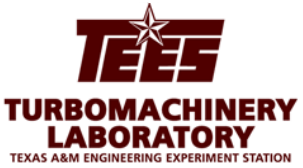
44TH TURBOMACHINERY & 31ST PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 14 – 17 2015
GEORGE R. BROWN CONVENTION CENTER

Circulating Water Pump Resonance

Monroe Voyles, Solutions Engineer

ITT Goulds Pumps
Seneca Falls, NY



Author / Presenter

Monroe Voyles III

(225) 573 2445

monroe.voyles@itt.com

Mechanical engineer with 20 years of experience; 7-chemical plant, 3-refinery, 10-pump OEMs.

B.S.M.E Louisiana State University 1994.

Professional Engineer Louisiana 2002/Texas 2014.

CAT IV Vibration Analyst (Vibration Institute 2010 & Mobius 2014)

Circulating Water Pump

- API 610-VS3 single stage
- 5 Impeller vanes
- 60,000 gpm
- 80 psig discharge
- 600 rpm
- Motor-1700 H.P.
- Two pumps; one primary and one spare

Circulating Water Pump

View Perpendicular To Discharge

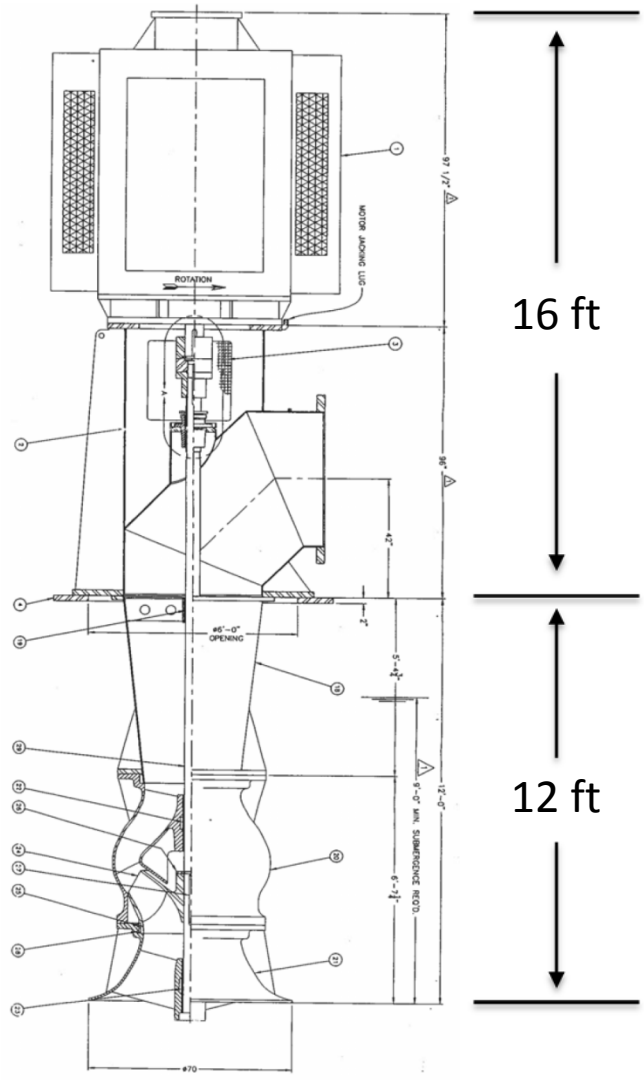
View In-Line With Discharge

Problem

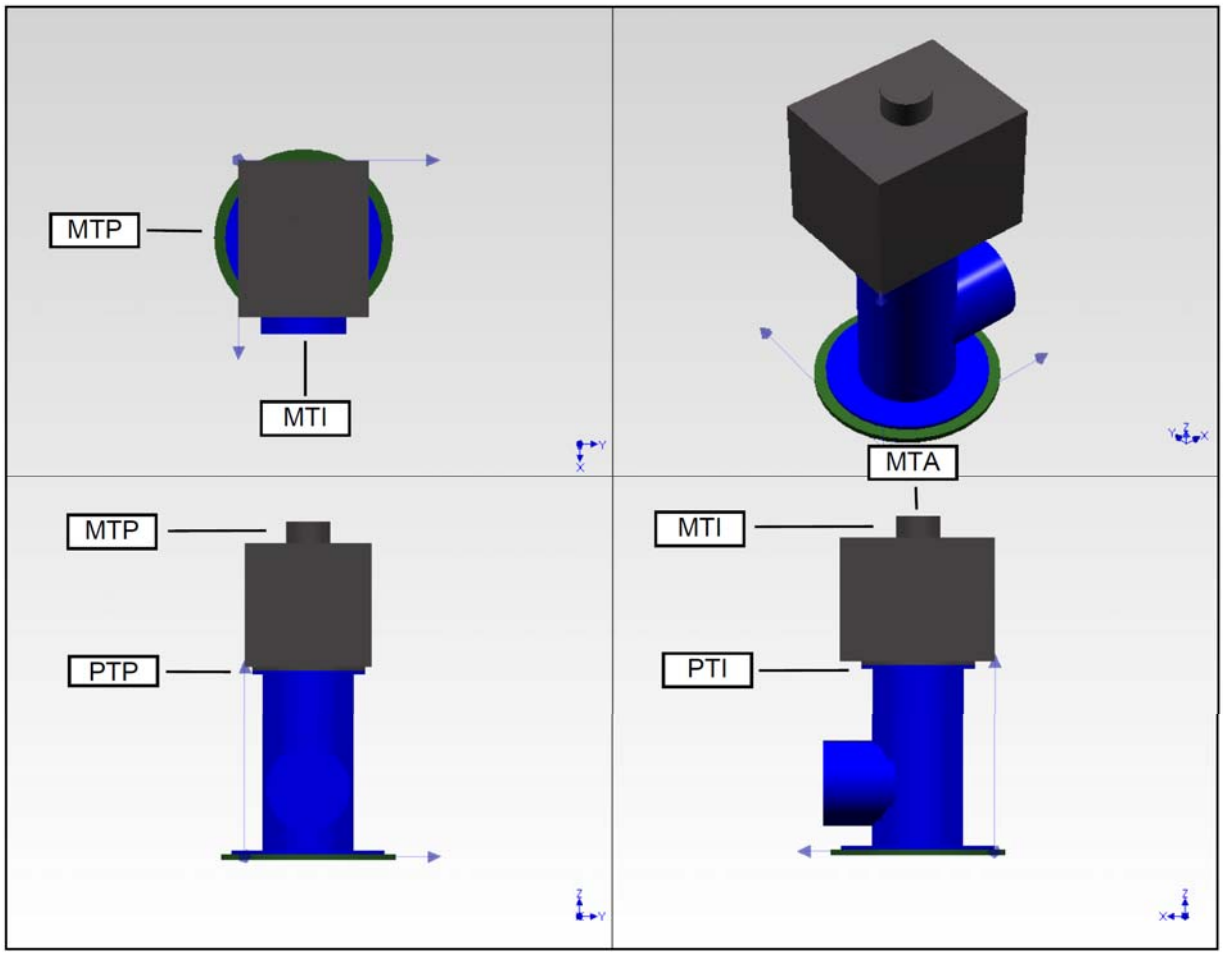
- Large 1X running speed vibration amplitudes at motor top
- Vibration increased significantly after an overhaul
- Pump operated for 9 years prior with low vibration amplitudes
- Spare pump did not resolve vibration issue
- Spare motor did not resolve vibration issue
- Precision alignment did not resolve vibration issue
- Field balancing reduced vibration amplitude to some degree, but not to acceptable levels.
- Depending on configuration/conditions vibration amplitudes varied from 1.0 ips rms to approximately .4 ips rms

Below Grade & Cross-Section

No measurements possible below grade

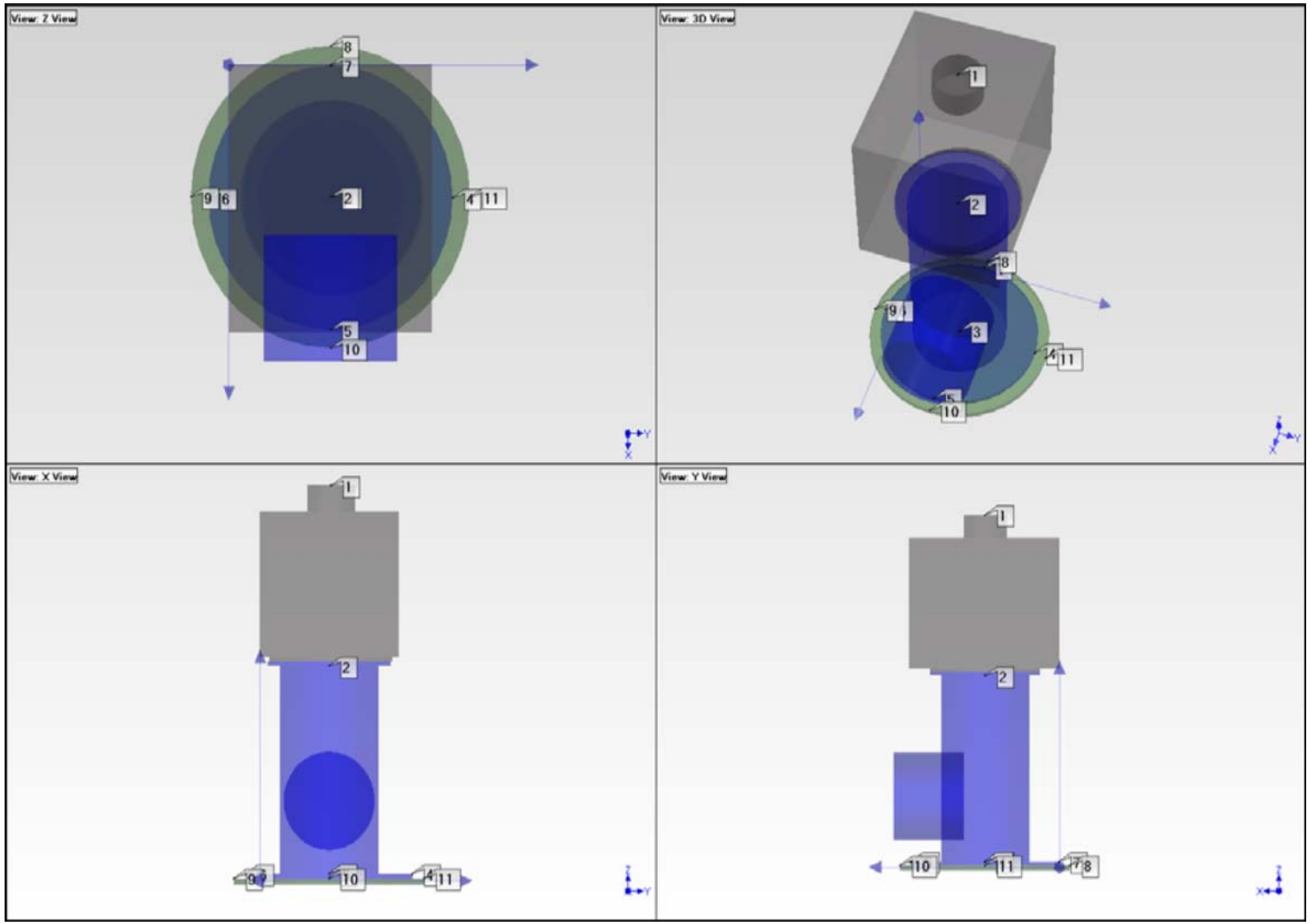


Primary Accelerometer Locations



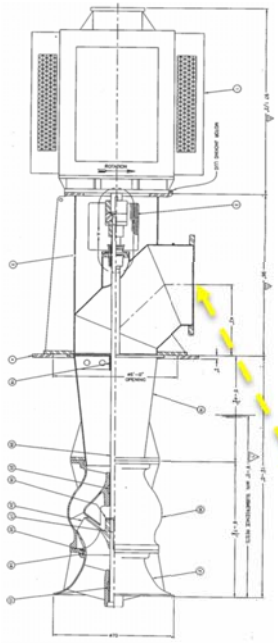
Measurement Stations For ODS/Modal

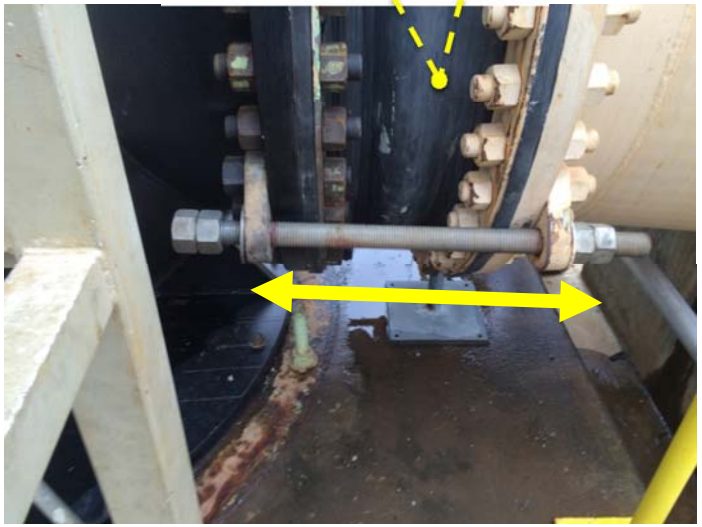
X,Y,Z data for each station



Discharge Expansion Joint

- The tie bolts were initially loose.
- Loose tie bolts allow hydraulic separation forces to be applied to the pump discharge head.
- Significant vibration changes were observed when the spare pump was started in parallel (higher discharge pressure/force)





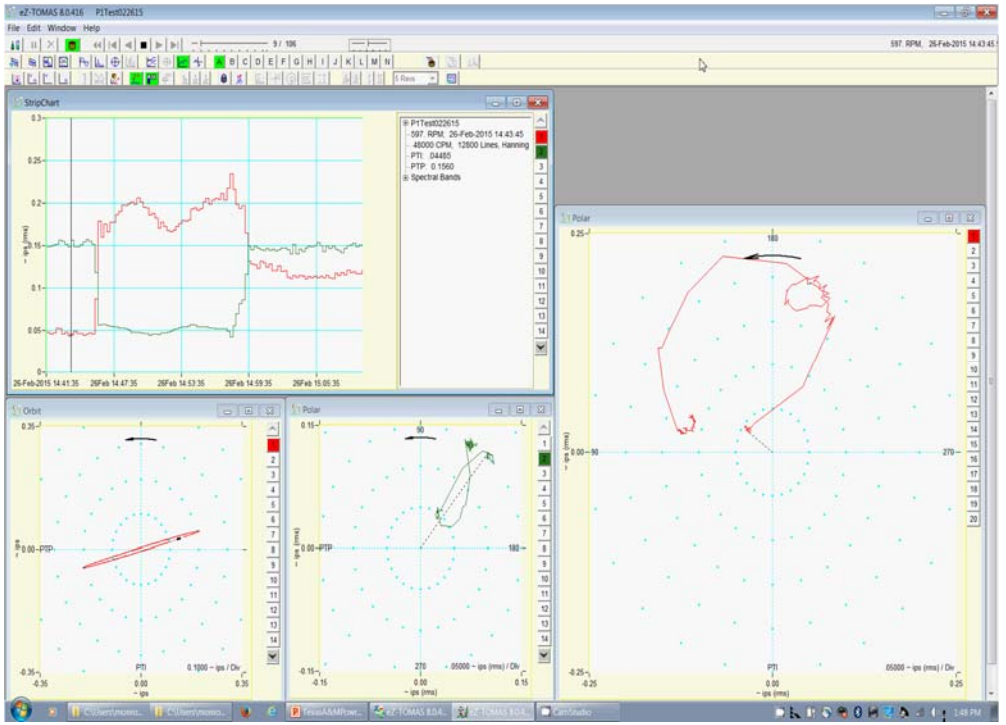
Operating Condition Changes

(animation)

1- Solo operation(tie bolts loose)

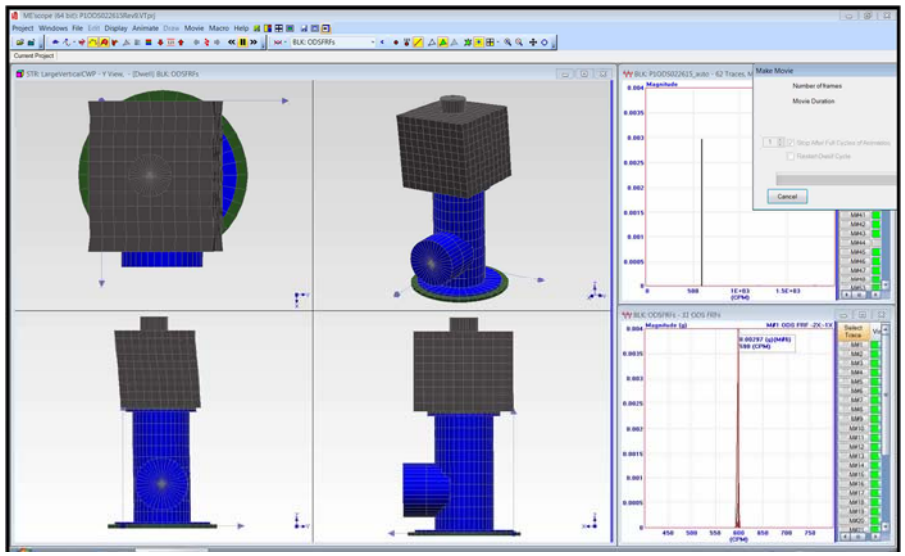
2- Start spare CWP in parallel operation; nat. freq. increased into operating speed. (note beat pattern)

3- While still in parallel operation the tie bolts were tightened; lower thrust force; nat. freq. lowered back below operating speed



Operating Deflection Shape (single pump operation) (animation)

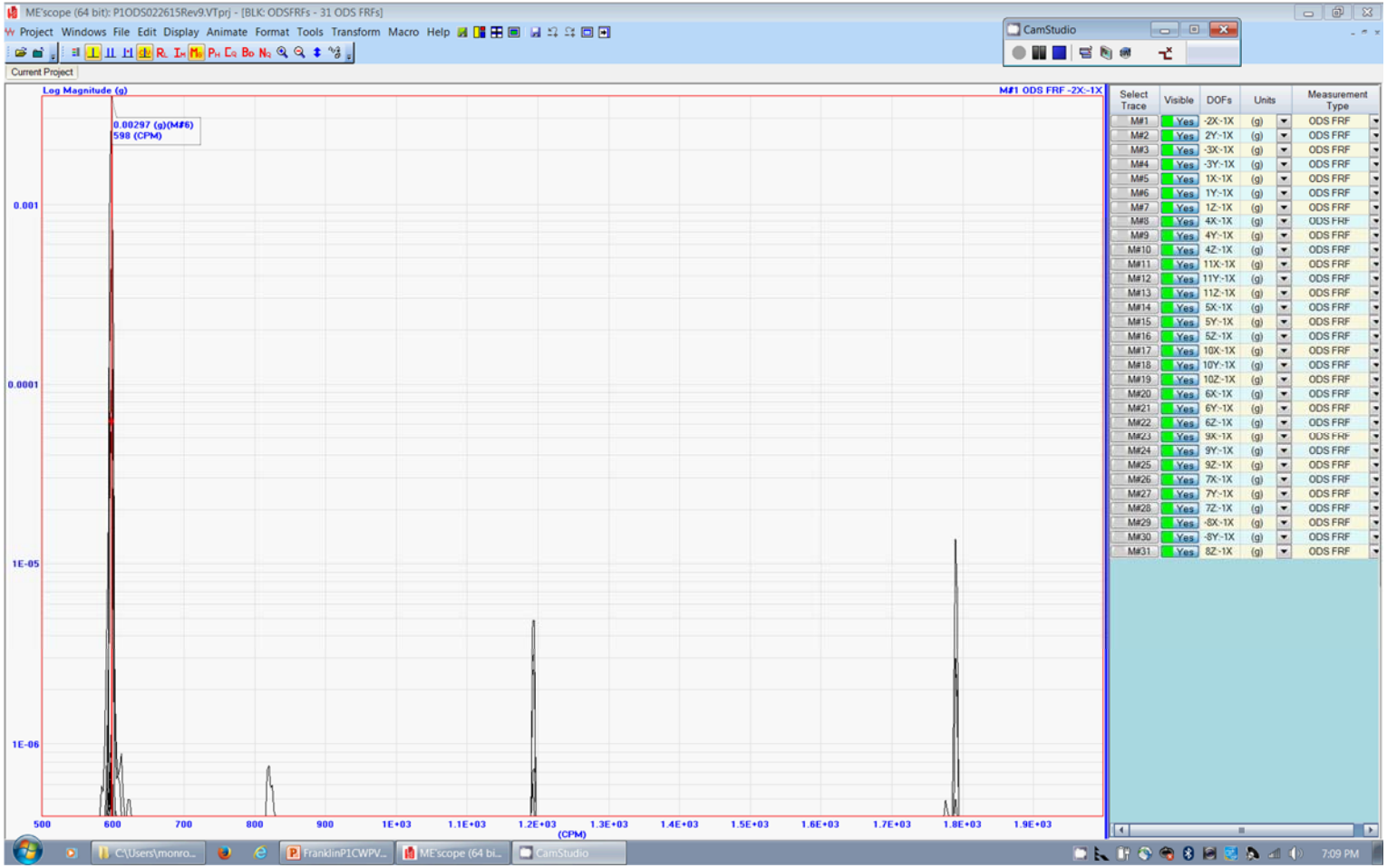
- 1X ODS (**O**perating **D**eflection **S**hape)
- ODS models are animated with operating vibration data.
- Forces related to 1X shaft frequency are causing vibration
- Maximum vibration amplitude is near .4ips rms
- Proximity to a nat. freq. at 584cpm is causing significant amplification in the perpendicular direction



ODS FRFs

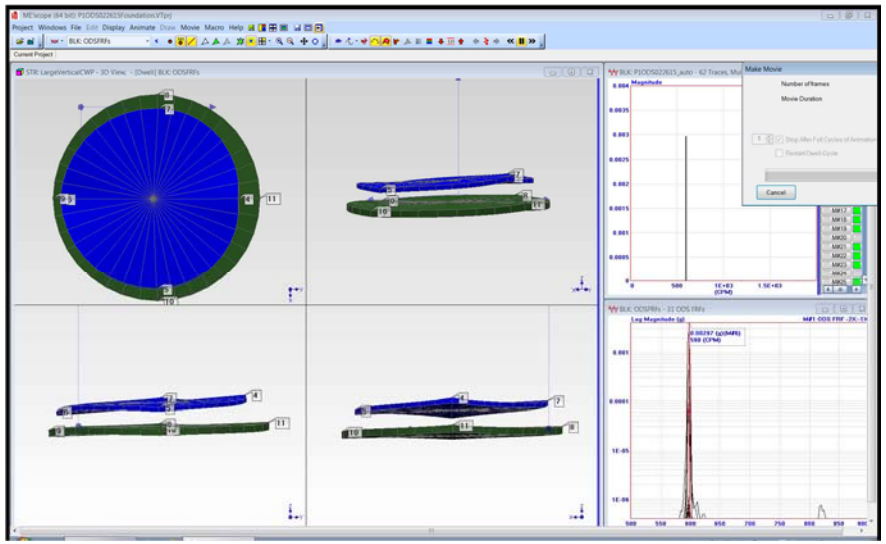
(Frequency Response Function) (animation)

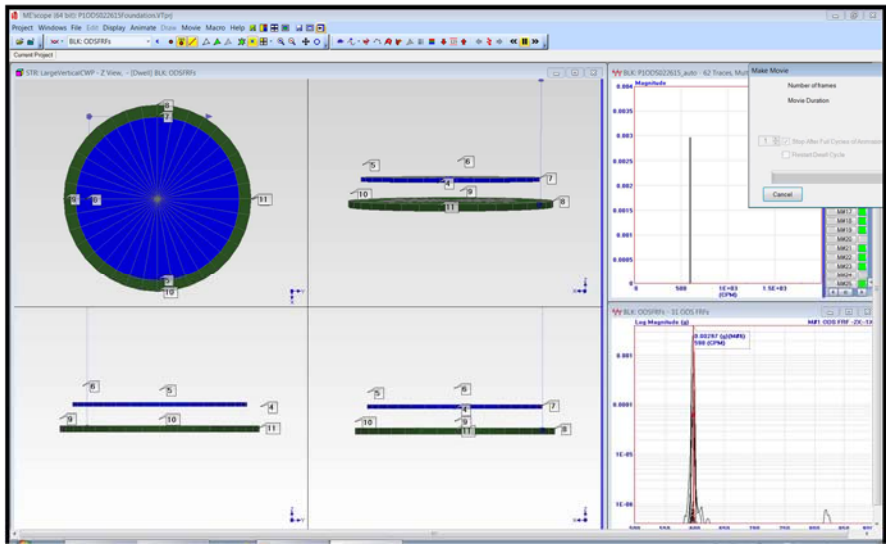
Single pump operation; all FRFs overlaid; log amplitude axis



Pump Flange and Soleplate ODS (animation)

- Soleplate and pump flange are essentially moving together.
- Stations 7 & 8 have little relative movement. Motion in the other 3 quadrants is higher than if properly grouted.
- The lower animation has no model interpolation





Click to Animate

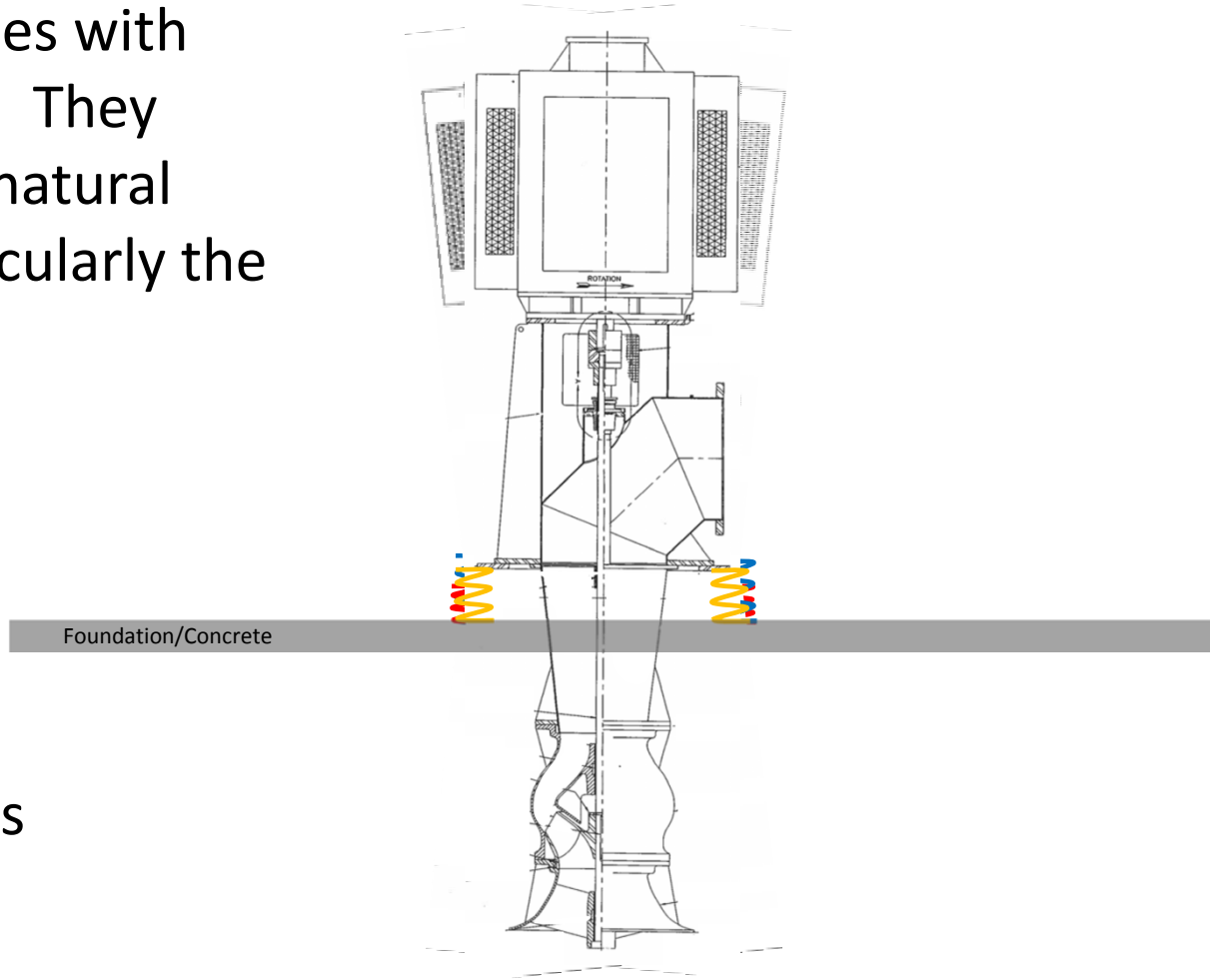
Foundation & Soleplate Are "Springs" In The Mechanical System (animation)

The foundation and soleplate act as springs in series with the pump structure. They affect the resulting natural frequency (f_n); particularly the 1st "Trunion" mode

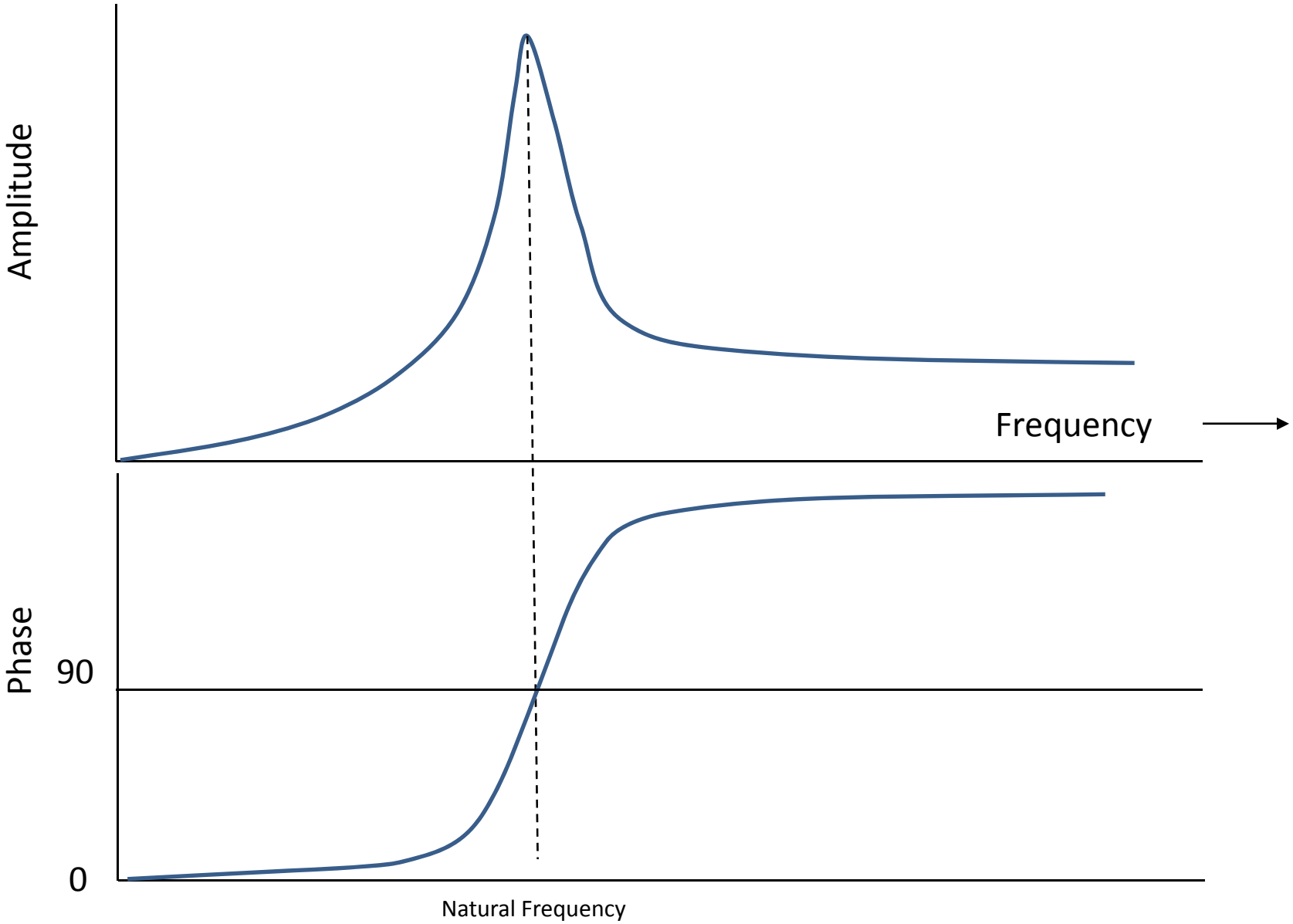
$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

k = effective stiffness

m = modal mass



Typical Resonance Response



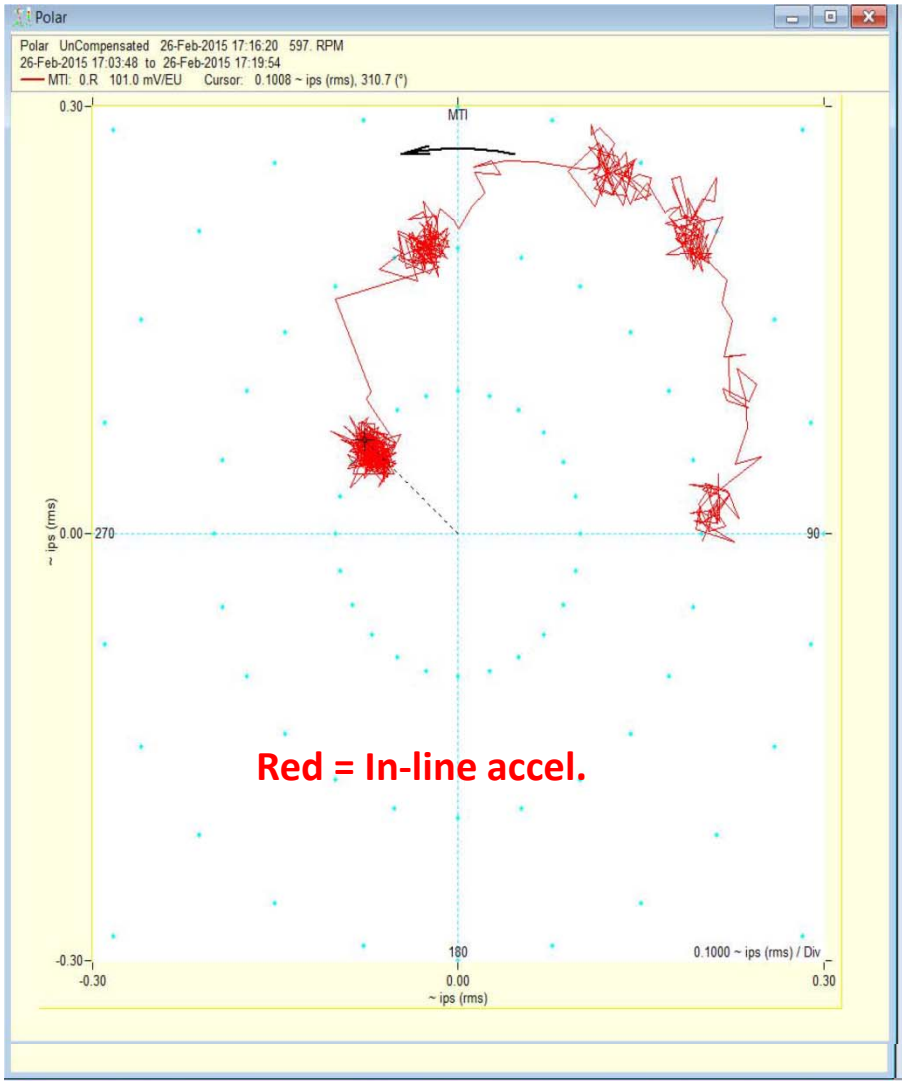
Solution

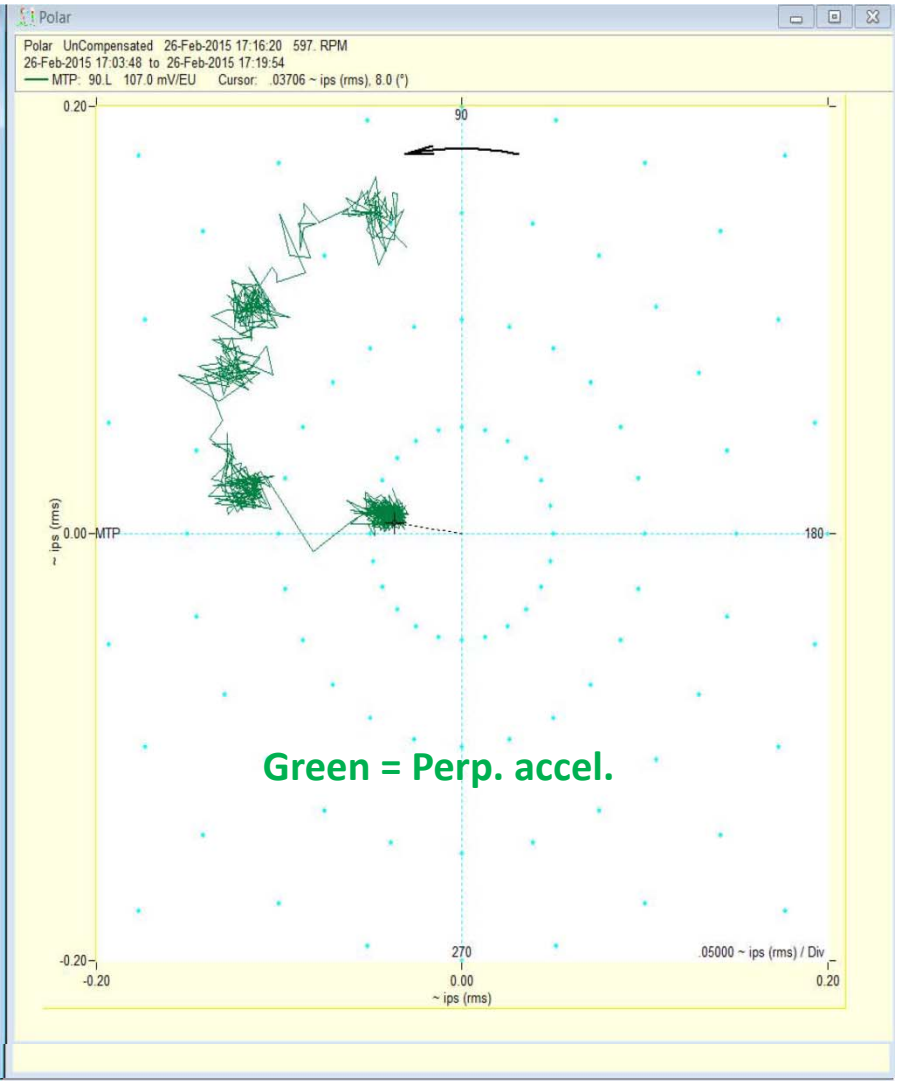
- Bubbles indicate relative movement
- Soleplate anchor studs were tightened to improve connection and increase stiffness of the pump/foundation system
- Nuts were tightened from the discharge moving CW viewed from the top down
- As studs were tightened vibration amplitude and phase changed
- Final vibration was decreased from .4ips rms to 0.08ips rms.

Video Of Movement/Bubbles

(animation)

Stud Torqueing Sequence

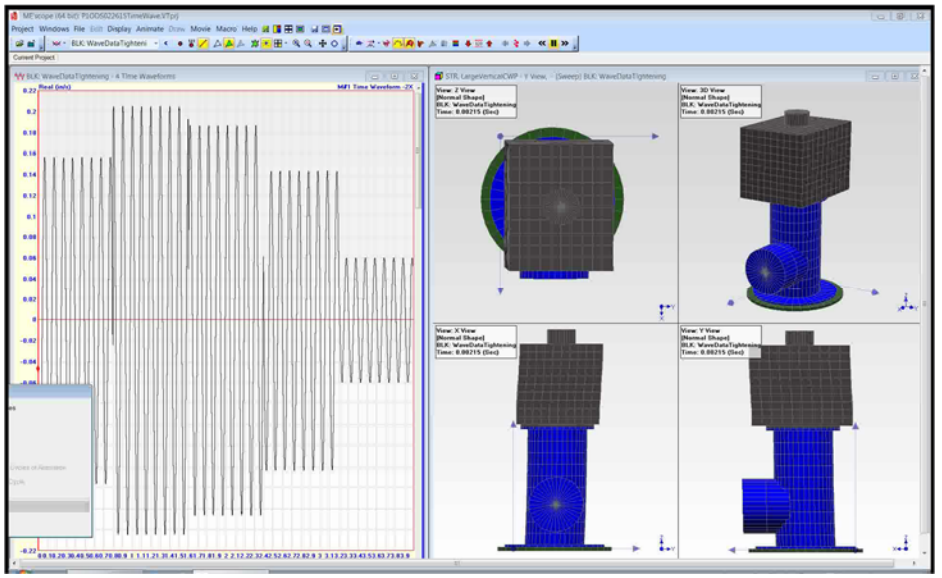




Operating Deflection Shape

(TIME-BASED ANIMATION)

- Stud torqueing sequence
- Waveform(1X filtered)
- Amplitude decreased 70% after soleplate anchor studs were torqued.
- Nat. freq. was raised to and then above 1X by increasing foundation/pump stiffness.

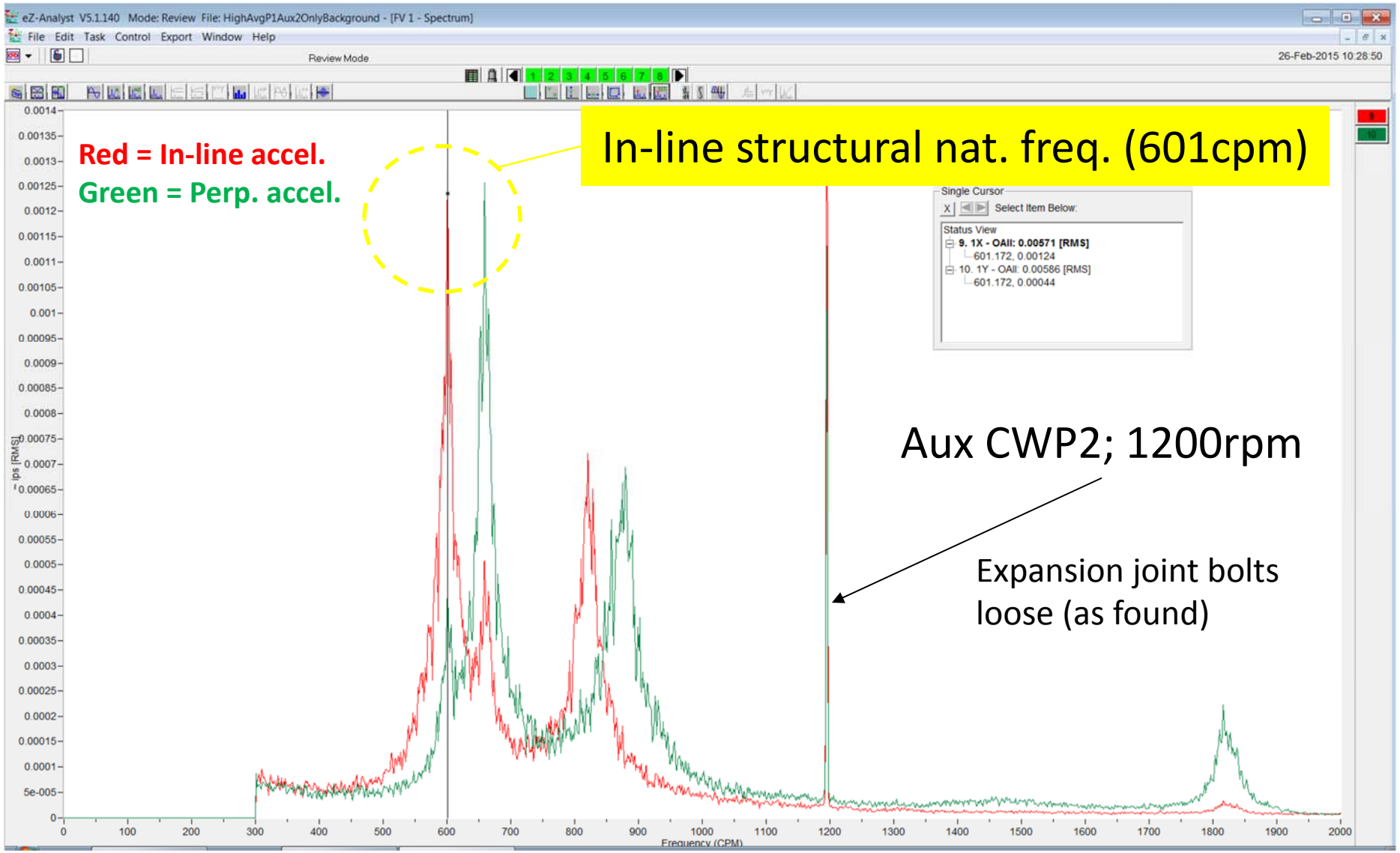


High Average/Resolution FFT

- Background or broad-band vibration energy can excite structural natural frequencies. A large number of averages and high frequency resolution attenuates noise and variability. Natural modes tend to absorb more energy and can be seen in the FFT spectrum.
- High average/resolution measurements were taken in the initial condition (solo), the spare CWP (solo), Aux CWP2 solo, and the final condition (solo operation) after the soleplate studs were torqued.
- Operating data (high average/resolution FFT) uses continuous broad band energy from sources like flow turbulence to excite natural modes. Fmax 30,000cpm & 25600 lines of resolution were used.

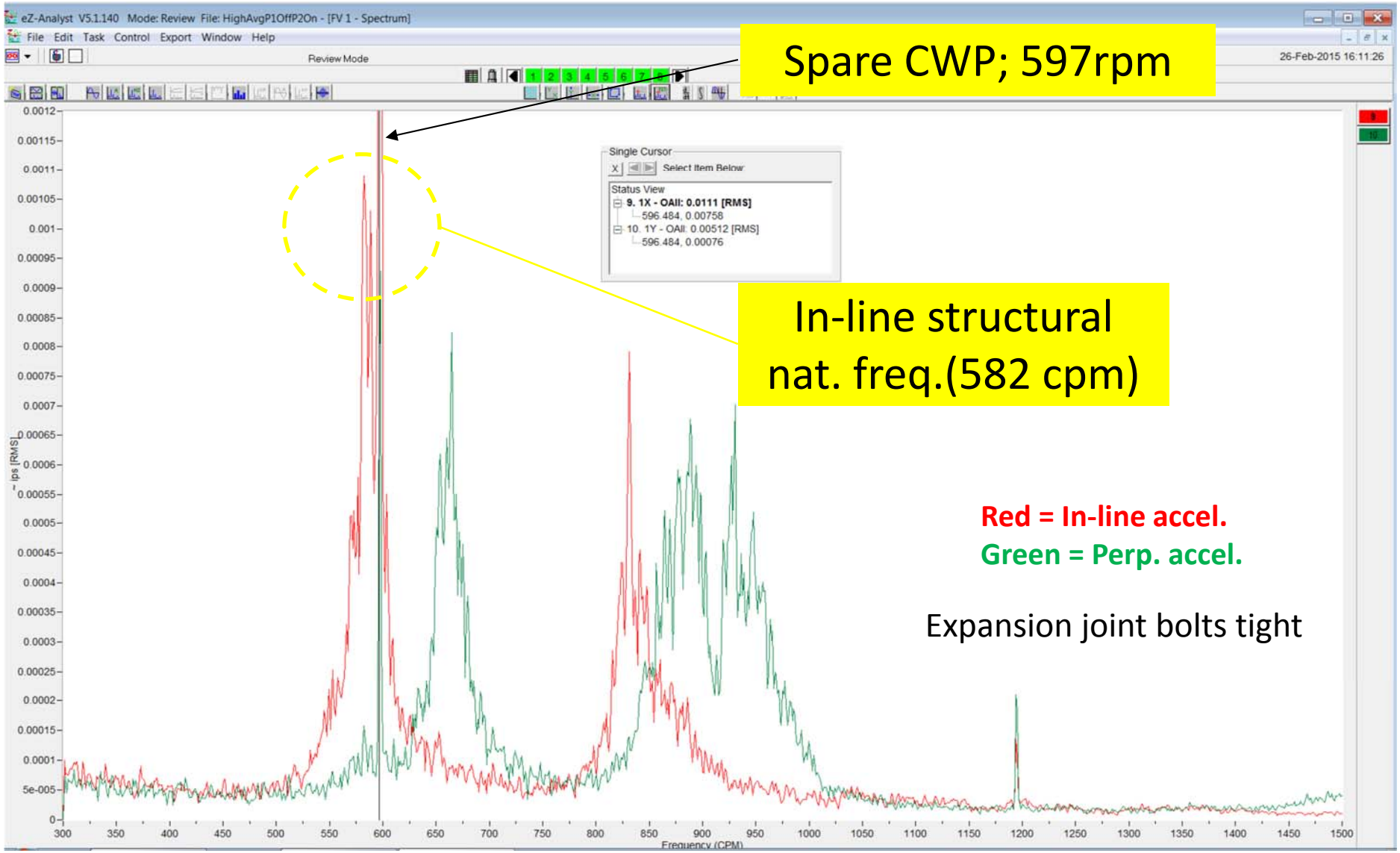
High Average/Resolution FFT

Broad-band vibration provided by Aux CWP2



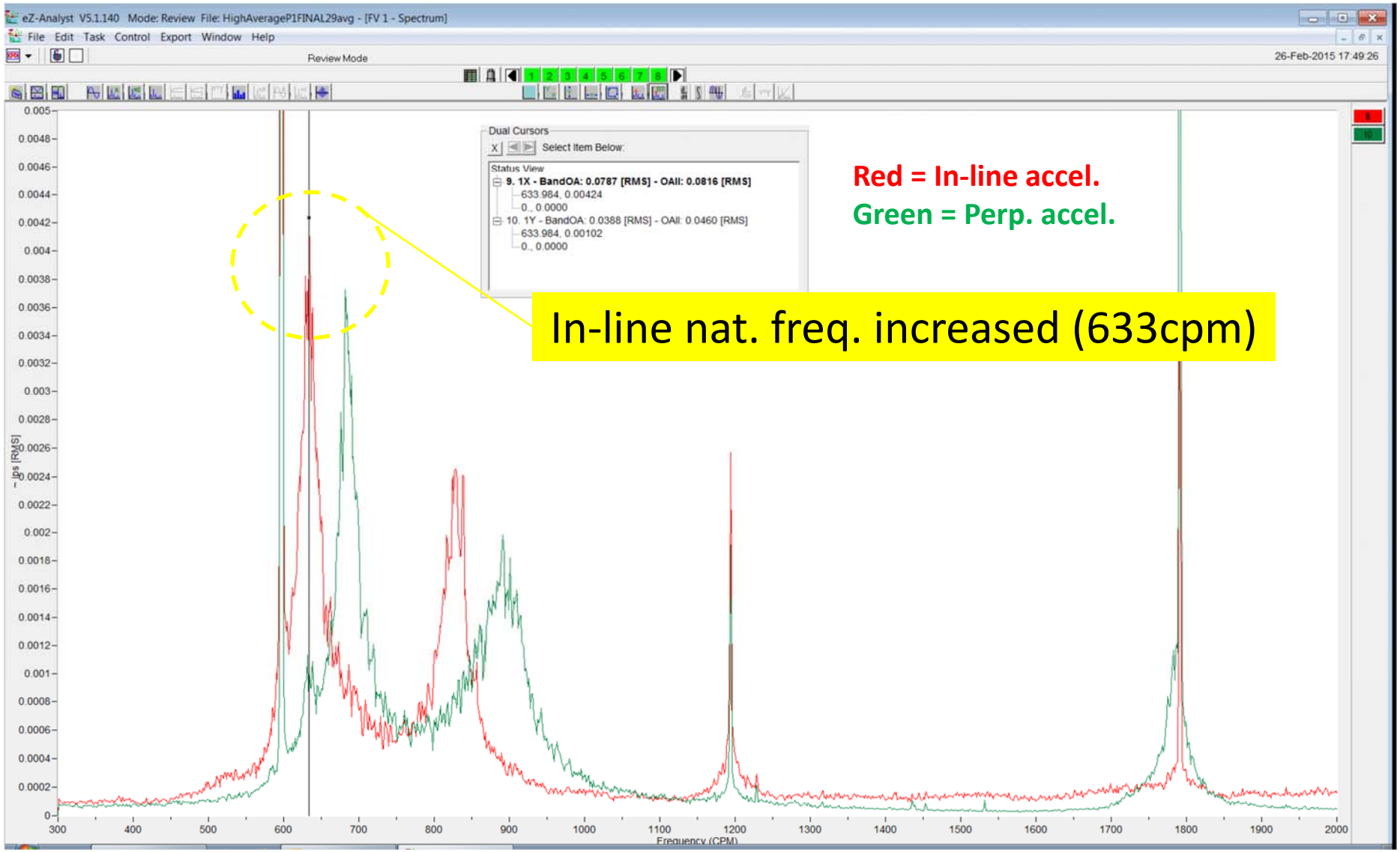
High Average/Resolution FFT

Broad-band vibration provided by spare CWP

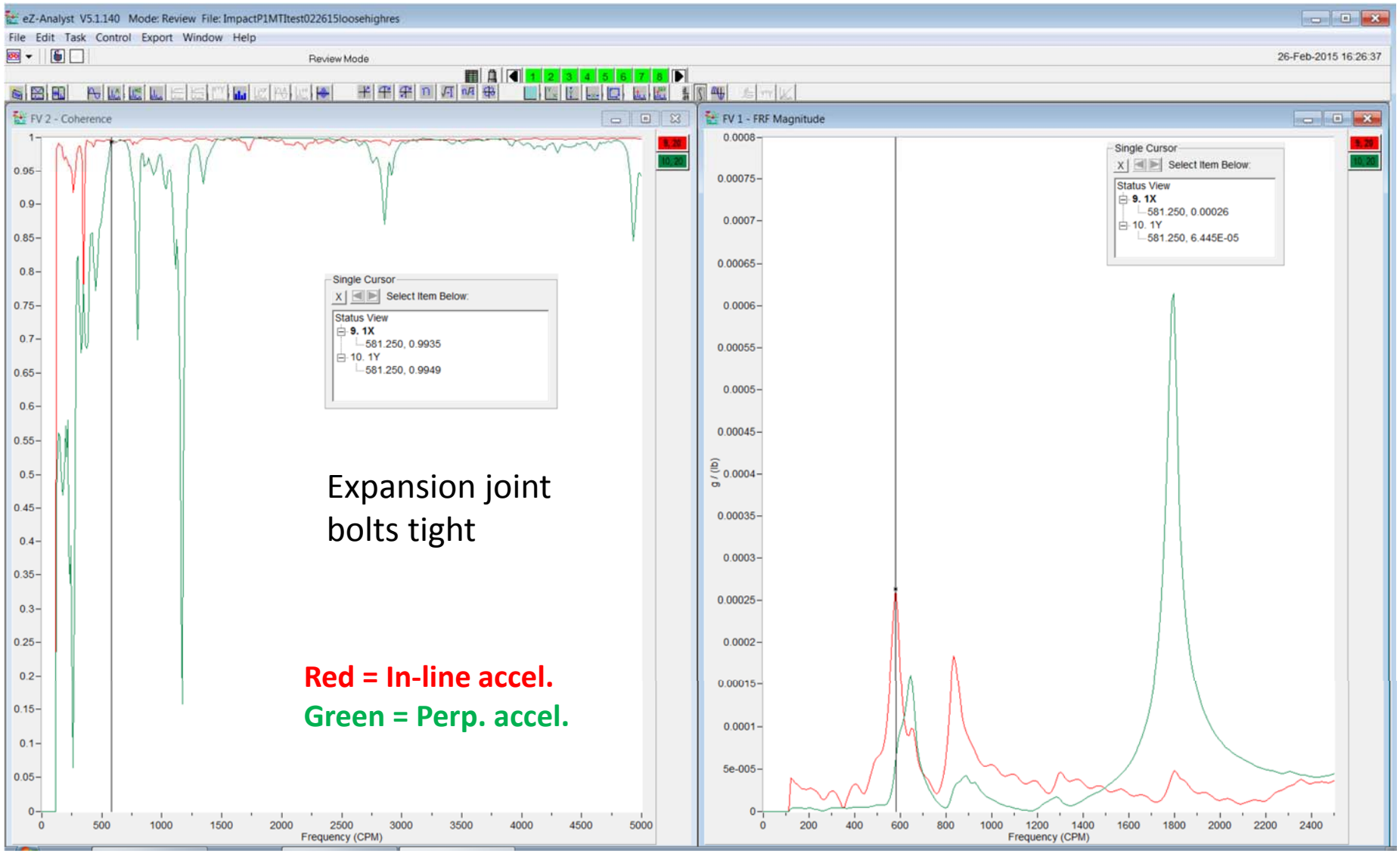


High Average/Resolution FFT

FINAL/AFTER SOLEPLATE STUD TORQUEING



Motor Top Inline Impact FRF

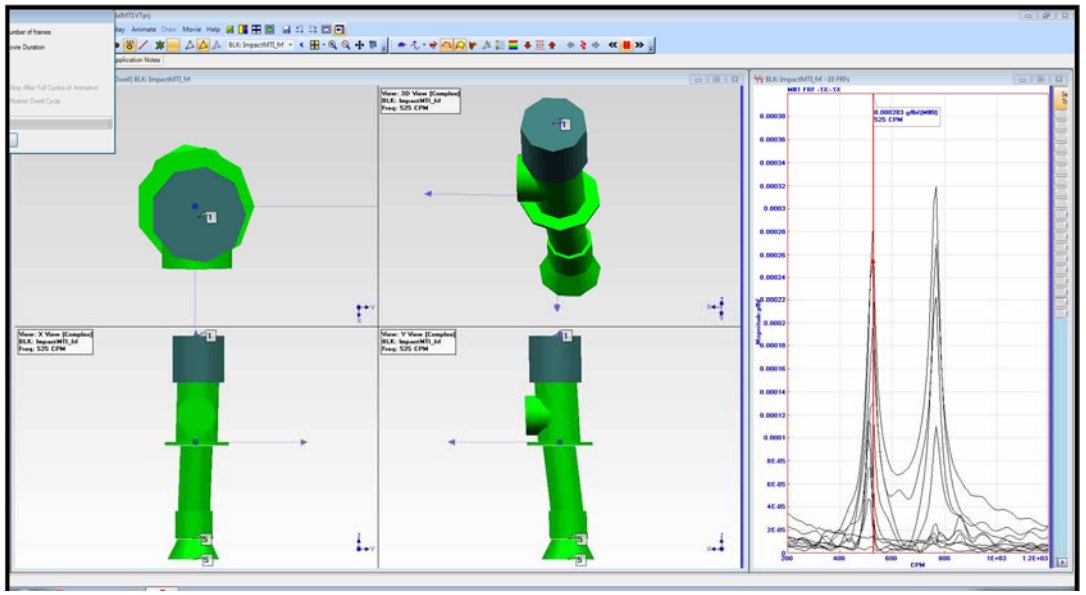


Natural Frequency Data(cpm)

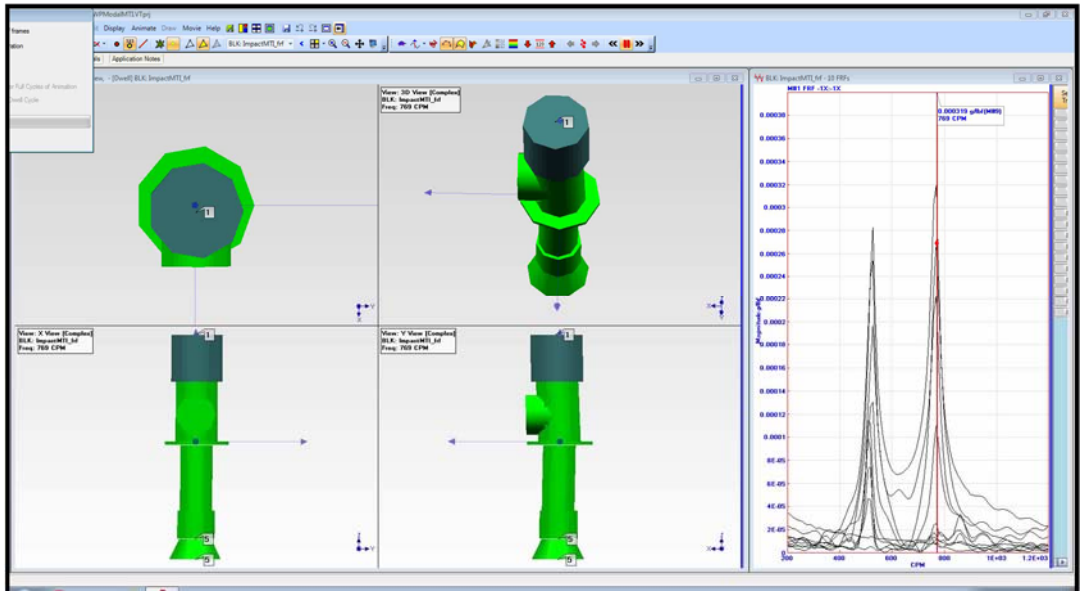
Condition	In-line	Perp
(Before) Background	**601**	658- 1st mode
Aux. CWP2 solo	820	880- 2nd mode
(Before) Background	582	664-1st mode
Spare CWP solo	830	889-2nd mode
(Before) Impact	581	656-1st mode
	843	881-2nd mode
(Final) Background	**633**	683-1st mode
tight soleplate	828	894-2nd mode

Mode Shapes (examples)

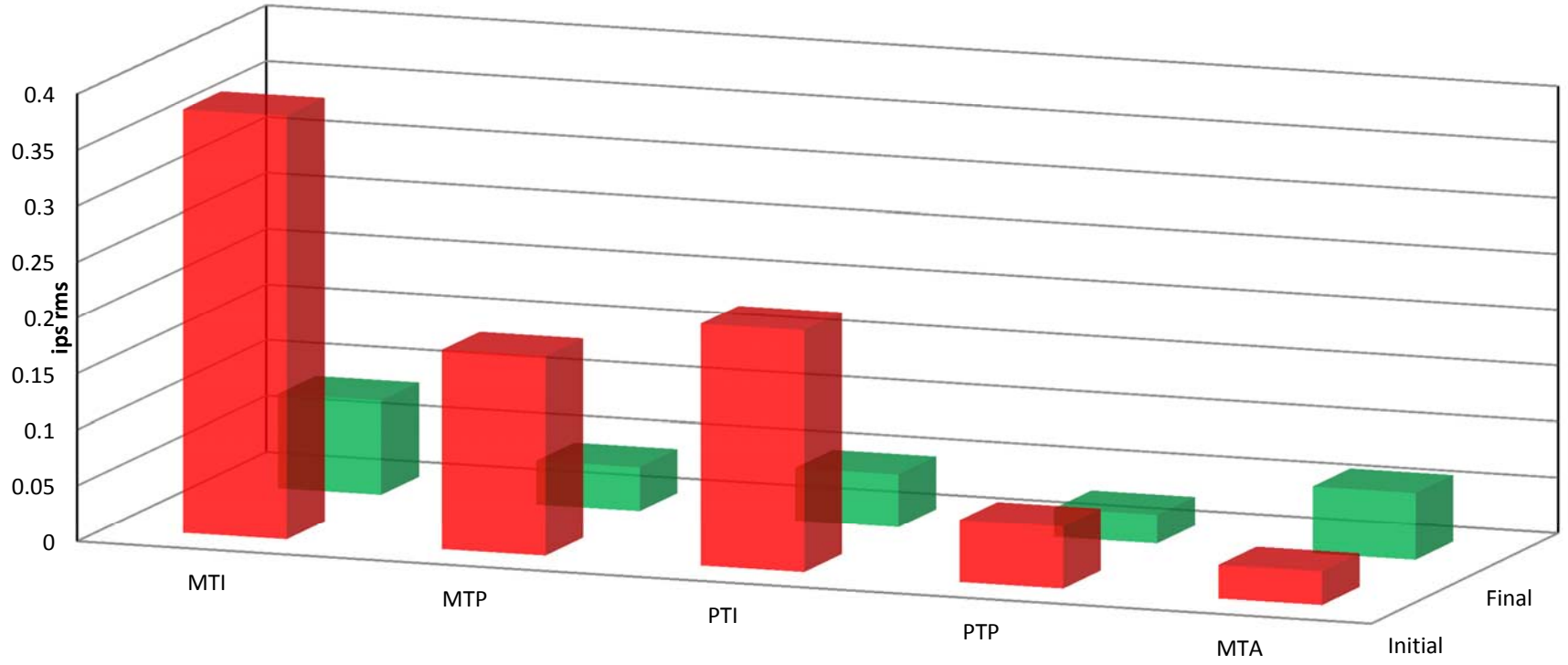
- 1st mode is the “Trunion” or pivoting mode. The column and motor are essentially a rigid body pivoting about the flange/soleplate.
- 2nd mode is a “C” shape bending mode. The column properties control the effective stiffness and natural frequency



(animations)



Overall Vibration Amplitudes



	MTI	MTP	PTI	PTP	MTA
Initial	0.379	0.178	0.216	0.0553	0.0298
Final	0.0839	0.0393	0.0474	0.0257	0.06

Lessons Learned

- The root cause of excessive vibration was a structural resonance at 1X shaft speed.
- A change in the soleplate/foundation connection likely occurred during the pump overhaul. The combination of corrosion over many years and disturbance of the soleplate during pump removal likely combined to create a “soft” interface between the pump structure and the concrete foundation.
- Reduced pump/foundation stiffness lowered the 1st or trunion mode natural frequency into the operating speed range.
- Soleplate/foundation condition should be inspected during pump removal/overhaul in the future.