ANALYZING CALENDAR ROLL DIRVE MOTOR TORSIONAL RESOANCE

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Abstract: Vibration analysts at a paper mill identified high vibration of a calendar roll drive motor. During an investigation, additional vibration data including an Operating Deflection Shape (ODS) and Experimental Modal Analysis (EMA) were measured to identify a torsional natural frequency of the motor and support. The mode shape of the natural frequency was twisting of the motor about the vertical or Z Axis. The data collection, analysis and Finite Element (FE) analysis modeling process are discussed. The solution was adding plates at each end of the motor supports to stiffen and raise the torsional mode well above the operating range of the motor.

Keywords: Motor, experimental modal analysis, operating deflection analysis, finite element modeling, torsional resonance.

Paper Mill Calendar Roll Motor Support Resonance: The paper mill vibration analysts identified high amplitude vibration of a calendar roll drive motor when the mill was operating within a certain speed range. The, motor is shown in **Figures 1 & 2**. The motor was supported on a base plate, which was welded to four square tubing legs. The legs were welded to a base plate (soleplate).

Figure 1. Calendar Roll Drive Motor, OB End

Figure 2. Calendar Roll Drive Motor, OB End

At the highest amplitude, vibration measured 0.468 in/sec pk at the Motor OB Hor bearing housing at 2X RPM = 3066 CPM = 51.1 Hz. Vibration at 1 X RPM was about 0.07 in/sec, pk at 1533 RPM (25.55 Hz).

<u>**Operation Deflection Shape Analysis (ODS)**</u>: An ODS measures the vibration of a structure at various points spatially located using at least two sensors which are typically accelerometers. One sensor remains at a fixed location (reference sensor) during the test. The other sensor (or multiple sensors) is moved to each defined point and direction or degree of freedom (DOF). The cross channel vibration data are measured using a multi-channel spectrum analyzer. The transmissibility or ODS FRF are calculated between the reference sensor and the roving sensor/sensors. These data were imported to ME'scopeVES and linked a 3D Model for animation. The 3D Model can be animated at each of the vibration frequencies of interest to display the vibratory amplitude and motion of the

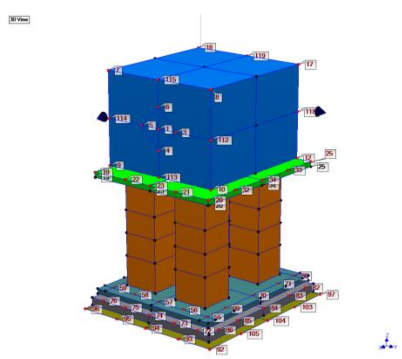

Figure 3. ODS Model Developed Using ME'scopeVES.

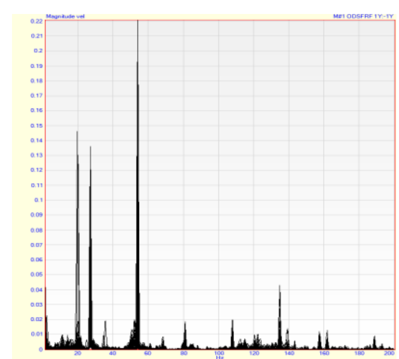

Figure 4. The ODS FRF are Shown Overlaid.

motor and support. ODS FRF (calculated from the cross power spectrum & cross phase or the time waveforms) provides the absolute vibration amplitude and relative phase. The ODS FRF overlaid plot is shown in **Figure 5**.

A total of 317 ODS DOF in X, Y and Z directions were measured on the motor, base and support. The ME'scopeVES model is shown in **Figure 4**.

The ODS showed that the vibration of the motor at 1X was rocking side to side as a result of flexure in the support square tubing, see **Figure 6**. At 2X (the frequency of highest amplitude) the motor was twisting about the vertical axis due to resonance of the motor and the square tubing, see **Figure 6**.

Note that paper machines change speed often. As a result of these speed changes the ODS did not measure the highest amplitude vibration that the motor had experienced. The ODS FRF at 1Y:-1Y, see **Figure 7**, plotted with log magnitude scaling clearly showed a resonance just below 2X motor run.

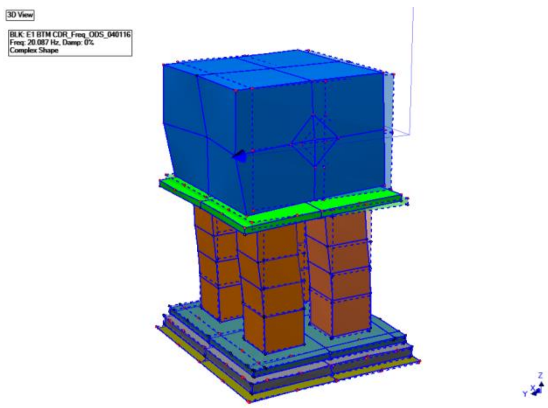

Figure 5. Motor Side-To-Side Vibration at 1X Run Speed.

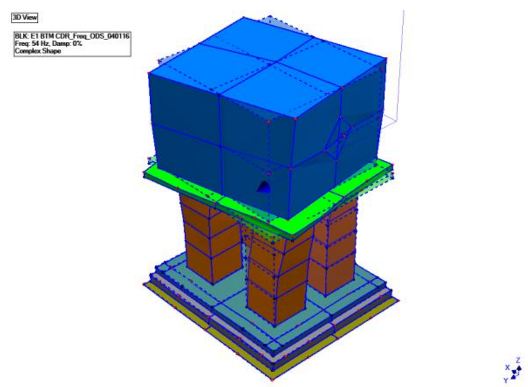

Figure 6. Motor Twisting About Vertical Axis 2X Motor Run Speed.

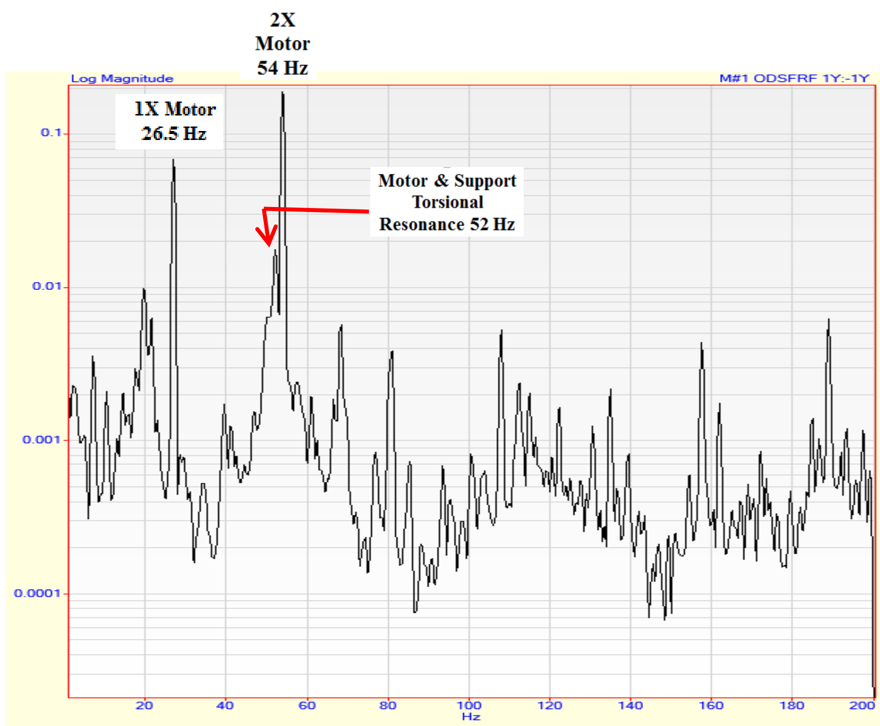

Figure 7. ODS FRF at 1Y:-1Y.

Experimental Modal Analysis: The natural frequencies and mode shapes of an elastic structure can be measured using experimental modal analysis. A controlled force is input to the structure typically using an instrumented hammer or shaker. The amount of force and the frequency span are controlled. The structure's response to the force is measured at various spatially identified locations on the structure typically using accelerometers. The most commonly used data measurement is the Frequency Response Function (FRF) in units of g's/lb_f (accelerance). The FRF provides a very good way of characterizing the dynamic response of a structure. A 3D modal of the test structure may be developed in ME'scopeVES which allows animation of the mode shapes at each of the measured natural frequencies (also called modes) in the FRF.

After the ODS was used to identify a potential torsional natural frequency of the motor and support, a modal test was conducted using the same ME'scopeVES structural model. This process of using EMA and ODS is discussed in References 2, 3 & 4. The reference (Driving Points) were 19X and 19Y at the Motor OB (Left Side) support plate. Two SISO (Single Input Single Output) modal tests were performed using the two driving points.

The driving point Frequency Response Function (FRF) 19Y:19Y and the curve fit shape table are shown in **Figure 8**. The 1st torsional or twisting mode was found to be 52.4 Hz (near 2X motor running speed depending on the paper mill speed).

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 Modifications (SDM): The finite elements in ME'scopeVES [Ret 1] provide options to modify the test structure's mathematical model obtained by curve fitting the modal test data. These modifications can be calculated to correct resonance problems using the finite elements listed as follows:

- FEA Springs
- FEA Dampers
- FEA Mass
- FEA Rods
- FEA Bars
- FEA Triangles
- FEA Quads
- FEA Tetras
- FEA Prism
- FEA Brick

SDM was used to add two 54" X 46" X ¾" carbon steel plates using the FEA Quads. The plates were attached to the motor support plate and the base plate (or soleplate). The SDM calculations predicted the torsional resonance mode would move up to about 72 Hz or approximately 20 Hz above 2X running speed.

During the SDM process, ½" thick plates were tried first as shown in **Figures 10-12**. But, there were standing wave modes of the plate when it was attached to the motor support and base as follows:

- **Figure 9**, 50.66 Hz (1st Bending) (Too close Motor 2X run speed).
- **Figure 10,** 57.29 Hz (1st Twisting) (Too close Motor 2X run speed).
- **Figure 11,** 83.79 Hz (2nd Bending).

For this calculation, the DOFs at the top and bottom of the plate were fixed which would represent being welded.

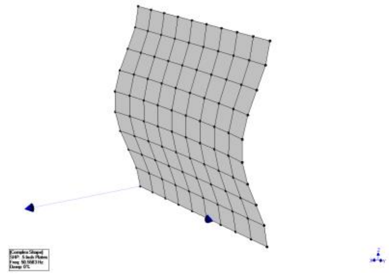

Figure 9. 1st Bending Mode 50.66 Hz.

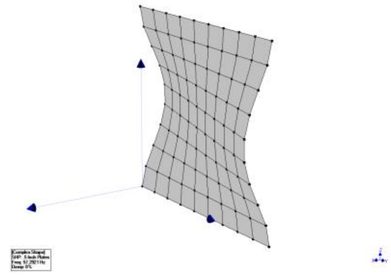

Figure 10. 1st Torsional Mode 57.29 Hz.

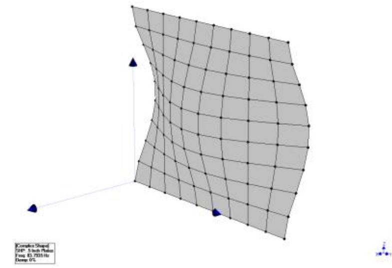

Figure 11. 2nd Bending Mode 83.79 Hz.

When the 3/4" thick plate was modeled, the 1st bending mode calculated to 75.7 Hz (well above the 52 Hz 2X motor running speed frequency), see **Figure 13**. Note that the ¾" plate was modeling using 6 Grade 5, 5/8" bolts which calculated to 14,400 lb_f/in stiffness when torqued to 150 lb_f-ft.

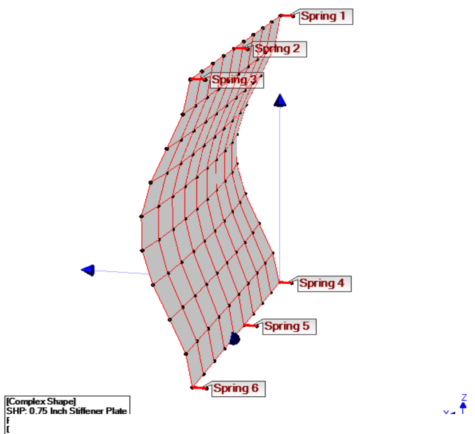

Figure 12. ¾" Plate Modeling With 5/8 Bolts (Springs 14,400 lb_f/in Stiffness) Attachments to Motor Base Plate and Sole Plate.

Figure 13. The Driving Point FRF 19Y:19Y (Top) and SDM Synthesized FRF (Bottom).

In **Figure 13** is shown the Driving Point FRF 19Y:19Y (top) and the calculated FRF with the ¾" plate attached (bottom). The 1st torsional was predicted to shift to about 72 Hz. Note that the modal test data was very high quality.

Recommendations to Client:

The recommendations made to the client were as follows:

1. Fabricate six 2" X 2" X 12" bars (hot rolled carbon steel). Drill and tap holes in the bars for 5/8-11 thd.
2. Bolt two 54" X 46" X ¾" carbon steel plates to the motor support plate and the base plate at the motor drive end and opposite drive end as illustrated in **Figure 14**.
3. If the stiffening plates are effective in reducing motor vibration, the plates can be welded to the motor support plate and base plate.

What the Client Implemented and the Results:

After about one year the results were obtained from the vibration analysts at the plant site. The recommended plates had been installed. The plates were welded in place as shown in **Figures 16 & 17**.

The before and after frequency spectra are provided in **Figure 18**. Vibration at Motor 2X reduced from 0.450 in/sec pk to 0.0388 in/sec pk which was 11.6:1 reduction (or 91.4%). The SDM calculation was within 0.25 Hz of the actual measured natural frequency with the stiffening plates installed.

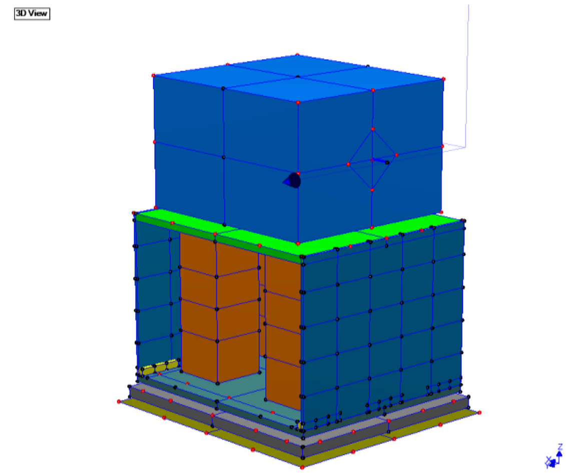

Figure 14. Final SDM Model Using ¾" Carbon Steel Plate Bolted to the Motor Base Plate and Support Plate.

Figure 15. Photo of Motor with ¾" Plates Welded to the Motor Support Plate and Base Plate.

Figure 16. Photo Motor Drive End with ¾" Plate Welded to Motor Support Plate and Base Plate.

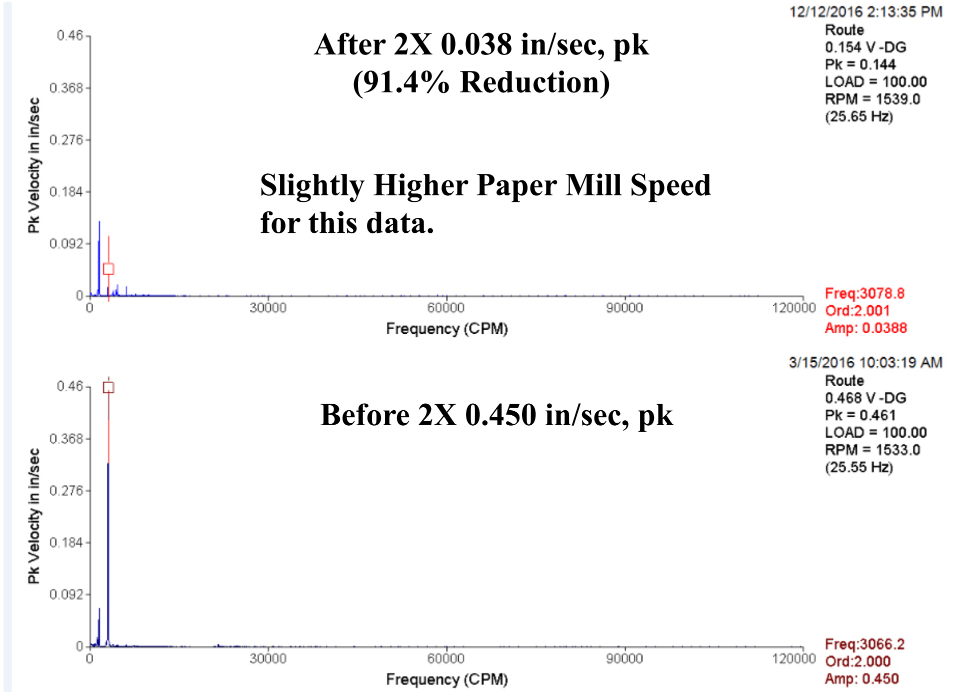

Figure 17. Before and After Frequency Spectra at Motor OB Hor Bearing Housing.

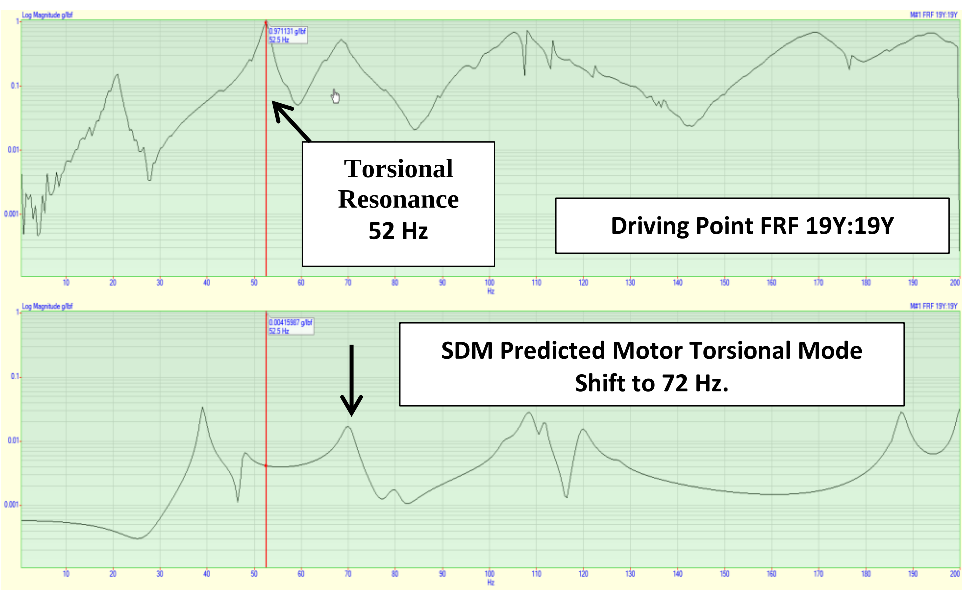

Figure 13. FRF Data Before Installation of Plates and SDM Predicted 52 Hz Torsional Mode Moves Up to 72 Hz.

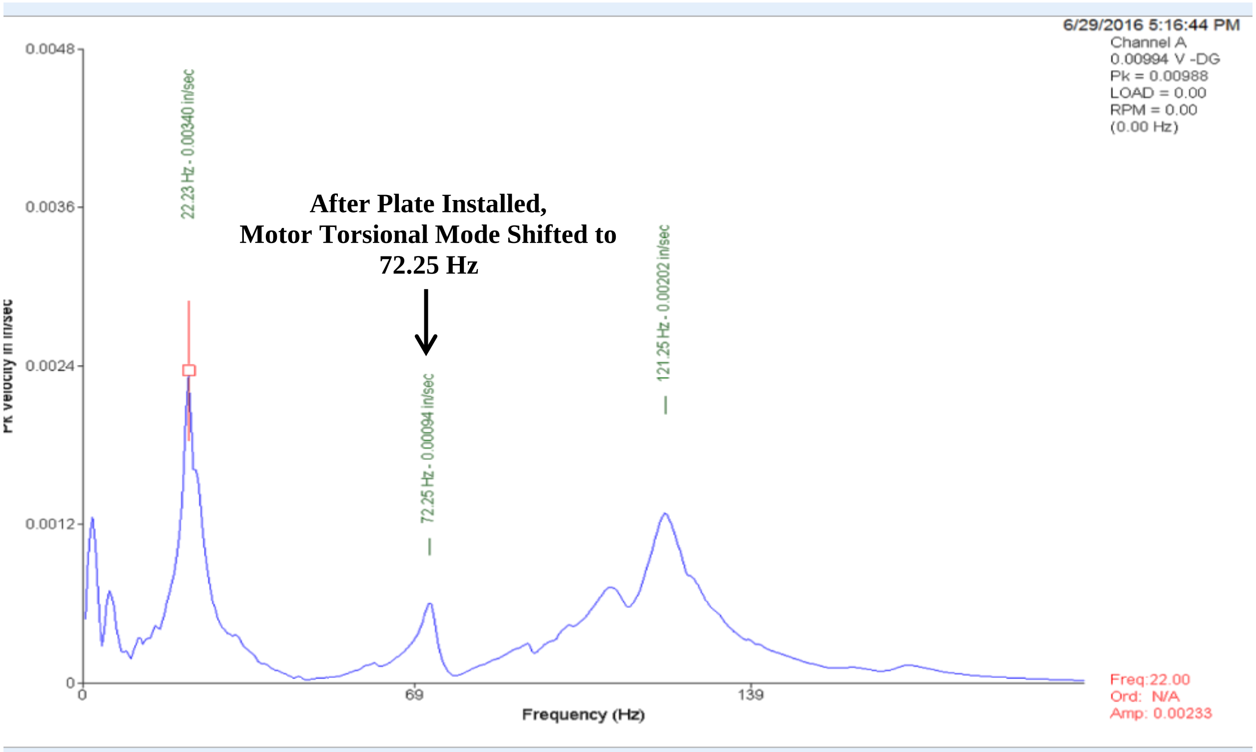

Figure 19. Bump Test by Plant Vibration Analyst at 19X (Horizontal at Motor Base).

Summary:

This case study used periodic vibration monitoring and analysis to identify a calendar roll motor with high amplitude vibration at 2X motor run speed. It has been demonstrated that ODS and EMA combined with SDM using the finite elements in ME'scopeVES [Ref 1] is an effective methodology to address structural resonance. The EMA data were very high quality which is a requirement for developing an accurate mathematical model that the SDM calculations use. The end result was shifting the Motor Torsional mode about 20 Hz higher, well above the excitation frequency of 2X Motor run speed. The Motor vibration at 2X was reduced about 91.4%. The predicted frequency shift was within 1 Hz.

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