Paper Mill
Calendar Roll
Motor Support Twisting
(Torsional) Resonance

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INTRODUCTION

- The machine in question was a large variable speed motor driving a calendar roll on a paper machine.
- From the route vibration data, the problem was high vibration at 2x motor rpm particularly in the horizontal direction at both ends of the motor.
- Depending on the paper machine speed (motor speed), the problem did get better and worse.
- No vibration problems were described at the calendar roll itself with low vibration levels there.

BACKGROUND 1

High vibration at the Calendar Roll Drive Motor.

Motor OB Horiz 2X 0.468 in/sec-pk.

Motor 1X RPM = 27 Hz (1620 RPM)
Motor 2X RPM = 54 Hz (3240 CPM)

Motor Support Fabricated Using Plates and Square Tubing.

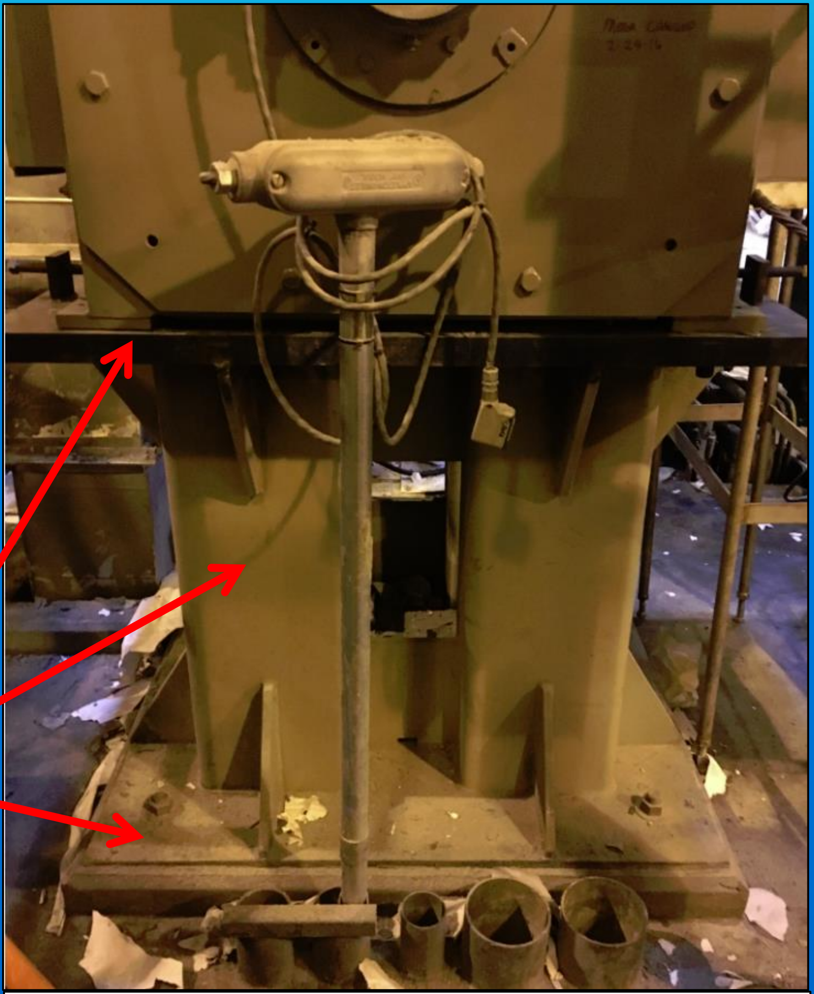


Figure 1. Calendar Roll Drive Motor, OB End.

BACKGROUND 2

Customer complained of high vibration at the Calendar Roll Drive Motor.

Motor OB Horiz 2X 0.468 in/sec-pk.

Motor 1X RPM = 27 Hz (1,620 RPM)
Motor 2X RPM = 54 Hz (3,240 CPM)

Motor Support Fabricated Using Plates and Square Tubing.

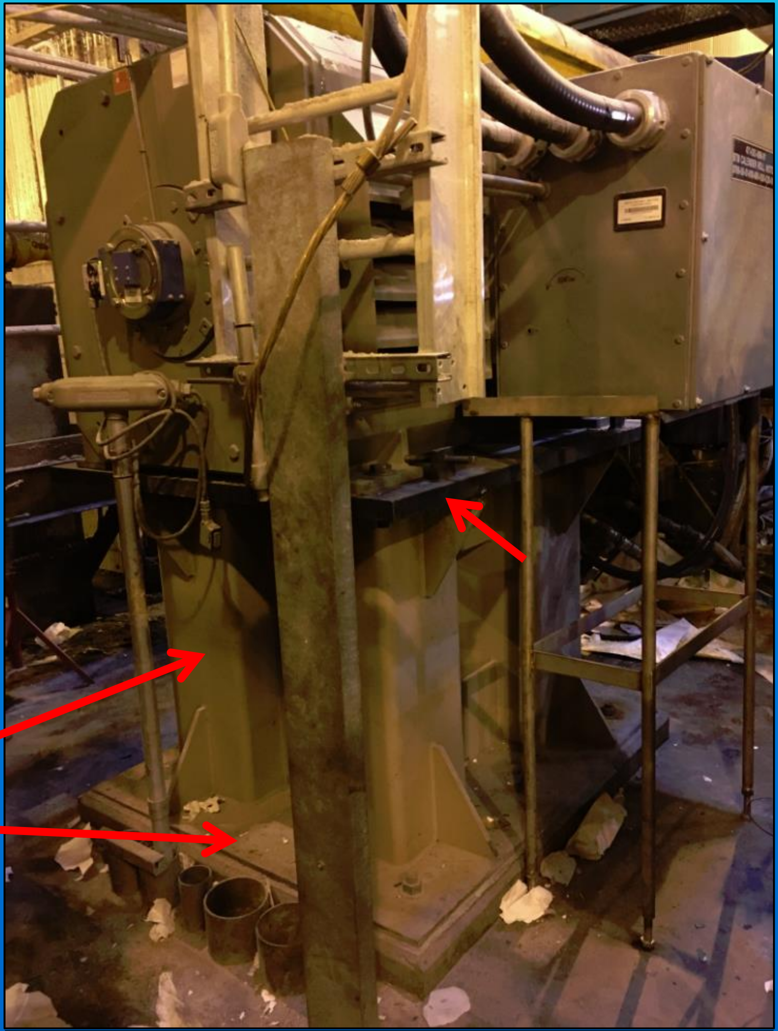


Figure 2: Calendar Roll Drive Motor, IB End

ODS & Modal Analysis

An ODS and Modal analysis were performed on the motor, base, pedestal & floor.

A graphic of the ME'scope VES Model used for ODS and Modal Analysis is shown at right.

317 ODS FRF measurements were collected across the machine & structure.

Driving point selected at the 19X & 19Y location (Two Modal Tests).

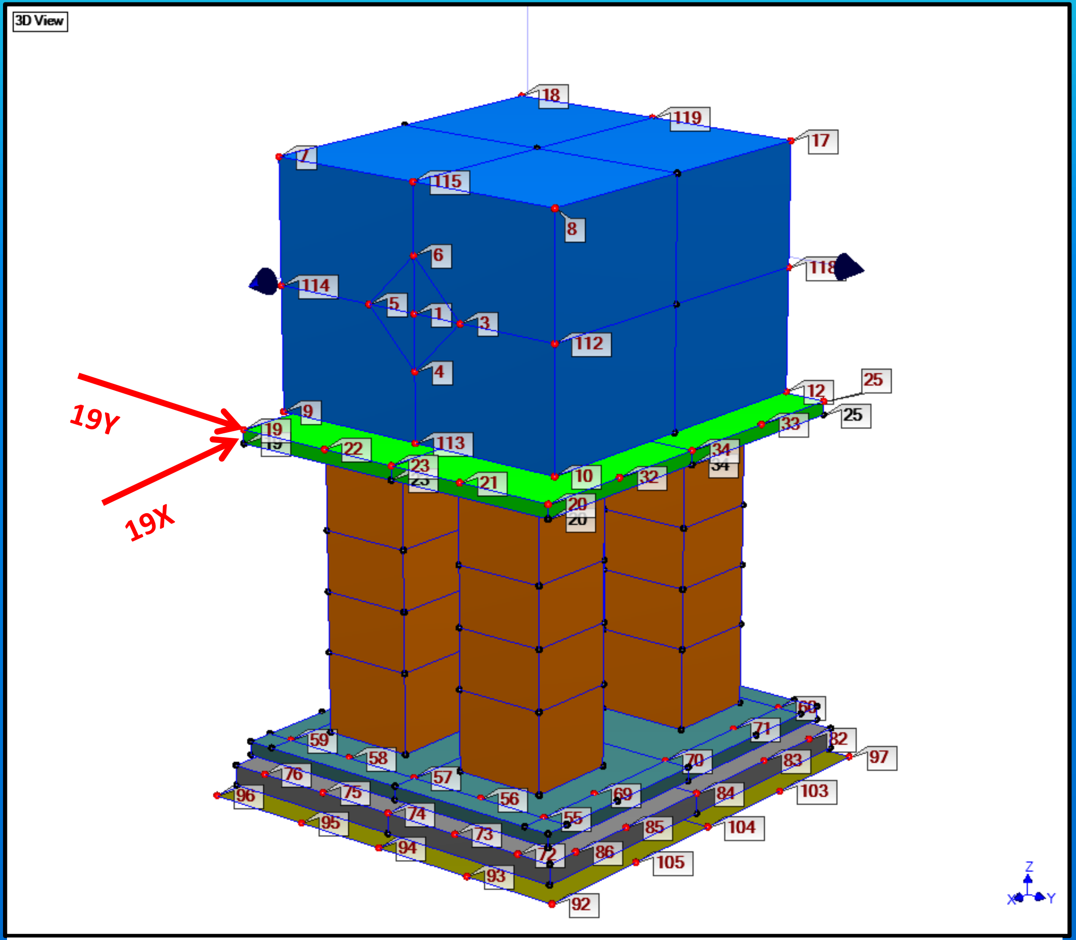


Figure 3. ODS Model Developed Using ME'scopeVES.

ODS ANALYSIS 1

Resonance 19.5 Hz
Rocking in Y Axis

Motor 1X 27 Hz
Rocking in X Axis

Motor 2X 54 Hz

- **ODS showed dominant (highest) vibration at 2X Motor RPM (this was the vibration that plant PDM personnel were concerned with).**
- **The shape or mode of vibration at 2x rpm was twisting of the motor & motor base about the Z axis (torsional mode).**
- **Deformation of square tubing legs was evident.**

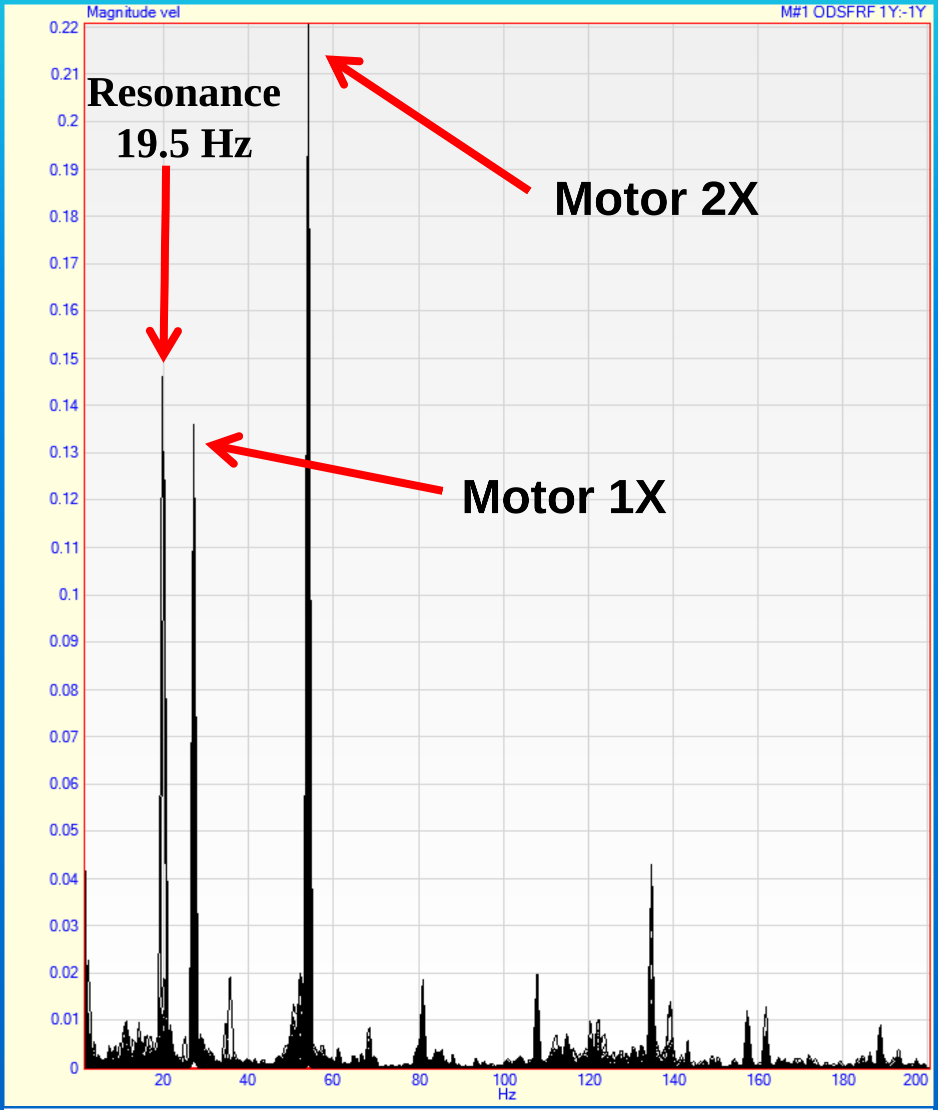


Figure 4. The ODS FRF are Shown Overlaid.

ODS ANALYSIS 2

- The ODS FRF at 1Y:1Y (Log Mag Scaling) Clearly Showed the 52 Hz Torsional Resonance just below 2X Motor Run Speed.
- Data measured when the paper machine was running at higher speed and the 2X motor frequency did not align exactly with the resonance.
- Note that paper machines change speed often (depending on the paper they are running).

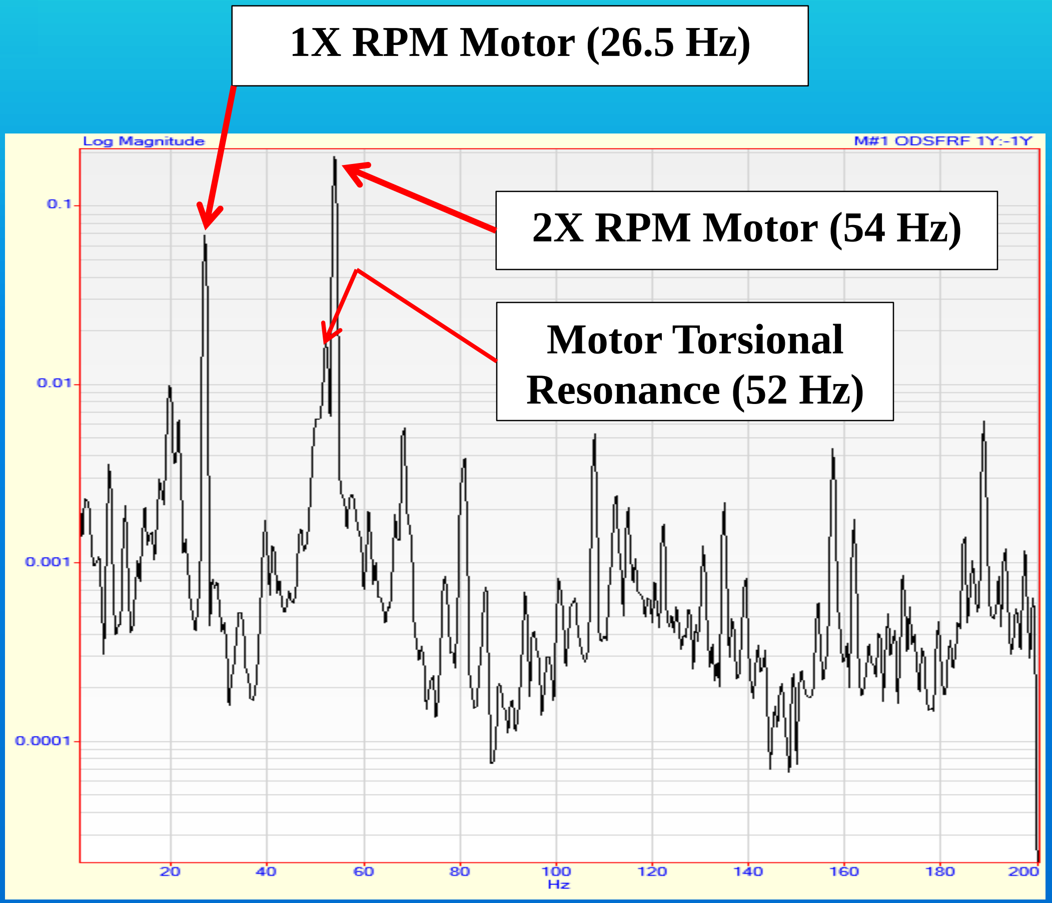


Figure 7. ODS FRF at 1Y:-1Y.

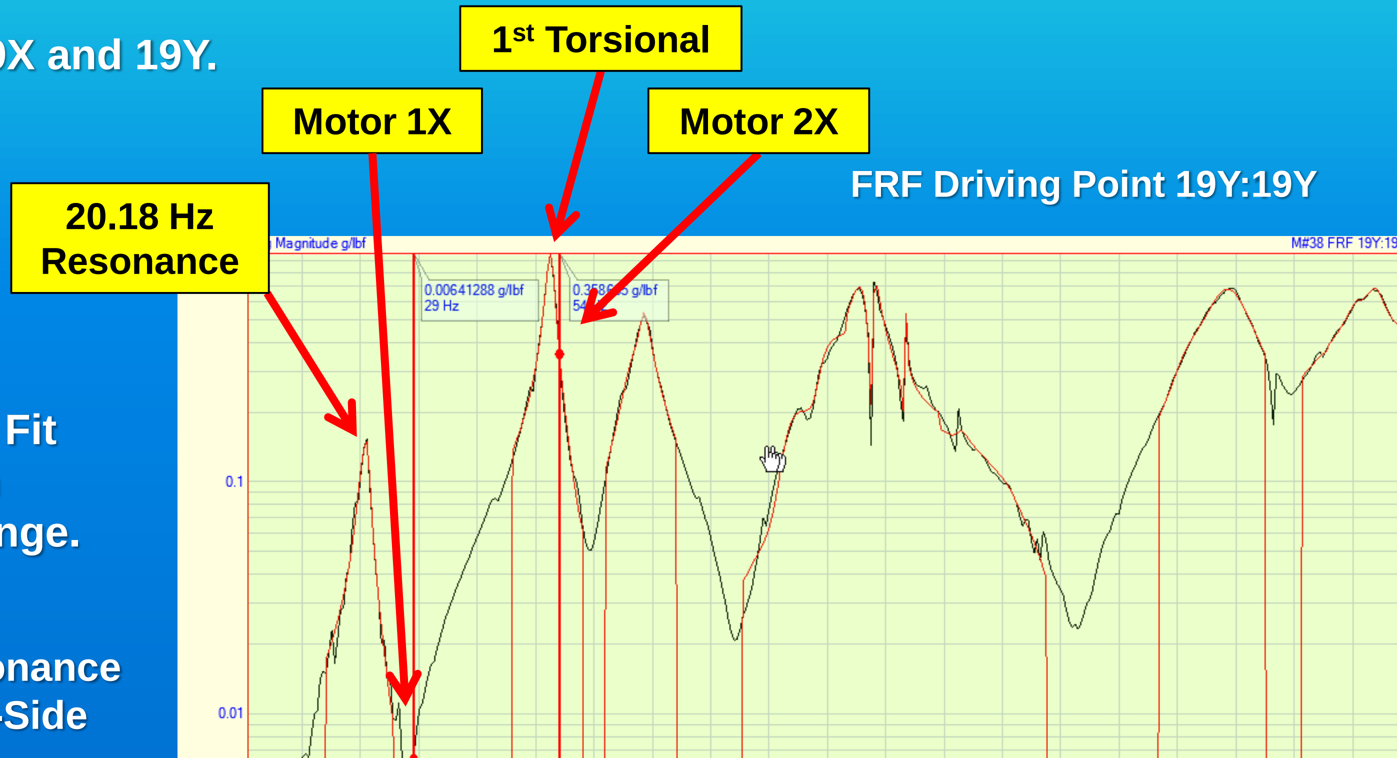
EXPERIMENTIAL MODAL TEST 1

The natural frequencies and mode shapes of a structure can be measured using Experimental Modal Analysis (EMA).

- A known force is input to the structure typically using a modal hammer or a shaker.
- The amount of force and the frequency span are controlled. Modal Hammers have both soft & hard tips to excite either low or high natural frequencies better. Some hammers allow adding mass (improves low freq response).
- The structure's response to the force is measured at various spatially identified locations on the machine & structure with the frequency response function (FRF). Depending on the frequencies of interest, the units can be g's/lbf (accelerance), ips/lbf (mobility), or mills/lbf (dynamic compliance).
- The FRF provides a very good way of characterizing the dynamic response of a structure.
- A 3D model of the test structure was developed in ME'scopeVES which allowed animation of the natural frequency mode shape.

EXPERIMENTIAL MODAL TEST 2

Driving Points at 19X and 19Y.



Mode Shapes Curve Fit from the FRF data in Operating Speed Range.

20.18 Hz Resonance Rocking Side-Side

21.0 Hz Resonance Rocking Side-Side

52.46 Hz Mode 1st Torsional About Z Axis.

Select Shape	Frequency (or Time)	Damping	Units	Damping (%)	Label	MPC
1	20.1802	0.977334	Hz	4.83737	1st Bending in Y	0.931122
2	21.0333	0.575662	Hz	2.73588	1st Bending in Y	0.968962
3	52.457	0.827633	Hz	1.57754	1st Torsional About Z	0.958654
4	52.8399	0.651041	Hz	1.23201	Global-Poly	0.589731
5	67.2159	2.28456	Hz	3.39687	Combined Bending in Y & Twisting Z	0.759467
6	68.395	0.965955	Hz	1.41218	Combined Bending in Y & Twisting Z	0.591974
7	92.7717	2.64134	Hz	2.84598	Global-Poly	0.64032
8	98.7331	2.10175	Hz	2.12823	Global-Poly	0.867955
9	106.005	2.11999	Hz	1.9995	Global-Poly	0.837863

Figure 8. Driving Point 19Y:19Y and Shape Table

Structural Dynamic Modification (SDM) 1

MEscopeVES has several Finite Elements which can be used to modify the test structure's mathematical model that is obtained from curve fitting the modal FRF data.

FEA Springs	FEA Triangle
FEA Dampers	FEA Quad
FEA Mass	FEA Tetra
FEA Rod	FEA Prism
FEA Bar	FEA Brick

Initially, considered diagonal or X Bracing using FE Bars.

Then ½ Thick Plate 54" X 46" was generated using Quad Elements and Attached to the Motor Support Plate and Base Plate.

Structural Dynamic Modification (SDM) 2

But there were standing wave modes near the Operating Speed Region with the ½" Thick Plate Elements.

Note that the Degrees of Freedom (DOF) at Top and Bottom of the Plate were Fixed to simulate welded attachment for this FE Calculation.

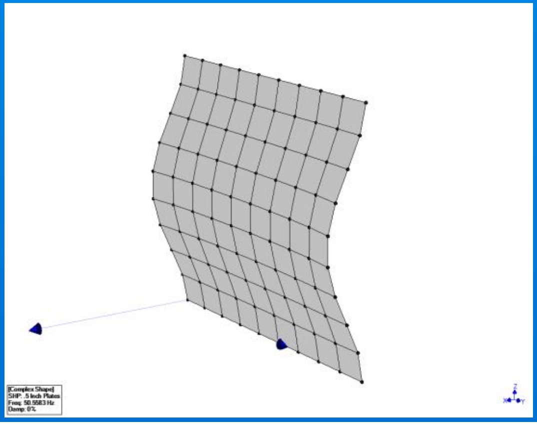


Figure 9. 1st Bending Mode
50.66 Hz
(Too Close Motor 2X).

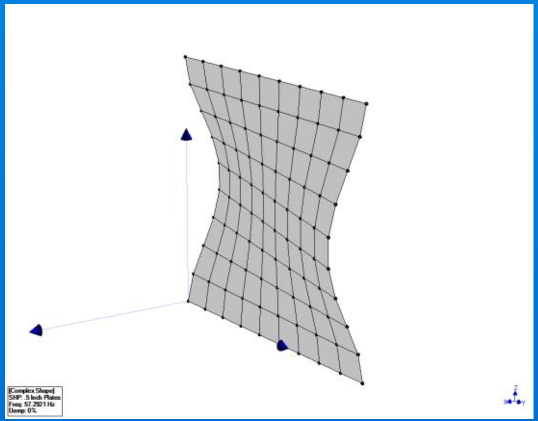


Figure 10. 1st Torsional Mode
57.29 Hz
(Too Close Motor 2X).

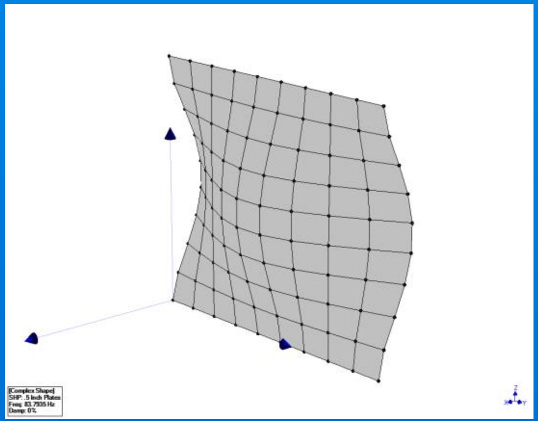


Figure 11. 2nd Bending Mode
83.79 Hz

The first two standing wave modes of the ½" plate were too close to the motor 2x rpm dynamic force, so a thicker ¾" plate was then considered.

Structural Dynamic Modification (SDM) 3

- **3/4" Thick Plate 1st standing wave mode calculated to 75.7 Hz, well above 52 Hz, which was 2X Motor Run Speed Frequency.**
- **All other modes were higher than this and presented no problem.**
- **Note that 6 DOF were modeled with FE Springs (14,400 lb_f/in stiffness to simulate Grade 5 - 5/8 Diameter Bolt preload) connected to the plate Top & Bottom and to fixed DOF.**

75.7 Hz Mode

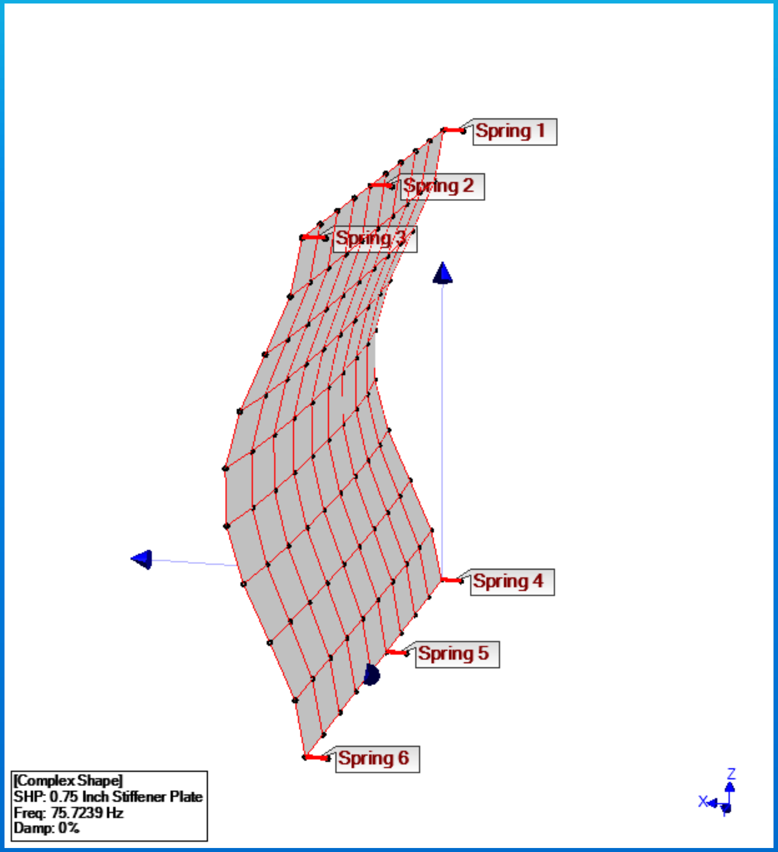


Figure 12. ¾" Plate FE Model With Grade 5 5/8 Bolts (Springs 14,400 lb_f/in Stiffness) Attachments to Motor Base Plate and Sole Plate.

Structural Dynamic Modification (SDM) 4

Figure 13 shows the Measured FRF Driving Point and the calculated FRF with the 3/4" Thick Plate. The 1st Torsional was predicted to move to about 72 Hz.

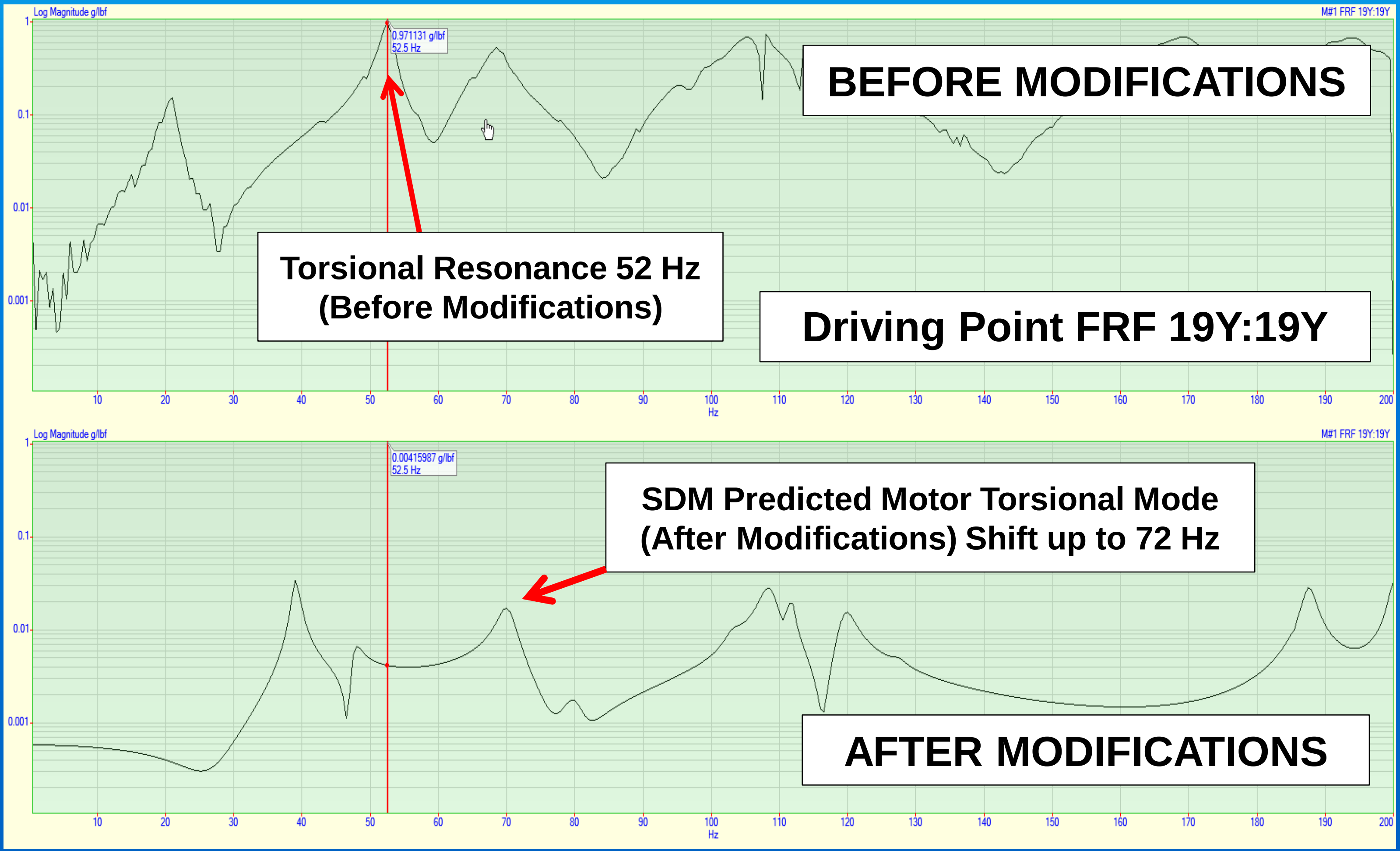


Figure 13. FRF Data Before Installation of Plates (Top) & SDM Predicted 52 Hz Torsional Mode Move Up to 72 Hz (Bottom).

Recommendations to Client 1

- **Fabricate Six 2” X 2” X 12” Hot Roll Bars.**
- **Drill and tap holes in bars for 5/8 - 11 thd bolts.**

  This would allow removal of plates if the natural frequencies were not moved higher sufficiently.
- **Bevel Bars ½” for welds.**
- **Skip Weld Bars at 2” intervals to the sole plate.**

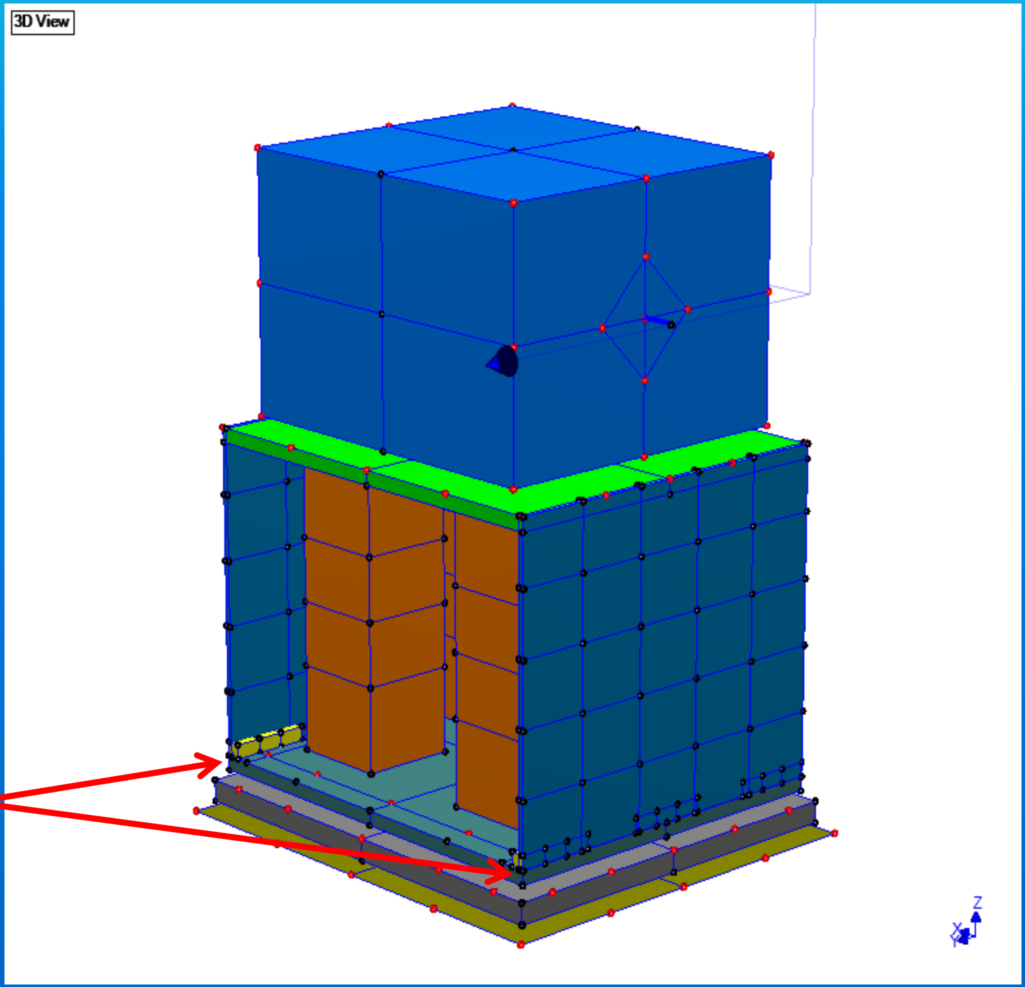


Figure 15. Final SDM Model ¾” Carbon Steel Plate Bolted to Motor Base Plate & Support Plate.

Recommendations to Client 2

- Bolt Two 54" W X 46" H X 0.75" plates to Motor Support Plate and to the 2" X 2" X 12" Hot Roll Bars (each end of motor). (Welding of Plate initially not recommended to allow easy removal).
- Clamp load calculated per bolt to 14,400 lb_f at 150 ft-lb torque.
- If stiffening plates effective reducing vibration, then plates could be welded to the motor support plate and base plate.

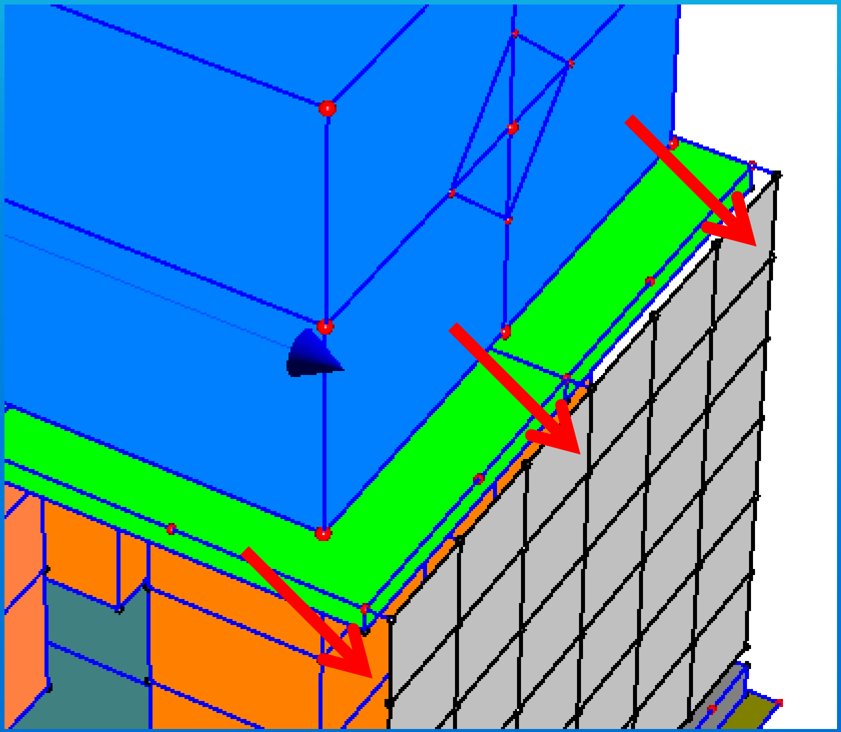


Figure 14. Final SDM Model ¾" Carbon Steel Plate Bolted to Motor Base Plate & Support Plate. View Showing FE Springs.

What Client Actually Implemented and Results 1

After about one year, the results were obtained from the client's PDM personnel.

The ¾" Plates were installed per recommendations but were welded in place rather than initially bolting.

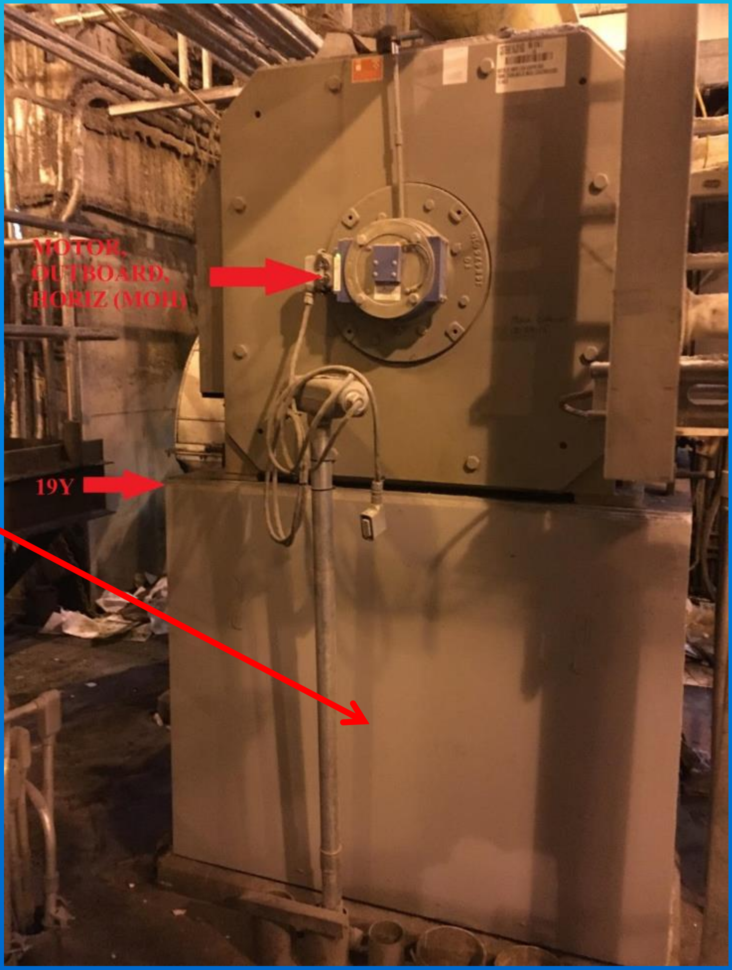


Figure 15. Motor Outboard End Showing Stiffening Plate.

What Client Implemented and Results 2

After about one year, the results were obtained from the client's vibration analysts.

The ¾" Plates were installed per recommendations with exception of welding rather than initially bolting.

Figure 16. Motor Inboard (IB)

What Client Implemented and Results 3

The Before & After Spectrum Motor OB Horizontal 2X Vibration showed 11.6:1 Reduction (or 91.4%)!!

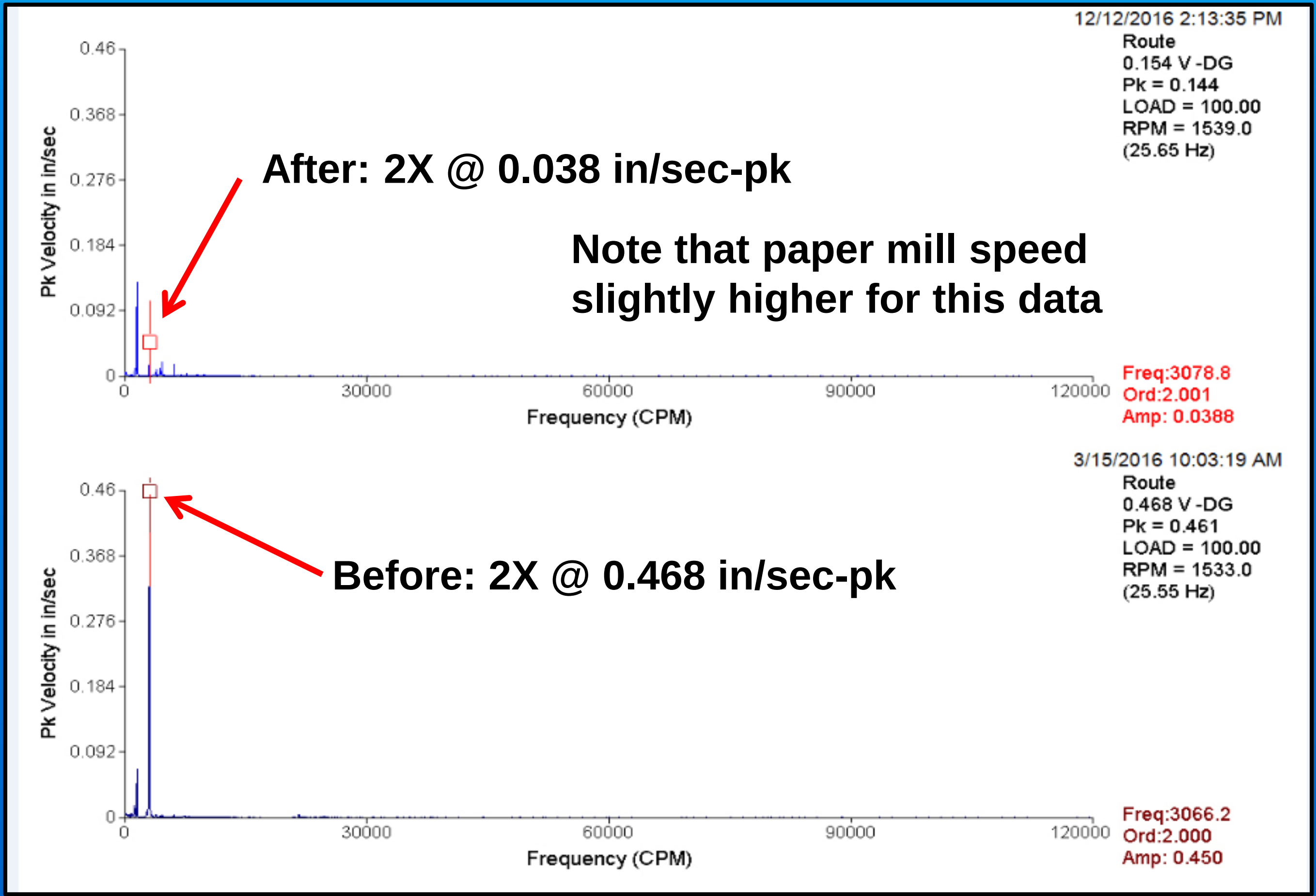


Figure 14. Before and After Frequency Spectra at Motor OB Hor Bearing Housing.

What Client Implemented and Results 4

FRF data before installation of plates and SDM predicted 52 Hz torsional mode move to 72 Hz. Note that the modal test data was very high quality.

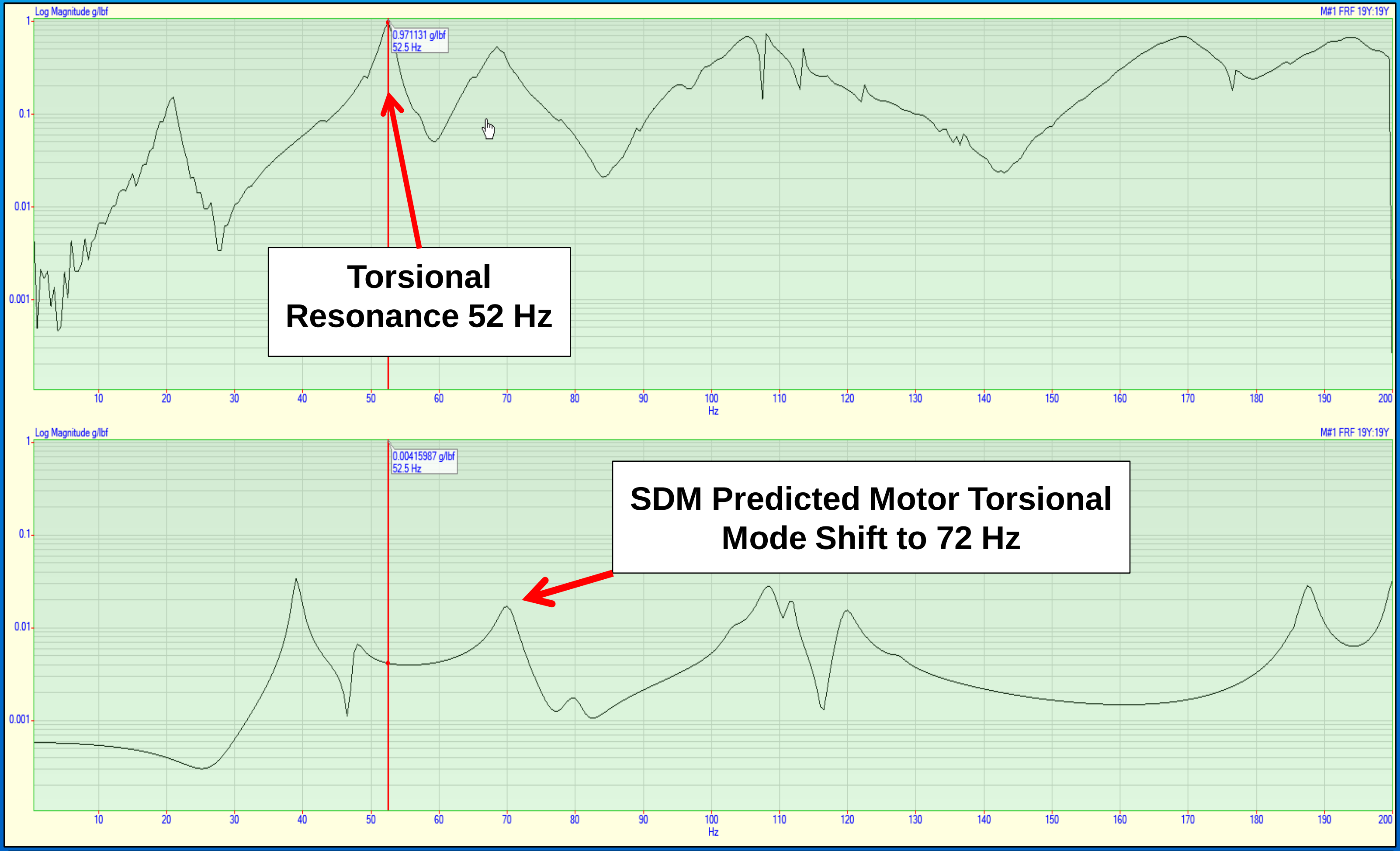


Figure 13. FRF Data Before Installation of Plates and SDM Predicted 52 Hz Torsional Mode Move Up to 72 Hz.

What Client Implemented and Results 5

Impact testing by plant PDM personnel showed the Torsional Resonance Moved to 72.25 Hz After Plates Installed (Only 0.25 Hz Higher than Predicted).

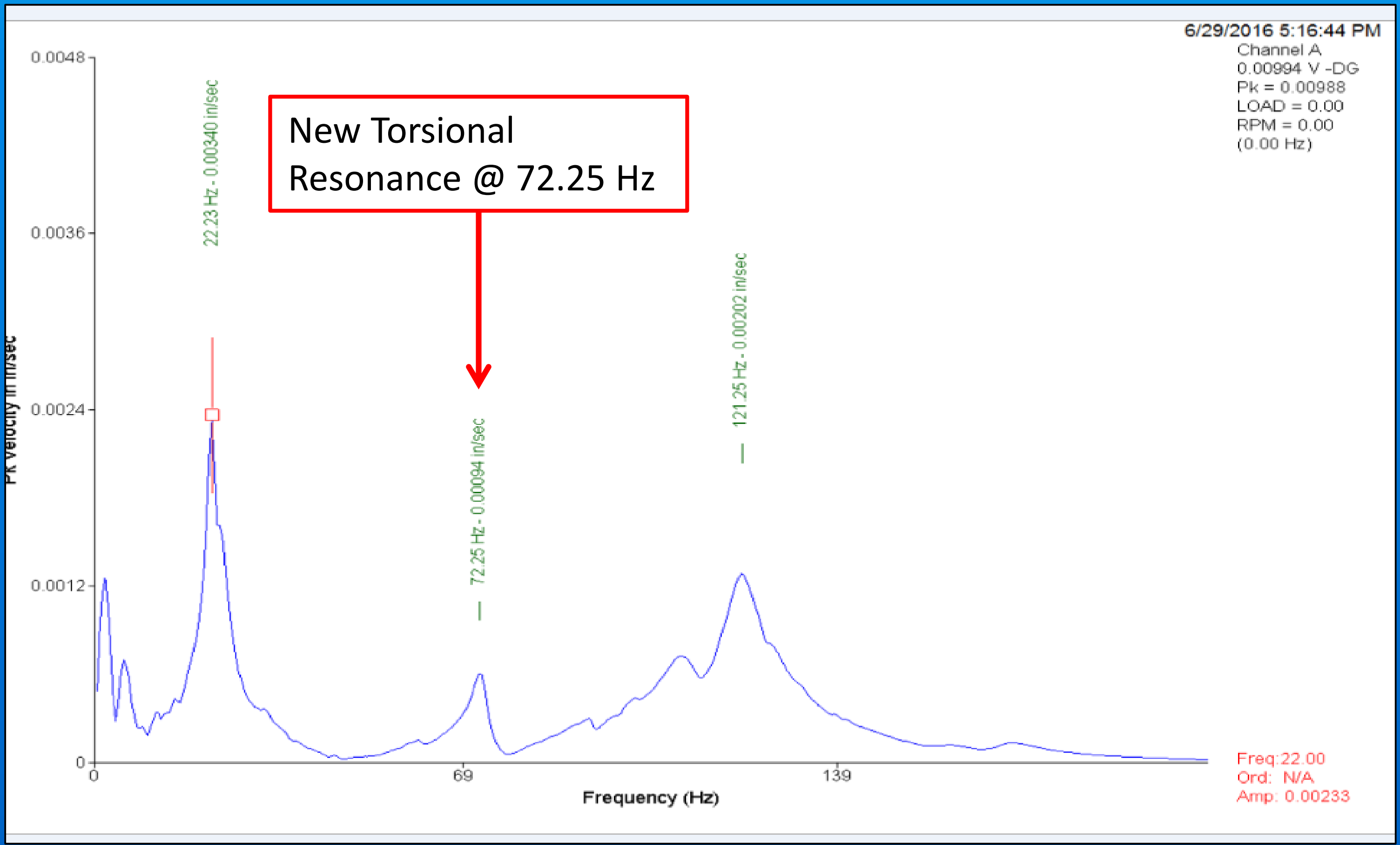


Figure 16. Bump Test by Plant Vibration Analyst at 19X (Horizontal at Motor Base).

END