Vibration-Induced Fatigue – A Risk-Based Approach

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Presentation Overview

1. Introduction
2. Common Vibration Issues
3. Sources of Vibration
4. The Industry Gap
5. Case Studies
6. Best Practices
7. A Risk-Based Approach
8. Summary
Introduction

• What is vibration-induced fatigue (API 571)?
• What causes it?
• How does it affect integrity?
  – Shaking mainline
  – Small-bore connections
  – Loosening of bolts and cracking of supports
• How can you prevent it?
Examples of Vibration Problems

Cause of Hydrocarbon Releases

- Fatigue / Vibrations: 21%
- Incorrect Installation: 21%
- Degradation of Material Properties: 28%
- Corrosion / Erosion: 13%
- Procedural: 10%
- Other: 7%

Source: UK Health and Safety
Vibration Excitation Mechanisms

- Machinery excitation
- Pressure pulsation
- Turbulence
- Flashing/cavitation
- Transients (water hammer)
- Rotating stall
- Dead-leg pulsation
- Acoustic-induced
The Industry Gap

What?
• Vibration is not properly managed in mechanical integrity programs
• Reoccurring failures
• Reactive approach

Why?
• Most integrity professionals lack tools/experience to address vibration
• Reliant on operator surveillance
• Focused on corrosion

Solution
Integrate vibration into your mechanical integrity program
Case Study #1 – Plunger Pump

Description:
- Quintuplex Plunger Pumps @ 297 HP
- Liquid Propane
- Speed Range 200-400 RPM
- 6 months in operation
- Very high piping vibrations!
Case Study #1 – Plunger Pump

Field Visit:
• High vibrations measured
• PSV resonant
• Dampener resonant
Case Study #1 – Plunger Pump

Vibration analysis (API 674):

- System modelled using proprietary software
- Very high shaking forces predicted
- Due to pressure pulsations
Case Study #1 – Plunger Pump

Field follow-up:

• NDT locations determined from highest predicted forces
• Significant cracking found
• Units shutdown
Case Study #1 – Plunger Pump

Outcome:

- Owner had to replace significant amounts of piping
- Downtime, however, **hydrocarbon release avoided!**

Vibration analysis integrates with integrity management
Case Study #2 – Acoustic-Induced Fatigue

Description:
• At pressure letdown (eg, control valve, blowdown, PSVs)
• Flare systems (API 521)
• Not visible, but frequently audible
• Short time to failure
• Failures at branches, supports, etc
Case Study #2 – Acoustic-Induced Fatigue

- Catastrophic failure
- 6” blowdown line to 16” flare header
- Desktop screening would have flagged the connection as a concern
Case Study #2 – Acoustic-Induced Fatigue

Recommendations:

• Conduct screening of pressure-relief systems (API 521)
• Use forged tees instead of fabricated tees
• Change from welded to bolted supports
• Reinforce branch connections, where necessary
• Target NDT at high-risk branch connections
Small-Bore Connections

Description:

• Problematic in vibrating service
• Should be removed, moved, redesigned or braced
Small-Bore Connections

**Recommendations:**
1. Avoid redundant connections (or remove them)
2. Reduce length and mass
3. Brace back to the vessel or pipe (not to anything else!)
4. Use Schedule 160 pipe for nipples
5. Use monoflange valves, or similar
Best Practice Recommendations

1. Conduct pulsation analysis for pumps > 25 hp
2. Conduct pulsation analysis for compressors > 75 hp/cyl.
3. Avoid elevated process piping and unsupported elbows
4. Ensure process piping supports are effective
5. Do not use U-bolts in vibrating service
6. Minimize or brace small-bore connections
A Risk-Based Approach

Background:
Regulators were concerned over number of fatigue failures
A JIP was formed including O&G majors and consultants
A Risk-Based Approach

Energy Institute
Guidelines for the Avoidance of Vibration-Induced Fatigue Failure in Process Pipework, 2nd Ed, 2008

• A screening process for facilities
• A proactive, risk-based approach
• Qualitative and quantitative assessment leads to a “Likelihood of Failure” (LOF) value
Complementary Approaches

- **Vibration**: 
  - Input: PFDs/P&IDs, HMBs, Plant History
  - Output: Marked-up PFDs/P&IDs
  - Advanced Analysis / Field Verification
  - Output: Risk Ranking (Vibration)

- **Corrosion**: 
  - Input: Marked-up PFDs/P&IDs, Corrosion mechanisms (e.g., SCC, etc.)
  - Output: Risk Ranking (Corrosion)
  - Output: Inspection Plan + IOWs
Marked-up PFDs/P&IDs

- Flow-induced turbulence
- Mechanical excitation
- Dead-leg pulsation
- Acoustic-induced vibration
### Modules / Qualitative Assessment

<table>
<thead>
<tr>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FIT) Flow induced turbulence (EI AVIFF Guidelines T2.2)</td>
<td>(fit)</td>
</tr>
<tr>
<td>Is the maximum value of kinetic energy ( (pv^2) ) of the process fluid above 5000 kg/m s(^2)?</td>
<td>Yes ▼</td>
</tr>
<tr>
<td>(SBC) Small bore connections (EI AVIFF Guidelines)</td>
<td>(sbc)</td>
</tr>
<tr>
<td>Is any of the main line LOF's ( \geq 1 )?</td>
<td>Yes ▼</td>
</tr>
<tr>
<td>Mechanical Excitation (EI AVIFF Guidelines T2.3)</td>
<td>(mex)</td>
</tr>
<tr>
<td>Is there any rotating or reciprocating machinery?</td>
<td>No ▼</td>
</tr>
<tr>
<td>Reciprocating items (EI AVIFF Guidelines T2.4)</td>
<td>(rec)</td>
</tr>
<tr>
<td>Are there any positive displacement pumps or compressors?</td>
<td>No ▼</td>
</tr>
<tr>
<td>Pressure drops &amp; valves (EI AVIFF Guidelines T2.8 and T2.9)</td>
<td>(prd)</td>
</tr>
<tr>
<td>Are there any systems which exhibit flashing or cavitation, or are there any fast acting opening or closing valves?</td>
<td>Yes ▼</td>
</tr>
<tr>
<td>Thermowells</td>
<td>(thw)</td>
</tr>
<tr>
<td>Are there any intrusive elements in the process stream?</td>
<td>No ▼</td>
</tr>
<tr>
<td>Known vibration problem (EI AVIFF Guidelines - Specialist)</td>
<td>(vib)</td>
</tr>
<tr>
<td>Is there a history of pipework vibration issues on this system, or similar systems?</td>
<td>No ▼</td>
</tr>
</tbody>
</table>
## Likelihood of Failure (LOF) Values

<table>
<thead>
<tr>
<th>Record ID</th>
<th>P&amp;ID</th>
<th>Line Reference</th>
<th>Description</th>
<th>Pipe Details</th>
<th>Stream</th>
<th>% of Stream</th>
<th>Qualitative Assessment (Modules)</th>
<th>Flow induced turbulence</th>
<th>Flow induced pulsation</th>
<th>Small bore connections</th>
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<tbody>
<tr>
<td>1</td>
<td>0428-MI20-90DP-3406</td>
<td>16-SW-N-40604 - 14&quot; section</td>
<td>System 1</td>
<td>14&quot; 7000M WT:9.0 Glass Reinforced Epoxy</td>
<td>System 1 - Stream 1(liquid)</td>
<td>100</td>
<td>Q1</td>
<td>0.97</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>0428-MI20-90DP-3406</td>
<td>16-SW-N-40604/3P2-3</td>
<td>System 1</td>
<td>16&quot; 7000M WT:10.3 Glass Reinforced Epoxy</td>
<td>System 1 - Stream 1(liquid)</td>
<td>100</td>
<td>Q1</td>
<td>1.13</td>
<td></td>
<td>1.06</td>
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<tr>
<td>3</td>
<td>0428-MI20-90DP-3160</td>
<td>24-SW-N-40615/3PU</td>
<td>System 1</td>
<td>24&quot; 7000M WT:15.4 Glass Reinforced Epoxy</td>
<td>System 1 - Stream 1(liquid)</td>
<td>100</td>
<td>Q1</td>
<td>1.13</td>
<td></td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>0428-MI20-90DP-3435</td>
<td>24-SW-N-42601</td>
<td>System 2</td>
<td>24&quot; 7000M WT:15.4 Glass Reinforced Epoxy</td>
<td>System 1 - Stream 1(liquid)</td>
<td>100</td>
<td>Q1</td>
<td>0.18</td>
<td></td>
<td>0.66</td>
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</table>
Modifications / Inspection Planning

- **Low Risk**
  - No further action
  - Operators to report concerns

- **Med. Risk**
  - Field inspection and monitoring
  - Specialist review

- **High Risk**
  - Advanced analysis
  - Process and design changes
Summary

1. Vibration is a **significant threat** to facility integrity
2. Vibration is **not managed effectively** in integrity programs
3. **Tools and experience exist** to assist integrity professionals
4. Vibration **screening is complementary** to integrity methods
5. **Field vibration measurement** is **effective** alongside NDT

A successful integrity program includes vibration!