Vibration integrity management
New tools to avoid fatigue failure
Speaker

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Service Lead Americas – Static Equipment and Structures, Wood
• 16 years’ industry experience
• Field of expertise: vibration engineering
Agenda

1. Introduction
2. Conclusions from 2017 Presentation
3. Complementary approach to RBI (API 570)
4. Excitation mechanisms
5. How companies can assess vibration risks
6. Recommendations
7. Conclusion
Introduction

• Vibration-related fatigue failure on piping is a real threat to facilities
• Vibration should be included in integrity programs
• How can owners/operators be proactive to understand this risk?
• How can owners/operators take corrective action before the failure and loss of containment occurs?
Conclusions (from 2017)

• Vibration is a significant threat to facility integrity
• Vibration is not managed effectively in most integrity programs
• Tools and experience exist to assist integrity professionals
• Vibration screening is complementary to integrity methods
• Field vibration measurement is effective alongside NDT

A successful integrity program includes vibration considerations
Avoid surprises!
Energy Institute

Guidelines for the **Avoidance of Vibration Induced Fatigue Failure in Process Pipework**
2nd Ed., 2008 (EI **AVIFF**)
## Complementary approach to API 570

<table>
<thead>
<tr>
<th>Piping mechanical integrity (per API 570)</th>
<th>Vibration assessment (per EI guidelines)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What's in scope?</strong></td>
<td><strong>Typically includes a mainline assessment (primary process piping) and rotating equipment</strong></td>
</tr>
<tr>
<td>Consequence and criticality assessment determines priority lines to focus on (safety and production critical)</td>
<td></td>
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<tr>
<td><strong>What could go wrong?</strong></td>
<td><strong>Small-bore connections, reciprocating equipment, turbulence, flare lines, valves, resonance</strong></td>
</tr>
<tr>
<td>Markup PFDs / P&amp;IDs (circuitization) Identify likely damage mechanisms</td>
<td></td>
</tr>
<tr>
<td><strong>How bad is it?</strong></td>
<td><strong>Assess vibration mechanisms using appropriate screening tools</strong></td>
</tr>
<tr>
<td>Assess process and materials to determine corrosion and environmental cracking threats</td>
<td></td>
</tr>
<tr>
<td><strong>How can we manage it?</strong></td>
<td><strong>Inspection locations included in ITP</strong></td>
</tr>
<tr>
<td>• Develop inspection test plans (ITPs) • Process/materials recommendations • Establish integrity operating windows (IOWs)</td>
<td>• Engineered solutions (clamps, braces, etc) • IOWs (flow limits, equipment speed range) • Manage anomalies until close-out</td>
</tr>
</tbody>
</table>
Excitation mechanisms from EI AVIFF

- Flow-induced turbulence
- Mechanical excitation and pulsation
- Pulsation: rotating stall
- Pulsation: flow-induced excitation
- High-frequency acoustic excitation
- Surge: momentum changes due to valve operation
- Cavitation and flashing
Flow-induced turbulence (FIT)

- Dominant source for FIV turbulence is generated at flow discontinuities in the system, such as:
  - Process equipment
  - Partially closed valves
  - Short radius or mitred bends
  - Tees and reducers
- Turbulence is generated in fluid flowing in piping, leading to vibration with frequency ranges up to 200 Hz
Mechanical excitation and pulsation

- Reciprocating and positive displacement machines
- Energy at orders of operating speed
- Mechanical excitation close to compressors
- Uncontrolled pulsations travel upstream and downstream, impact piping
Pulsation: rotating stall

Creates sub-synchronous pulsations
Pulsation: flow-induced excitation

- Deadleg pulsation
- Flow creates vortices
- Deadleg has resonance frequency
- Problems occur if vortex frequency coincident with deadleg quarter wave resonance frequency
High-frequency acoustic excitation (AIV)

• High levels of acoustic energy can be generated in high-capacity gas-pressure-reducing systems such as:
  – Pressure relief
  – Blow down
  – Flow or pressure control
• High levels of acoustic energy can **result in severe piping vibration**, leading to piping component fatigue failure in as little as a few hours
  – Typical frequency range: 300 Hz to 4000 Hz
High-frequency acoustic excitation (AIV)
Surge: momentum changes due to valve operation

- Localized changes in the fluid velocity
  - Valve closing
  - Pump start and stop
- Pressure peaks traveling through the pipe
  - Excitation of localized pipe resonance
  - Trip relief valve
Cavitation and flashing

- When local pressure in liquid goes below vapor pressure
- Occurs near pressure-reducing areas like pump inlets, valves, orifice plates
- Cavitation is when the bubbles quickly collapse
- Flashing is when the bubbles remain in the liquid
How you do know when to be worried?
Know where to focus your efforts
Vibration screening tool Veridian

Free, web-based application that applies the EI standard to proactively identify piping vibration integrity threats
Vibration screening approach

1. Design stage
2. Operational plant
3. Piping information
4. Vibration screening
5. Process information
6. Identify hotspots
7. Target actions
Enter piping information

**Piping information**

**Vibration screening**

**Process information**

**Design stage**

**Operational plant**

**Identify hotspots**

**Target actions**

### Piping details - Upstream of E401

<table>
<thead>
<tr>
<th>Select below</th>
<th>Spec.</th>
<th>Nominal bore</th>
<th>Schedule</th>
<th>Outside diameter [mm]</th>
<th>Wall thickness [mm]</th>
<th>Liner thickness [mm]</th>
<th>Material</th>
<th>Pipe Pressure Rating [bara]</th>
</tr>
</thead>
<tbody>
<tr>
<td>14&quot; STD Carbon Steel</td>
<td>14&quot;</td>
<td>STD</td>
<td>355.6</td>
<td>9.525</td>
<td></td>
<td></td>
<td>Carbon Steel</td>
<td></td>
</tr>
<tr>
<td>8&quot; 120 Carbon Steel</td>
<td>8&quot;</td>
<td>120</td>
<td>219.075</td>
<td>18.263</td>
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<td></td>
<td>Carbon Steel</td>
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<tr>
<td>4&quot; 120 Carbon Steel</td>
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<td>120</td>
<td>114.3</td>
<td>11.125</td>
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<td></td>
<td>Carbon Steel</td>
<td></td>
</tr>
<tr>
<td>6&quot; STD Carbon Steel</td>
<td>6&quot;</td>
<td>STD</td>
<td>168.275</td>
<td>7.112</td>
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<td></td>
<td>Carbon Steel</td>
<td></td>
</tr>
<tr>
<td>20&quot; STD Carbon Steel</td>
<td>20&quot;</td>
<td>STD</td>
<td>506</td>
<td>9.525</td>
<td></td>
<td></td>
<td>Carbon Steel</td>
<td></td>
</tr>
<tr>
<td>12&quot; STD Carbon Steel</td>
<td>12&quot;</td>
<td>STD</td>
<td>323.85</td>
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<tr>
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<td>STD</td>
<td>273.05</td>
<td>9.271</td>
<td></td>
<td></td>
<td>Carbon Steel</td>
<td></td>
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</table>
Enter stream information

**Diagram:**
1. Enter stream information
   - Piping information
   - Vibration screening
2. Identify hotspots
3. Target actions

**Stream details - Upstream of E401**

<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Select Stream 4(gas)</td>
<td>Stream 4</td>
<td>gas</td>
<td>58358</td>
<td>141.9</td>
<td>10</td>
<td>26</td>
<td>0.00002</td>
<td>425.7984</td>
<td>1.22</td>
<td>23.22</td>
</tr>
<tr>
<td>Select Stream 5(gas)</td>
<td>Stream 5</td>
<td>gas</td>
<td>93538</td>
<td>30</td>
<td>26</td>
<td>24.5</td>
<td>0.00001</td>
<td>373.6421</td>
<td>1.3</td>
<td>23.22</td>
</tr>
<tr>
<td>Select Stream 6(gas)</td>
<td>Stream 6</td>
<td>gas</td>
<td>53452</td>
<td>30</td>
<td>23</td>
<td>24.5</td>
<td>0.00001</td>
<td>394.0547</td>
<td>1.34</td>
<td>21.75</td>
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<td>Select Stream 7(gas)</td>
<td>Stream 7</td>
<td>gas</td>
<td>53452</td>
<td>136.7</td>
<td>62</td>
<td>88</td>
<td>0.00002</td>
<td>456.4</td>
<td>1.33</td>
<td>21.75</td>
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<tr>
<td>Select Recycle low pressure(gas)</td>
<td>Recycle low pressure</td>
<td>gas</td>
<td>53452</td>
<td>141.9</td>
<td>18</td>
<td>26</td>
<td>0.00002</td>
<td>425.7984</td>
<td>1.22</td>
<td>23.22</td>
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<tr>
<td>Select Relief high pressure(gas)</td>
<td>Relief high pressure</td>
<td>gas</td>
<td>53452</td>
<td>136.7</td>
<td>62</td>
<td>88</td>
<td>0.00002</td>
<td>456.4</td>
<td>1.33</td>
<td>21.75</td>
</tr>
<tr>
<td>Select Relief low pressure(gas)</td>
<td>Relief low pressure</td>
<td>gas</td>
<td>53452</td>
<td>88</td>
<td>4</td>
<td>1</td>
<td>0.00001</td>
<td>428.4</td>
<td>1.33</td>
<td>21.75</td>
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<tr>
<td>Select Stream 1 (original)(multiphase)</td>
<td>Stream 1 (original)</td>
<td>multiphase</td>
<td>461764</td>
<td>50</td>
<td>930</td>
<td>6.5</td>
<td>0</td>
<td>310.0077</td>
<td>1.01</td>
<td>26.09</td>
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<tr>
<td>Select Stream 2 (original)(gas)</td>
<td>Stream 2 (original)</td>
<td>gas</td>
<td>27180</td>
<td>50</td>
<td>5</td>
<td>6.5</td>
<td>0.00001</td>
<td>389.2291</td>
<td>1.24</td>
<td>21.99</td>
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<tr>
<td>Select Stream 3 (original)(liquid)</td>
<td>Stream 3 (original)</td>
<td>liquid</td>
<td>303160</td>
<td>50</td>
<td>930</td>
<td>6.5</td>
<td>3935</td>
<td>275.2810</td>
<td>1.08</td>
<td>38.29</td>
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</tbody>
</table>
# Qualitative screening

## Modules / Qualitative Assessment

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FIT) Flow-induced turbulence (EI AVIFF Guidelines T2.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the maximum value of kinetic energy ((p \nu^2)) of the process fluid above 5000 kg/m s(^2)?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Mechanical Excitation (EI AVIFF Guidelines T2.3)</td>
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<td></td>
</tr>
<tr>
<td>Is there any rotating or reciprocating machinery?</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Pulsation from reciprocating items (EI AVIFF Guidelines T2.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are there any positive displacement pumps or compressors?</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Pulsation from rotating stall (EI AVIFF Guidelines T2.5)</td>
<td></td>
<td></td>
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<tr>
<td>Are there any centrifugal compressors which have the potential to operate under rotating stall conditions?</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Pulsation from corrugated pipes (EI Subsea AVIFF Guidelines E4.3)</td>
<td></td>
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<tr>
<td>Does the system contain any rough bore flexibles?</td>
<td>No</td>
<td></td>
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<tr>
<td>(ALV) High frequency acoustic excitation (EI AVIFF Guidelines T2.7)</td>
<td></td>
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<tr>
<td>Is choked flow possible, or are sonic flow velocities likely to be encountered? <strong>only applies to pressure reducing systems, not the main line</strong></td>
<td>No</td>
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<tr>
<td>Valve transients (EI AVIFF Guidelines T2.8)</td>
<td></td>
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<tr>
<td>Are there any fast acting opening or closing valves?</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Thermowells (ASME PTC 19.3 TW - 2016)</td>
<td></td>
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<tr>
<td>Are there any intrusive elements in the process stream?</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(SBC) Small bore connections (EI AVIFF Guidelines)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are any of the main line LOFs (\geq 0.3)?</td>
<td>No</td>
<td></td>
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</table>
Qualitative screening

Piping information

Vibration screening

Identify hotspots

Target actions

Design stage

Operational plant

Veridian
Web tools for vibration, dynamics and noise

Energy Institute AVIFC - Worked Examples

| Record ID | P&ID | Line reference | Description | Notes | Pipe details | Stream | % of stream | Qualitative assessment (modules) | Fatigue | Mechanical vibration | Radiation from heating fuel | Radiation from combustion | High frequency vibration | High frequency pressure | Acoustic
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Figure D-1</td>
<td>Stream 4</td>
<td>Upstream of E401</td>
<td>14&quot; STD Carbon Steel</td>
<td>Stream 4 (gas)</td>
<td>100</td>
<td>10.3 mpa, 1.32 k</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>2</td>
<td>Figure D-1</td>
<td>Stream 5</td>
<td>Downstream of E401, upstream of K402</td>
<td>14&quot; STD Carbon Steel</td>
<td>Stream 5 (gas)</td>
<td>100</td>
<td>7.3 mpa, 1.32 k</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>3</td>
<td>Figure D-1</td>
<td>Stream 6</td>
<td>Downstream of K402, upstream of V402</td>
<td>14&quot; STD Carbon Steel</td>
<td>Stream 6 (gas)</td>
<td>100</td>
<td>7.3 mpa, 1.27 k</td>
<td>0.01</td>
<td>0.40</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.29</td>
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<tr>
<td>4</td>
<td>Figure D-1</td>
<td>Stream 7</td>
<td>Downstream of K402</td>
<td>8&quot; 120 Carbon Steel</td>
<td>Stream 7 (gas)</td>
<td>100</td>
<td>7.3 mpa, 1.19 k</td>
<td>0.02</td>
<td>0.40</td>
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<td>0.00</td>
<td>0.66</td>
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<tr>
<td>5</td>
<td>Figure D-1</td>
<td>Recycle line (compressor)</td>
<td>From downstream of K402 back to</td>
<td>8&quot; 120 Carbon Steel</td>
<td>Stream 7 (gas)</td>
<td>100</td>
<td>7.3 mpa, 1.19 k</td>
<td>0.02</td>
<td>0.40</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.29</td>
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<tr>
<td>6</td>
<td>Figure D-1</td>
<td>Recycle line (compressor)</td>
<td>From upstream of recycle valve to</td>
<td>6&quot; STD Carbon Steel</td>
<td>Recycle low pressure (gas)</td>
<td>100</td>
<td>38.5 mpa</td>
<td>0.28</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.29</td>
<td></td>
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<tr>
<td>7</td>
<td>Figure D-1</td>
<td>Relief line (upstream of PSV)</td>
<td>Downstream of K402 to upstream</td>
<td>4&quot; 120 Carbon Steel</td>
<td>Relief high pressure (gas)</td>
<td>100</td>
<td>38.5 mpa</td>
<td>0.34</td>
<td>0.40</td>
<td>0.29</td>
<td>0.00</td>
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<td>0.00</td>
<td>3.77</td>
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<td>8</td>
<td>Figure D-1</td>
<td>Relief line (downstream of PSV to flare)</td>
<td>Downstream of PSV to flare</td>
<td>6&quot; STD Carbon Steel</td>
<td>Relief low pressure (gas)</td>
<td>100</td>
<td>7.3 mpa, 1.19 k</td>
<td>0.88</td>
<td>1.00</td>
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<td>1.77</td>
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</table>

2019 INSPECTION AND MECHANICAL INTEGRITY SUMMIT

API Energy
Target actions

1. Design stage
2. Operational plant
3. Piping information
4. Vibration screening
5. Process information
6. Identify hotspots
7. Target actions
Target actions
When to perform a screening and why?

- **New facility**
  - FEED
  - Detailed design
  - Results in a better designed system
- **Existing facility**
  - If vibration risk is unknown
  - When facility requirements change (during management of change)
  - Increased throughput
  - When designing the upgrade of a facility
  - Enables owners to know where to focus their effort
Vibration screening (VS) can fill the gap
Case study

• Work scope: two assessments
  1. FIV on all main-line, hydrocarbon process pipework
  2. AIV on flare system pipework

• Three different facility design cases (including 100% and 120% design)

• All main-line pipework assessed for:
  – Flow-induced turbulence
  – Flow-induced pulsation/vibration (FIV)
  – Mechanical
  – Machinery-generated pulsation (reciprocating compressors)
  – Fast acting valves – eg, flashing, cavitation
FIV results and recommendations

66 required actions identified
- 2 critical priority actions – require immediate attention
- 6 high priority actions – closeout target date <3 month
- 58 medium priority action – closeout target date <6 month
- (+ 61 low priority actions – closeout target date <12 month)

Specific actions required:
- 13 anti-vibration brace drawings for fabrication, installation and subsequent operator check measurements
- 11 engineering actions
- 6 engineering actions followed by subsequent operator check measurements
- 18 check measurements
- 18 locations recommended for detailed vibration measurement survey under representative flow conditions
AIV results and recommendations

**Identified 65 risk areas** on flare piping and common 42” header; welded tee, side branch and pipe support connections
- 10 sliding shoe pipe supports on 42” header cleared, based on detailed FEA modeling
- 11 connections require visual inspection to confirm appropriate bracing has been installed
- 5 require valve diffuser performance – if better than assumed then can be removed from list
- 6 weldolets require bolted or welded 2–plane braces installed
- 3 fabricated tees with repads on 12” local header to be extended to full encirclement wraps
- 15 sliding shoe pipe supports on 42” header to be extended to full encirclement wraps
- 15 other tee connections with repads on 42” header to be extended to full encirclement wraps
Conclusion

• Vibration is a real threat that should be included in an effective integrity program

• Tools enable asset owners to ensure current standards (EI) are applied

• Vibration screening tools are available that implement the current standards (EI) to quickly identify where attention is needed

• Required data is most likely already compiled for your existing RBI program

• Vibration can be managed proactively, and this allows owners to prevent costly fatigue failures
Thank you

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Vibration dynamics and noise
Wood

woodplc.com/vdn