49TH TURBOMACHINERY & 36TH PUMP SYMPOSIA

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TEXAS A&M UNIVERSITY | TEES TURBOMACHINERY LABORATORY TEXAS A&M ENGINEERING EXPERIMENT STATION

Analyzing and Resolving an ID Fan Failure Due to Torsional Vibration

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CARMEUSE

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Presenter Bios

Gary Galloway

- Attended Eastern KY for Industrial Electronics
- Attended University of Cincinnati for Electrical Engineering
- 40+ years in maintenance in Lime and Mining industry
- 35 years in supervisory role in maintenance

CARMEUSE

Dan Phillips, CMRP

- B.S. Mechanical Engineering, University of Maryland Baltimore County
- Category III Vibration Analyst, specializing in torsional vibration
- 15+ years of field experience with rotating equipment for O&G and Heavy Industries

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Short text of an Abstract (approx.80 words) to print in show guide

In order to better control speed of the electric motor-driven ID Fan, the existing fluid coupling was replaced with a variable speed drive, but this led to two failures of the motor shaft and coupling. The drivetrain was instrumented to measure bearing vibration, transient torque, and speed during various operating conditions. Testing of the drivetrain highlighted that the excitation source was likely a structural resonance, with the greatest amplitudes occurring on the bearing pedestals. A new elastomeric coupling was designed and tuned for the drivetrain, reducing torsional vibration by 80%.

Case Study Overview

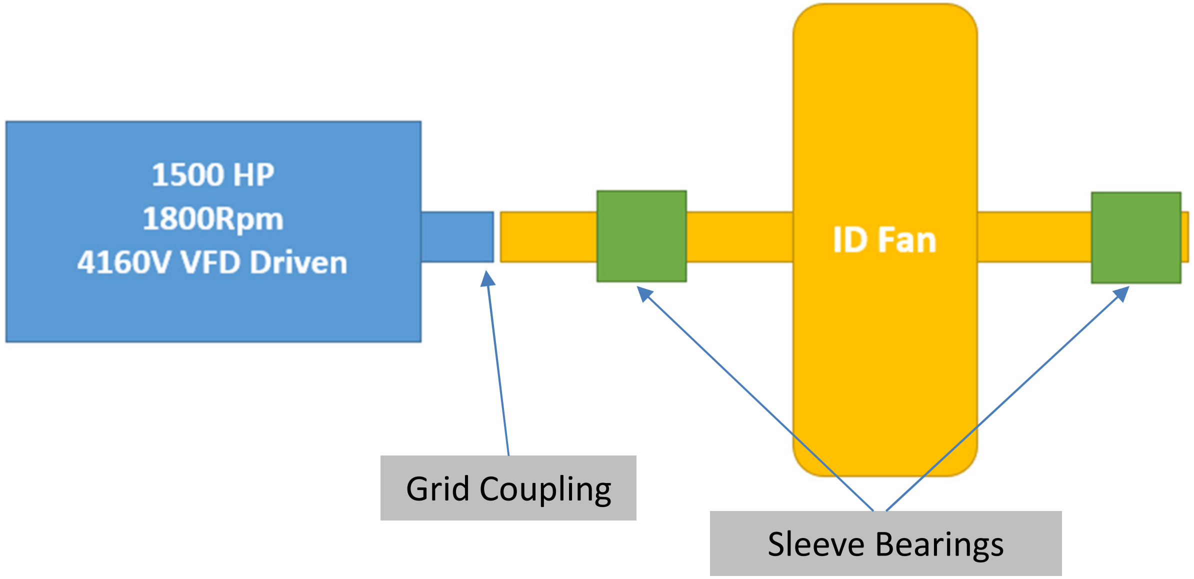
- Application Overview
- Equipment Failure Details
- Drivetrain Instrumentation & Diagnostics
- Coupling Design & Selection
- Verification

Application Overview

- Carmeuse Facility produces Quicklime (Calcium Oxide) and Chemical Grade Limestone
- ID Fans used in Rotary Kilns

- Facility removed existing Fluid Drive between Motor and Fan to reduce preventive maintenance activities

- New variable frequency drive installed to better control speed



Failure History

First Failure
- Occurred approximately 3 days after start-up, following removal of the fluid drive and VFD installation
- Motor shaft cracked at 45 degree angle, originating at the keyway
- Grid coupling element showed signs of excessive heat

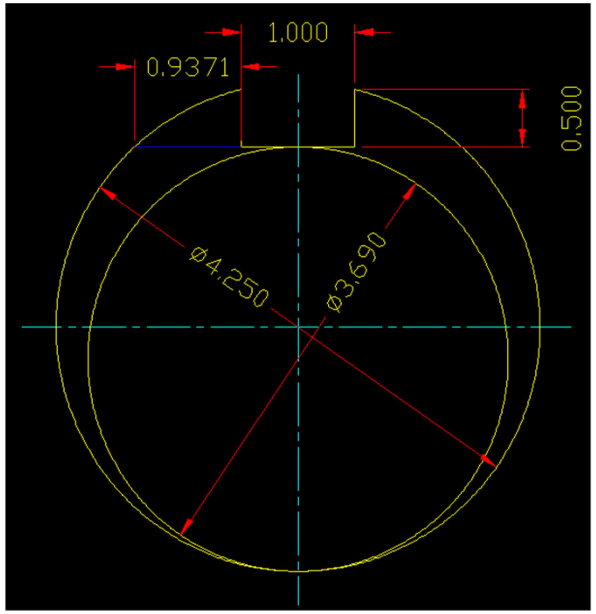
Second Failure
- Motor was replaced with a spare
- Similar symptoms as previous failure

Broken Grid Coupling Element + Indications of Excessive Heat

Motor Shaft Crack @ 45 degrees

Initial Stress Analysis

- Stress Analysis of Shaft and Fan shaft locations was performed to estimate the magnitude of loads required to damage shafts.
- Calculations also utilized to convert values of strain measured on shaft elements to torque
- Torque (and stress) used to determine allowable loading, both static and dynamic

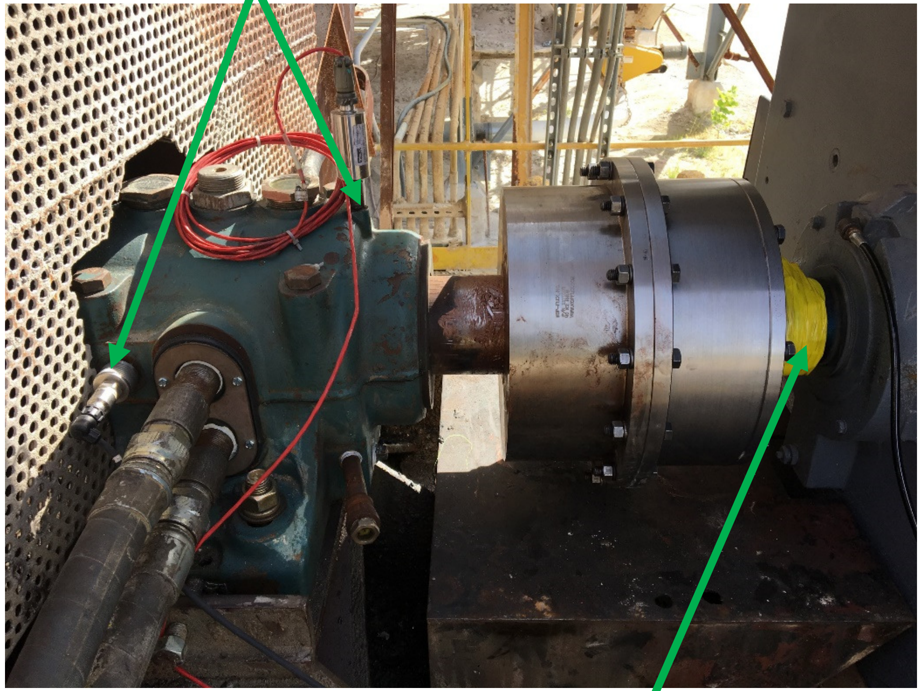


Location	Safety Factor @ Normal Torque	Safety Factor @ Peak Torque (1.91 X Nominal)	Considered Shaft Material
Motor Shaft	6	3.15	AISI 4140
Fan Shaft	8.13	4.26	AISI 1045

Instrumentation & Diagnostics

- In order to diagnose the cause of the failures, the drivetrain was instrumented to measure bearing vibration, transient torque, and speed during various operating conditions.
- A replacement elastomeric coupling (with cylindrical blocks, K2 style) was installed, chosen based on availability only.
    - K2 Style coupling is not intended for these applications, but was necessary to complete the initial testing.

Bearing Vibration Sensors



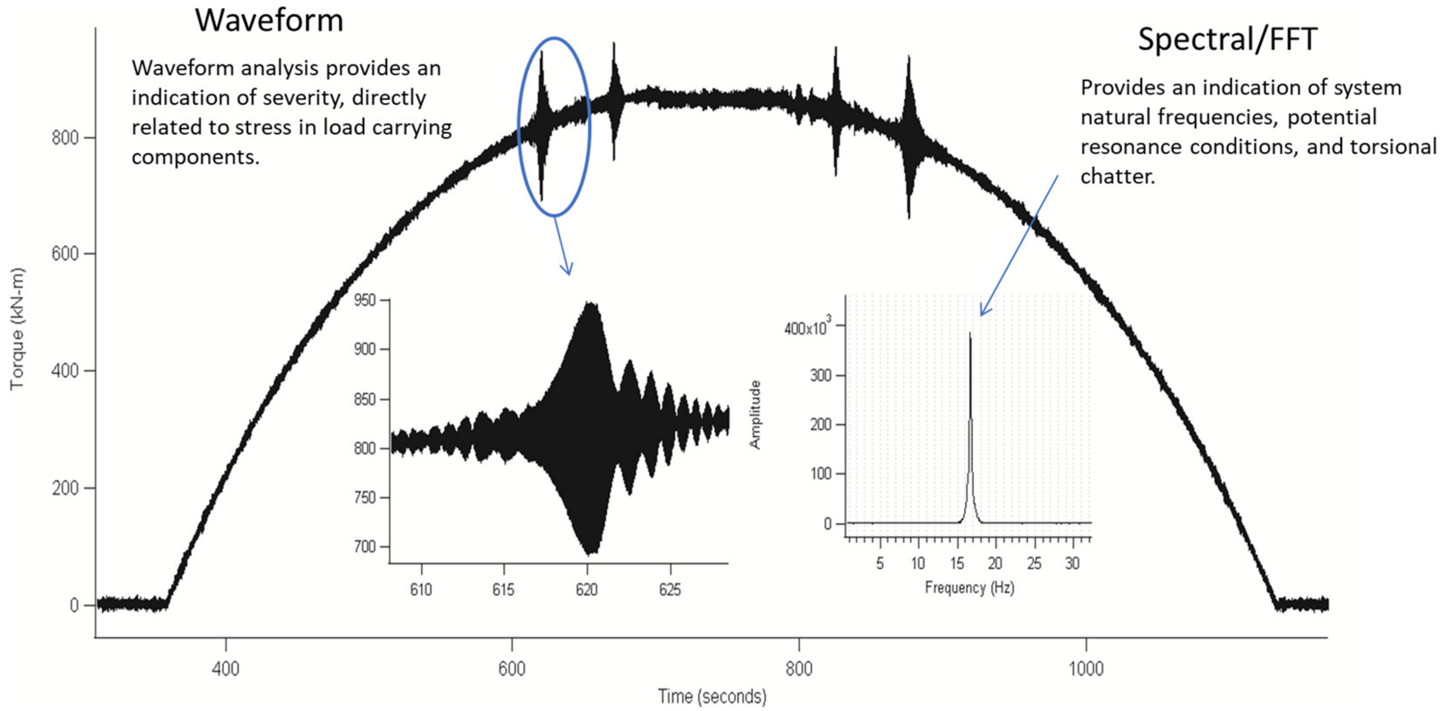
Strain Gage Telemetry (Torque)

Laser Tachometer

Remote Connectivity for Real-Time Data analysis

Instrumentation & Diagnostics

- Transient Torque
  - Strain Gage Telemetry installed on motor and fan shafts
  - Allowed for measurement redundancy and evaluation of flexible coupling effects
  - Strain data converted to torque based on geometry & shaft material
  - Recorded at 2,000 Hz (Samples/Sec)
  - Waveform and spectral analysis utilized

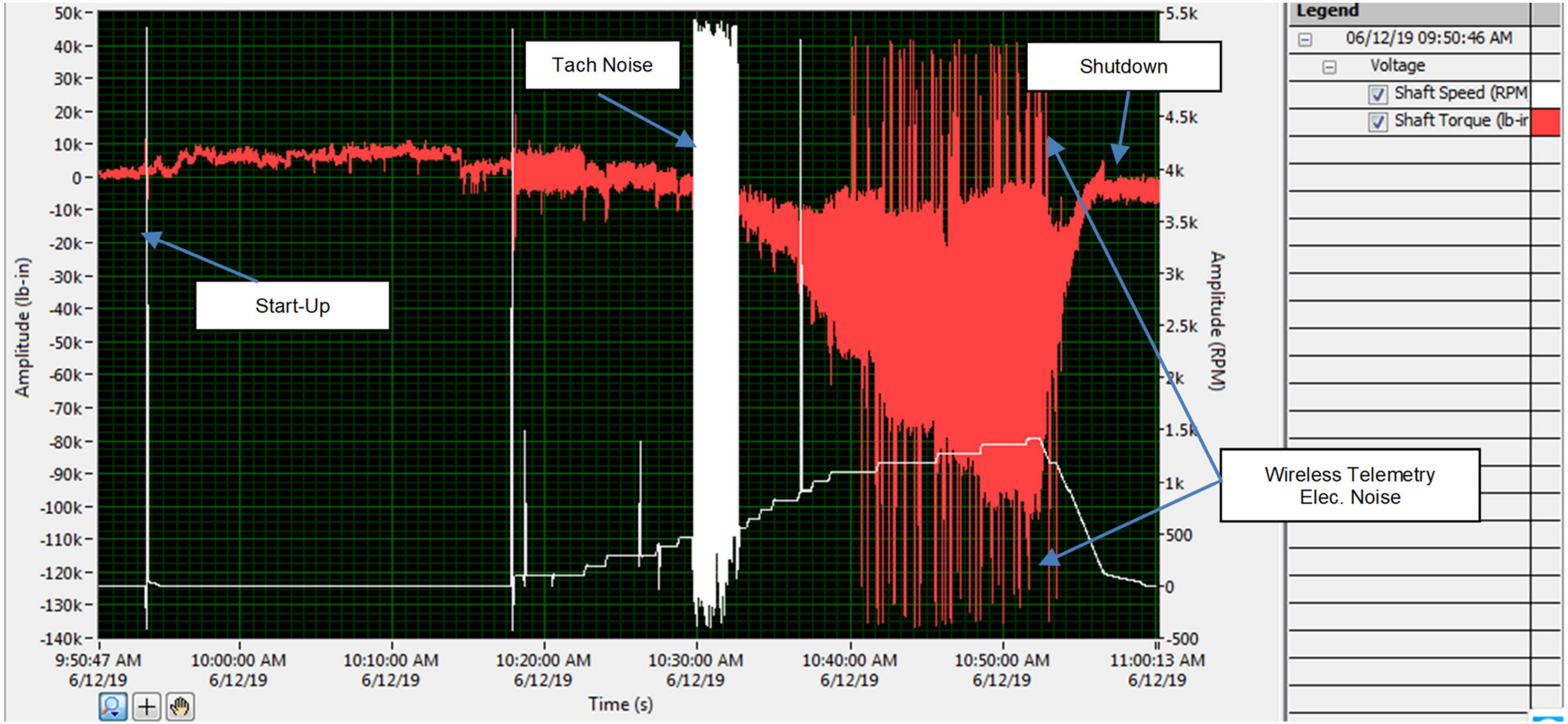


Wedge-block style Elastomeric coupling installed following torsional analysis

Subsequent tests measured torque at fan and motor shaft

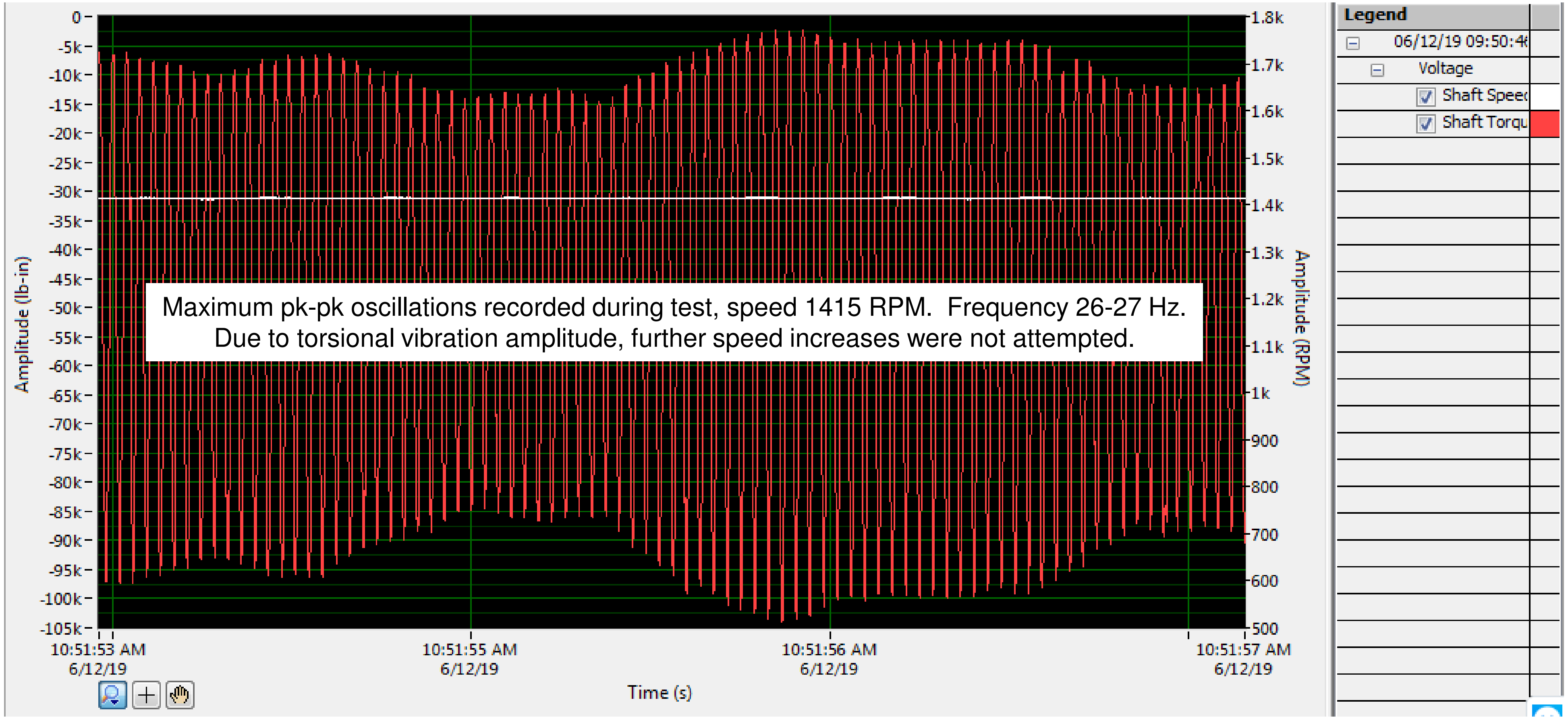
Diagnostic Testing

- During start-up there were minor reversing torques, typical in these applications due to the fan inertia.
- Frequency of oscillations occurred at 21 Hz, most likely the torsional natural frequency (TNF)
- Frequency of oscillations increased with load - Elastomeric blocks do not have a constant stiffness across the entire load range, stiffness increases with torque - and increases the TNF of the system.



Diagnostic Testing

- As speed increased, the magnitude of the oscillations increased to over 2X nominal torque and frequency steadily increased to 26-27 Hz. There was some modulation which was noted in the torque waveform.
- Suspected that oscillations could be from gain settings in the PID controller integral to the drive. Testing of the drive in conjunction with torque measurements showed no effect.



Diagnostics Testing

During testing with K2 coupling, oscillations started at 21 Hz, and increased to 27 Hz as speed and load increased.

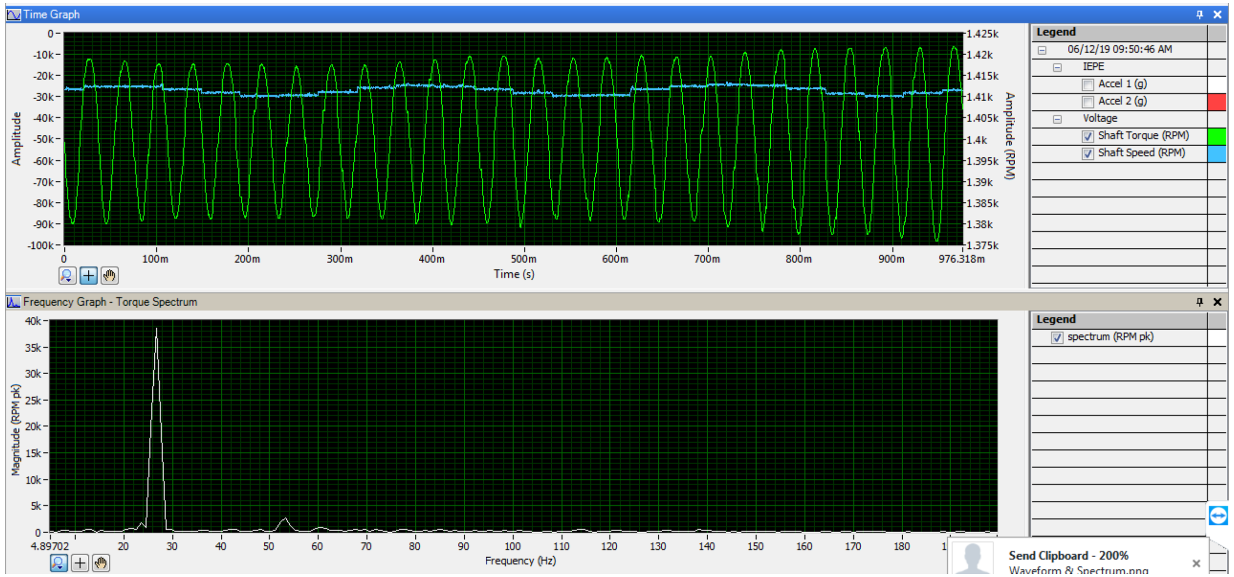
The stiffness of the elastomeric coupling will increase with load, creating an increase in the natural frequency of the drivetrain. The TNF measured corresponds with the expected range of the coupling stiffness + load.

TNF (0 to 60% Normal Torque)

K2 Size	Rated Torque (lb-in)	Torsional Stiffness (LB-INCH/RAD) (0 to 60% Normal Torque)	TNF (Hz)
4.0	185,000	3,550,000	21.08
4.5	265,000	5,080,000	25.05
5.5	420,000	6,150,000	26.72

TNF (> 60% Normal Torque)

K2 Size	Rated Torque (lb-in)	Torsional Stiffness (LB-INCH/RAD) (>60% Normal Torque)	TNF (Hz)
4.0	185,000	10,300,000	35.91
4.5	265,000	14,700,000	42.61
5.5	420,000	17,900,000	45.59



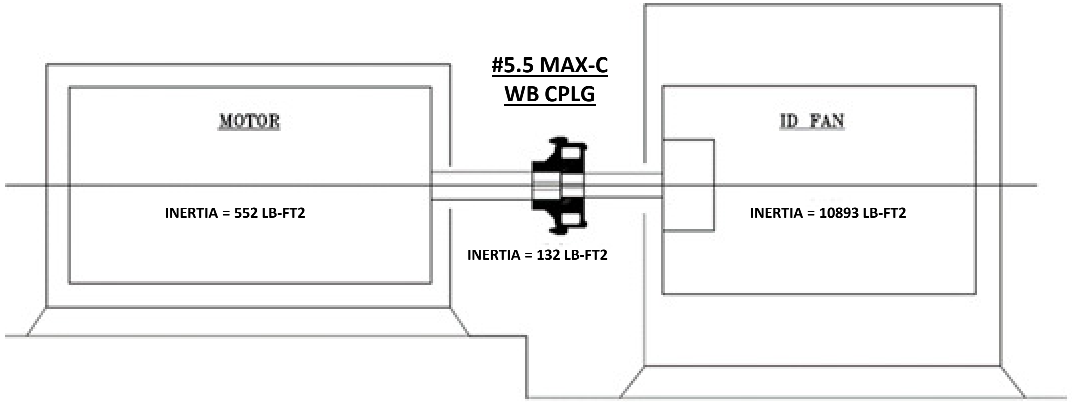
Dominant 27Hz frequency at 1410 RPM

Testing ceased before further speed increases due to torsional amplitude.

Mechanical Tuning – Coupling Design & Selection

Torsional Analysis Performed on ID Fan Drivetrain

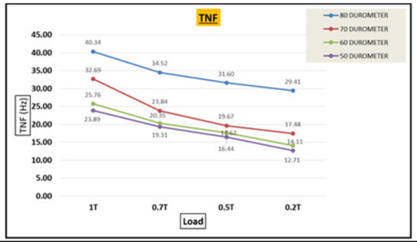
J1= 552+66 = 618 LB-FT2
K1= See Table
J2= 10893+66 = 10959 LB-FT2



NOTE** : COUPLING STIFFNESS CHANGES PER TORQUE

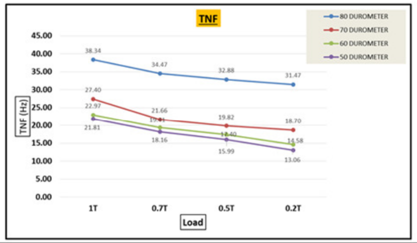
4.0 WB Coupling

	80 DUROMETER	70 DUROMETER	60 DUROMETER	50 DUROMETER
1T	40.34	32.69	25.76	23.89
0.7T	34.52	23.84	20.35	19.31
0.5T	31.60	19.67	17.62	16.44
0.2T	29.41	17.48	14.11	12.71



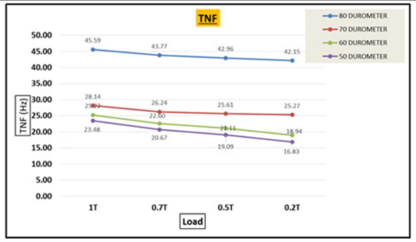
4.5 WB Coupling

	80 DUROMETER	70 DUROMETER	60 DUROMETER	50 DUROMETER
1T	38.34	27.40	22.97	21.81
0.7T	34.47	21.66	19.41	18.16
0.5T	32.88	19.82	17.40	15.99
0.2T	31.47	18.70	14.58	13.06



5.5 WB Coupling

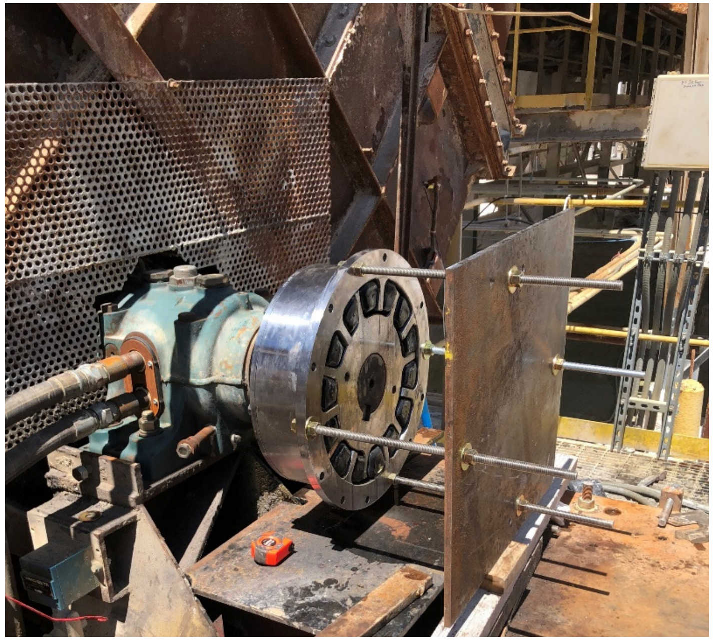
	80 DUROMETER	70 DUROMETER	60 DUROMETER	50 DUROMETER
1T	45.59	28.14	25.22	23.48
0.7T	43.77	26.24	22.60	20.67
0.5T	42.96	25.61	21.11	19.09
0.2T	42.15	25.27	18.94	16.83

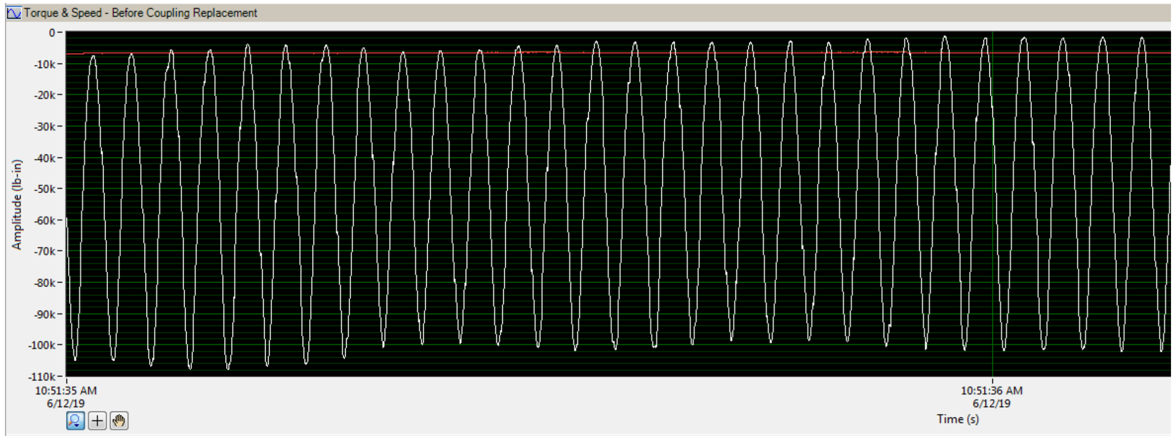


Size 5.5 WB (Wedge Block) Selected based on increased system natural frequency and allowable dynamic torque ratings

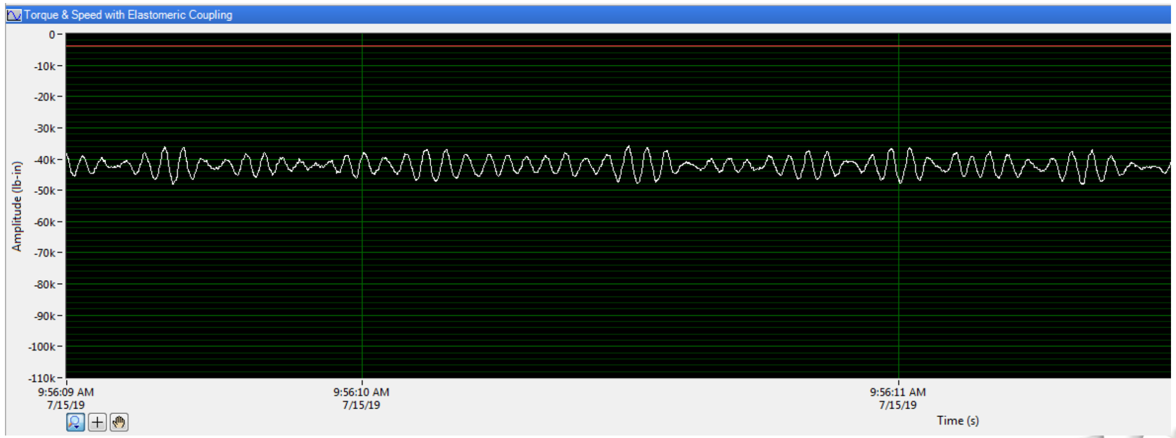
Verification

- Final testing showed a significant reduction (80%) in the torsional vibration, keeping the stress in the motor shaft below the endurance limit for the material.
- Testing was performed throughout the entire speed range with the kiln at ~ 600 °F and showed no torsional oscillations of concern.





Before Coupling Replacement

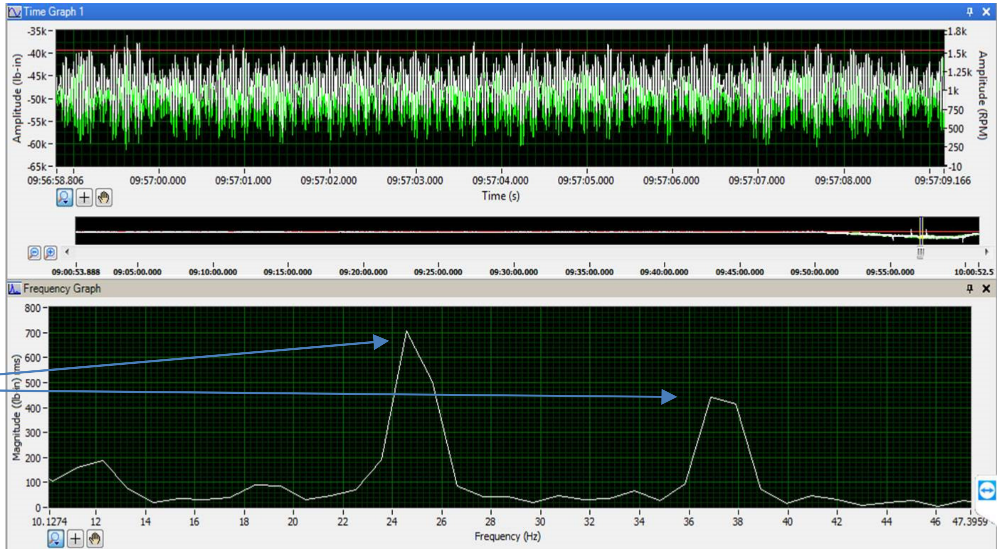


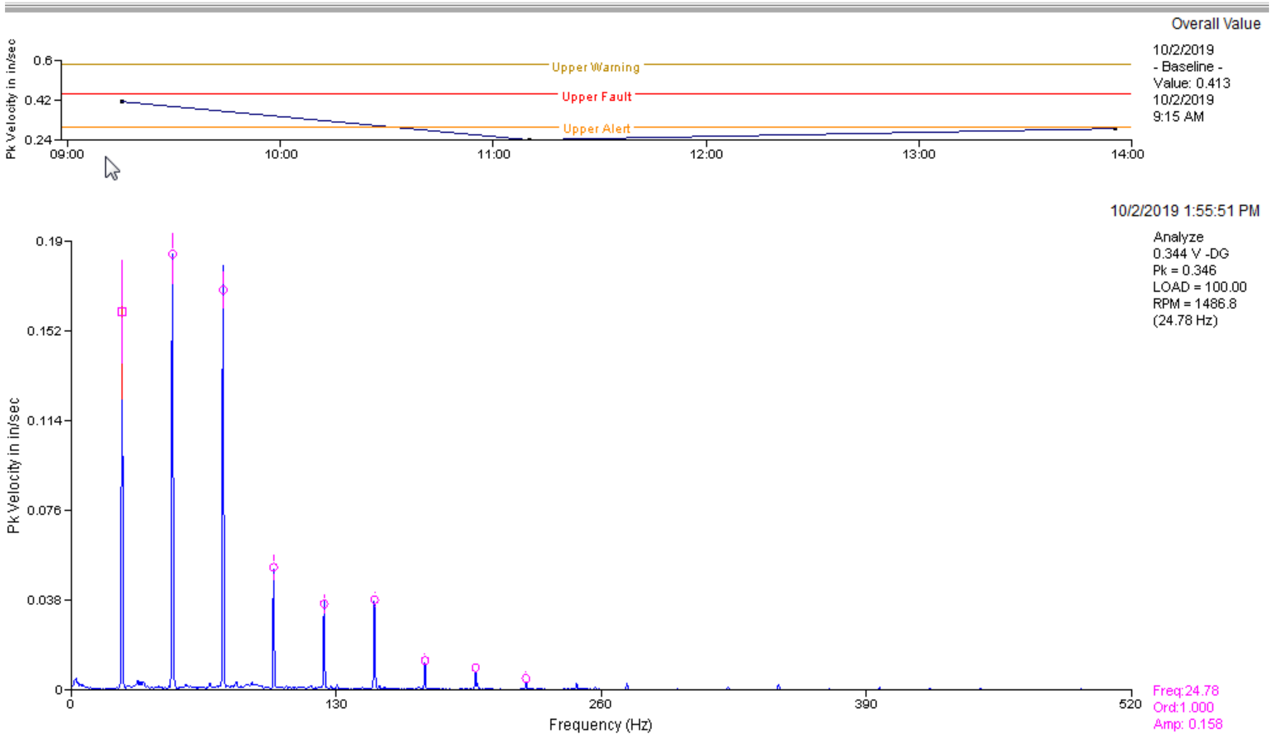
After Coupling Replacement

Harmful oscillations reduced by 80%

Verification

- From the torsional analysis, a TNF of ~40 Hz (dependent on torque applied) is expected. From the measurements, we see that there are oscillations occurring at 37 Hz (2220 CPM).
- Torsional Vibration Spectral data shows (2) distinct peaks now
- Additional Vibration testing on the bearings





Radial Vibration levels on the inboard fan bearing show high harmonics at 1-3x RPM which is a sign of looseness and misalignment.

Phase readings across the coupling show a phase shift of 110° in the horizontal plane, 180° in the vertical and axial planes.

Conclusions

- Torsional vibrations can occur due to process conditions and transient events, or can simply be inherent to the design of the drivetrain.

- Most equipment is not instrumented to measure these vibrations, failure is often the first indication of their presence.
  - Be proactive - Measurement and analysis is necessary when equipment configuration or operating parameters are changed.

- Field measurements should be conducted in addition to theoretical analyses for normalization of TVA model and verification.

- Follow API guidelines regarding margin of separation for natural frequencies and excitation sources.