Abstract

37th Turbomachinery Symposium

Case Study:

TORSIONAL OSCILLATION TROUBLE ON VFD MOTOR DRIVEN RECIP COMPRESOR

Authors:

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Machinery Specialist, ExxonMobil

High vibration problems including failed coupling parts on a VFD motor driven reciprocating compressor are analyzed and the root causes and solutions are discussed in this costly field issue.
TORSIONAL OSCILLATION TROUBLE ON VFD MOTOR DRIVEN RECIP COMPRESSOR

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Initial Problem

- VFD Controlled Electric Motor Driving a 4 Throw Reciprocating Compressor (1230 Kw @ 600 RPM – 1000 RPM)
- Connected by an Elastomeric Block Type Coupling
- High Vibrations Noticed on the Motor
Initial Problem
Initial Problem

- In Depth Vibration Readings Taken to Determine Root Cause
- 5 mm/sec @ 83.2 Hz Horizontal on Motor NDE
- Approximately 5x Running Speed
- However, Frame Measurements Led to Discovery of Foundation Bolts not Tightened Properly
Initial Problem

- Bolts Tightened and New Measurements Taken
- Now Dominant Frequency is @ 66.5 Hz Axial, with Amplitudes Above 6 mm/s on Both Ends of Motor
- Approximately 4X Running Speed
- Everything is Questioned, Including Coupling
- Coupling has 10 Blocks in Cavities, but Only 5 are Driving; so Coupling Problem Could Explain 5X but not 4X
Tightening of Bolts Changed the Dominant Frequency

Natural Frequencies on the Motor (non-tightened bolts) Measured at 42, 73, and 95 Hz

High Vibration Coming from Amplification of Resonance of Motor Base/Frame Suspected

Dynamic Stiffness of Motor Feet/Base Connection Needs to be Increased
# Measurement Results

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<td>Y</td>
<td>Z</td>
<td>X</td>
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<td>Overall [mm/s]</td>
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<td>5.0 @ 83.2</td>
<td>1.0 @ 66.5</td>
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<td>[mm/s] @ 66.5 Hz</td>
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<td>Overall [mm/s]</td>
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<tr>
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<td>1.8 @ 66.5</td>
<td>2.5 @ 66.5</td>
<td>1.4 @ 66.5</td>
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<td>[mm/s] @ 66.5 Hz</td>
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<td>1.4</td>
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<td>[mm/s] @ 83.2 Hz</td>
<td>0.5</td>
<td>1.4</td>
<td>0.2</td>
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</table>

*E-motor Overall ? 2.5 mm/s*
**Coupling Problem Suspected**

- Motor Foot Bolts Regrouted
- At or About the Same Time the “Smell of Burned Rubber” was Noticed Around the Machine
- At the First Opportunity, the Machines were Shut Down for Inspection
- Rubber Blocks were Damaged
Coupling Problem Suspected
Coupling Problem Suspected
Coupling Problem Suspected
Coupling Problem Suspected
Coupling Problem Suspected
Coupling Problem Suspected
Coupling Problem Suspected

- Did the Coupling Cause the Machine Vibration Leading to its Failure? or
- Did the Machinery Vibrations Cause the Failed Coupling?
Coupling Problem Suspected

- Original Torsional Analysis Reviewed by Coupling Vendor

- Issues Found
  - Only One Coupling Stiffness Used in Model (Block Coupling Stiffness Varies with Torque and Alignment, Amongst Other Factors)
    - Tolerance
    - Durometer, Age
    - Temperature
Coupling Problem Suspected

MASS ELASTIC SYSTEM

\[ J_1 = \left( \frac{1}{2} \text{ BLOCKS + HUB} \right) = 40.13 \text{ LB-IN-SEC}^2 \]

\[ K_1 = \text{ BLOCK STIFFNESS} = 4.65 \times 10^6 \text{ LB-IN/RAD} \]

\[ J_2 = \left( \frac{1}{2} \text{ SPACER + SLEEVE ASSEY + 1/2 BLOCKS} \right) = 51.34 \text{ LB-IN-SEC}^2 \]

\[ K_2 = \text{ SPACER STIFFNESS} = 480 \times 10^4 \text{ LB-IN/RAD} \]

\[ J_3 = \left( \frac{1}{2} \text{ SPACER + RIGID} \right) = 43.70 \text{ LB-IN-SEC}^2 \]
Coupling Problem Suspected

Torsional stiffness of “WB” Couplings can be calculated by the same method as shown for the “CB” Couplings.
Coupling Problem Suspected

- Damping of the Rubber Blocks not Modeled

\[
C = \frac{K}{(M \times w)} \quad [\text{lb} \times \text{in} \times \text{sec} / \text{rad}]
\]

\[
K - \text{coupling stiffness (table)} \quad [\text{lb} \times \text{in} / \text{rad}]
\]

\[
M - \text{magnification factor} \quad [\text{dimensionless}]
\]

\[
W - \text{torsional vibration freq.} \quad [\text{rad/sec}]
\]

for Duro 80 \( M_{\text{Natural Rubber}} = 5.0 \); \( M_{\text{SBR}} = 3.0 \)

- Most Importantly, the Vibratory Torque Capacity of the Blocks was Exceeded
Coupling Problem Suspected

- Coupling was Selected early Using a Service Factor
- Coupling Dynamic Torque Capacity was +/-63,000 lb-in up to Vibration Frequency of 500 cpm and less beyond
- The Torsional Report Predicted Values Varied with Different Cases, but Largest Value was +/- 75,000 lb-in in the Running Speed Range, but Not at a Resonant Frequency
- An Issue of Poor Communication Between the Coupling Supplier and Analysts
**Coupling Problem Suspected**

<table>
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<tr>
<th>Case</th>
<th>Predicted Torque [Nm]</th>
<th>Allowable Torque [Nm]</th>
<th>Comments</th>
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<tr>
<td></td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
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<td>Case 1</td>
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<td>Case 6</td>
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</table>
Possible Solutions

- Replace Coupling with One with Higher Vibratory Torque Capacity (would take too long to manufacture)

- Introduce Flywheel(s) into System to Reduce the Vibration Magnitude which would also Change the Resonant Frequencies

- Internal Flywheels were Available from the Compressor Manufacturer, but did not have Enough Inertia to Reduce Amplitude
**Actual Solution**

- A Large Flywheel Bolted to the Coupling Hub/Spacer Connection
- Plus Using High Damping Material Blocks of the Same Size as Before but with Lower Dynamic Magnification Factor (3 vs. 5)
- This Put Resonant Points into the Running Speed Range, but the Magnitudes were Sufficiently Reduced to be Within the Coupling Vibratory Torque Capacity
Actual Solution

1025 lb
375000 lb-in²
Actual Solution
Actual Solution

Vibratory Torque at Predicted Natural Frequency

- Resonant Nat. Rubber
- Resonant (SBR)
- Limits @ Res. RPM

Vibratory Torque [Nm]

Case (RPM)

2 (716 rpm) 5 (606 rpm) 11 (637 rpm) 13 (716 rpm) 14 (660 rpm) 19 (716 rpm)
## Actual Solution

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<tr>
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<td>3291.2</td>
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Lessons Learned

- Complete Torsional Analysis in a Timely Manner and Review with ALL Equipment Suppliers

- Equipment Suppliers Need to be Clear on the Limitations and Assumptions in Their Data Used for the Torsional Model

- On Trains Prone to Torsional Issues, Complete an Analysis – Do Not Use Service Factors

- Even if the Analysis is Complete, There are Many Possibilities for Errors, So an Actual Vibration Measurement is Recommended
  - Before Equipment is Needed to be in Operation
  - At the Most Possible Loading Conditions