Vertical Pump Resonance, F.E.M., and Purchase Specifications

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ITT
GOULDS PUMPS

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Mechanical engineer with 24 years of experience; 7 in a chemical plant, 3 in a refinery, 14 with pump manufacturers. Primary responsibilities involved rotating equipment. Experience includes work on large electric motors, gas turbines, centrifugal compressors, reciprocating compressors, steam turbines, large API pumps, ANSI pumps, high pressure boiler feed water pumps, cooling tower fans/gear boxes, and large compressor gear boxes. Proficient with finite element modeling (CREO/Simulate) and rotor-dynamic modeling (DyRoBes)

Abstract

When natural frequencies are well separated from machine generated vibration/forcing frequencies there is little amplification, but when not well separated significant vibration amplification can occur due to resonance. This presentation provides 2 vertical pump resonance examples and solutions. Often finite element modeling is provided before purchase to ensure acceptable frequency separation margins. Finite element modeling(F.E.M) can be a very good tool, but it requires many assumptions regarding boundary conditions and motor properties. The purchaser should know the potential problems with F.E.M when reviewing purchase specifications and results.

Example 1

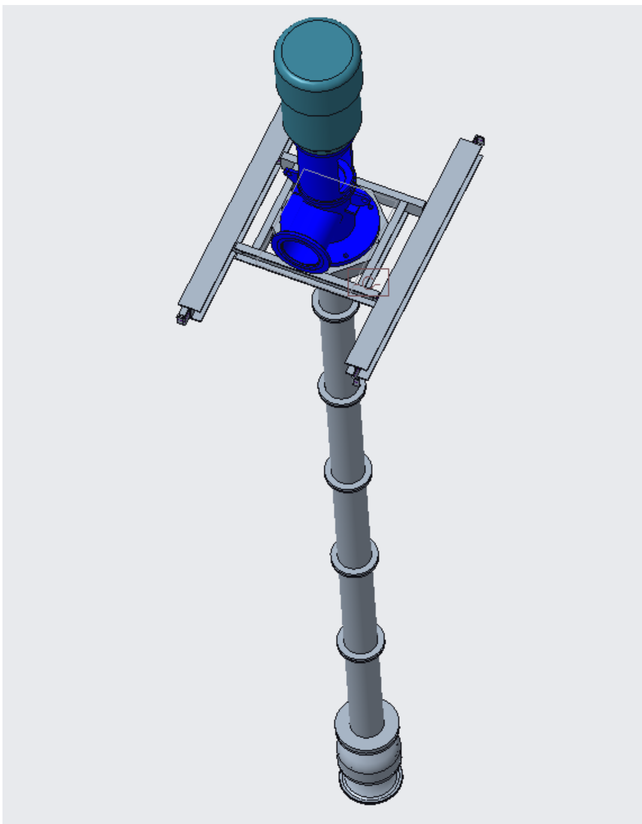
Steel Beam Support Structure, Variable Speed, Variable Liquid Level

- Existing speed restrictions(based on pre-purchase finite element model results) did not allow pump speeds to be reduced enough to provide lower flow requirements.
- A site study determined the actual natural frequencies and vibration amplitudes during all speeds.
- A “tuned” or adjusted finite element model was used to evaluate possible modifications.
- A pump modification was proposed to achieve sufficient 1X frequency separation margin for all modes/frequencies from 900-1800rpm.
- The modifications were successful and there are no significant vibration issues in the desired speed range from 900-1800rpm.
- The actual foundation details were not provided for the pre-purchase modeling; therefore, a typical assumption of a rigid foundation connection was used.

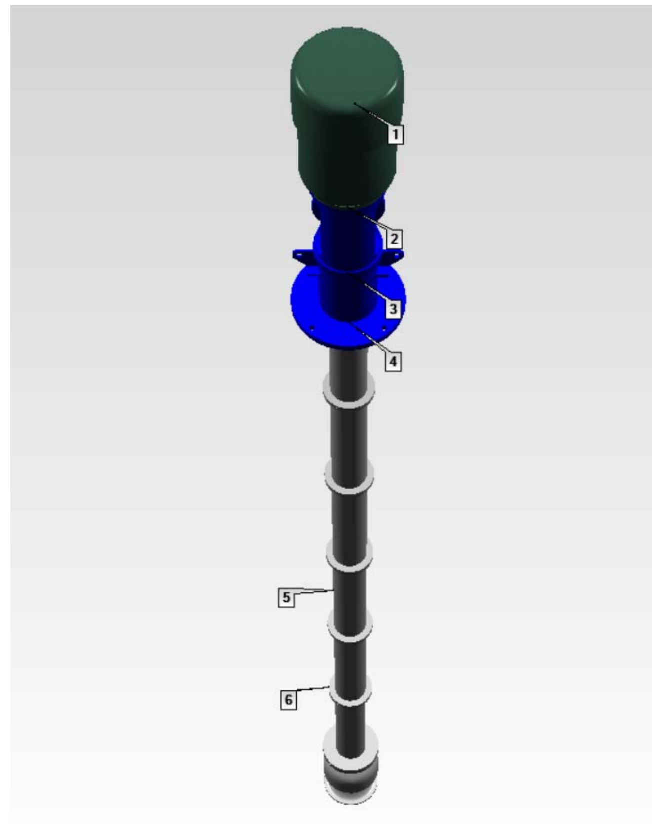
Effluent Pumps

Models & Measurement Locations

FE Model



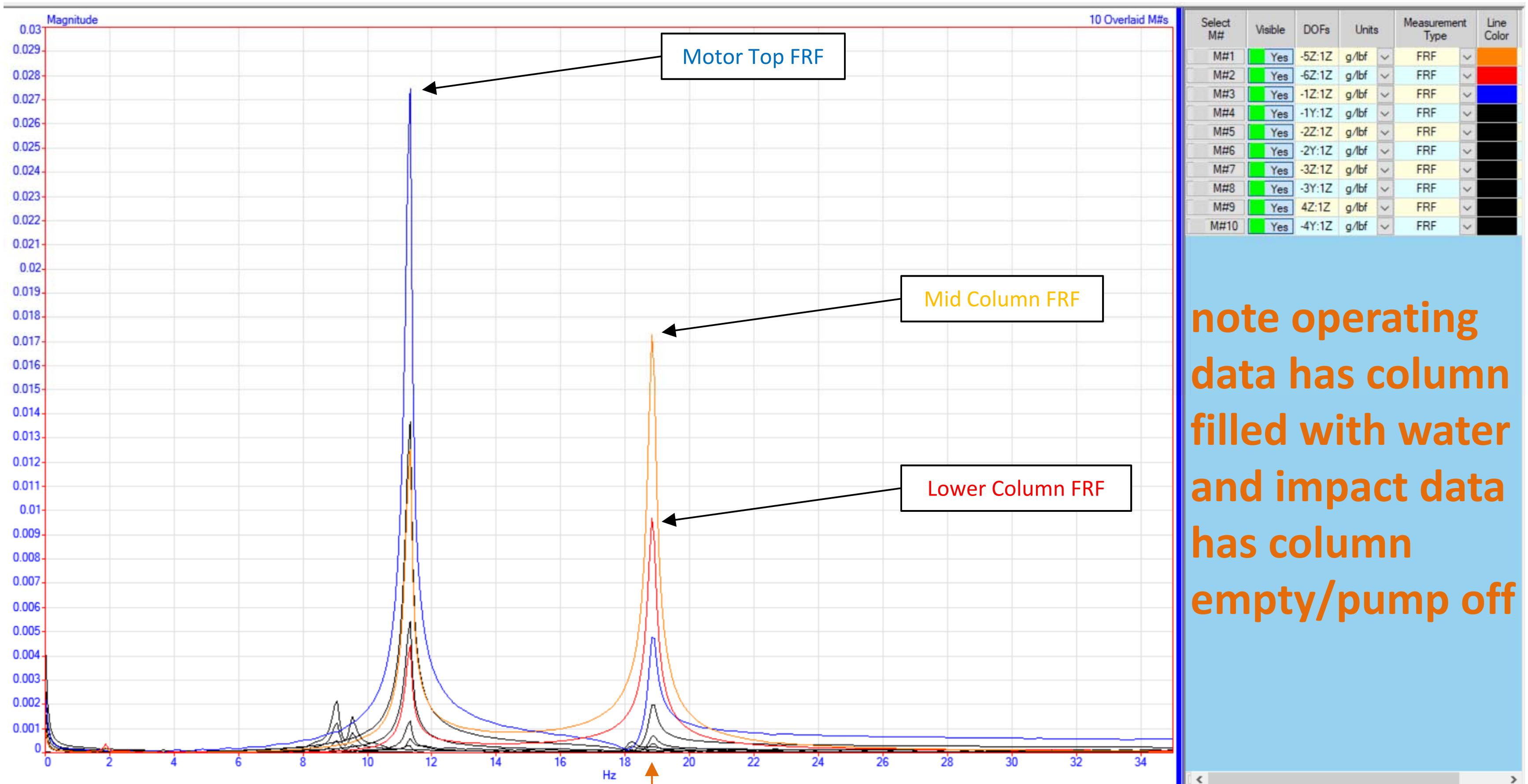
Experimental Modal Model



Modal FRFs

Impact Motor Top Perpendicular To Discharge

(pump not operating and empty)



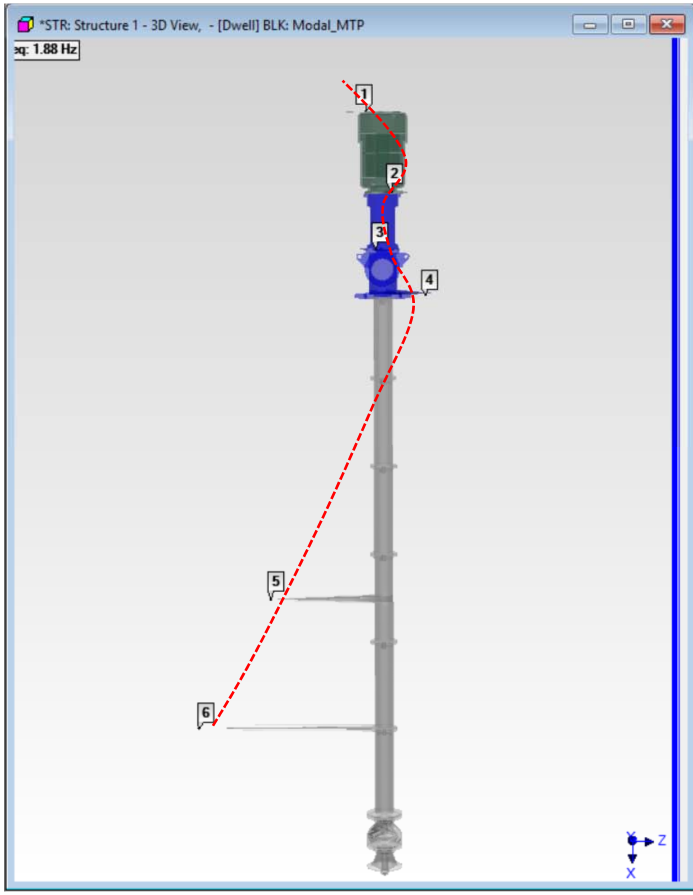
Problematic 3rd Mode

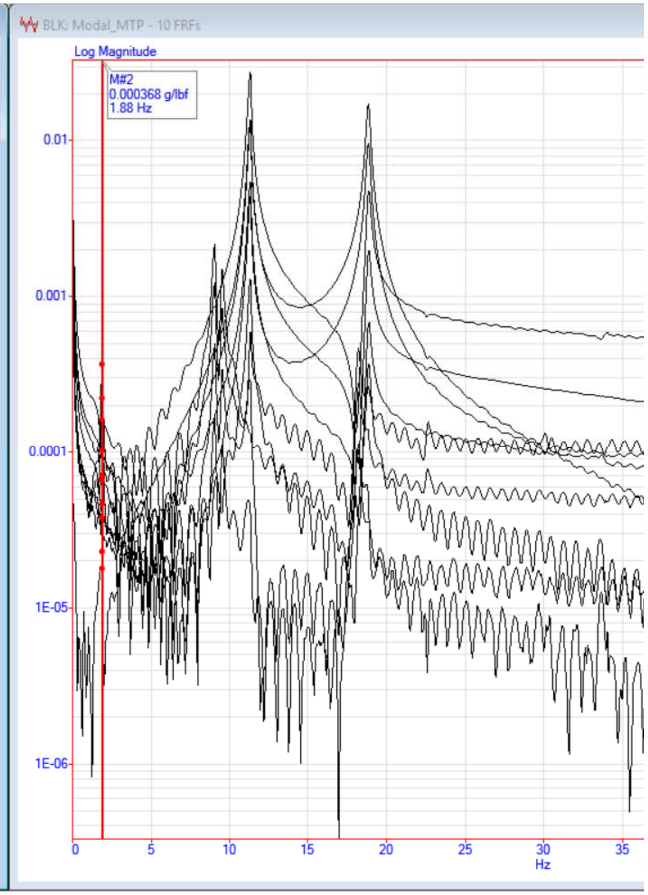
Mode Shape 1 (1.9Hz)

No Interpolation

Experimental Modal Results

Original FEA Results





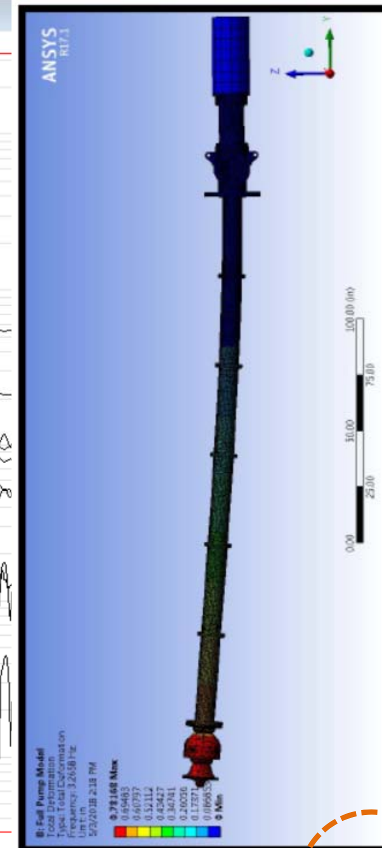


Figure 4: Perpendicular @ 3.3 Hz

Original FEA includes water mass in column; Experimental Modal has empty column above water line

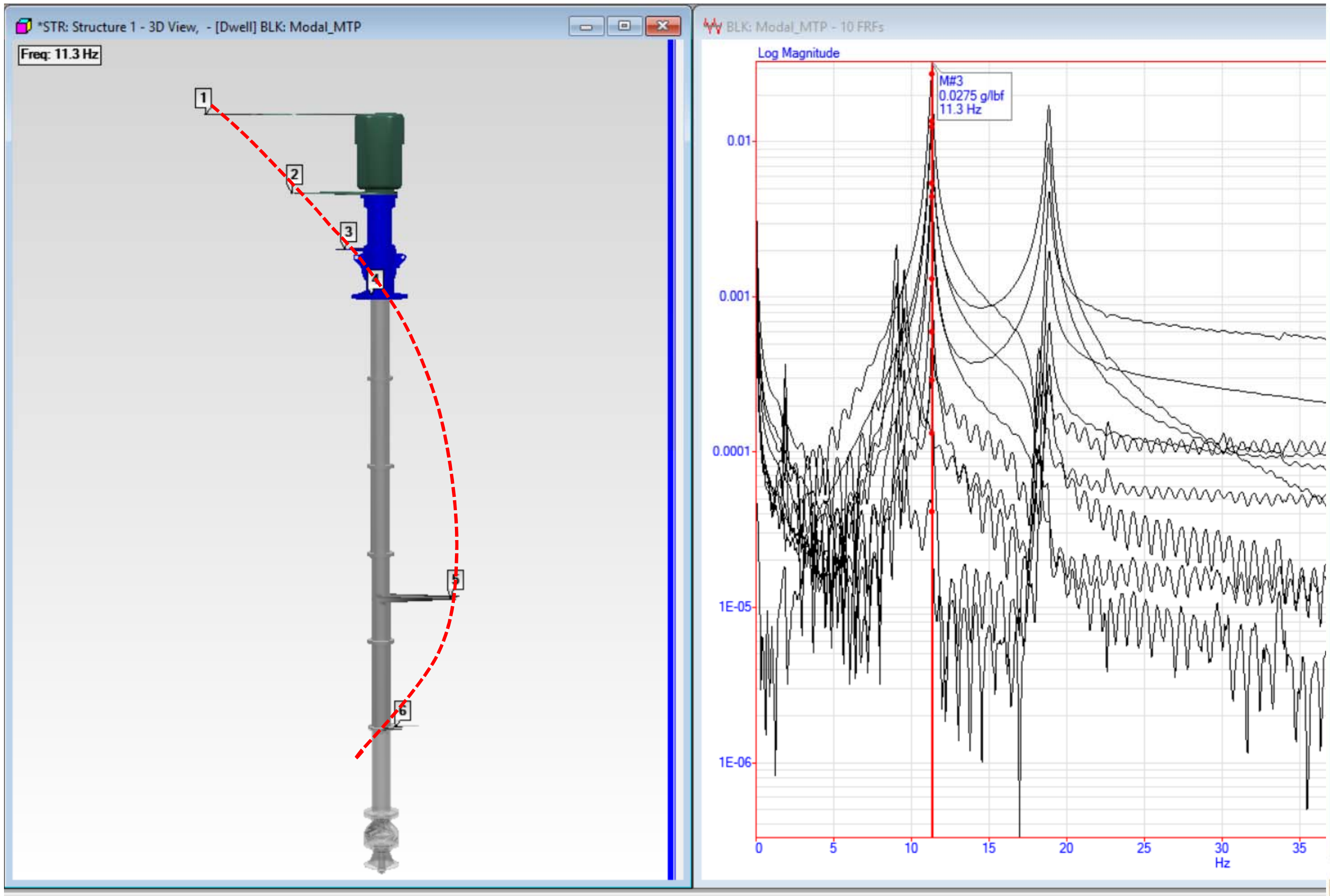
Large error (+75%); will increase with water in column

Mode Shape 2 (11.3Hz)

No Interpolation

Experimental Modal Results

Original FEA Results



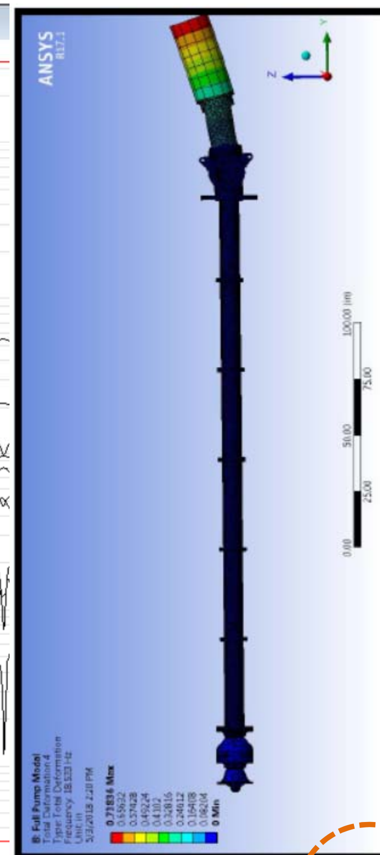


Figure 6: Perpendicular @ 18.5 Hz

Original FEA includes water mass in column; Experimental Modal has empty column above water line

Large error (+64%); will increase with water in column

Mode Shape 3 (18.8Hz)

No Interpolation / Problem mode

Experimental Modal Results

Original FEA Results

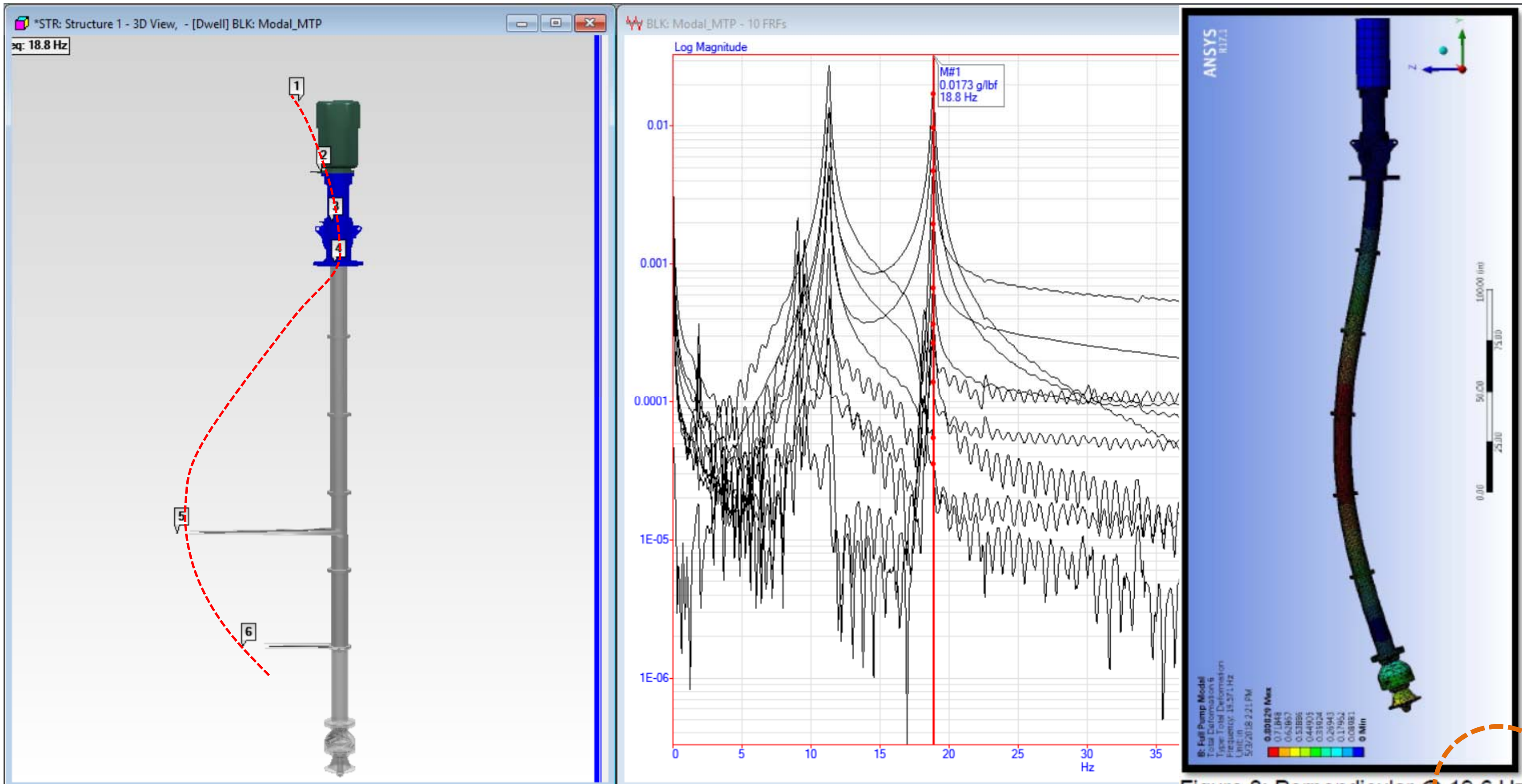


Figure 8: Perpendicular @ 19.6 Hz

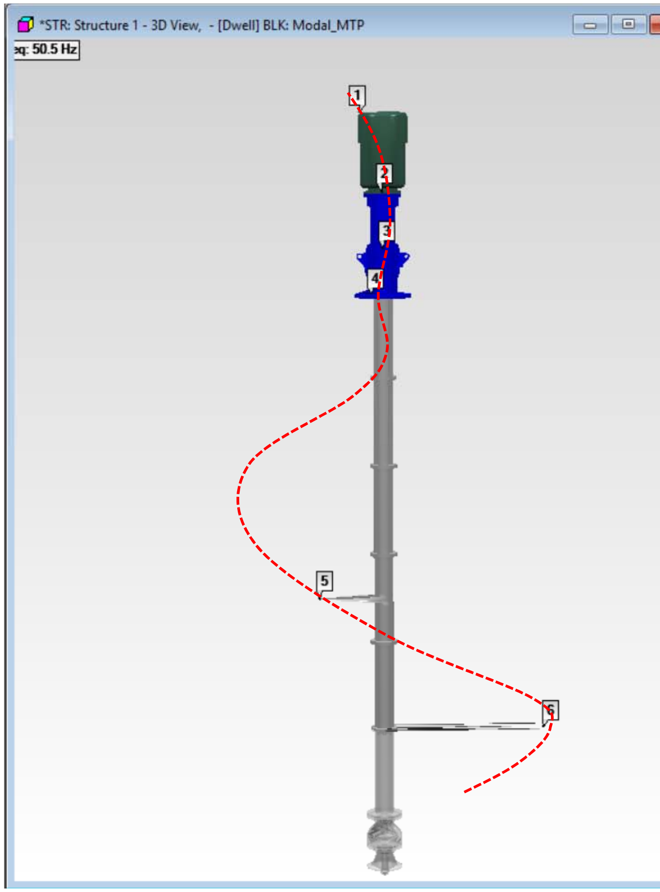
Original FEA includes water mass in column; Experimental Modal has empty column above water line

Slight error (+4%); will increase with water in column

Mode Shape 4 (50.5Hz)

No Interpolation

Experimental Modal Results



Original FEA Results

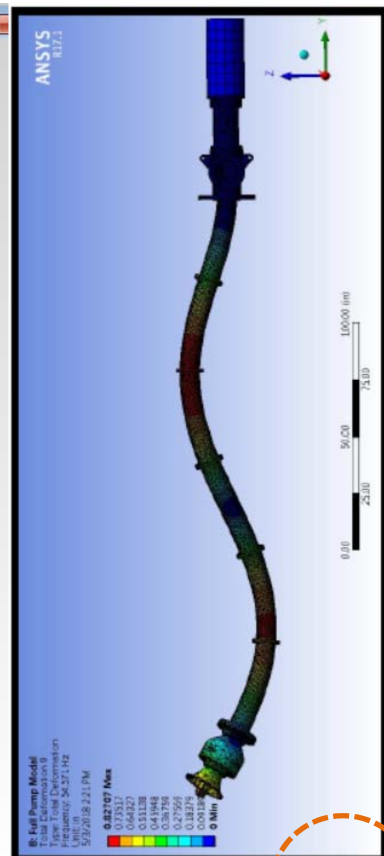
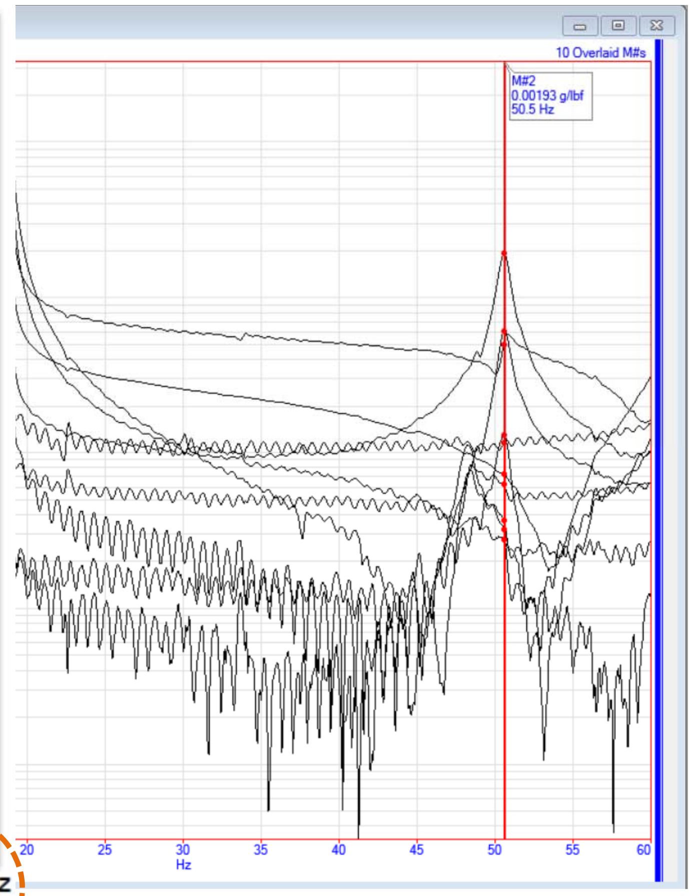


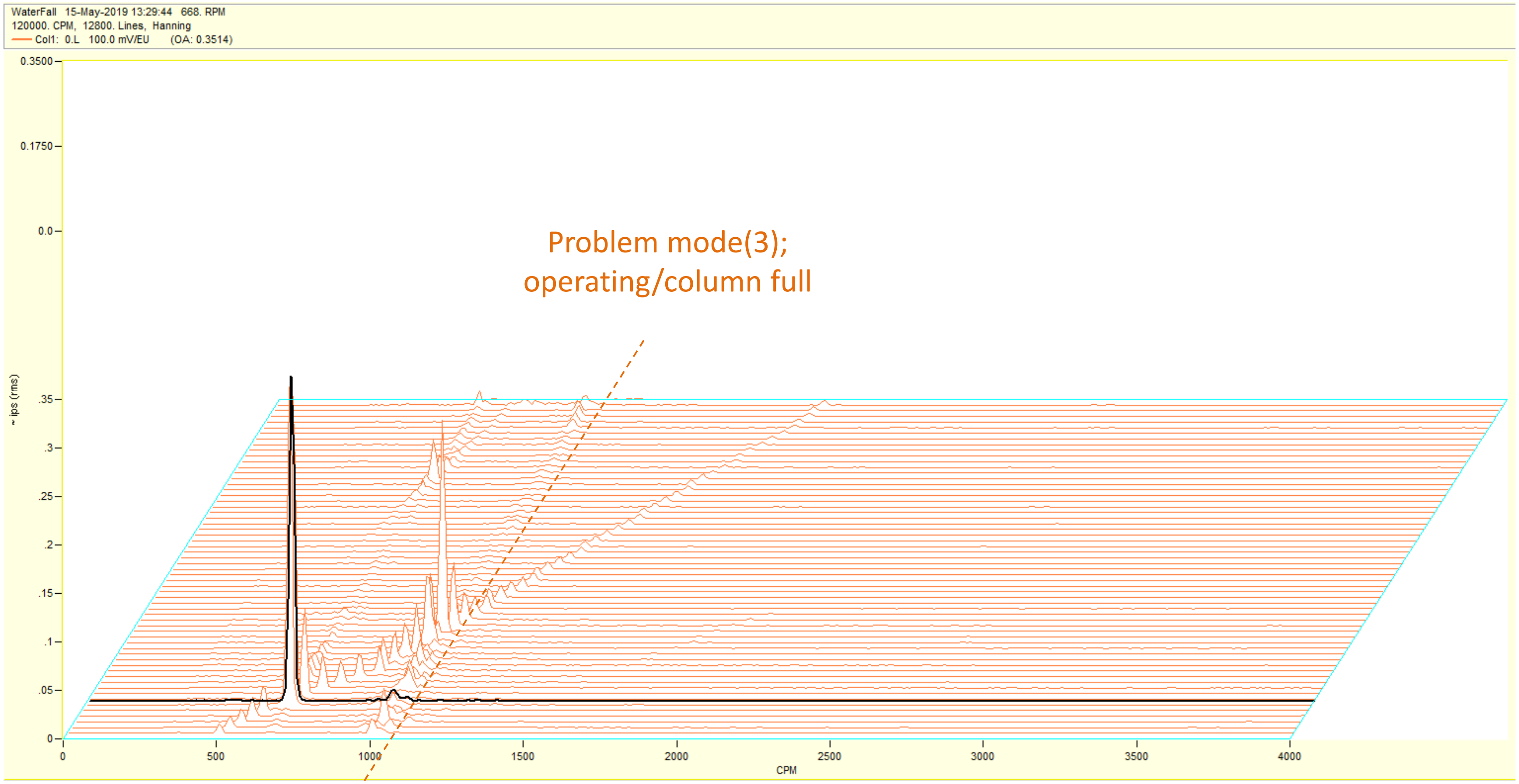
Figure 10: Perpendicular @ 54.6 Hz



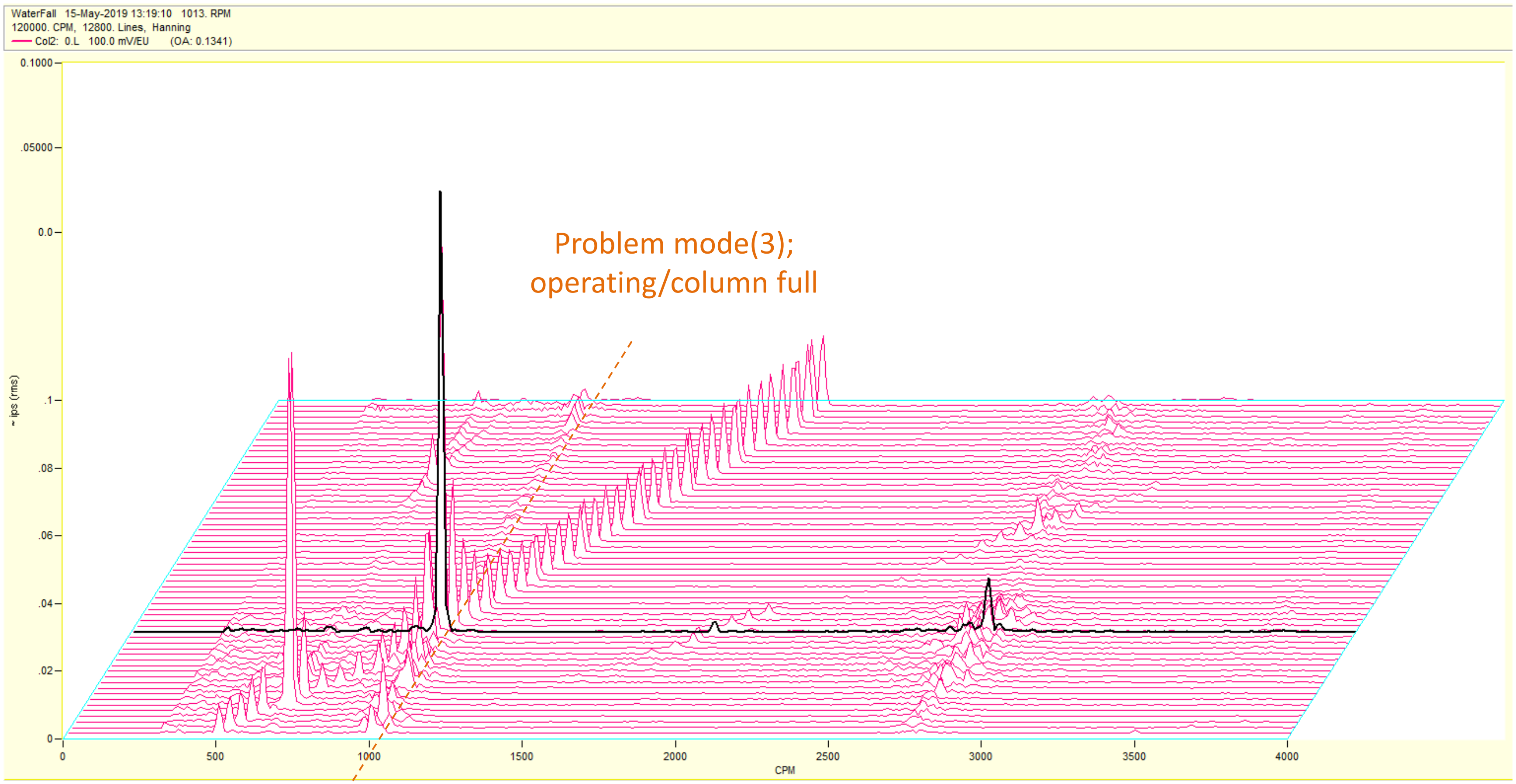
Original FEA includes water mass in column;
Experimental Modal has empty column above water line

Moderate error (+8%); will
increase with water in column

Mid Column Waterfall



Lower Column Waterfall



Frequency Comparison Problem Mode 3

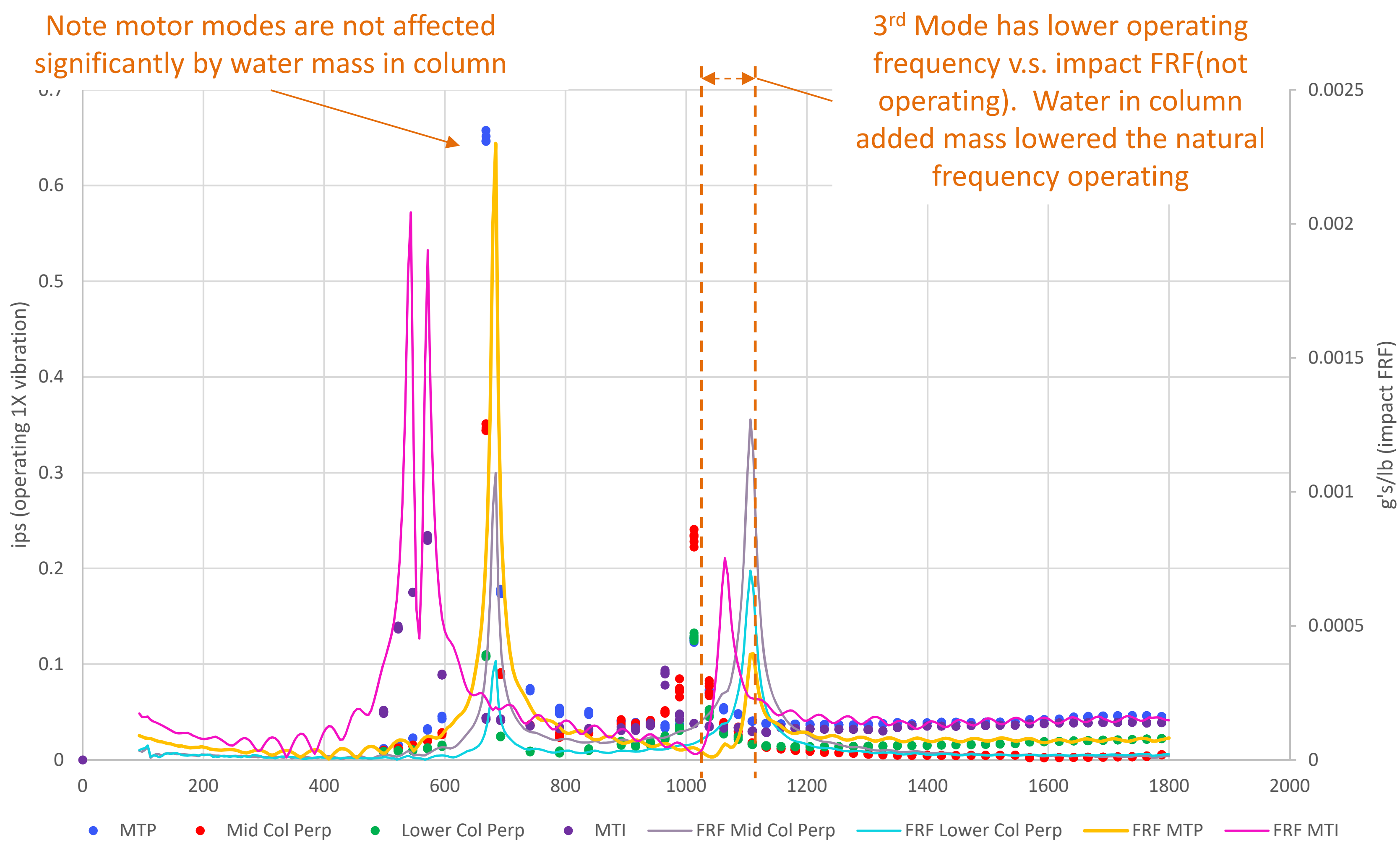
	FEA Original	Actual	FEA Field Adjusted	FEA Modified Pump
Mode 3	19.6	16.9	17.08	13.59
Minimum Speed		900	rpm	
Maximum Speed		1800	rpm	

Actual After Modification		% Deviation from model	% Margin(1X Low)	% Margin(1X High)
A	13.42	-1.3	10.5	65.3
B	13.6	0.1	9.3	65.3
C	13.7	0.8	8.7	65.3

Lowest rpm for low vibration	% Margin(1X Low)
854	5.7
857	4.8
848	3.1

Nearest mode above full speed is 49.6Hz, 49.38Hz, 50Hz on A/B/C

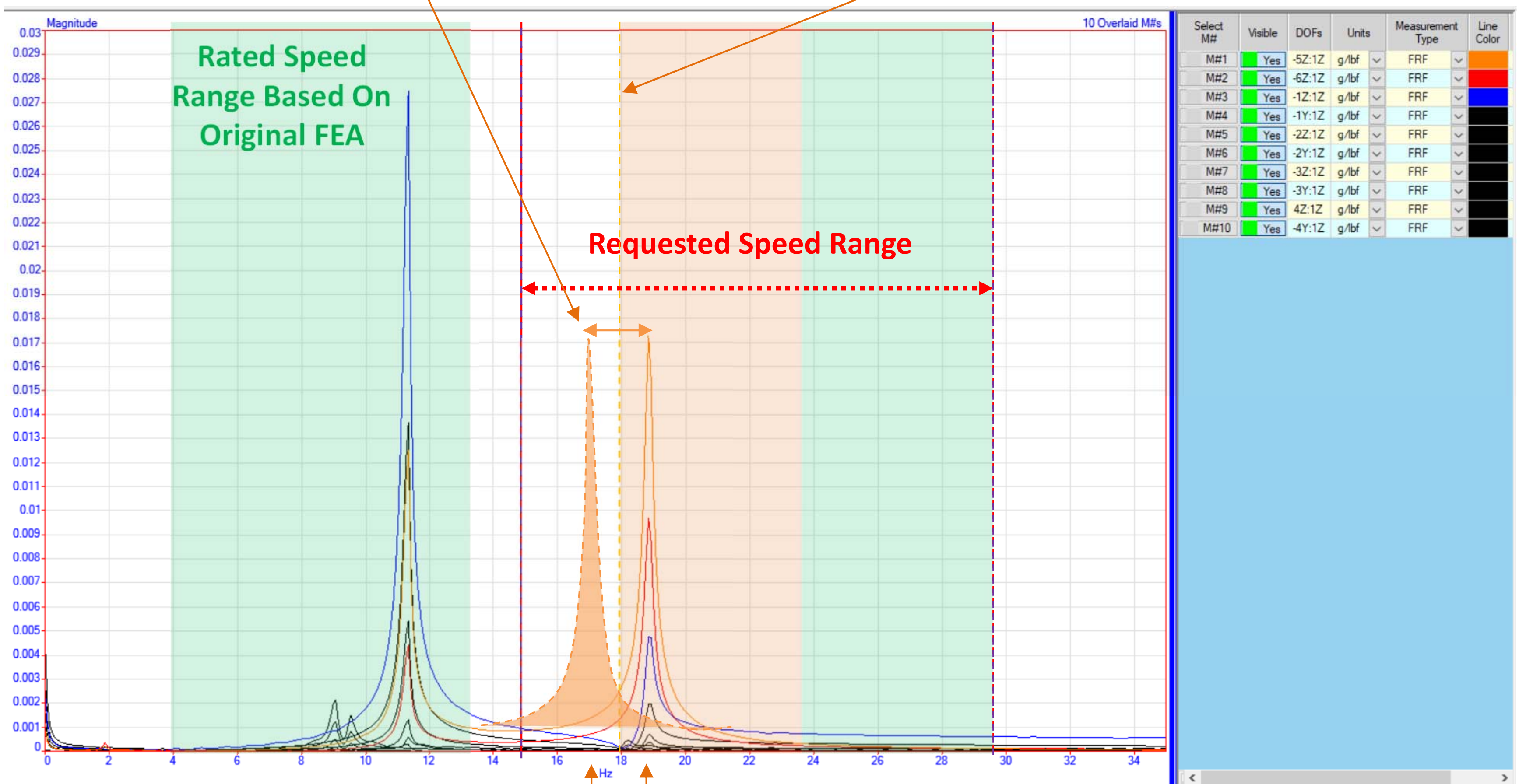
FRF v.s. Operating Vibration



Operating Speeds V.S. Natural Frequencies (column is empty/lower mass)

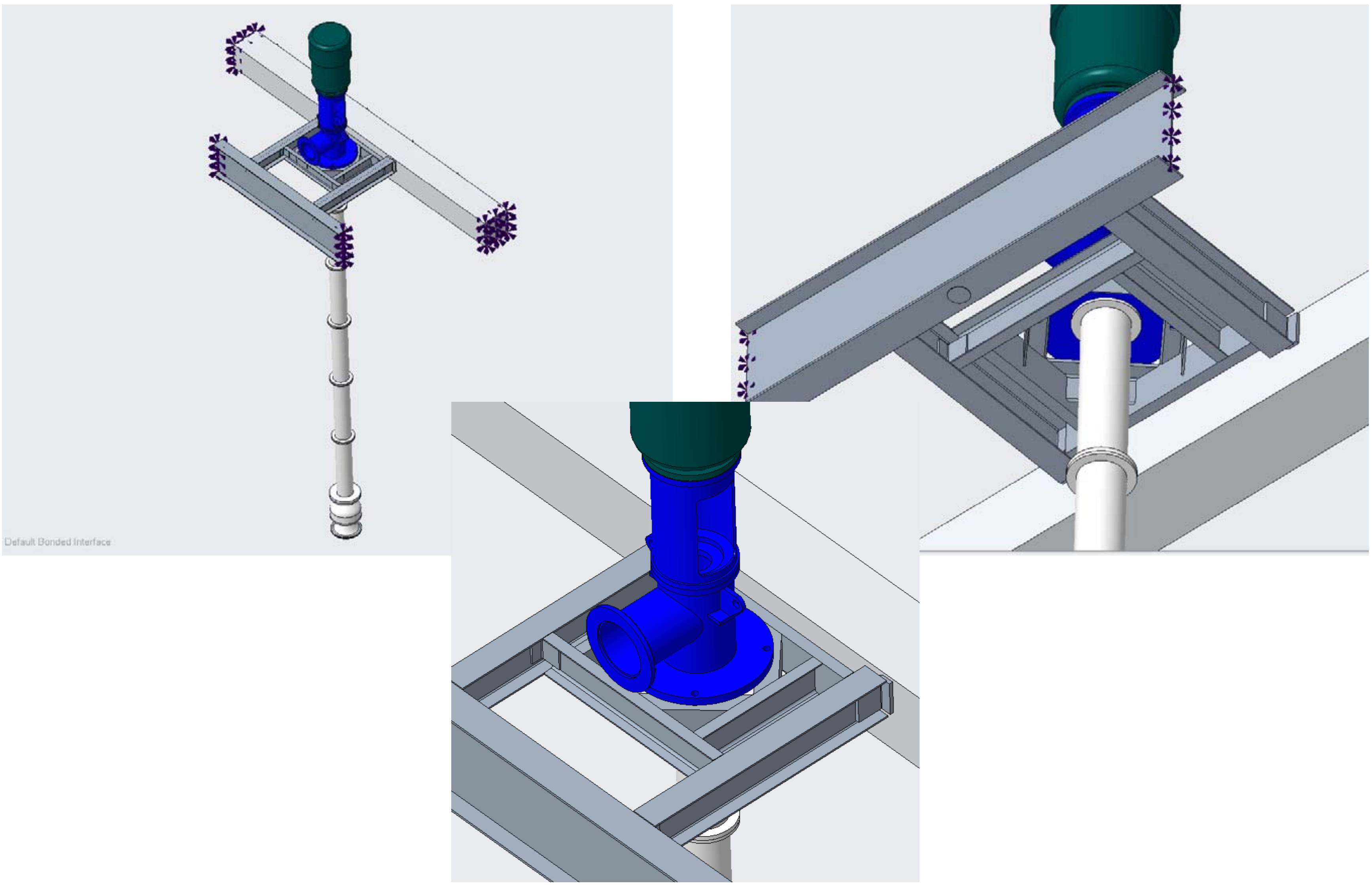
Note the 3rd mode lowers when the column is filled with water; FRF was taken offline with column partially filled.

Possible speed reduction based on site test data.



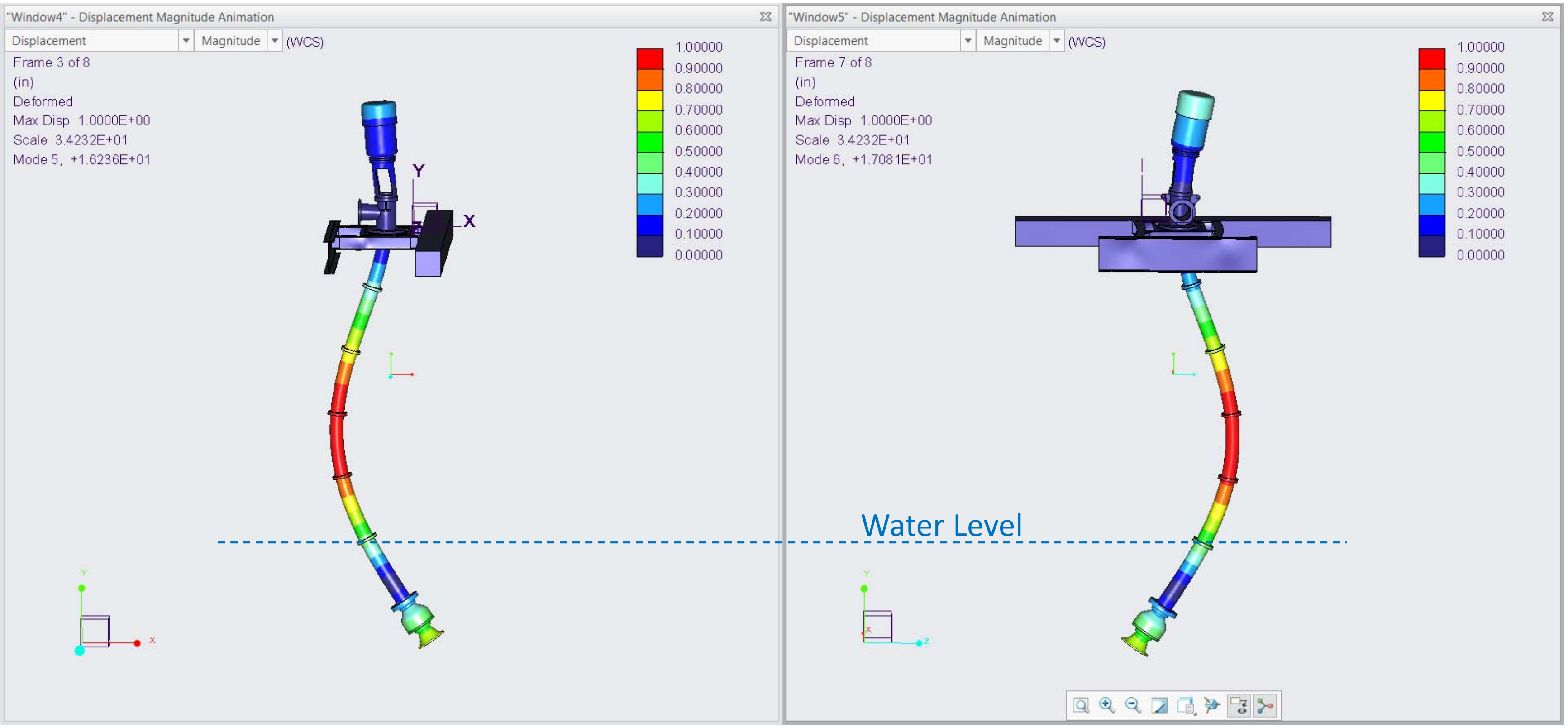
Problematic 3rd Mode

Tuned FE Model



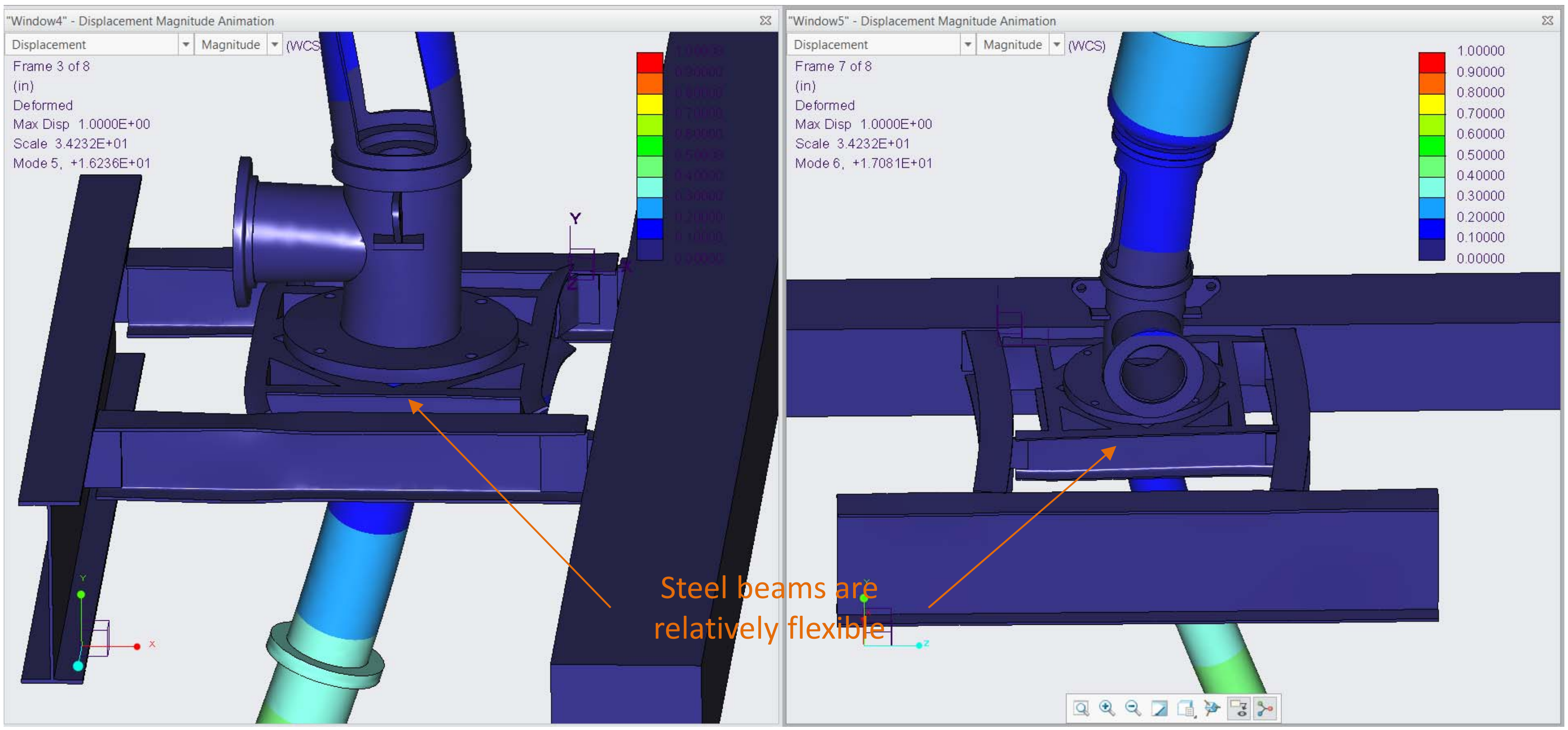
Tuned Model Mode 3

average sump level; top of column 6



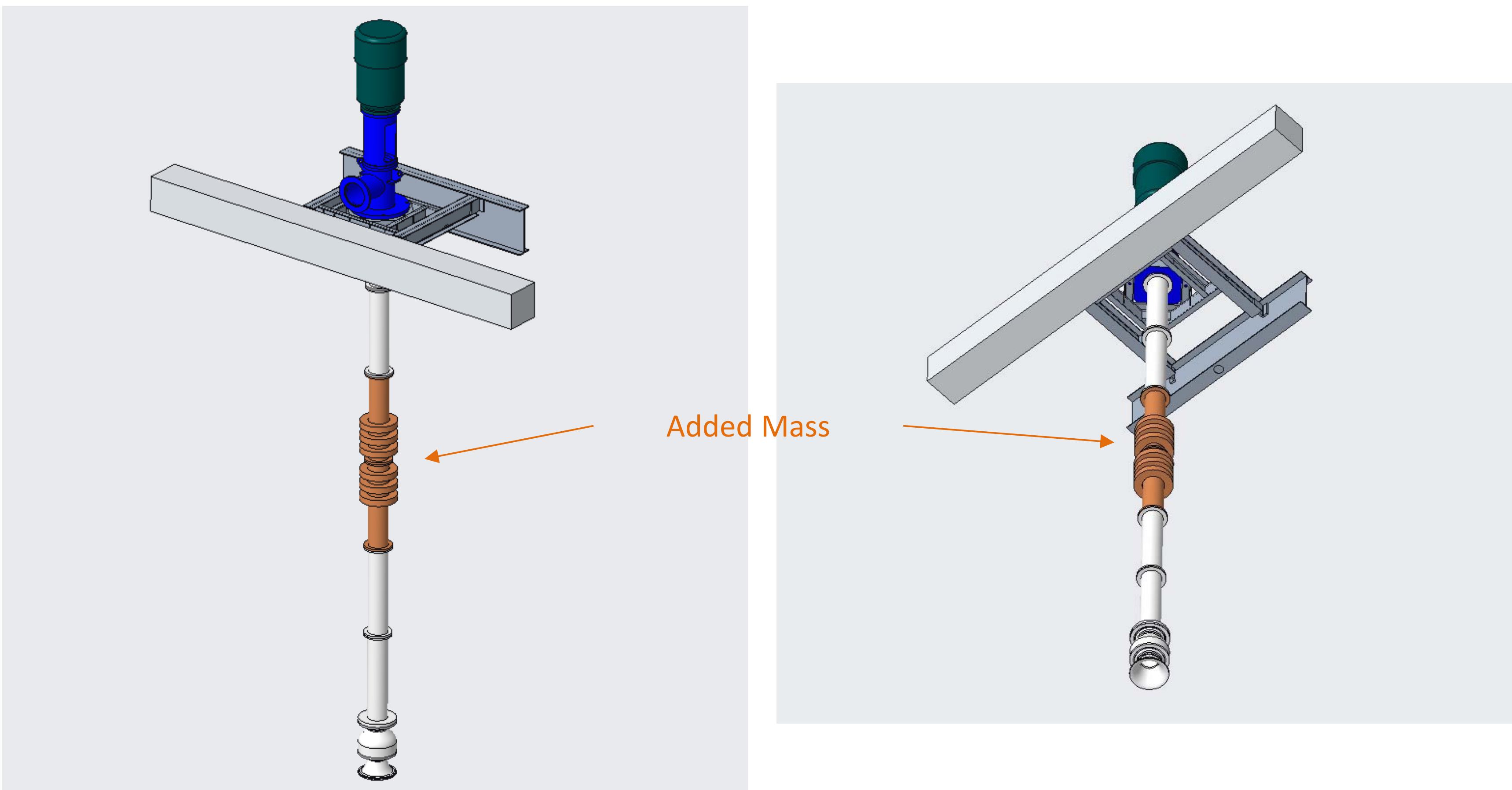
Tuned Model Mode 3

average sump level; top of column 6

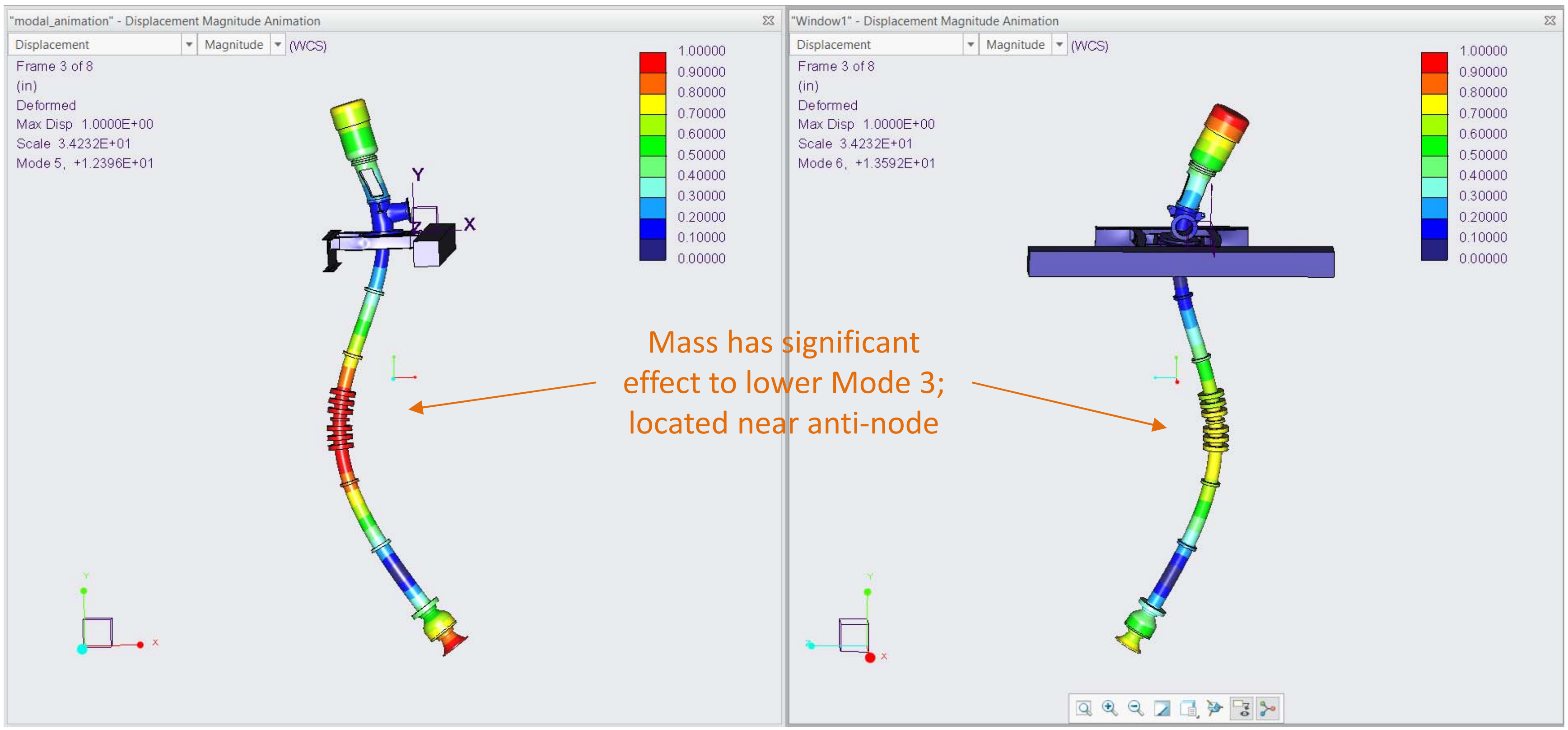


Modified Model

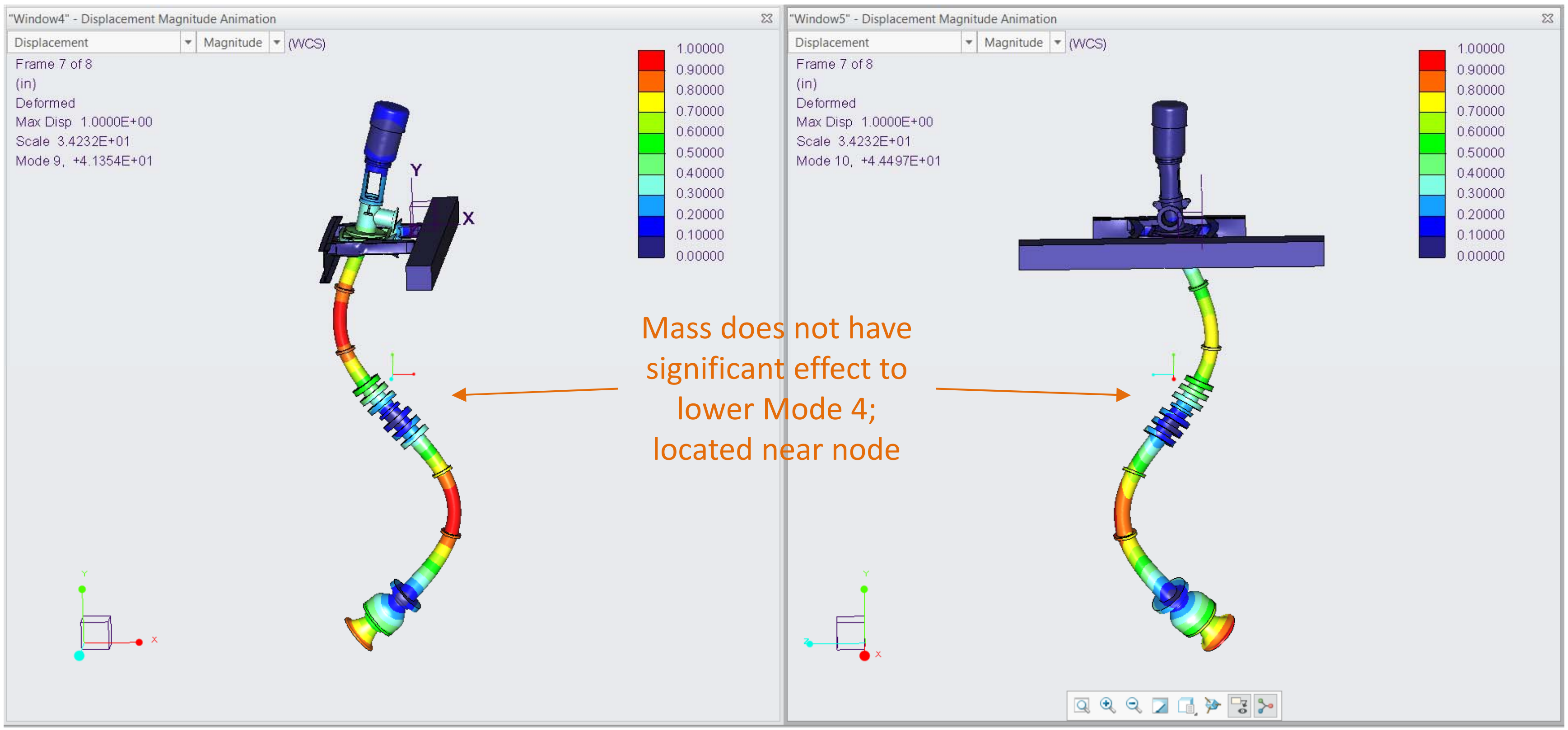
column 3 & 4 additional 318lbs



Modified Model Mode 3

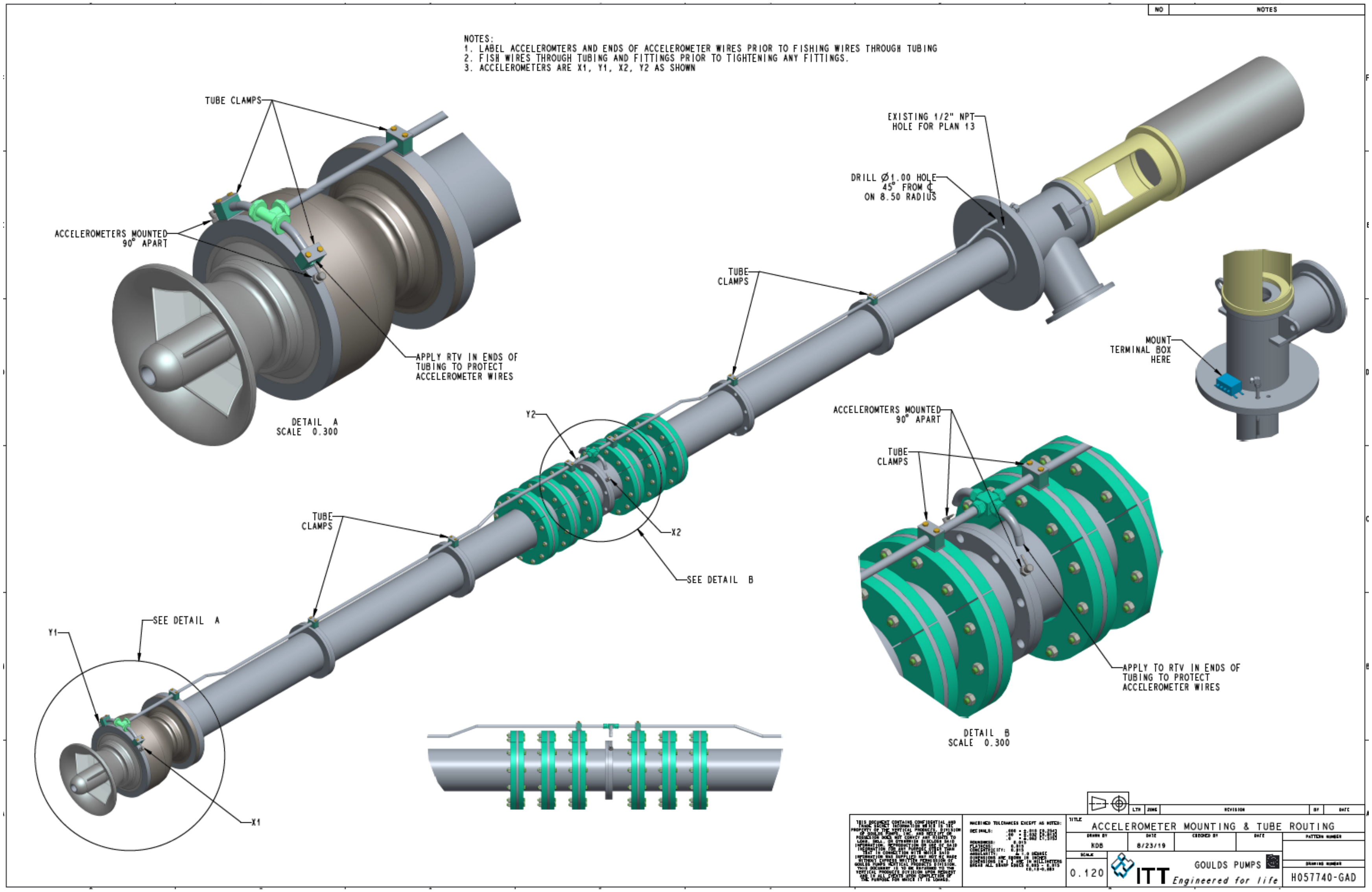


Modified Model Mode 4



Mass does not have significant effect to lower Mode 4; located near node

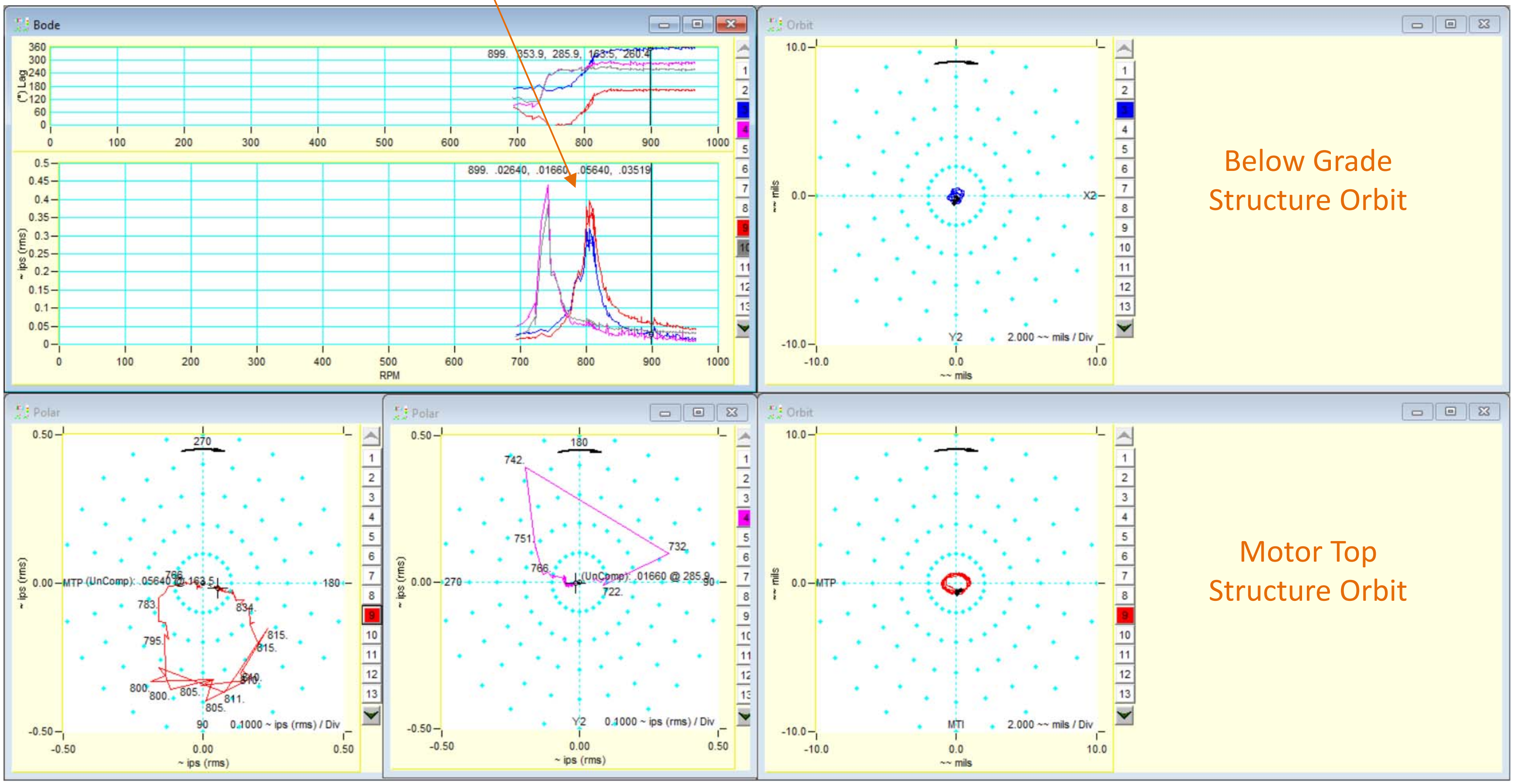
Modifications



Below Grade Accelerometer Installation

After Modification 900RPM(minimum speed)

Natural frequencies well below minimum speed (900rpm)

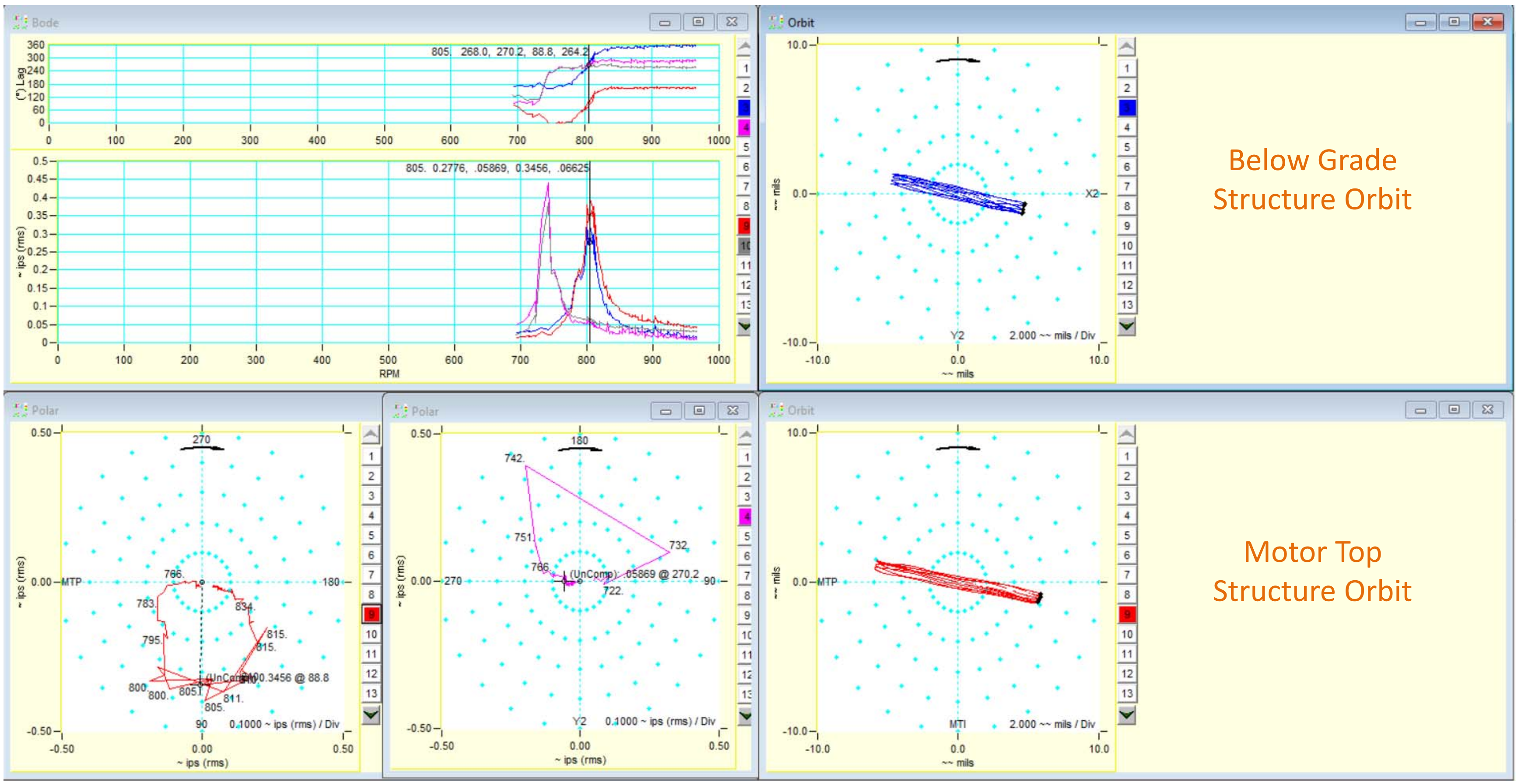


Below Grade Structure Orbit

Motor Top Structure Orbit

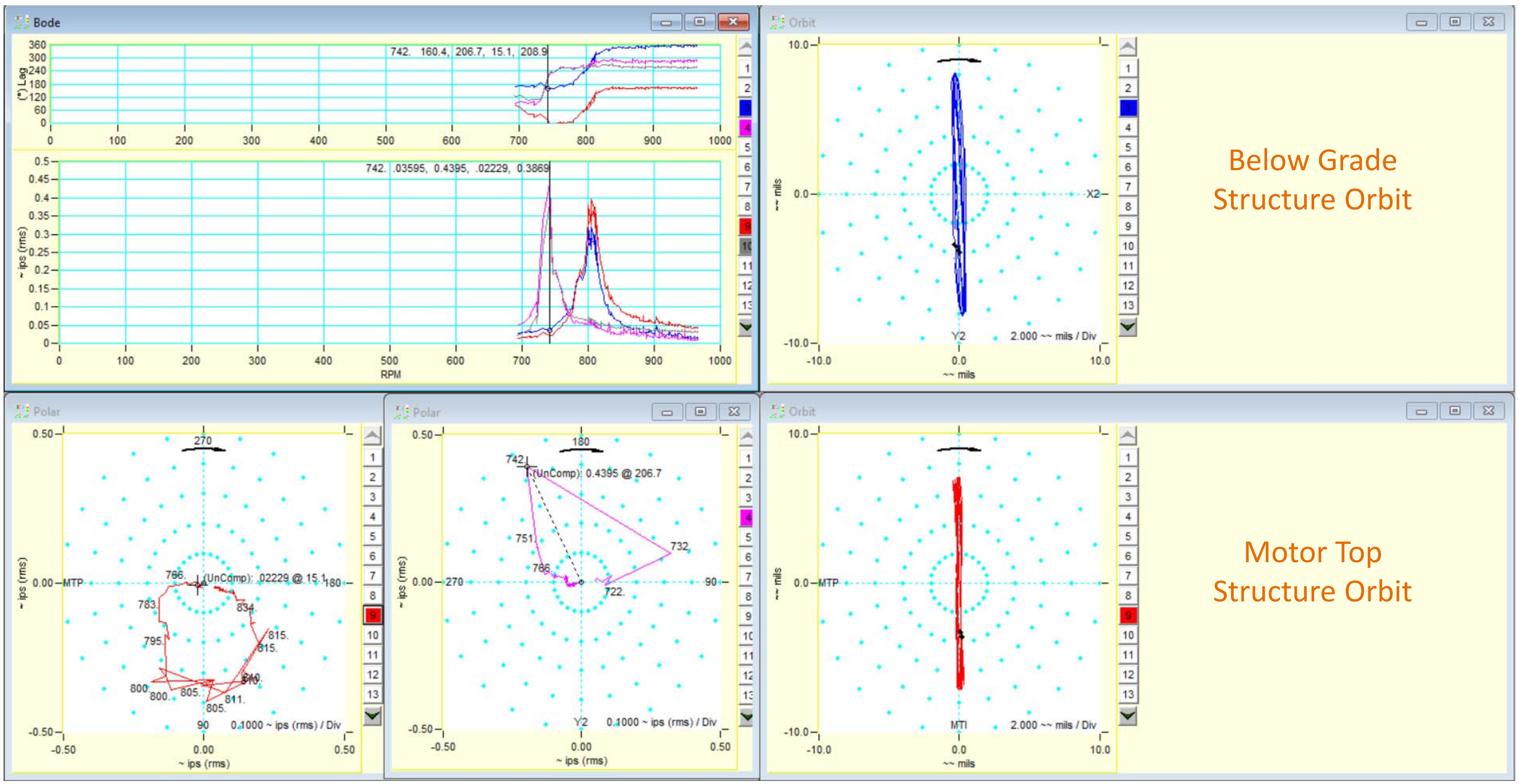
After Modification 805RPM

Perpendicular Critical Speed

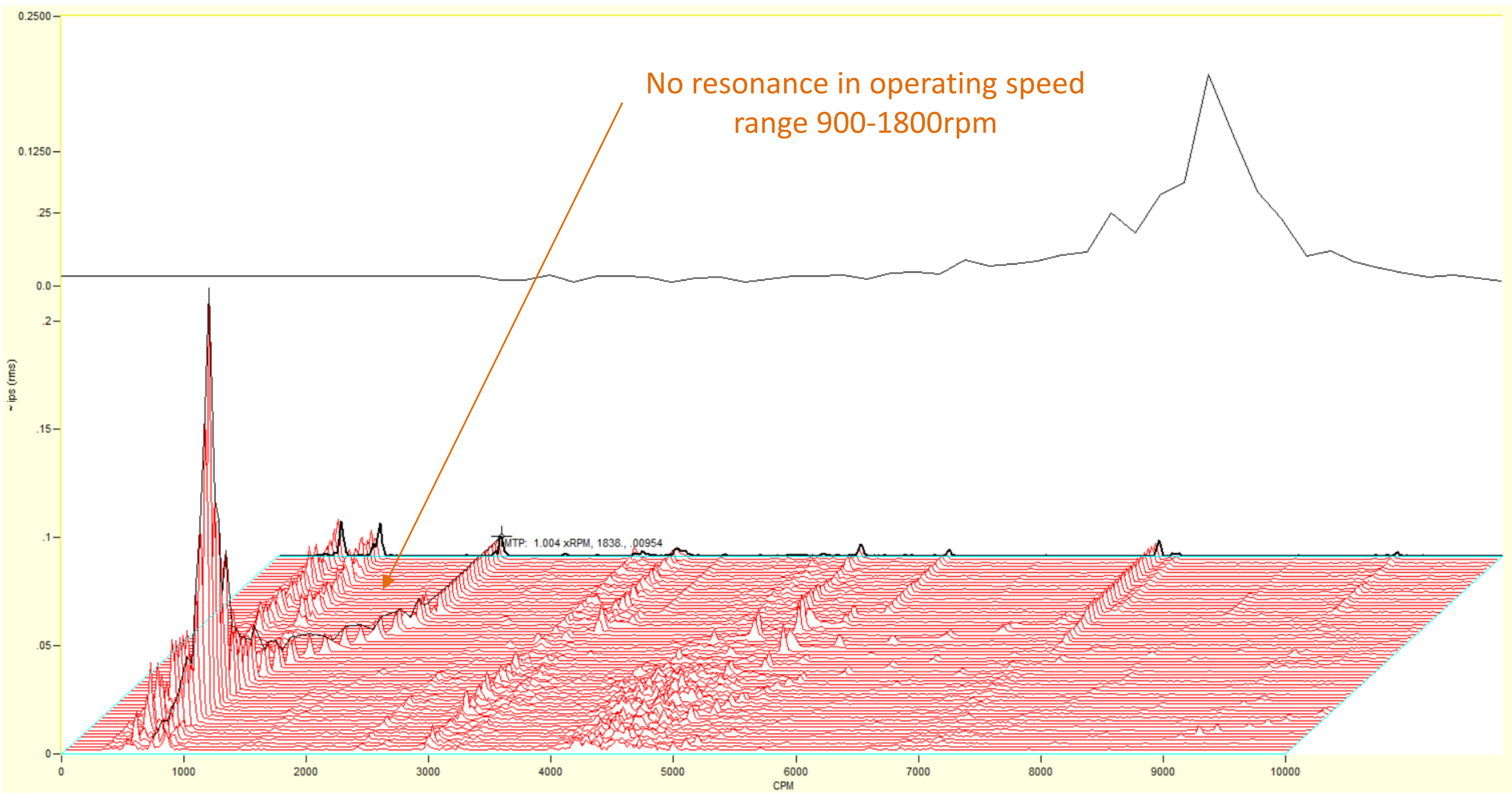


After Modification 742RPM

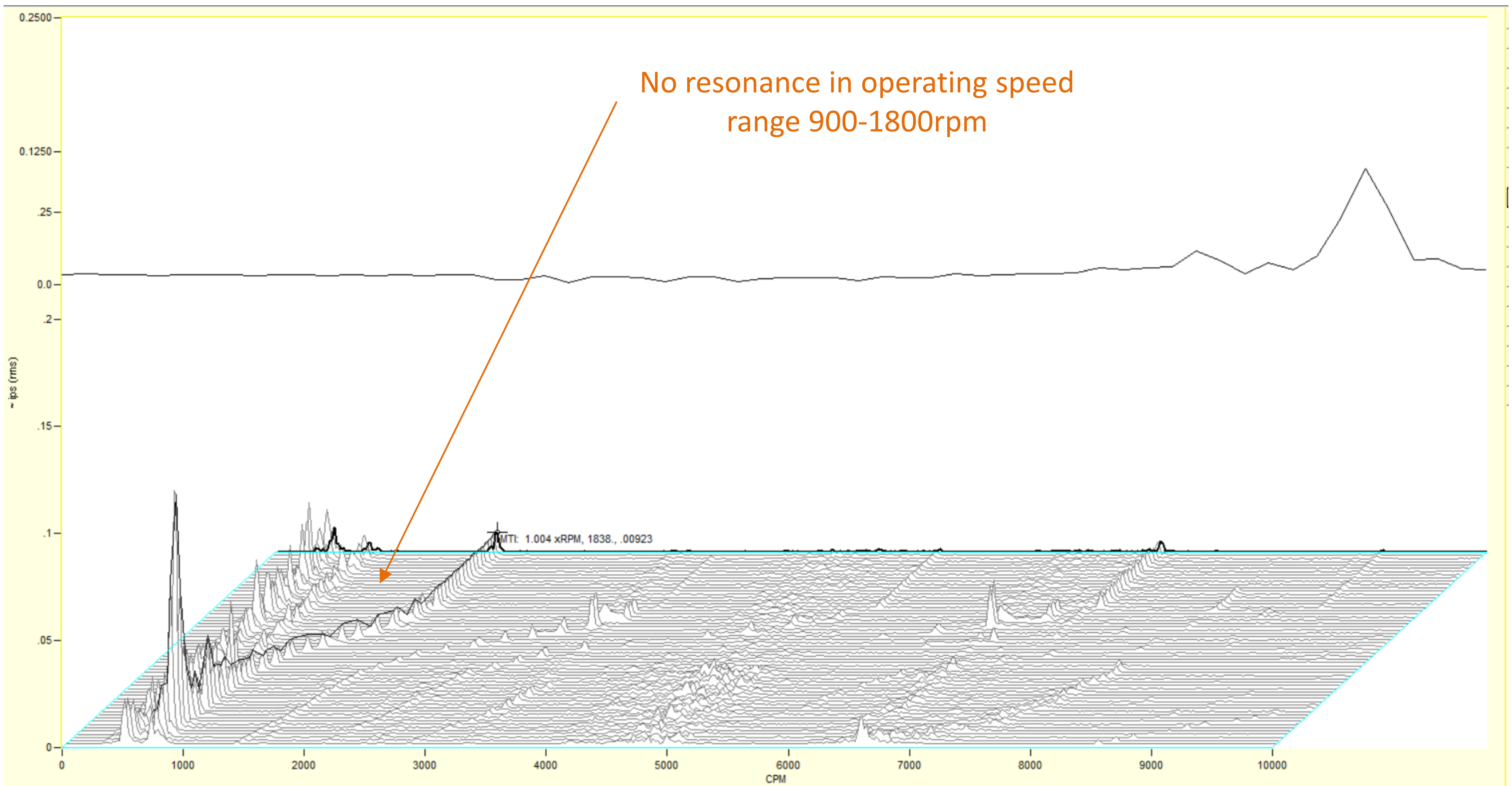
In-line Critical Speed



After Modification MTP



After Modification MTI



Example 2

Low frequency separation margin, foundation damage

- The primary cause of high 1X vibration amplitude was low joint stiffness/damaged grout and resonance.
- Numerous cracks were often found on pumps during repairs.
- F.E. modeling found the pump needed modification to raise the 2nd mode further above 1X frequency without increasing the 1st mode too close to 1X frequency. Modifications evenly split the spacing between 1X and both modes; 20-30% separation margins above and below 1X frequency.
- Actual frequencies correlated well with F.E. model predictions
- Vibration amplitudes were reduced to acceptable levels.
- Raising Mode 2 further above 1X frequency will make the system more tolerant of foundation or structure degradation in the future.
- The original design did not have enough <u>actual</u> frequency separation margin for the "C" mode; likely unrealistic foundation stiffness was used in original design modeling. Foundation damage reduced stiffness further.

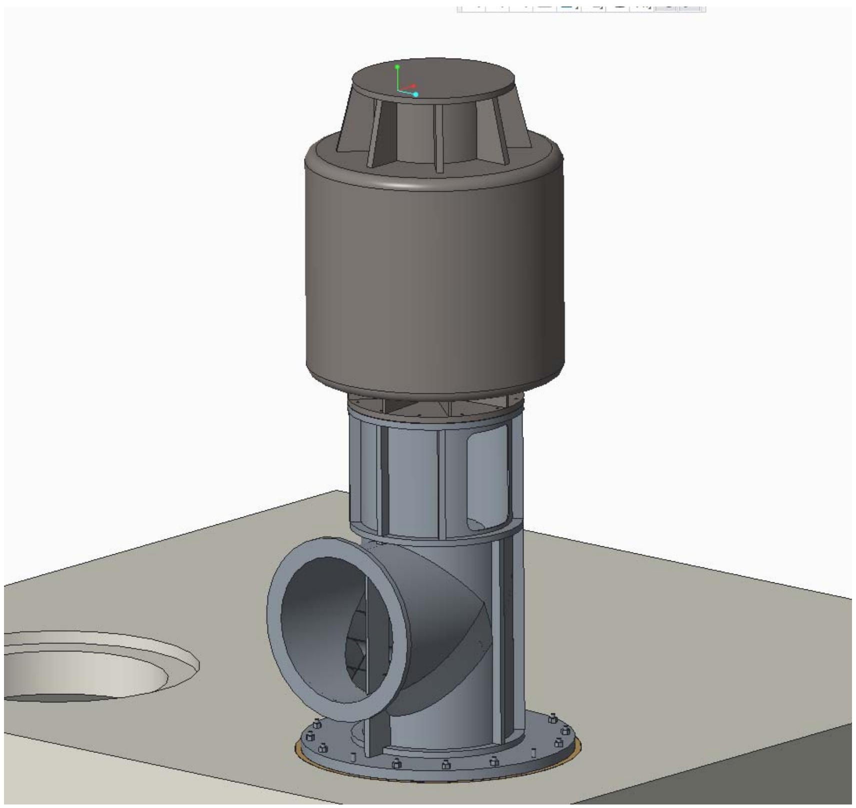
Circulating Water Pumps

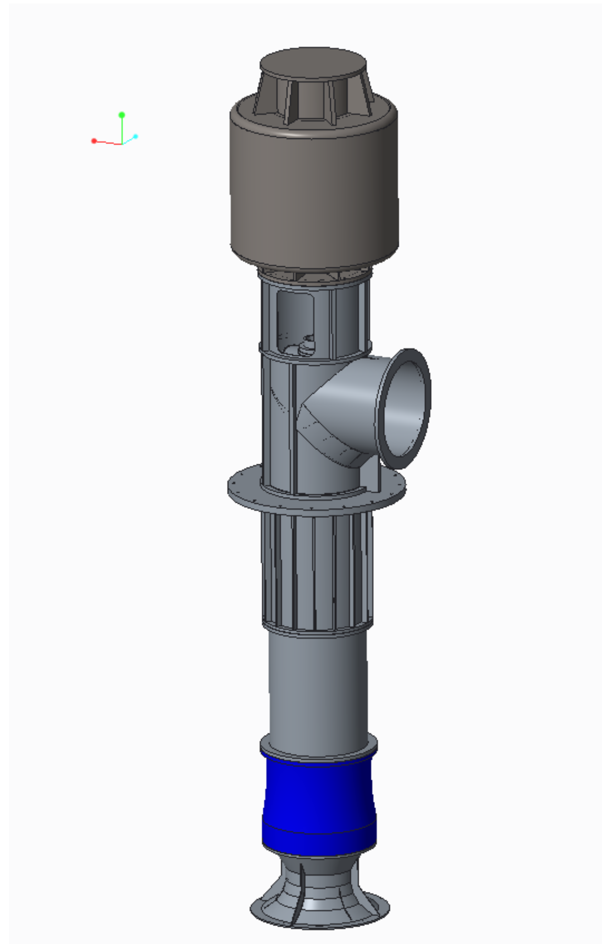
CWP 1 (original)

CWP 2 (modified)

F.E. Model

Modified Pump



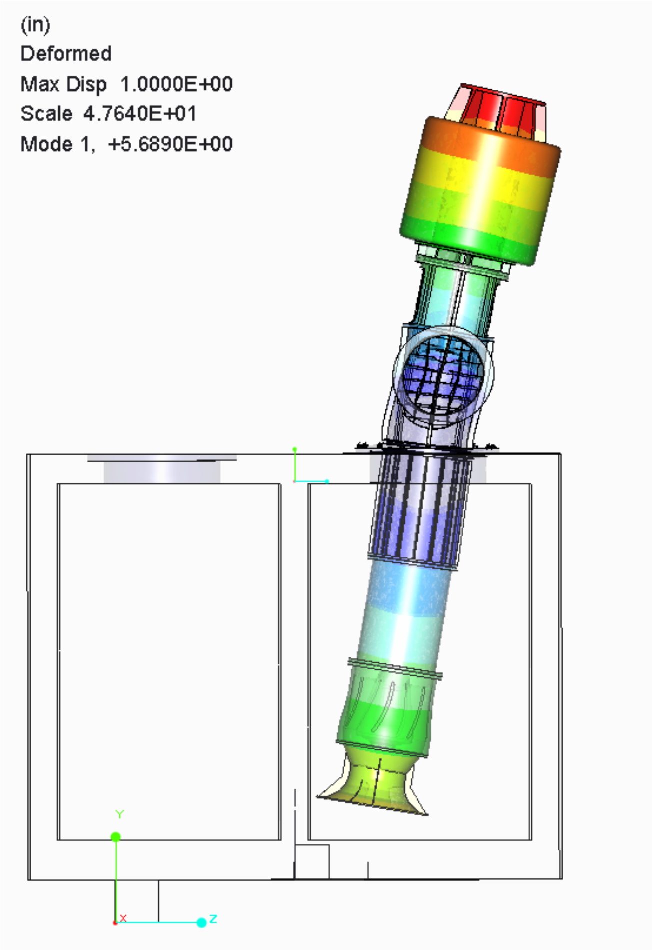


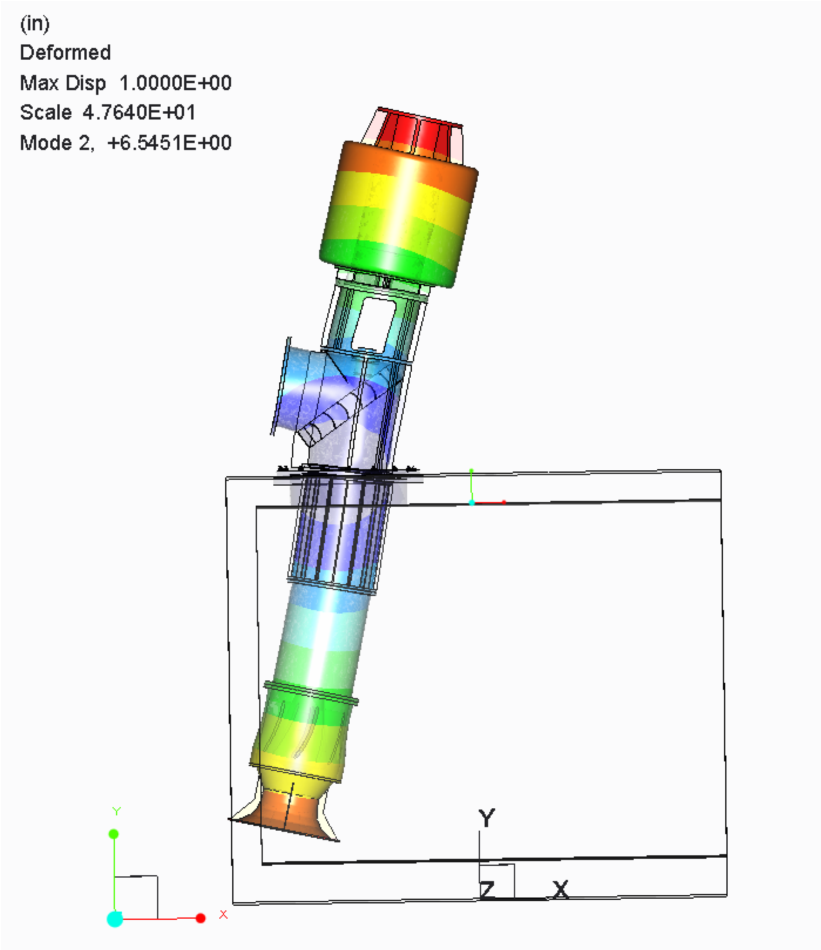
Modes

- This pump/motor/foundation system has two primary modes in the frequency range of concern. There are two different frequencies for each mode corresponding to the in-line with discharge and the perpendicular to discharge directions.
- The lower mode(below 1X) is a “pivotal” mode that involves the pump/motor assembly essentially moving as a rigid body with flexing of the pump discharge head flange at the foundation.
- The 2nd mode(above 1X) is a “C” shape bending mode where the pump/motor assembly essentially bends near the foundation.

Results

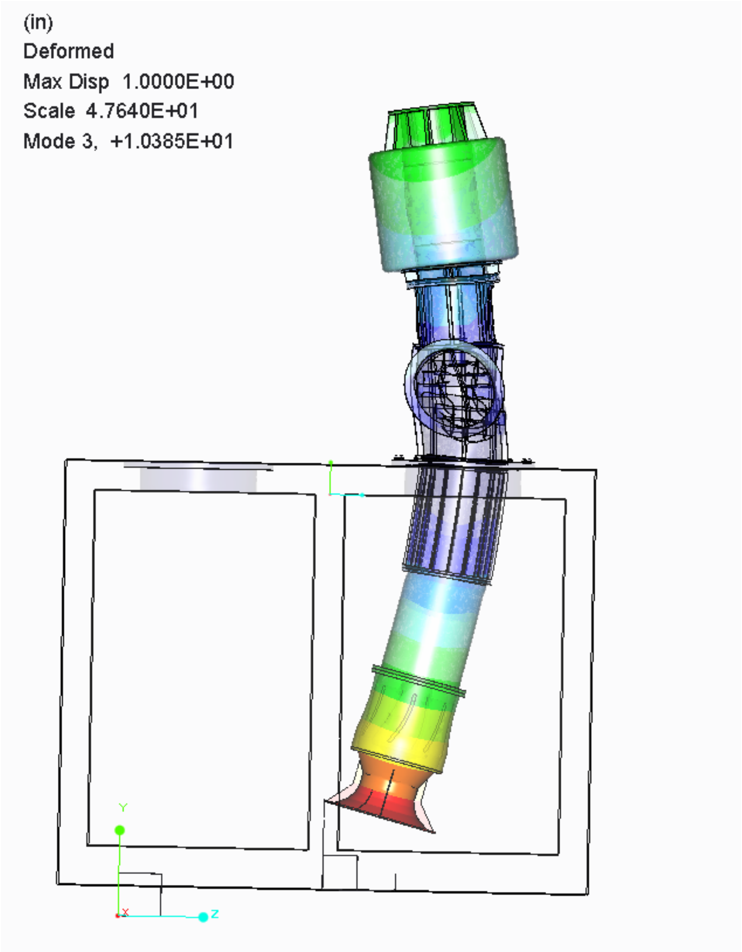
Pivotal Mode

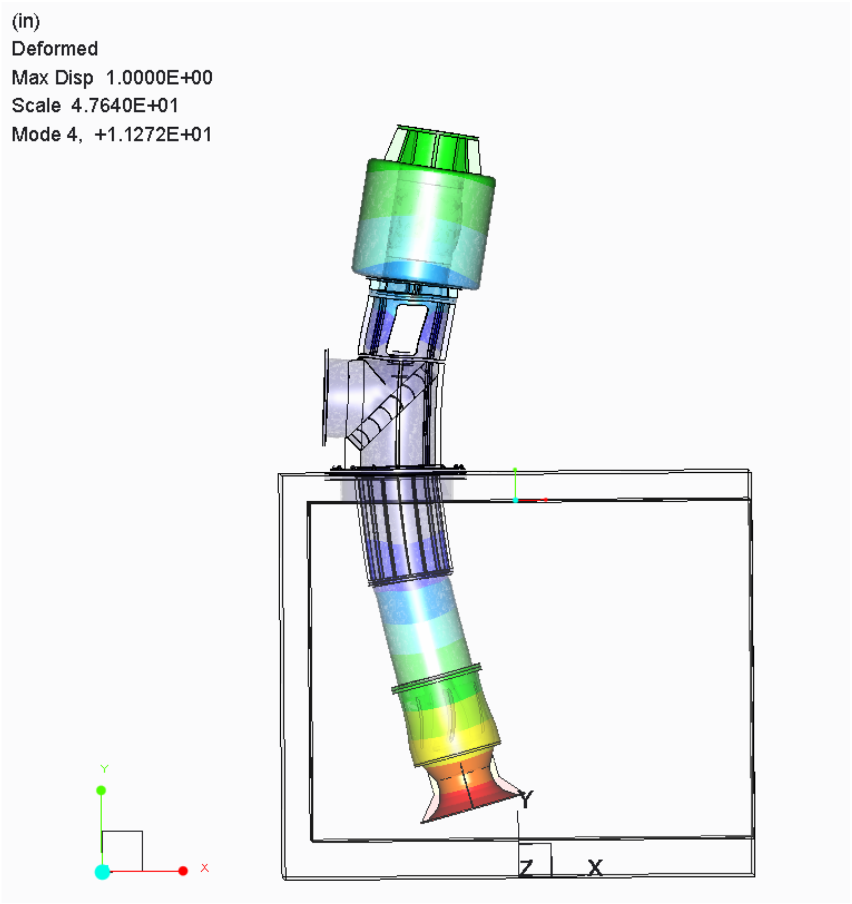




Results

“C” Mode

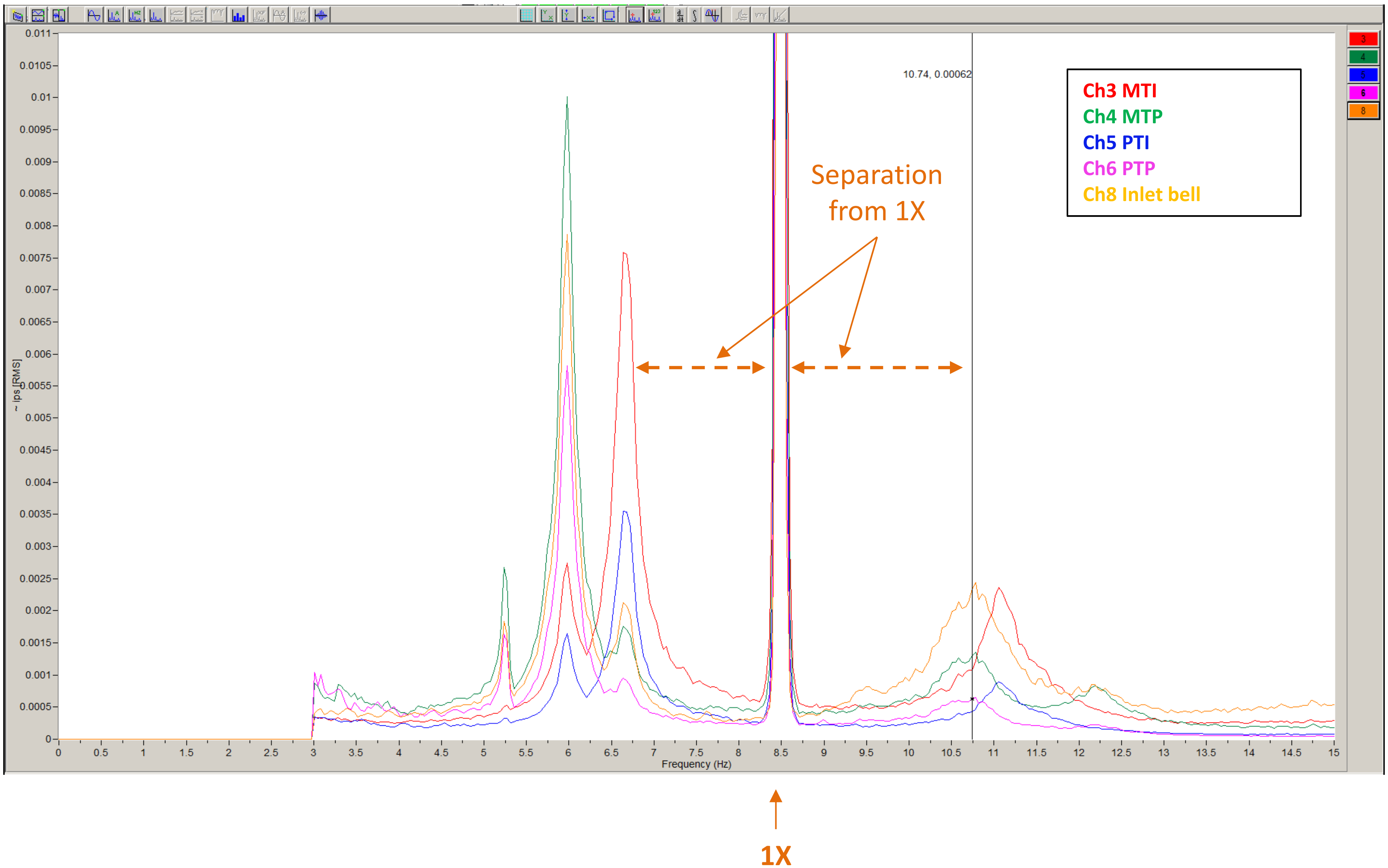




Cracks Found During Previous Repair

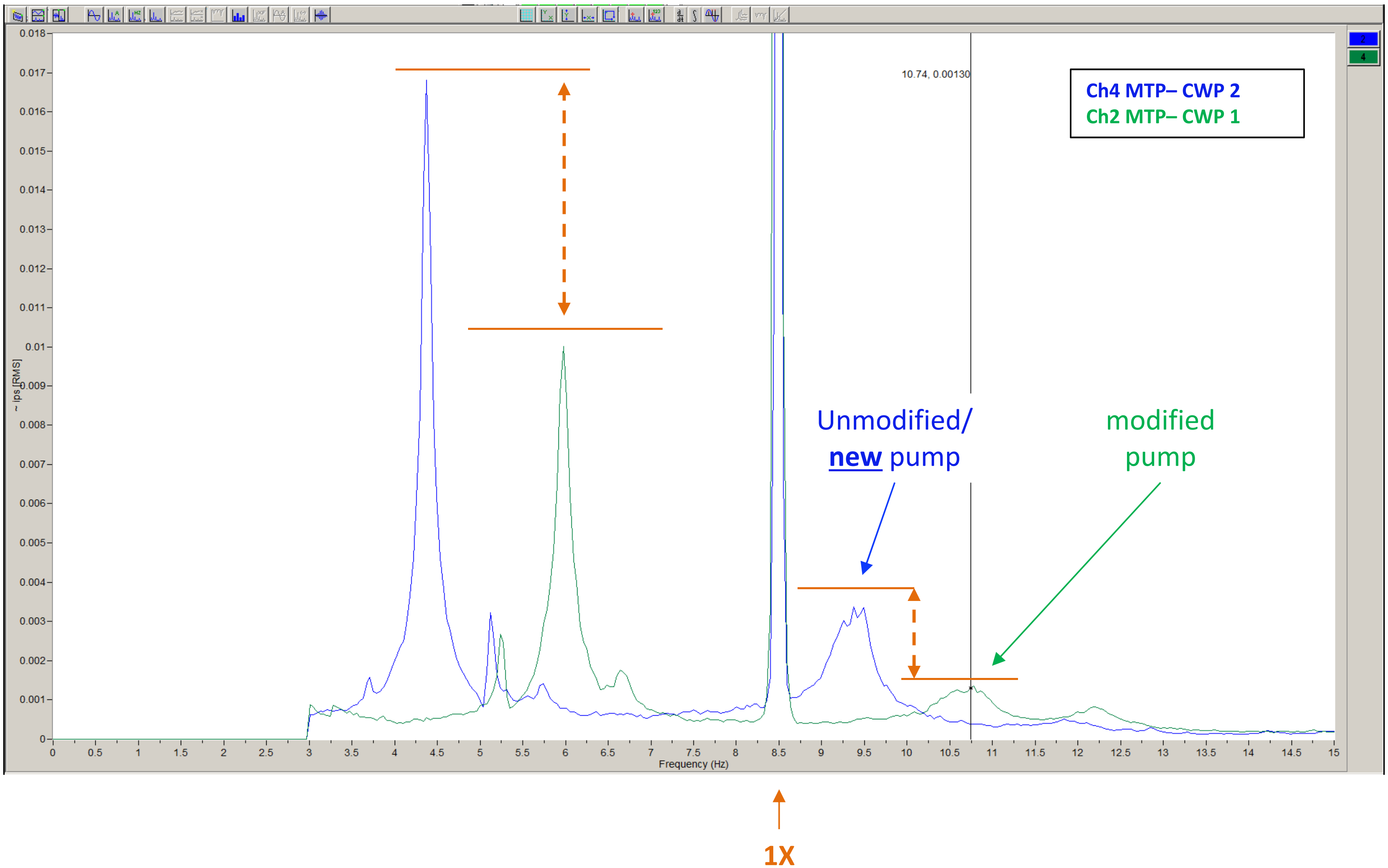

CWP 2 Natural Frequencies

After Modification



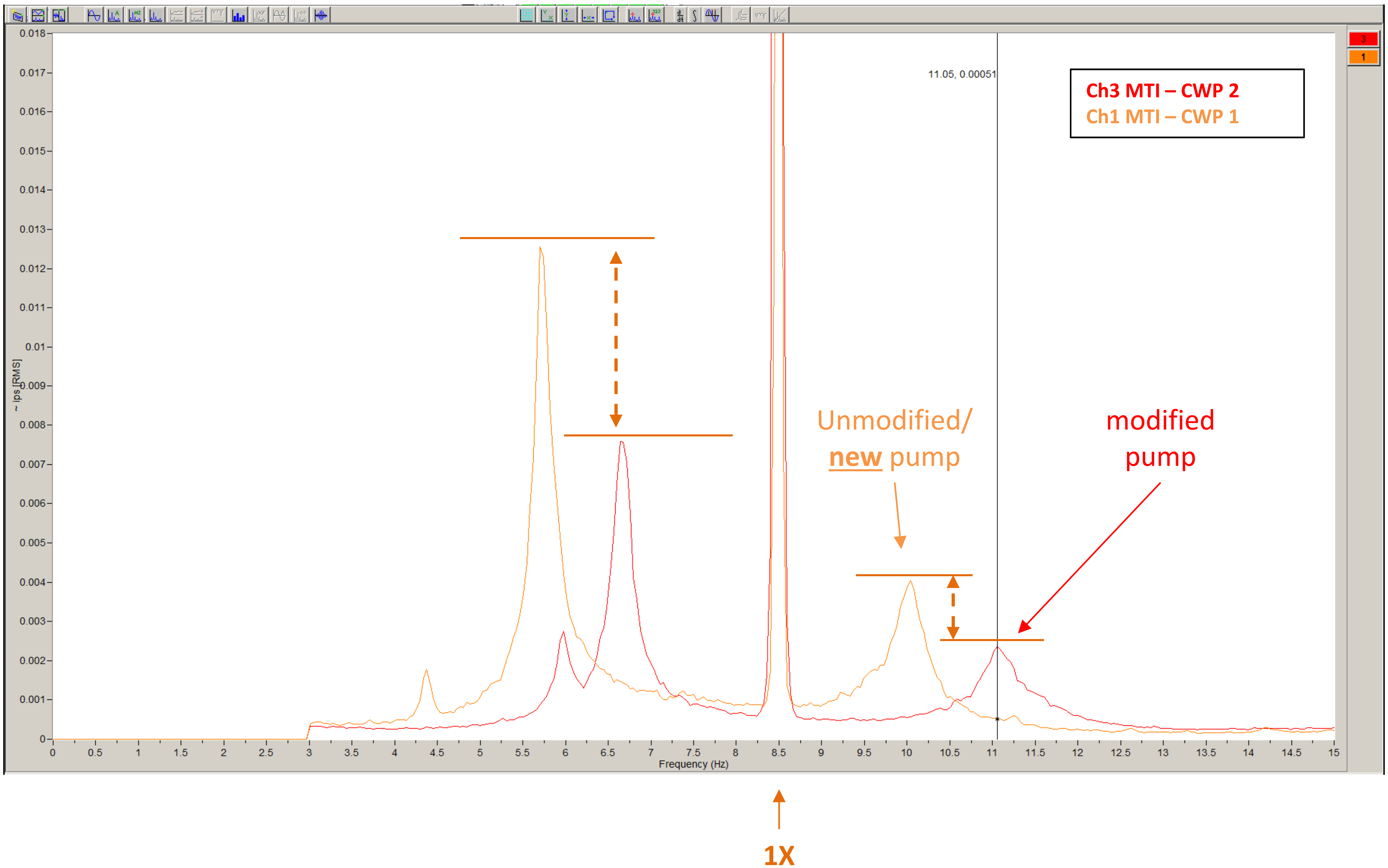
CWP 2 V.S. CWP 1

perpendicular natural frequencies

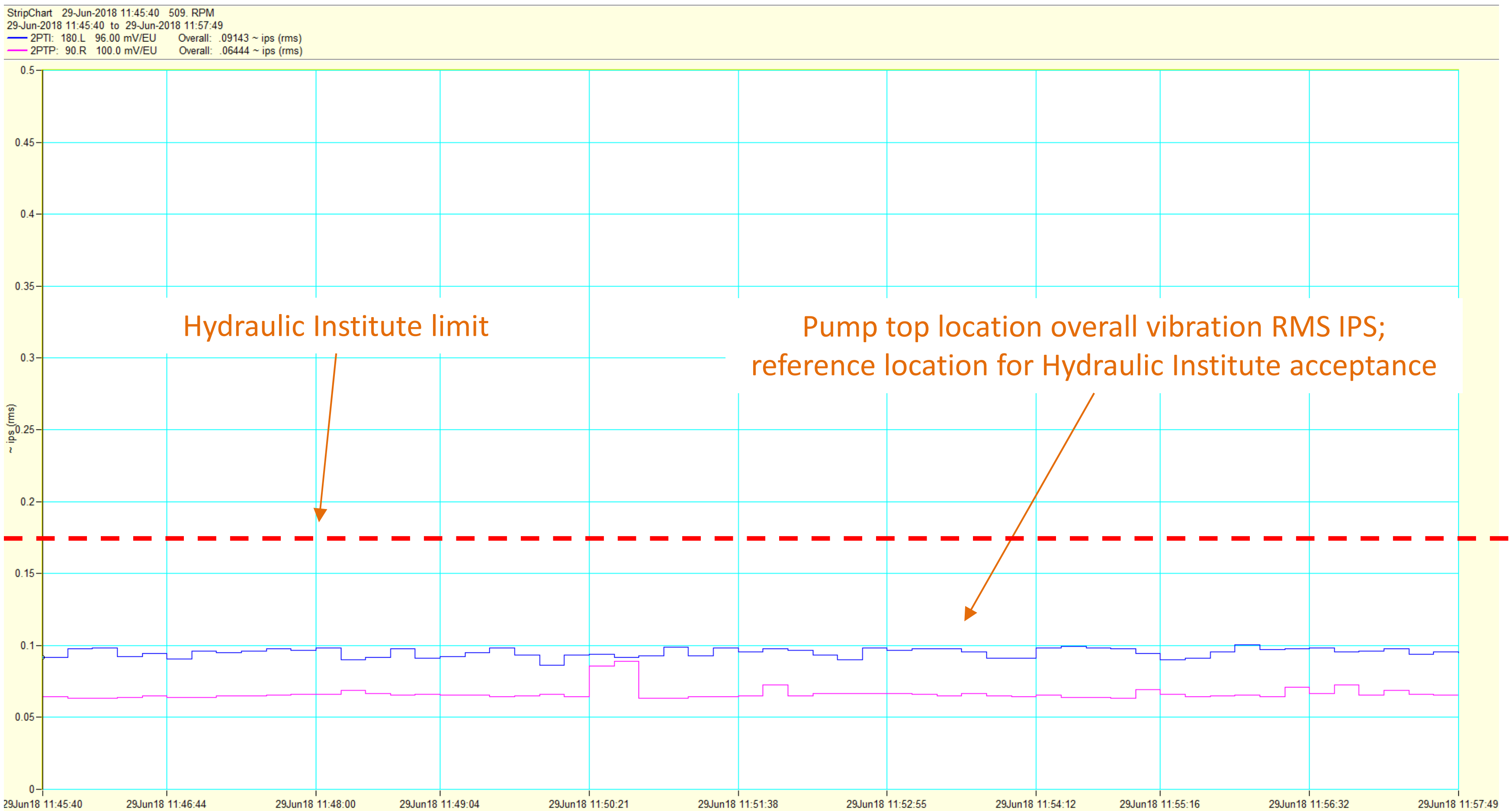


CWP 2 V.S. CWP 1

inline natural frequencies



Hydraulic Institute Guideline V.S. Actual Vibration Amplitudes(at pump top location)



Final Results

(natural frequencies in Hz)

- Adjusted FE model (test data before modification)

		% margin from 1X
Pivotal Inline	5.00	-41
Pivotal Perpendicular	4.11	-51
"C" Inline	9.52	12
"C" Perpendicular	8.93	**5**

- FE model with modifications

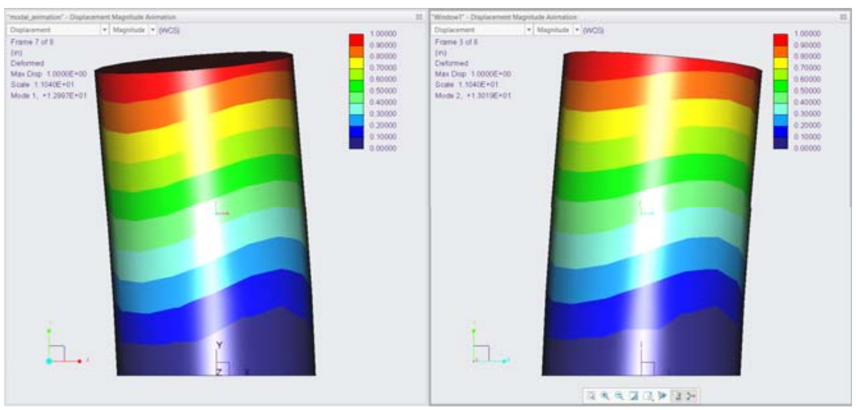
		% margin from 1X
Pivotal Inline	6.55	-23
Pivotal Perpendicular	5.69	-33
"C" Inline	11.27	33
"C" Perpendicular	10.38	23

- Modified pump (actual field results CWP2)

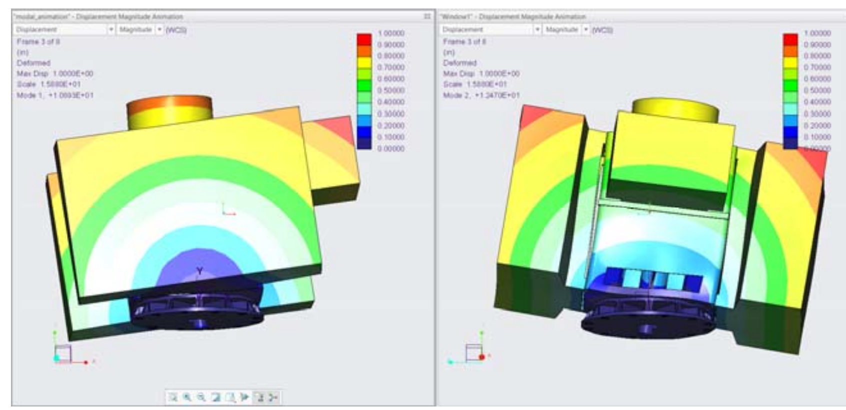
		% margin from 1X
Pivotal Inline	6.68	-21
Pivotal Perpendicular	5.98	-29
"C" Inline	11.05	30
"C" Perpendicular	10.74	**27**

Motor Models

Standard Cylinder Model



Detailed Model



Conclusions

- F.E. Modeling of vertical pumps is most accurate when adjusted or "tuned" with experimental modal data collected on the installed pump.
- Pre-purchase modeling can be useful:
  - With frequency separation margins of +20%/-15%.
  - With actual foundation details used in the model.
  - With accurate motor RCF data. Consider testing. Often RCF data is estimated by the motor manufacturer.
  - With proper installation, grout, bolt torque, etc.
  - With realistic motor model; homogenous cylinder model can have significant errors.
- Don't trust F.E. modeling that uses pinned or fully constrained foundation connections; particularly if the foundation is relatively flexible.