2X PINION VIBRATION PROBLEMS AND SOLUTIONS FOR MOTOR-GEAR-COMPRESSOR TRAINS DURING COMMISSIONING

CASE STUDY
2014 TAMU TURBO SYMPOSIUM
2X Pinion Vibration Problems and Solutions for Motor-Gear-Compressor Trains During Commissioning

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Problem Description

- **Basic information:**
  - Customer: ******
  - Gear Vendor: ******
  - Where: ******
  - When: 2013
  - RADIAL BEARING: PRESSURE DAM
  - THRUST BEARING: TILTING PAD
  - MINIMUM SPEED [rpm]: 1196 / 9796
  - RATED SPEED [rpm]: 1495 / 12245
  - MAX SPEED [rpm]: 1570 / 12857
  - GEAR RATIO, # OF TEETH: 8.1905 (21/172)
  - TRANSMISSION POWER (RATED/NOR) [kW]: 4500/3604

- **What happened:**
  - 4 identical equipment trains, 3 tested. All 3 have the same symptom: 2X vibration at coupling side of the pinion. Vibration from all other probes including the motor and the compressor is low.
Problem Description - Continued

• Waterfall plots

VXT-7827 : Pinion coupling side

VYT-7827 : Pinion coupling side

2X:22um

VXT-7828 : Pinion non coupling side

VYT-7823 : Pinion non coupling side
Problem Description – Continued

Bode Plot: Pinion Coupling Side X Direction

Operating speed
9796 12245
Root Cause Analysis

• Possible causes:
  – 1*: Coupling misalignment
  – 2*: Motor/VFD
  – 3: Bearing looseness
  – 4: Gear imbalance/bad teeth/alignment
  – 5: Gear soft-foot
  – 6: Shaft run-out
  – 7: Bad measurements
  – ...

*: Most possible reasons
Root Cause Analysis – Continued

• Investigation:
  – Coupling alignment was the first thing checked (cold alignment only)
  – Bearing looseness: tolerance checked
  – Gear imbalance/bad teeth: blue checked/visual
  – Gear soft-foot: checked
  – Shaft run-out: checked
  – Bad measurements: checked

The above are not likely the true causes, because three identical trains exhibit exactly the same symptom
Motor/VFD problem is ruled out by cutting off the power:
   – 2X shows up even with power cut-off
The only possibility left: hot/dynamic misalignment generates 2X excitation

What causes the 2X?
- Literature: only parallel misalignment yields 2X (Ovalle etc.). The sources could be:
  - The disk, diaphragm, bolts, etc. characteristics
  - Interaction between Pinion and Compressor/ coincidence of critical speeds (Seon etc.)
- The simplistic modeling for 2X excitation is (Ovalle):
  - \( K = A \sin(\omega t) \), so that \( F = K \sin(\omega t) = A \sin^2(\omega t) = A(1 - \cos(2\omega t))/2 \), where
    - \( K \) is the dynamic stiffness of the coupling
    - \( \omega \) is the running speed
    - \( A \) is the magnitude
    - \( F \) is the force/excitation from the coupling

How to predict/calculate misalignment force?
- For constant misalignment force (Gibbons): 5-6 lbf, calculated based on the alignment measurement, transmitted power, speed etc.
- For dynamic misalignment force: ?

Measure hot misalignment?
- Schedule is tight
- Hot misalignment may not be reflecting/equal to the dynamic force
- Effectiveness of correcting hot misalignment is questionable
Solution and Result

An relatively simple solution: change the coupling weight to shift the critical speed

<table>
<thead>
<tr>
<th>NO.</th>
<th>DESCRIPTION</th>
<th>CRITICAL SPEED by Gear Vendor (CPM)</th>
<th>CRITICAL SPEED by ELLIOTT (CPM)</th>
<th>REMARKS (HALF WEIGHT ON PINION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Original Coupling</td>
<td>23614 (11807 rpm)</td>
<td>23400-24000 (11700-12000 rpm)</td>
<td>4.9kg(10.7Lb)</td>
</tr>
<tr>
<td>2</td>
<td>Titanium Space Coupling</td>
<td>25545 (12773 rpm)</td>
<td>25000-25800 (12500 – 12900 rpm)</td>
<td>3.4kg(7.6Lb)</td>
</tr>
<tr>
<td>3</td>
<td>Heavy Adapter Coupling</td>
<td>19158 (9579 rpm)</td>
<td>19000-20000 (9500-10000 rpm)</td>
<td>9.5kg(21Lb)</td>
</tr>
</tbody>
</table>

Note: Pinion model and bearing coefficients are provided by Gear Vendor
Solution and Result - continued

• Heavy Adapter Coupling Test Result

Operating Speed Range

2X: ~9500 rpm

The prediction is close, and the problem is solved!
Lessons Learned

• There are many gears with VFD/Turbine drives may operating smoothly with 1st critical speed in the 2X range, why these gears have problems?
• What are different/special about these gears?
  – Bearing load: 440 psi (high in general, but common for gears)
  – Bearing design: with fins
  – Coupling: with power wheel (complex and heavy)
  – Pinion: very sensitive to coupling unbalance/excitation (see plots below)
  – Compressor second critical speed: 21400-22800 rpm (close to 2X)
Lessons Learned - continued

• Analytically, with the current pinion-bearing model, the excitation from the coupling needs to be ~100 lbf to reach the maximum measured 2X amplitude (~1.4 mils), but the calculated misalignment force is only 5-6 lbf. There are a few possibilities:
  – The calculated Bearing coefficients may not be very accurate (damping might be significantly lower) for high load and/or high speed (see Kocur’s survey for the diversity of the calculated coefficients by different vendors).
    • Gear vendor tried to modify the location of the bearings to lower the 2X, but not effective enough.
  – Dynamic excitation from the coupling might be much larger than static/constant alignment force.
  – The second critical speed of the compressor might contribute significantly to the dynamic excitation (Seon).
Lessons Learned – continued2

• What can we do to prevent problems in the future?
  – Avoid pinion 2X speed range if possible.
  – Otherwise (open for discussion)
    • For gear:
      – Check bearing load
      – Check bearing type/design
      – Check coupling side unbalance sensitivity (overhung length/bearing span)
      – Check empirical data to backup the design/application
    • For compressor:
      – Check the possible coincidence of the critical speed.
    • For Coupling:
      – Check coupling type, structure
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