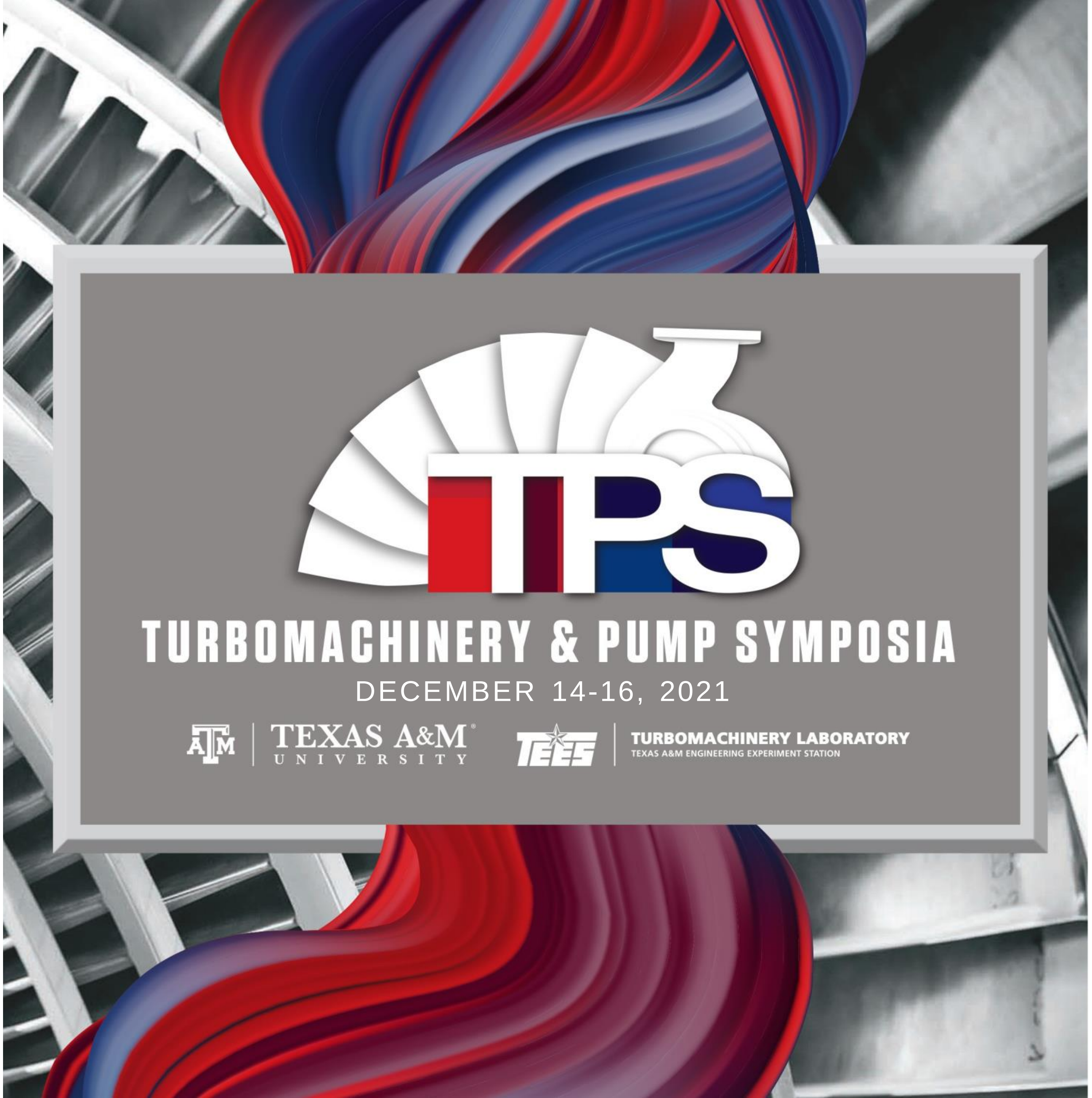

Modifying a Non-Clog Pump Experiencing Multiple Natural Frequency issues Based on Field Vibration Testing and FEA Analysis

by
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Test ▪ Analyze ▪ Solve ▪ Design ▪ Products

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- Lead Analytical Engineer for Major Compressor and Pump Manufacturers
- Member of the API Machinery Standards Committee and a Standards Partner of the HI
- Co-Author Pump Vibration Chapter, McGraw-Hill Pump Handbook

Abstract

In order to fully understand the true causes of the elevated vibration of a non-clog pump, driven by a long drive-shaft, a detailed FEA analysis was used to simulate the entire pump system (foundation and piping) to identify not only the structural modes but shaft lateral critical speed modes as well. This case study will provide the detailed vibration data as well as the FEA modeling that was used to provide solutions to this complex structural and rotordynamic resonance issues.

General Pump Information

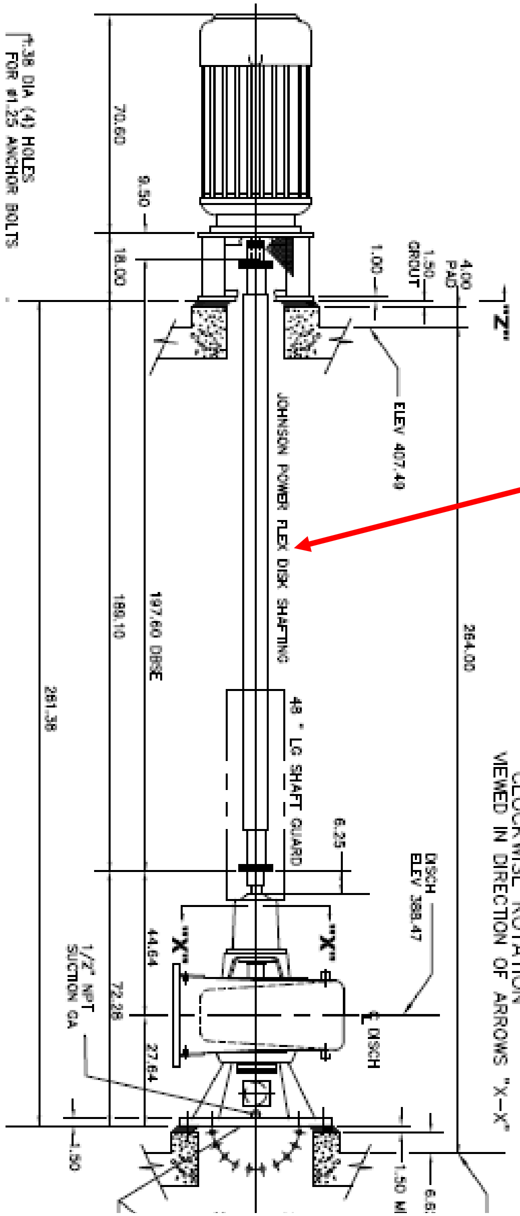
Pump:

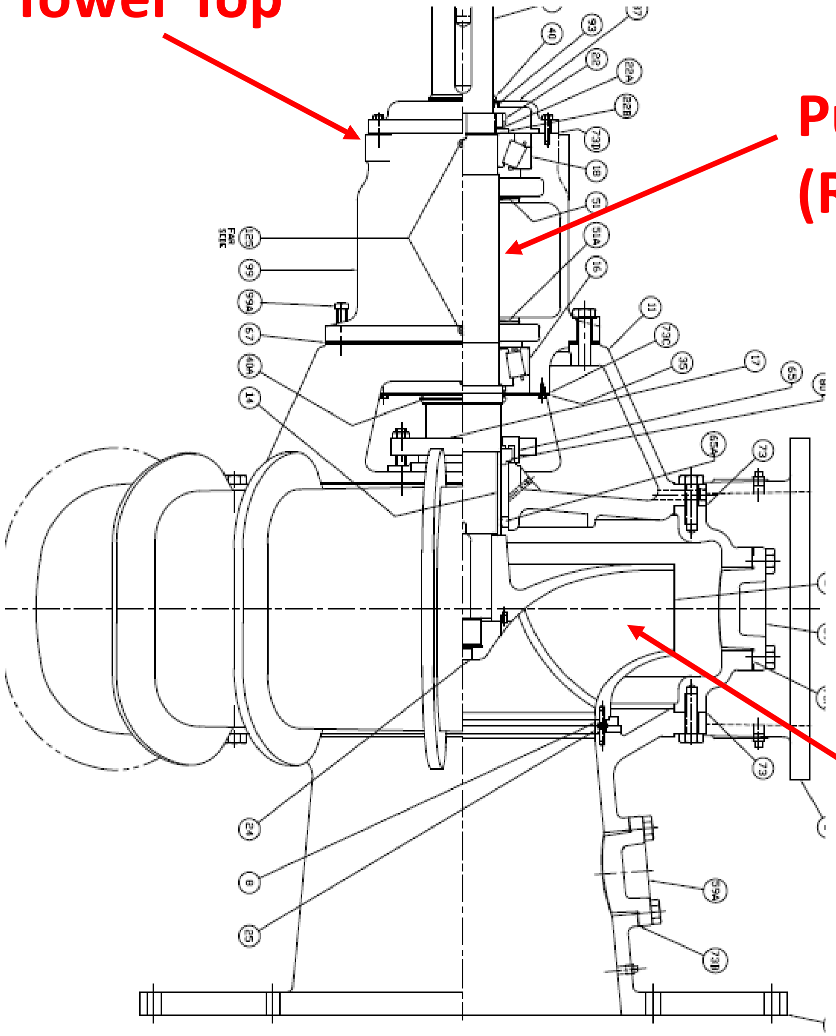
TDH:	69 ft
Capacity:	17360 gpm
Speed Range:	600 rpm (10.0 Hz) to 714 rpm (11.9 Hz) with VFD
No. Vanes:	3-vane impeller (6.0” solids passage)
Vane Pass Range:	30 Hz to 35.7 Hz
Pump Tag Name:	1B

Driver:

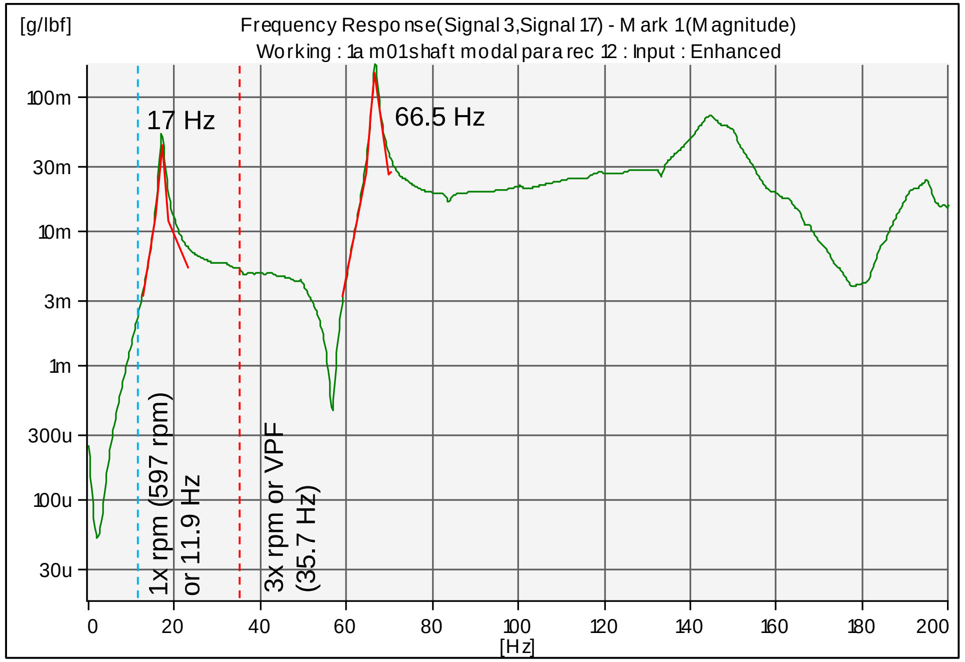
Induction Motor:	400 HP mounted on separate floor

General Pump Assembly Layout

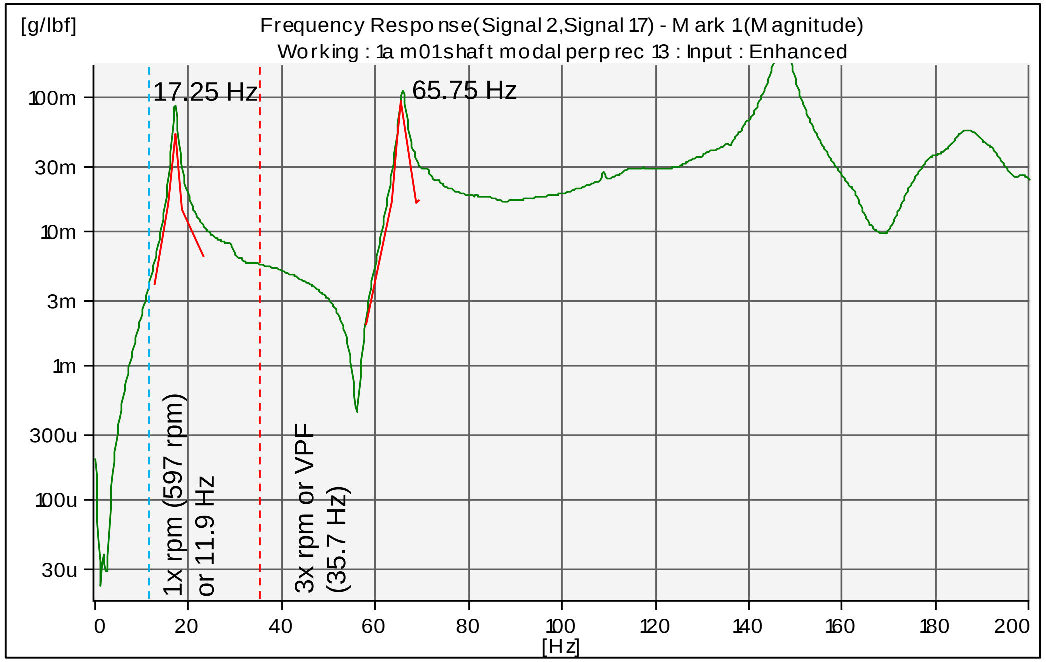




Drive Shaft "Bump Test" Natural Frequencies



Drive Shaft Parallel

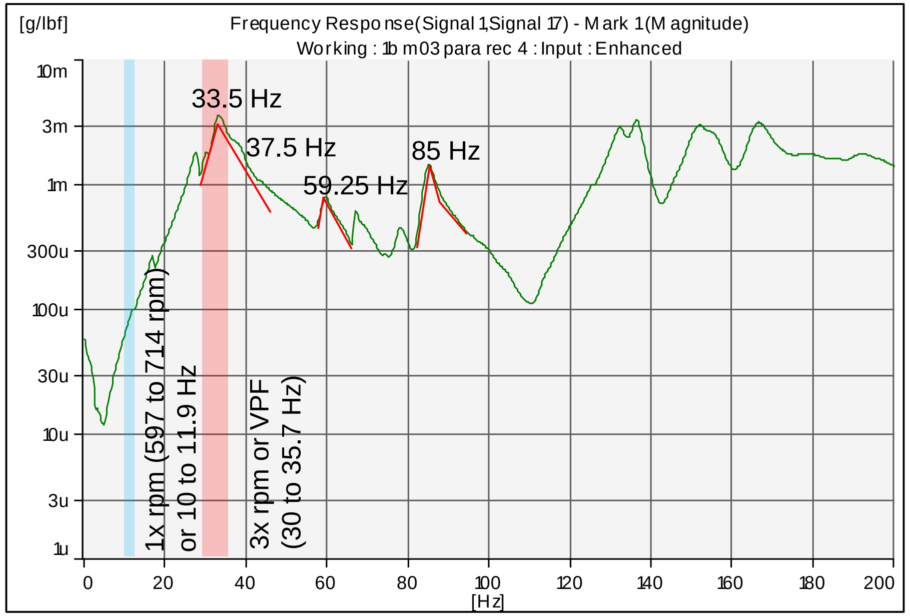


Drive Shaft Perpendicular

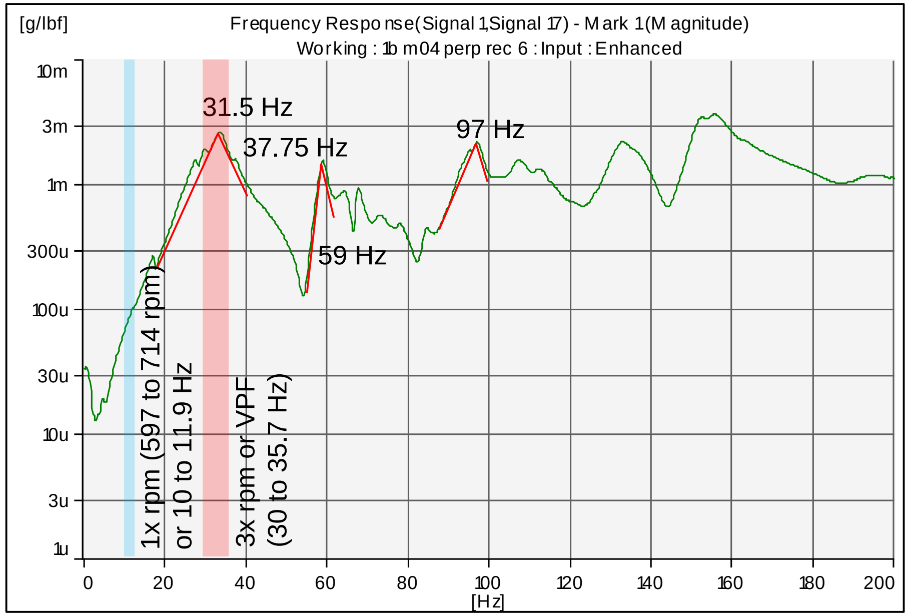
Note: Red lines are to highlight the natural frequencies at ~17 Hz & ~65 Hz

TURBOMACHINERY & PUMP SYMPOSIA

Bearing Tower / Pump Casing "Bump Test" Natural Frequencies



Bearing Tower Parallel

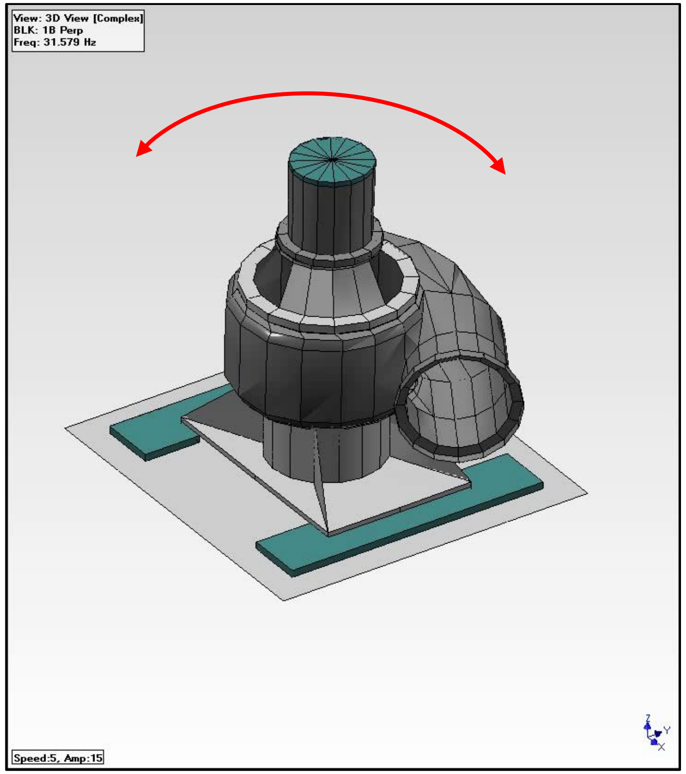


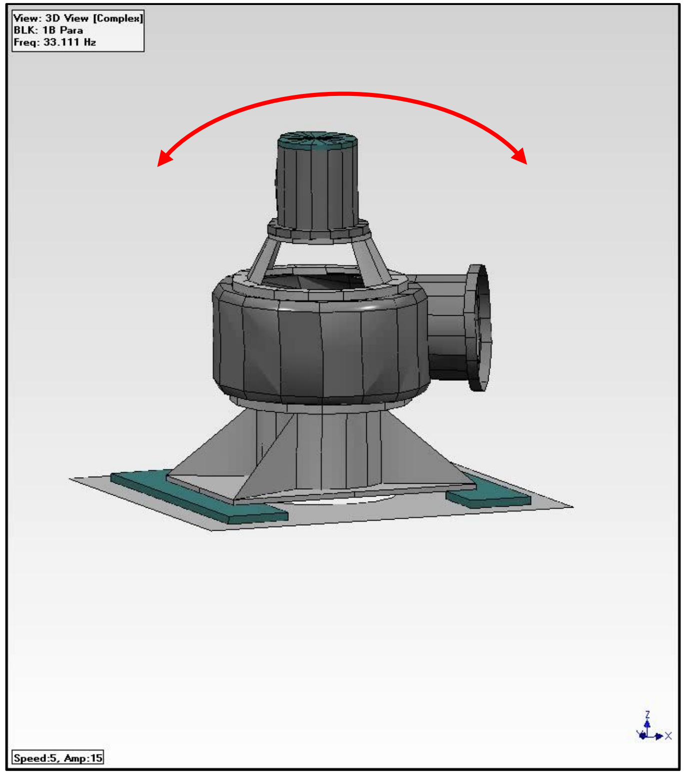
Bearing Tower Perpendicular

Note: Red lines are to highlight the natural frequencies

TURBOMACHINERY & PUMP SYMPOSIA

Experimental Modal Analysis (EMA) Test
Pump 1B Typical Pump Casing Modes





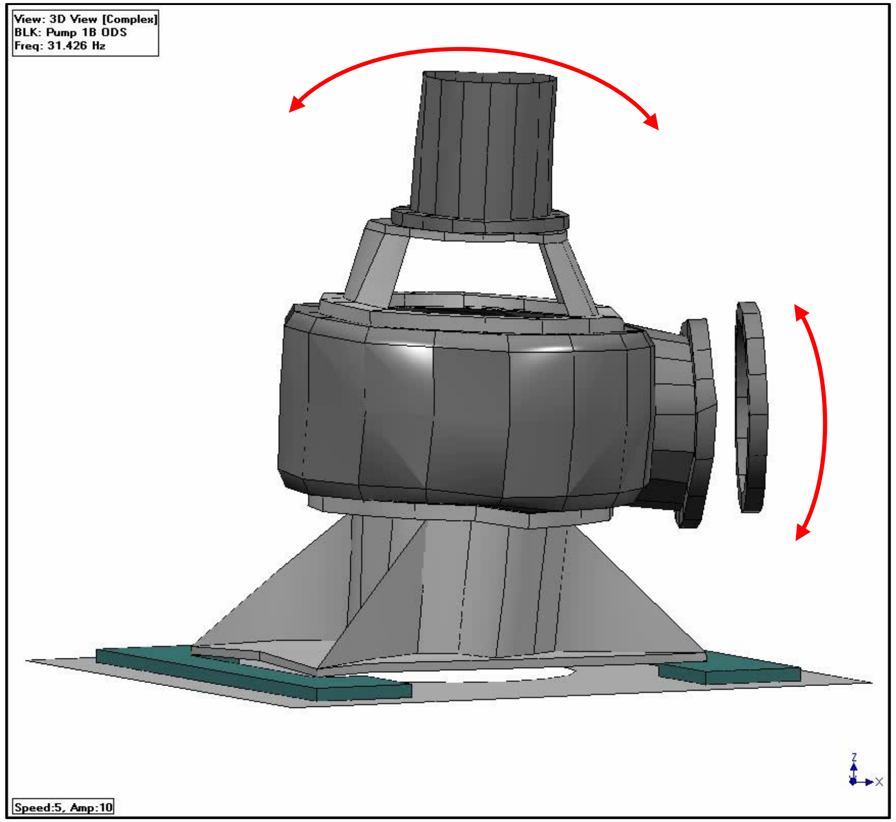
Typical global rocking mode at 31.5 Hz in the perpendicular direction

Typical global rocking mode at 33.5 Hz in the parallel direction

TURBOMACHINERY & PUMP SYMPOSIA

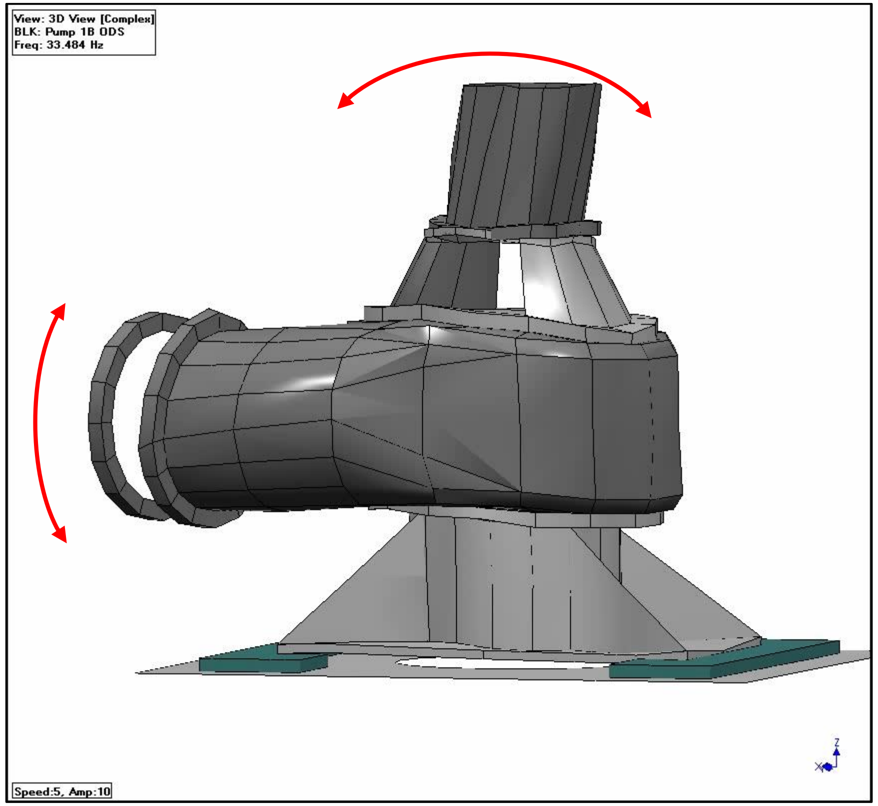
Pump 1B ODS Animations

Pump 1B ODS @ 31.5 Hz



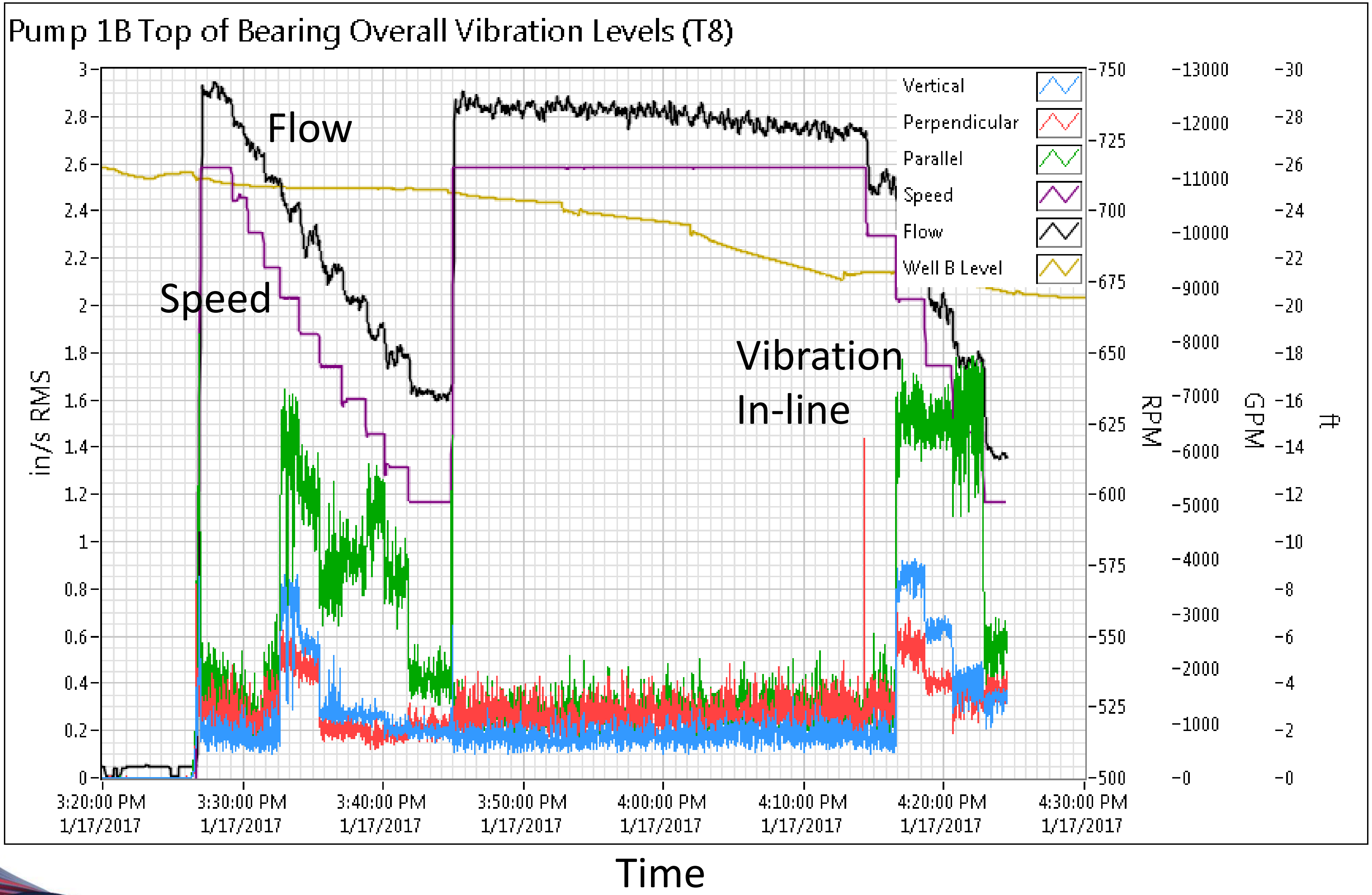
Pump casing rocking mode

Pump 1B ODS @ 33.5 Hz

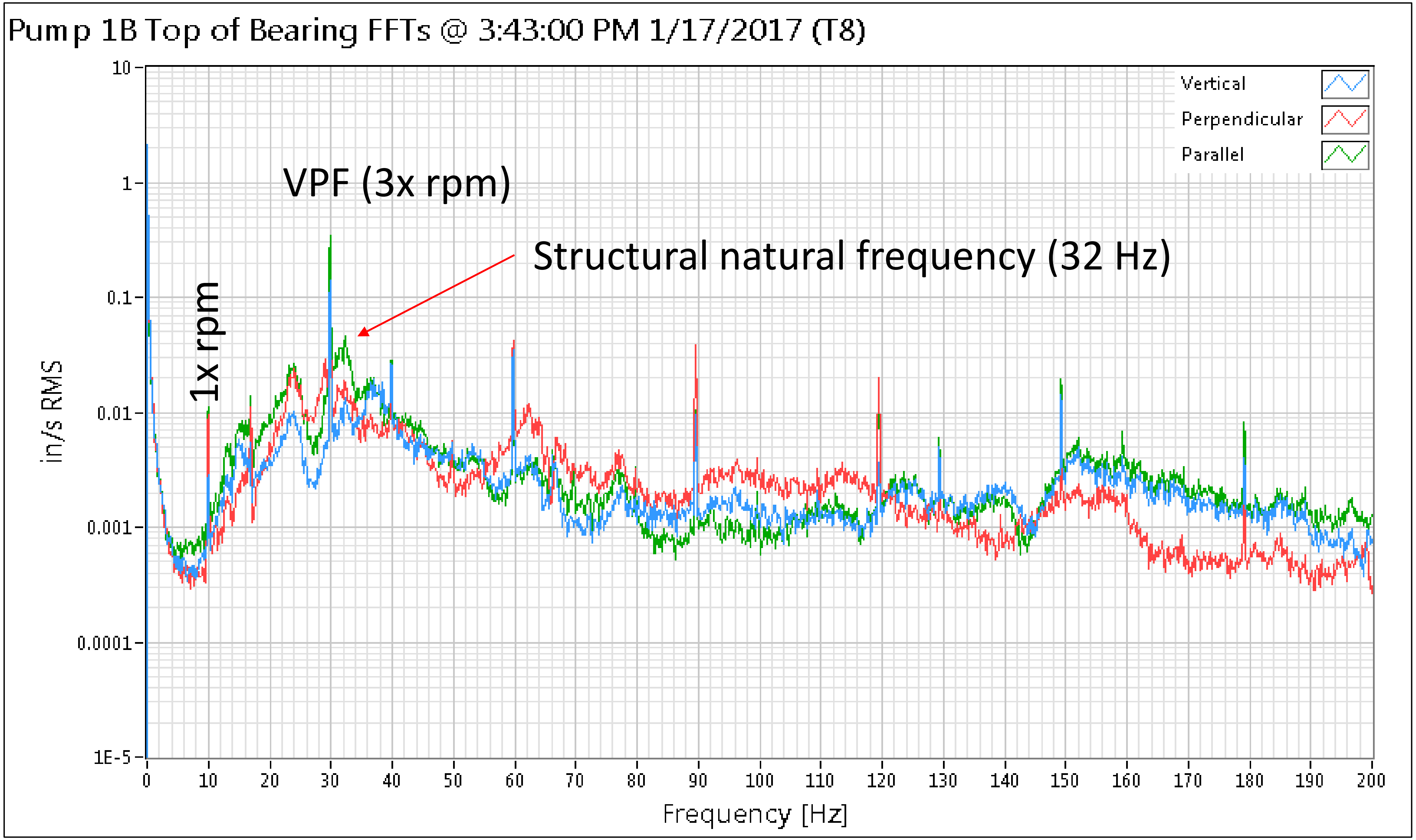


Pump casing rocking mode

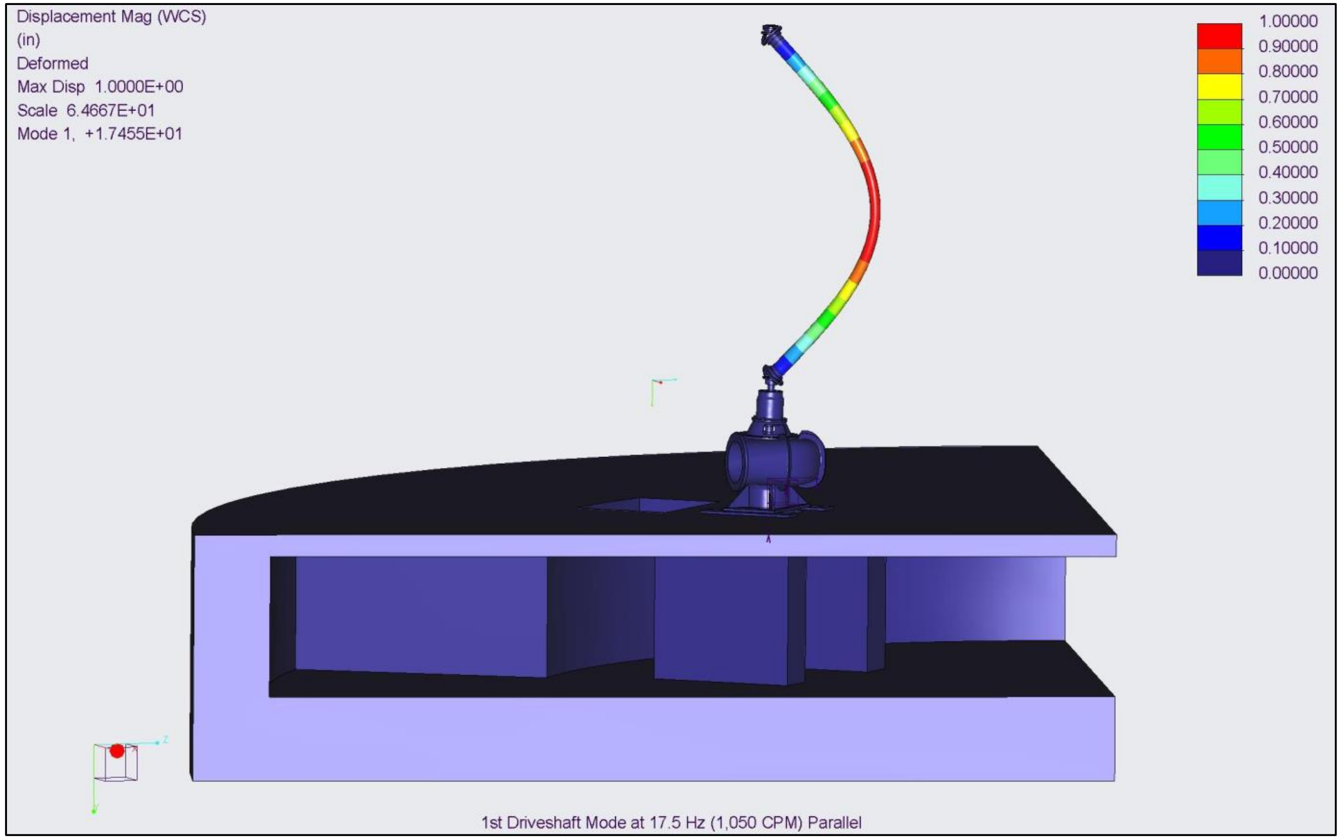
Pump 1B Top of Bearing Overall Vibration



Pump 1B Top of Bearing FFT at 600 RPM

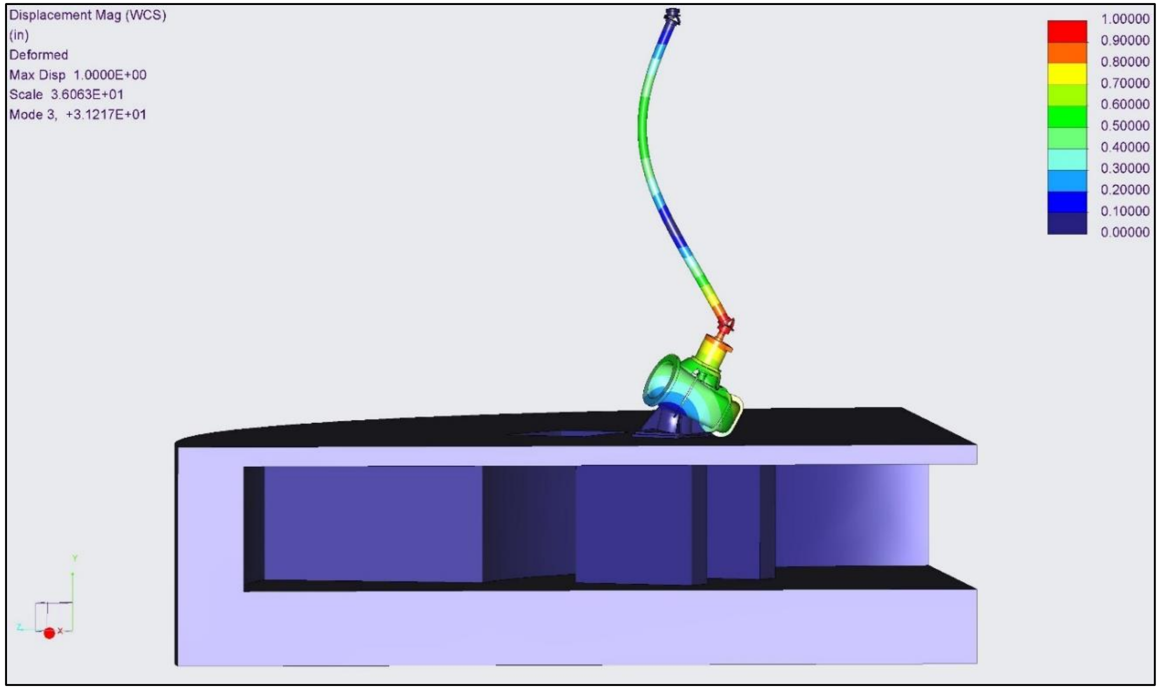


Finite Element Model Results

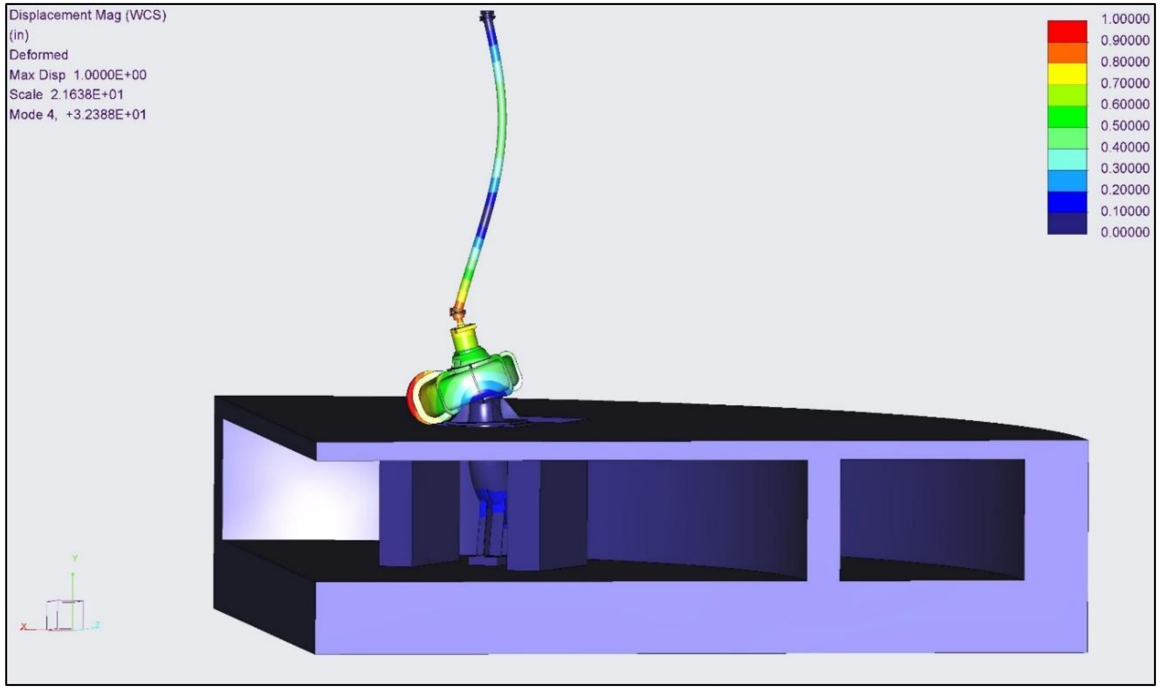


Driveshaft mode predicted at ~17 Hz similar to test data

Finite Element Model Results – cont.



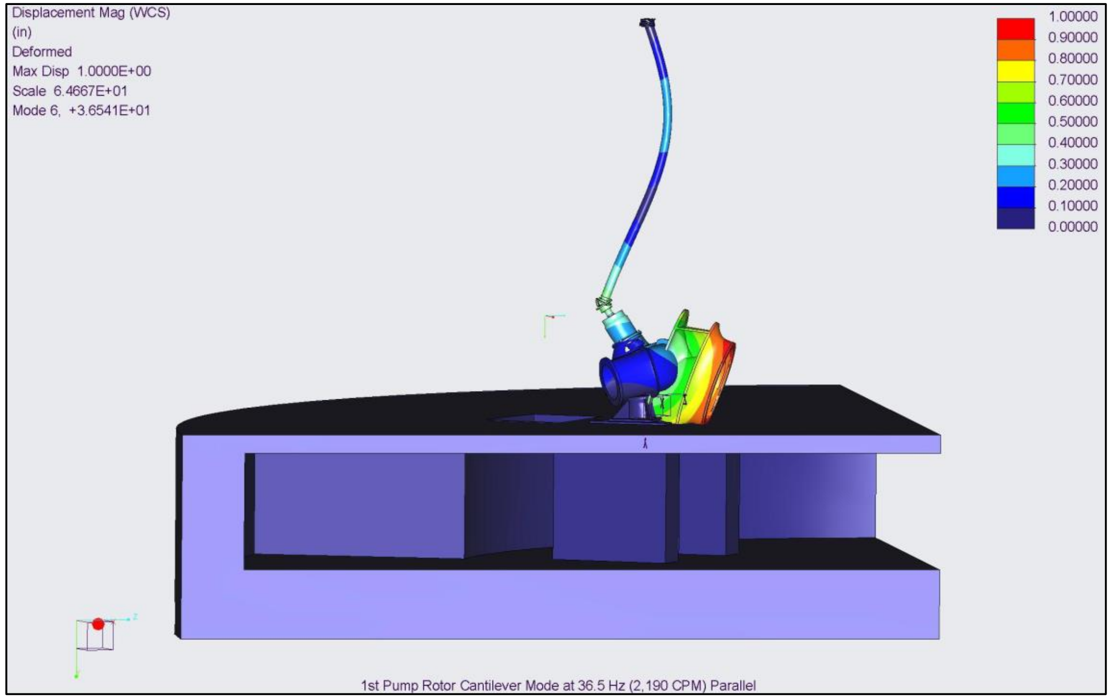
Casing rocking mode predicted at 31.2 Hz

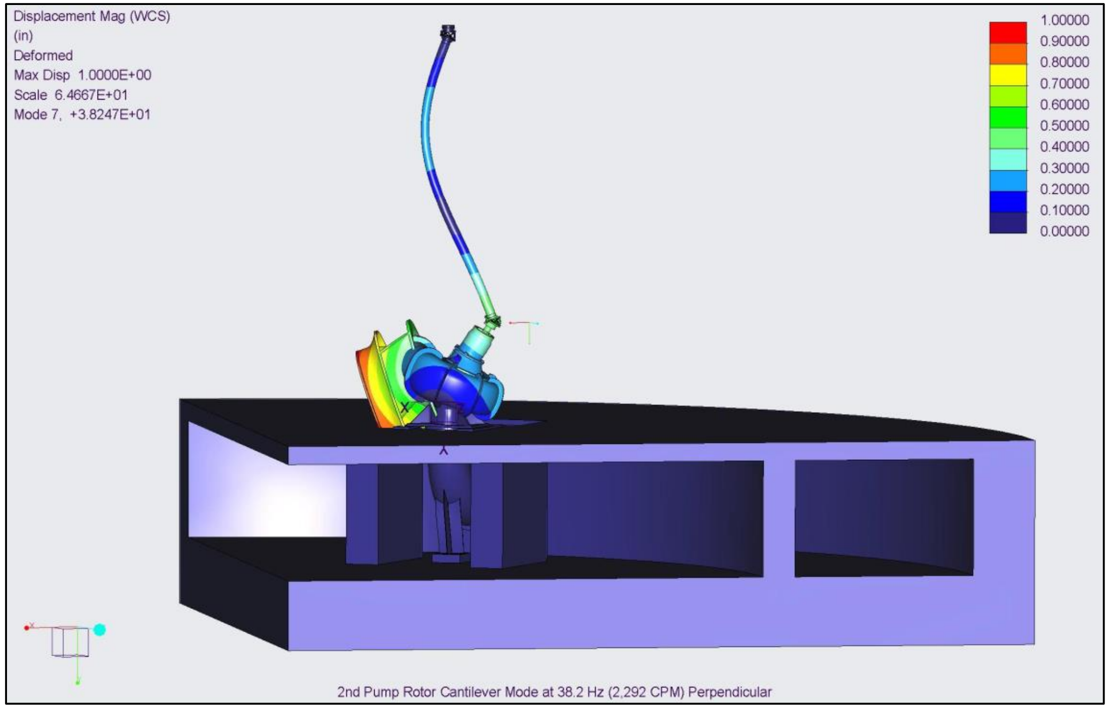


Casing rocking mode predicted at 32.4 Hz

These structural modes fall within the VPF range of 30 Hz to 35.7 Hz

Finite Element Model Results – cont.





Shaft lateral mode predicted at 36.5 Hz

Casing rocking mode predicted at 38.2 Hz

These shaft lateral modes fall ~2% to 7% above VPF range of 30 Hz to 35.7 Hz

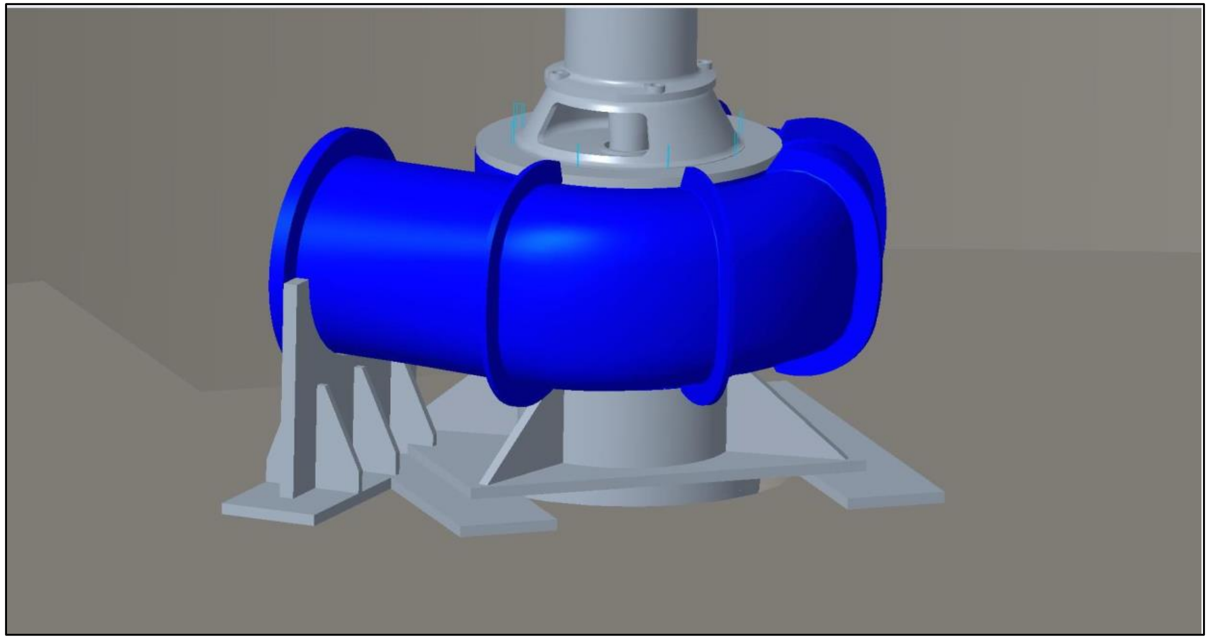
Potential Fixes Evaluated

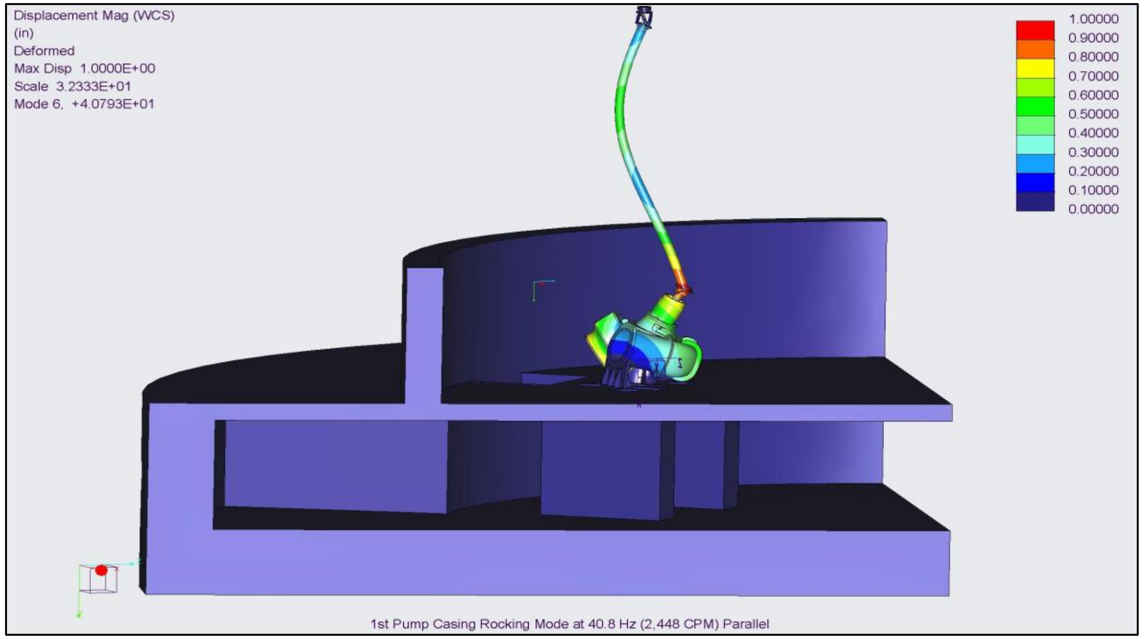
1. Bracing of the discharge nozzle to raise the structural rocking modes

2. Bracing the top of the bearing tower to the neighboring walls

3. Potential change to a heavier 4 vane impeller

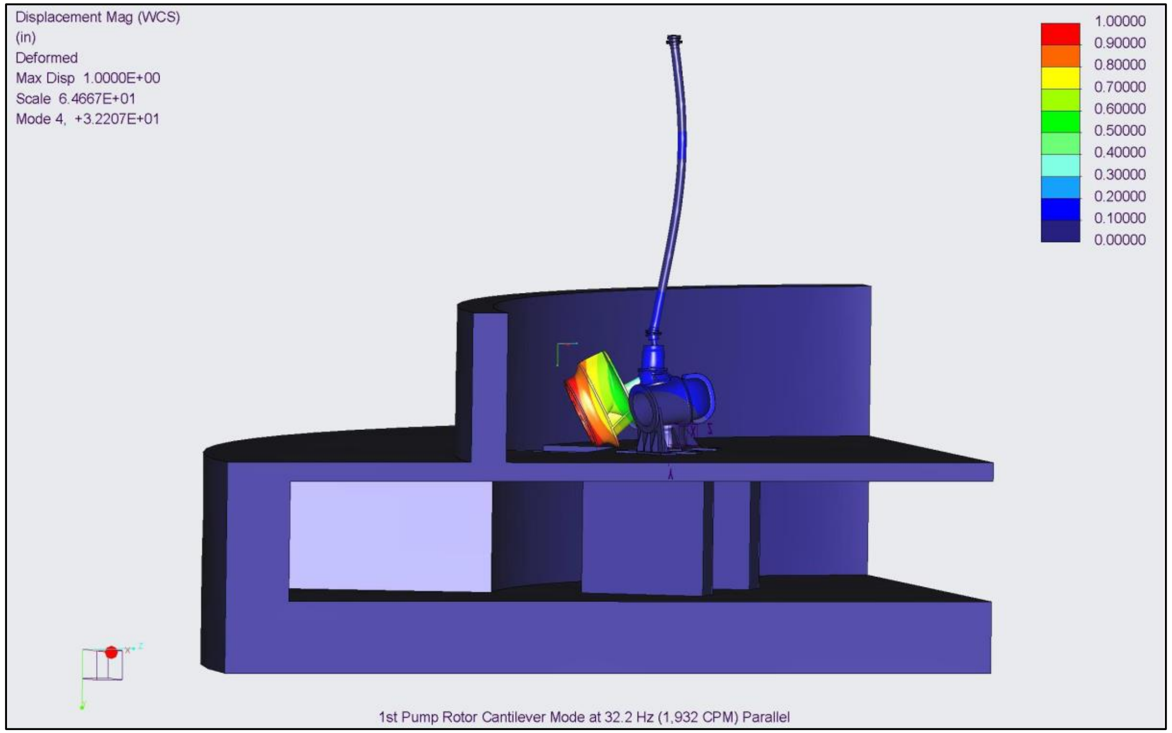
Bracing the discharge nozzle

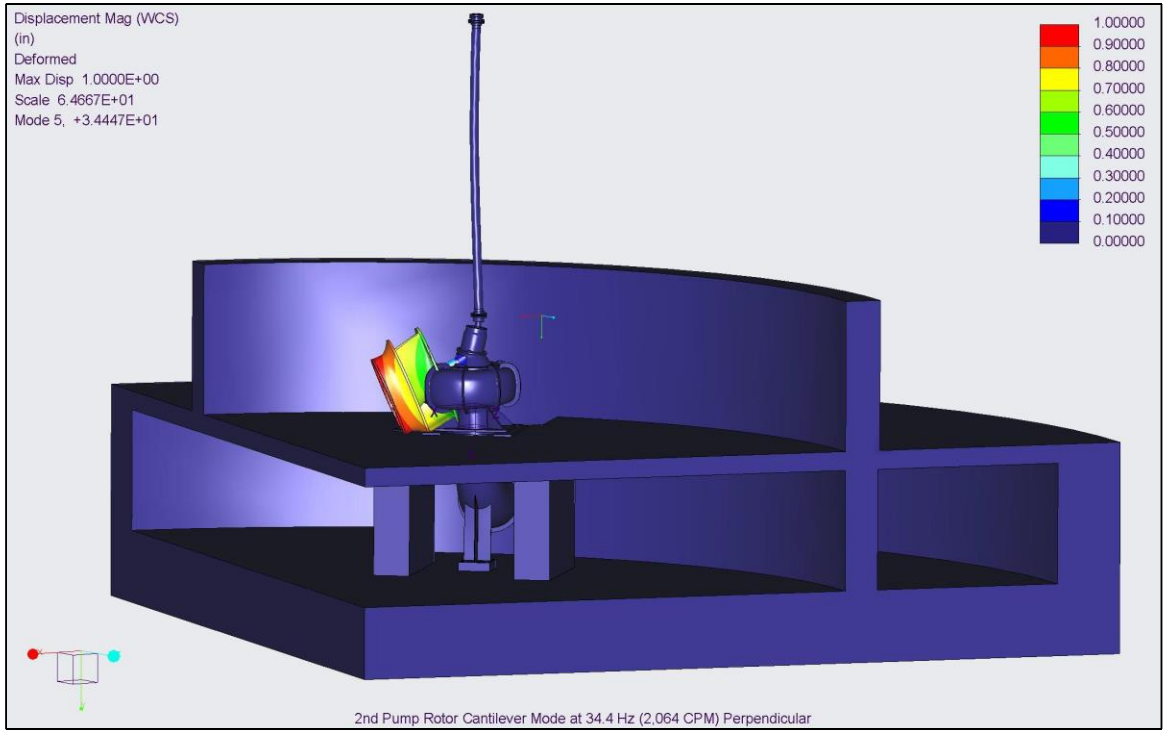




Bracing the discharge nozzle raised the lowest casing rocking mode to over 40 Hz

Bracing the discharge nozzle



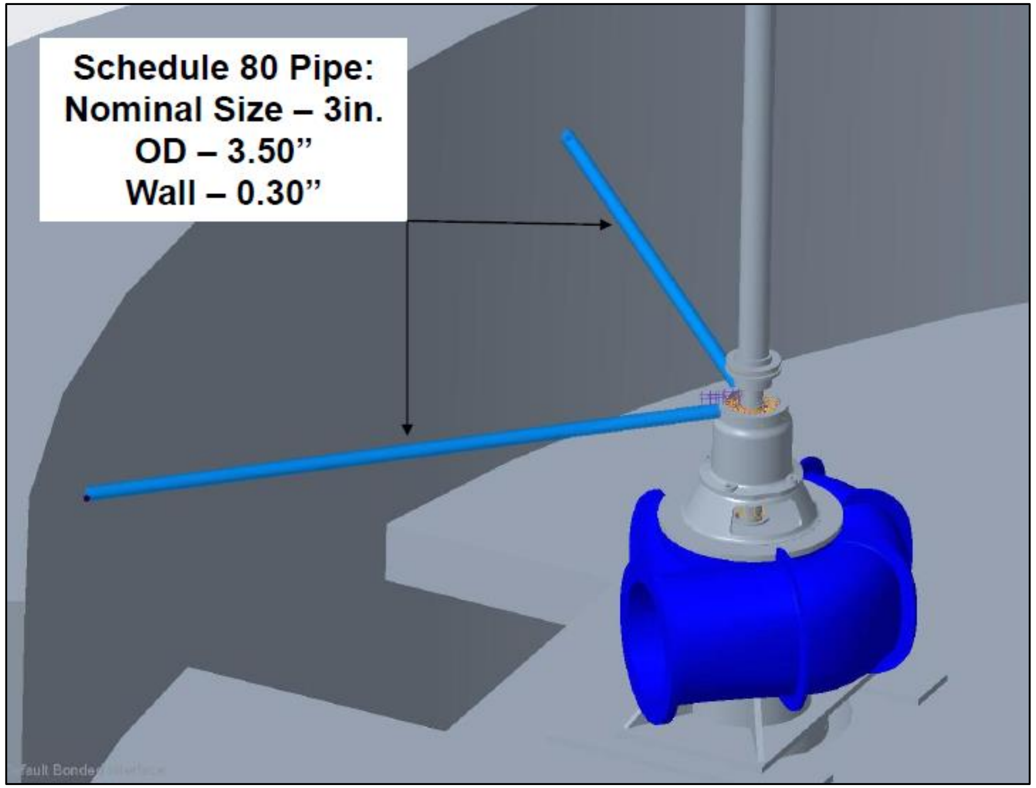


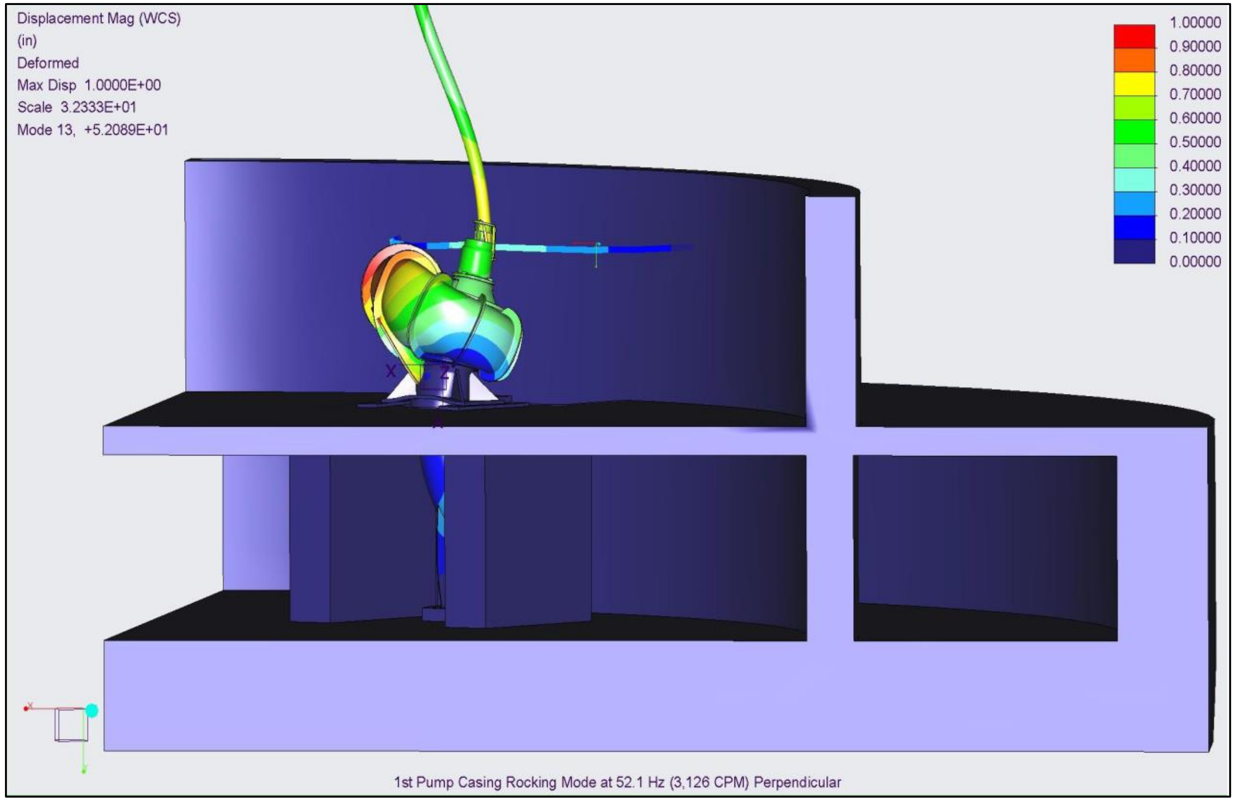
Shaft lateral dropping to 32.2 Hz

Shaft lateral dropping to 34.4 Hz

While bracing the discharge nozzle raised the casing rocking modes outside of the VPF range, the shaft lateral modes actually dropped into the VPF range

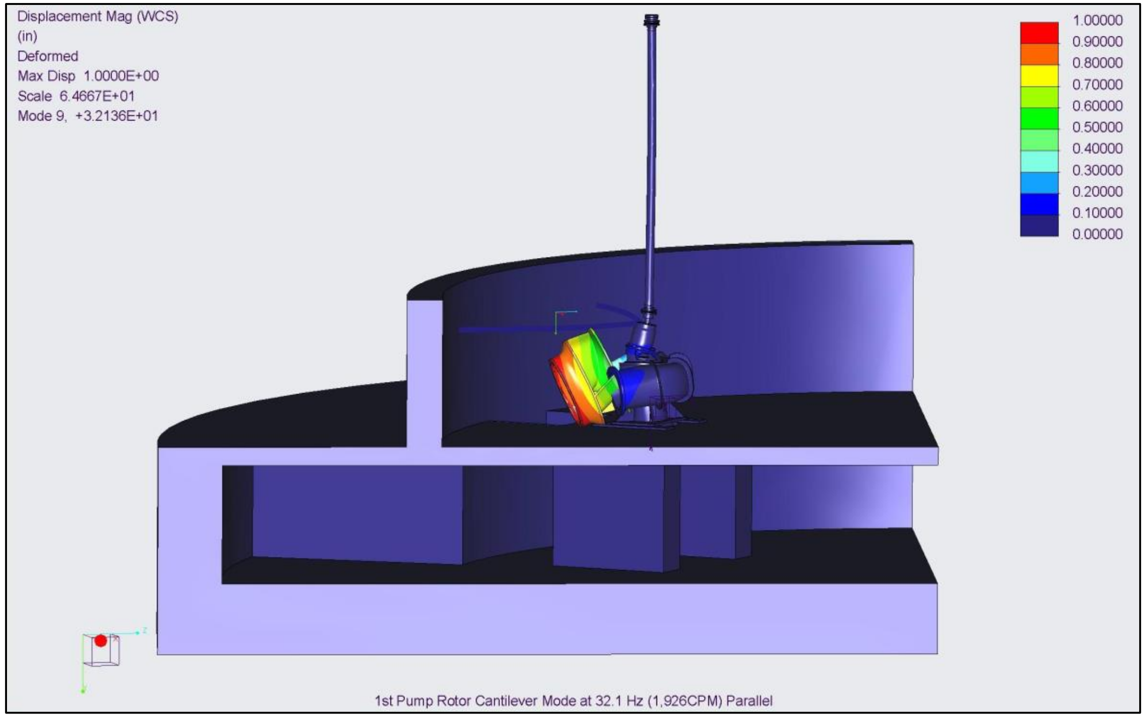
Bracing the top of the bearing tower to the wall

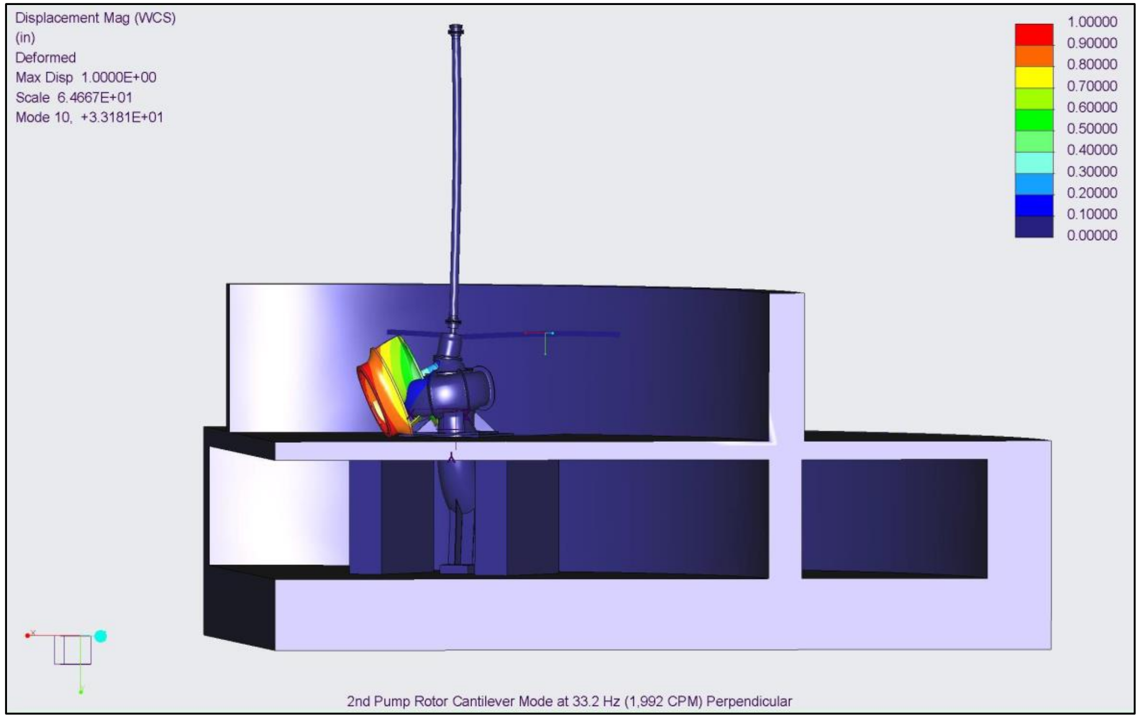




Bracing the bearing tower raised the lowest casing rocking mode to over 52 Hz!

Bracing the top of the bearing tower to the wall





Shaft lateral at 32.1 Hz

Shaft lateral at 33.2 Hz

While bracing the bearing tower raised the casing rocking modes well outside of the VPF range, the shaft lateral modes actually dropped into the VPF range similar to when the discharge nozzle was braced.

Switching to a 4-vane impeller

1. After discussions with the OEM and end user, it was decided that the best approach would be to switch to 4-vane impeller, which would shift the VPF excitation range from 30.0 Hz - 37.5 Hz up to 40 Hz - 47.6 Hz. The OEM determined that the hydraulics would still be satisfactory in this application.

2. This modification would provide over 20% separation margin from the low end of the vane pass range and casing rocking modes. However, the shaft lateral pendulum mode (38.5Hz) would potentially be still fall within 5% of the low end of the VPF range of 40 Hz.

3. To help lower the shaft lateral modes, the proposed 4 vane impeller was made heavier (thicker shrouds) to help shift the frequencies down. Analysis with the new impeller indicated the shaft laterals would be less than 10% below the low end of VPF range, which could still result in vibrations above the 0.27 in/s RMS limit, but the plant indicated that the low end speed could be shifted to 625 RPM instead of 600 RPM if needed.

Actual Vibration Results with 4-Vane Impeller

The pump vibrations were within the 80% HI 9.6.4 limits and just met it at 609 RPM as was expected (vibration data taken by others).

Top Bearing Peak Vibration Amplitudes

Displacement data is provided for reference, and is not used for severity assessment.

Exceeds 80% of ANSI/HI 9.6.4 at 597.4 RPM (50 Hz VFD) pump speed only.
All other measurements points meet limits of 0.27 In/sec rms.

Inches per Second - rms (In/s)

Axial

RPM	VFD Hz	1X	2X	4X	8X	Overall
597.4	50	0.008	0.011	0.136	0.025	0.295
609.0	51	0.011	0.005	0.144	0.025	0.269
620.9	52	0.011	0.013	0.066	0.014	0.232
633.0	53	0.014	0.008	0.043	0.016	0.187
645.1	54	0.011	0.006	0.036	0.018	0.168
656.7	55	0.015	0.004	0.019	0.017	0.168
668.3	56	0.016	0.008	0.021	0.018	0.148
681.0	57	0.014	0.006	0.028	0.018	0.182
692.8	58	0.017	0.011	0.018	0.016	0.204
704.9	59	0.018	0.019	0.018	0.018	0.173
715.6	60	0.020	0.019	0.020	0.017	0.178

Vertical

RPM	VFD Hz	1X	2X	4X	8X	Overall
597.4	50	0.005	0.004	0.195	0.021	0.243
609.0	51	0.005	0.003	0.160	0.011	0.204
620.9	52	0.006	0.007	0.060	0.006	0.139
633.0	53	0.006	0.004	0.071	0.012	0.127
645.1	54	0.004	0.004	0.078	0.021	0.139
656.7	55	0.007	0.001	0.054	0.024	0.125
668.3	56	0.006	0.004	0.062	0.016	0.113
681.0	57	0.008	0.003	0.056	0.063	0.128
692.8	58	0.008	0.006	0.037	0.014	0.122
704.9	59	0.007	0.011	0.045	0.023	0.117
715.6	60	0.009	0.013	0.044	0.014	0.119

Perpendicular

RPM	VFD Hz	1X	2X	4X	8X	Overall
597.4	50	0.011	0.002	0.020	0.067	0.184
609.0	51	0.011	0.002	0.073	0.045	0.189
620.9	52	0.013	0.008	0.057	0.051	0.185
633.0	53	0.016	0.016	0.049	0.031	0.169
645.1	54	0.013	0.003	0.041	0.040	0.182
656.7	55	0.022	0.004	0.018	0.043	0.146
668.3	56	0.021	0.006	0.009	0.030	0.133
681.0	57	0.021	0.008	0.008	0.035	0.149
692.8	58	0.022	0.009	0.006	0.033	0.151
704.9	59	0.018	0.017	0.023	0.043	0.149
715.6	60	0.022	0.005	0.025	0.040	0.149

mils - pk-pk

Axial

Hz	RPM	1X	2X	4X	8X	Overall
50	597.4	0.44	0.04	1.59	0.13	3.87
51	609.0	0.42	0.22	1.02	0.10	2.90
52	620.9	0.45	0.28	0.67	0.09	3.06
53	633.0	0.53	0.07	0.53	0.08	2.34
54	645.1	0.56	0.16	0.41	0.08	2.05
55	656.7	0.55	0.20	0.15	0.08	2.16
56	668.3	0.61	0.19	0.14	0.08	2.10
57	681.0	0.40	0.27	0.20	0.08	2.25
58	692.8	0.67	0.17	0.17	0.07	2.24
59	704.9	0.79	0.29	0.26	0.09	2.11
60	715.6	0.65	0.43	0.22	0.09	2.23

Vertical

Hz	RPM	1X	2X	4X	8X	Overall
50	597.4	0.13	0.05	2.27	0.11	2.90
51	609.0	0.17	0.04	1.72	0.06	2.38
52	620.9	0.16	0.03	1.29	0.05	1.95
53	633.0	0.17	0.07	0.64	0.06	1.67
54	645.1	0.22	0.06	0.80	0.11	1.40
55	656.7	0.28	0.11	0.70	0.15	1.59
56	668.3	0.23	0.07	0.49	0.08	1.41
57	681.0	0.24	0.08	0.55	0.10	1.46
58	692.8	0.31	0.10	0.35	0.06	1.53
59	704.9	0.40	0.17	0.41	0.09	1.47
60	715.6	0.34	0.19	0.40	0.08	1.49

Perpendicular

Hz	RPM	1X	2X	4X	8X	Overall
50	597.4	0.53	0.10	0.61	0.38	2.40
51	609.0	0.43	0.08	0.74	0.25	2.30
52	620.9	0.59	0.03	0.55	0.27	2.53
53	633.0	0.71	0.05	0.51	0.18	2.32
54	645.1	0.71	0.10	0.40	0.22	2.03
55	656.7	0.72	0.15	0.23	0.21	1.91
56	668.3	0.80	0.14	0.07	0.14	1.93
57	681.0	0.76	0.26	0.06	0.21	1.94
58	692.8	0.48	0.18	0.08	0.15	1.87
59	704.9	0.74	0.26	0.20	0.16	1.78
60	715.6	0.83	0.44	0.23	0.11	2.03

Largest Magnitude

The color gradient scale used is a relative measure of the magnitude of the individual values, compared to the largest value in the data set. It is intended to be a quick visual guide to the largest and smallest vibration amplitudes.

Smallest Magnitude

Conclusions

1. The original 3-vane pump design had not only structural natural frequencies within the operating vane pass frequency range of 30 Hz to 35.7 Hz, but also has shaft lateral natural frequencies that fell with less than 10% above maximum speed vane pass operating range. Unfortunately, the natural frequencies could have been adequately predicted with up-front finite element analysis (FEA) by the OEM to avoid these issues being installed in the field.

2. Via the analysis conducted, the foundation in this installation was found to be essentially rigid and did not adversely affect the casing rocking modes.

3. While bracing options would certainly have shifted the structural rocking modes outside of the vane pass operating range, the behavior of the shaft laterals dropping into the vane pass operating range would most likely have led to elevated vibrations and potential seal failures. This phenomenon was replicated using different analysis software and is related to how the masses interact with each other in the free state and being held by the bracing.

Conclusions – cont.

4. The success of the 4-vane impeller to shift the vane pass excitation frequencies away from the structural modes resulted in the bearing tower overall vibrations reducing from over 1.75 in/s RMS down to 0.17 in/s RMS, clearly indicating that the elevated vibrations were due to structural resonance and not inlet flow conditions.

5. With the 3-vane impeller design, the vibrations (> 0.45 in/s RMS) exceeded limits at full speed since the pump at full speed was operating within 10% of the shaft laterals that were on the fringe of becoming fully resonant. With the 4-vane design, the vibrations were less than 0.18 in/s RMS easily meeting the vibration criteria as the separation margins were greatly increased. However, as predicted, the vibration at the extreme low end were just meeting or slightly exceeding the 0.27 in/s RMS limit due to the shaft laterals now being within -10% of the low end of the 4-vane VPF range (40 Hz to 47.6 Hz). The increase in the minimum speed to 625 RPM made this a non issue.