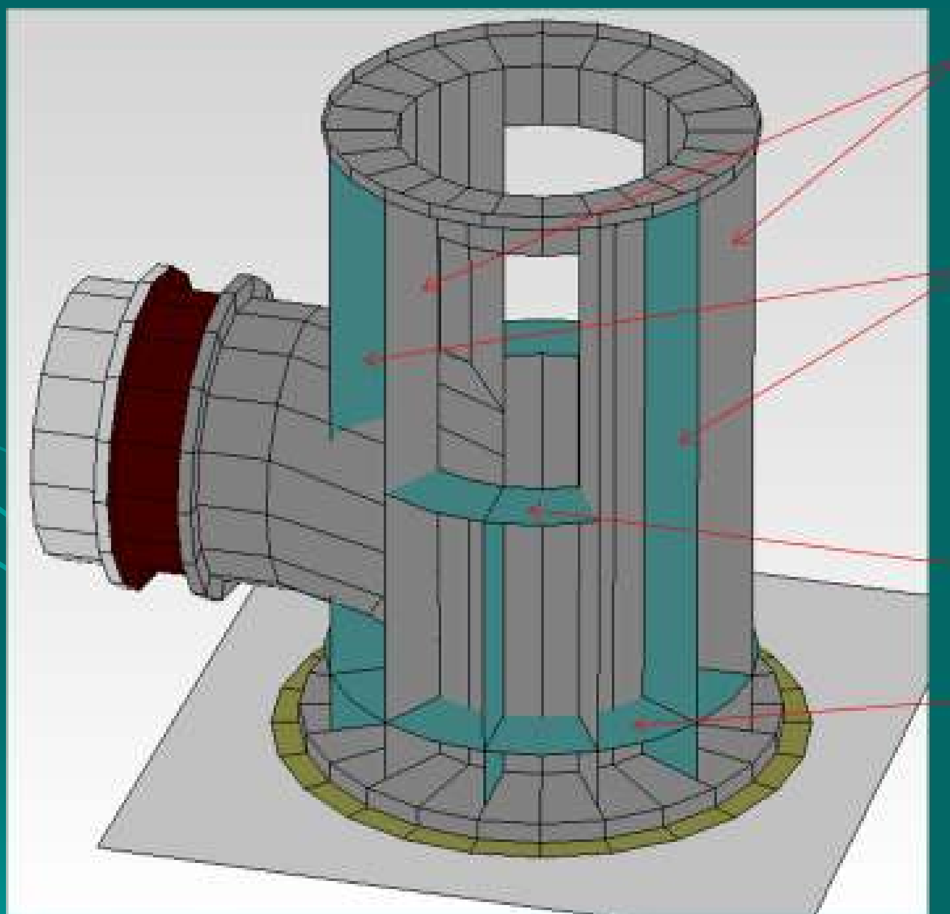
Discharge head mounting flange loosened to reduced the vibration amplitude at the top of the motor.

Orbiting motion at the top of the motor mostly in the perpendicular direction to the discharge nozzle.

Soft-foot all the way around the discharge head mounting flange due to shimming and looseness between parts.

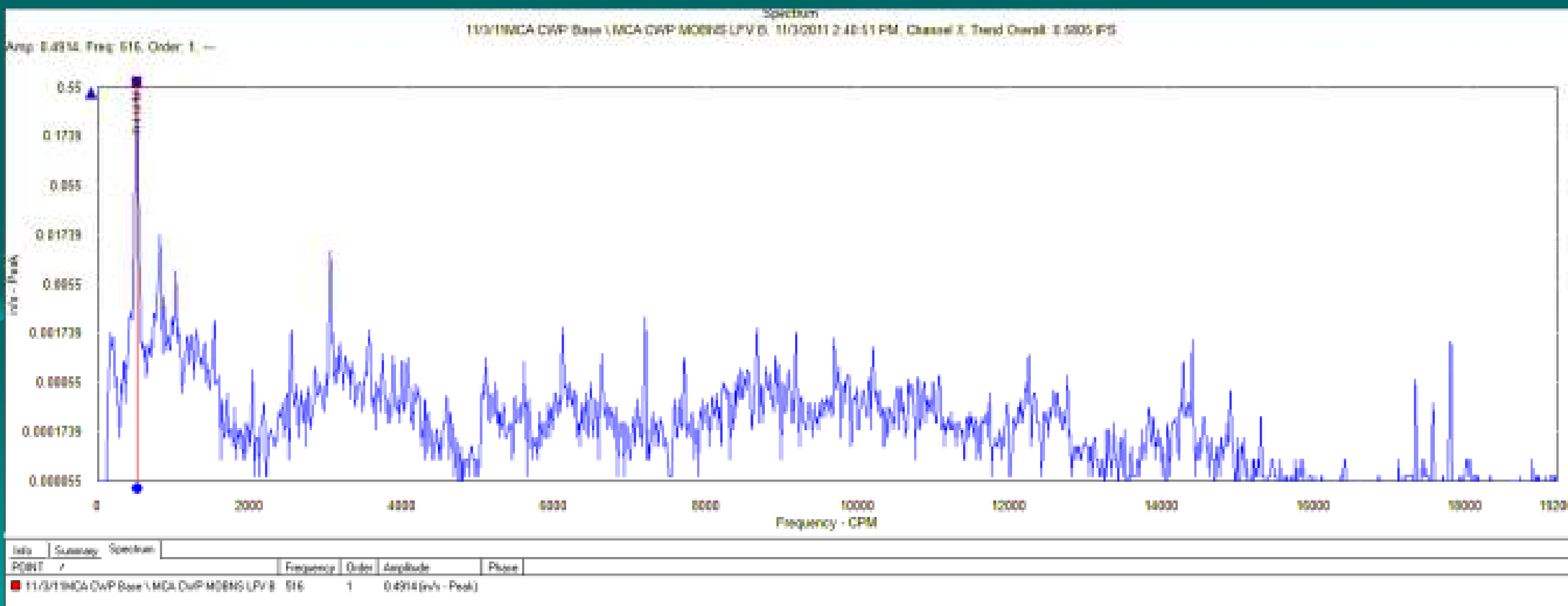
Preliminary Recommendations

- **Increase the stiffness of the discharge head**
- **Eliminate the looseness of the soleplate with respect to the concrete floor**



Follow Up Testing

- **50% reduction in vibration amplitude at the top of the motor, but still high (0.50 in/s pk).**
- **The increase in the above-ground stiffness did not shift the offending mode of the system as expected.**



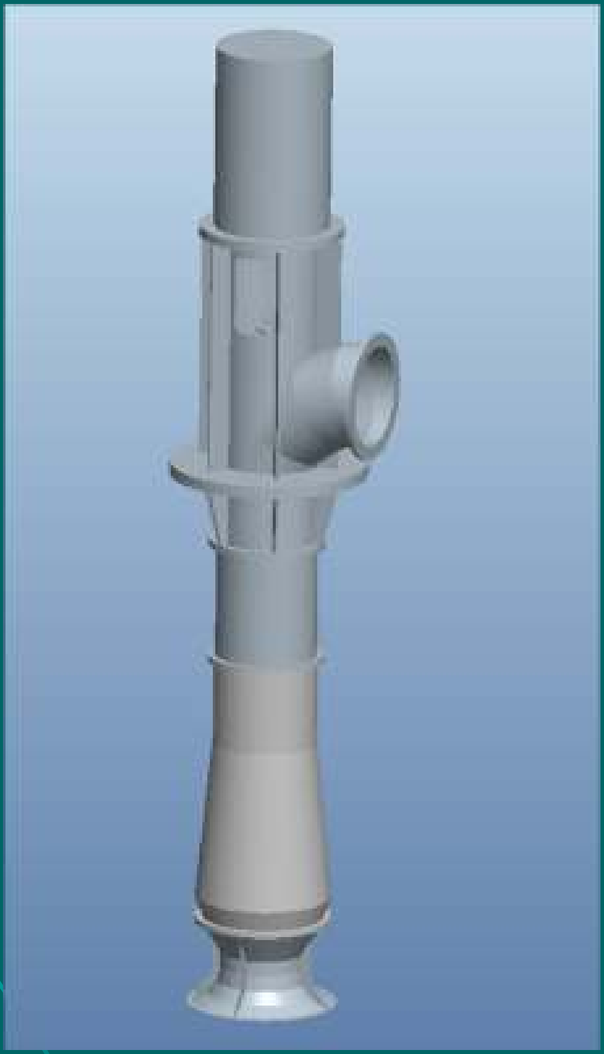
Follow Up Testing

- **Two months later, during the next outage the pump column was lifted from the sump, and a crack was identified in one of the lower gusset welds**

Follow Up Testing

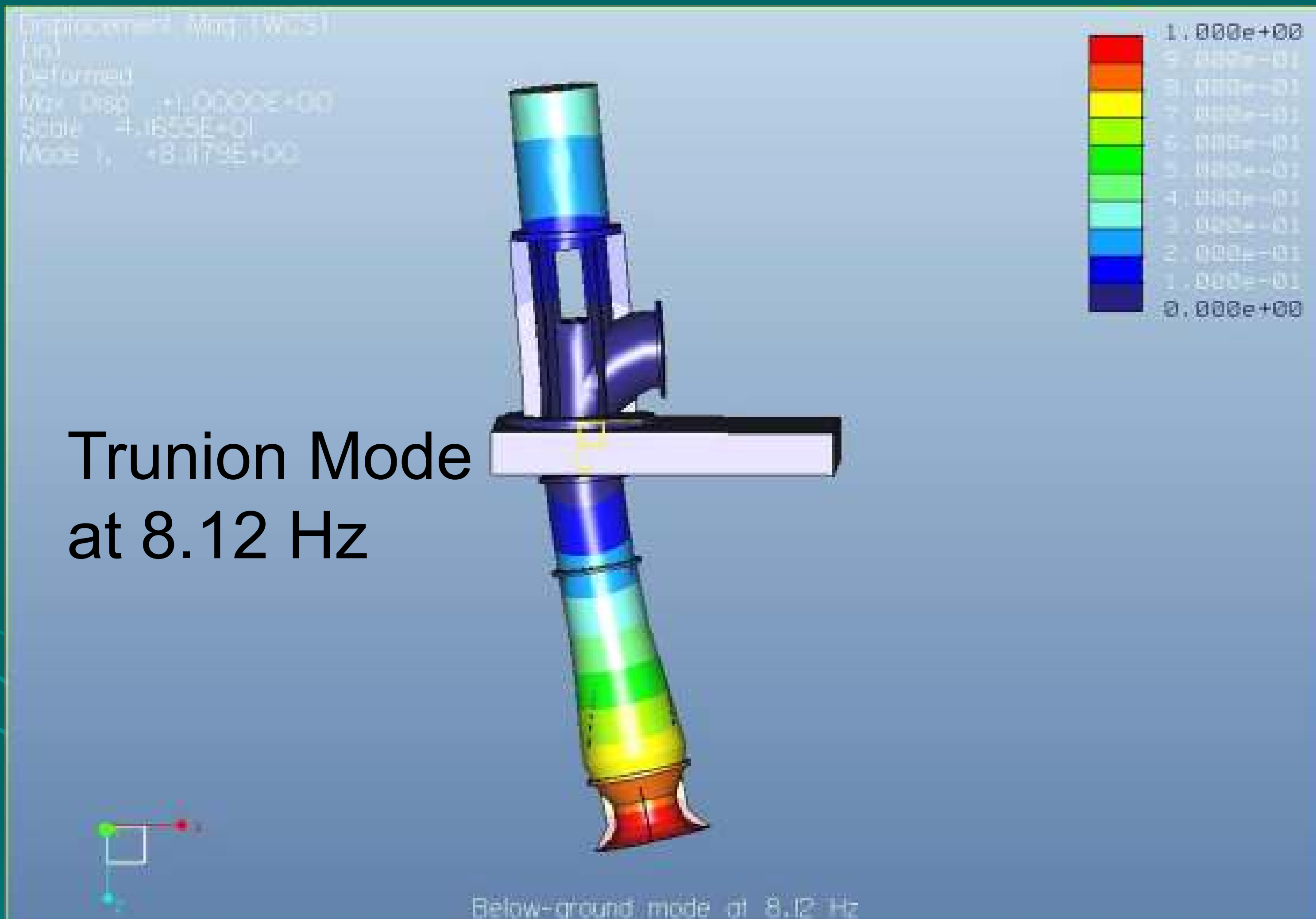
- Below-ground accelerometers were installed at the suction bell flange in two orthogonal directions.

FEA Modal Analysis



Detailed solids model of the pump

FEA Modal Analysis

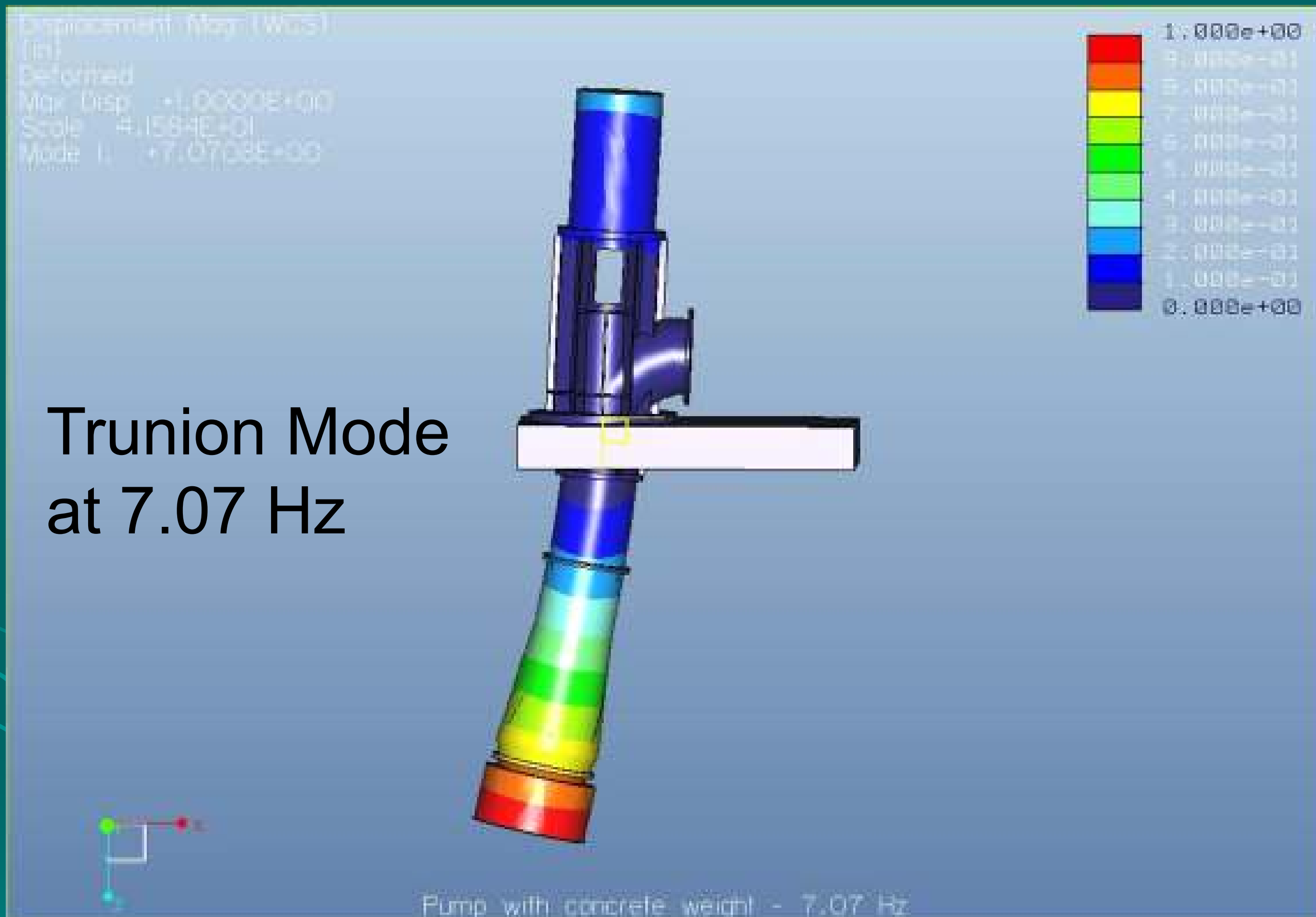


Calibrated FEA model for original pump

FEA Modal Analysis

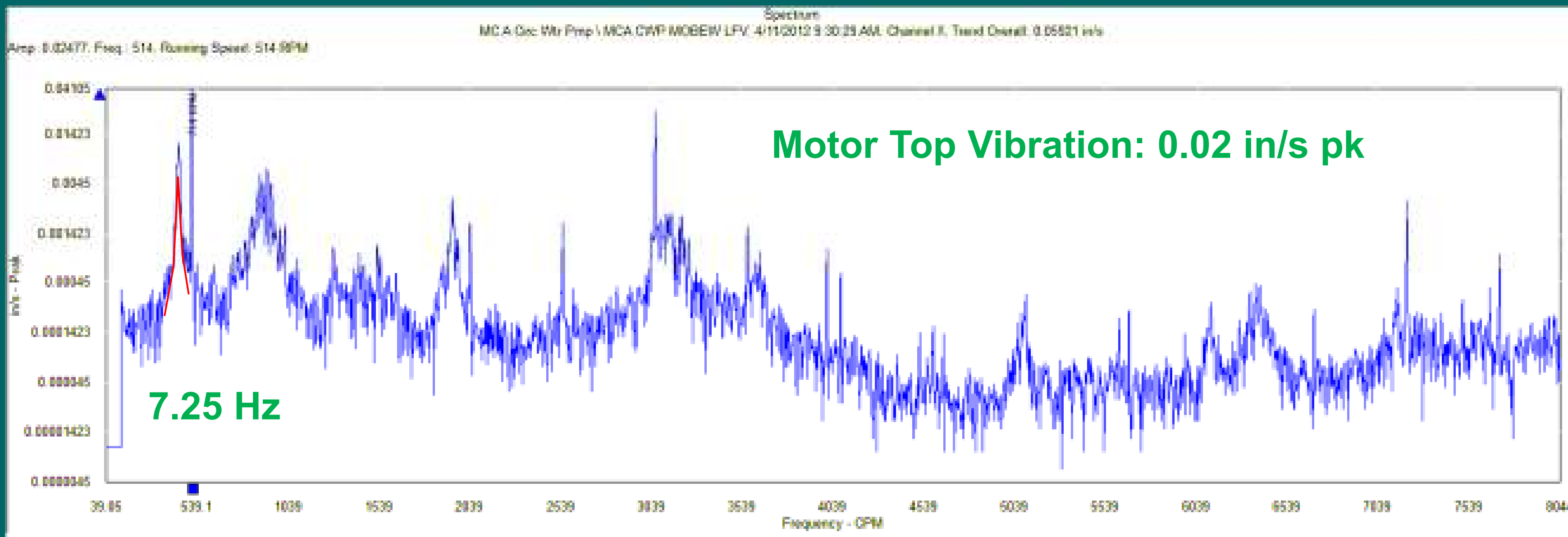
Proposed modification of the suction bell

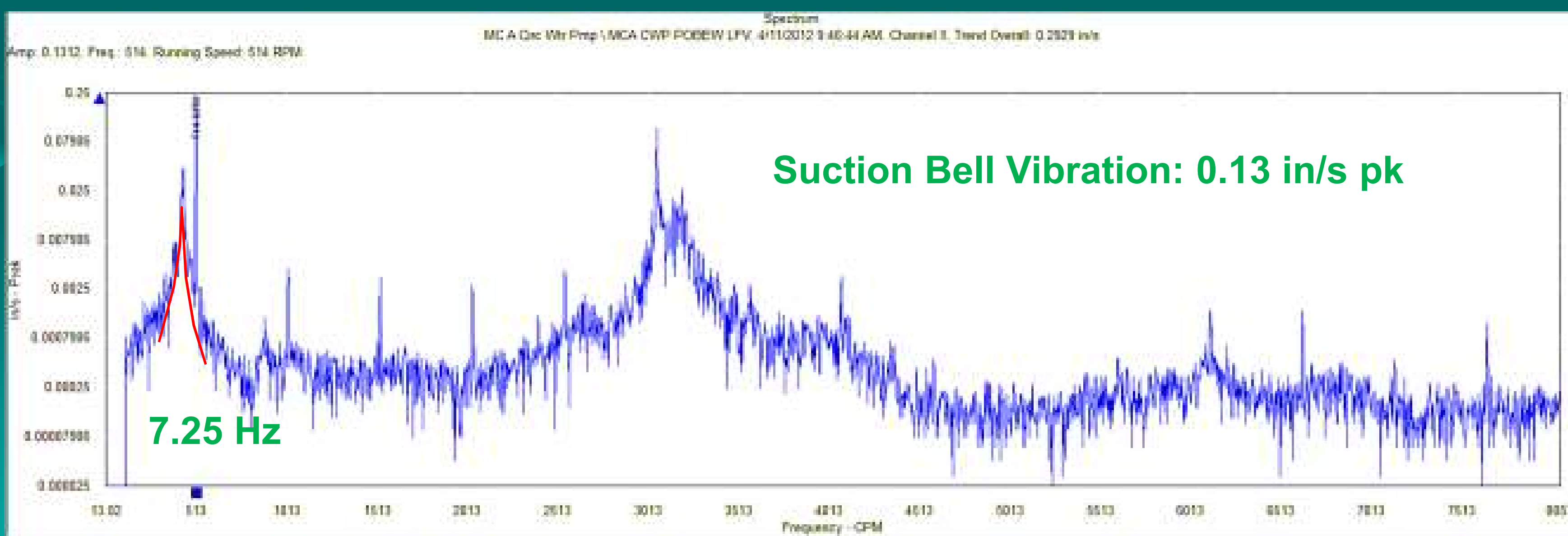
FEA Modal Analysis



Predicted modified structural natural frequency

Follow-Up Testing with Weight





Conclusions

- The root cause of the high vibration at the top of the motor was due to a below-ground dominated mode (trunion mode) rather than the typical motor cantilever rocking mode. This is why the additional ribbing of the above ground structure did not significantly shift the offending natural frequency.
- The looseness between the discharge head mounting flange and the soleplate shifted the offending mode away from the 1x running speed frequency.
- The addition of weight to the bottom of the suction bell in conjunction with the increased added mass effect of the surrounding water lowered the offending below-ground natural frequency to have sufficient separation margin (~15%) from the running speed.

Recommendations

- Testing combined with FEA analysis are excellent tools when good engineering judgment and experience have not been successful in diagnosing and fixing vibration problems in vertical pumps.
- The use of below-ground accelerometers can greatly help identify below-ground modes on VTPs.
- Closer examination of the spectrum modal plots may be able to distinguish between whether a frequency is an above-ground or below-ground dominated mode based on the relative size of the peaks.
- Shifting below-ground modes by attaching mass to the bell must also consider the added mass effects of the surrounding water to achieve the desired results.

Thank you

Any Questions?