STLE Houston Chapter Lunch Seminar

Equipment Condition Monitoring Using Vibration Analysis

January 12, 2018
Andy Walker
Reliability Solutions Service Supervisor
Puffer-Sweiven
Safety Moment
Integrity  Commitment  Accountability  Teamwork  Customer Centric  Results Driven
Who is Puffer-Sweiven Reliability Solutions?

- Reliability Consulting
  - Reliability Program Gap Assessment
  - CMMS/EAM Master Data Development - Data Integrity & Criticality Ranking
  - Reliability Focused CMMS/EAM Implementation Support & Accelerators
  - RCM/FMEA Based Reliability Strategy Development
  - Materials Master & BOM Development, Spares Stocking Strategy
  - The Reliability Game® Workshop
  - Customized Reliability Business Case Development

- Machinery Health PdM
  - Vibration Data Collection, Analysis, Reporting Services
  - Technology Mentoring and Equipment Training
  - AMS Machinery Manager Vibration Database Optimization
  - Infrared Thermography & Ultrasound Inspections
  - Lube Oil Handling, Dispensing, Sampling and Analysis
Who is Puffer-Sweiven Reliability Solutions?

- Online Vibration Monitoring Systems
  - Turnaround Support — System and Sensor Field Validation and Documentation, Sensor Additions with Design Drawings, System Additions, and Configuration Improvements
  - Project Management & Support — System Design, Staging, Configuration, Field Installation, Upgrades, Repairs
  - On-Demand Support — Scheduled Upgrades or Emergency Troubleshooting and Repair
- AMS Device Manager (DM) Optimization and HART Loop Commissioning
  - Develop Loop Commissioning Procedures Leveraging AMS DM QuickCheck™ SNAP-ON™ Application
  - Reduce Loop Commissioning Time and Headcount
  - Automate Interlock Validation to Save Days on Start-ups
  - Improve Commissioning Documentation With Audit Trail
  - Optimize Alert Monitor to Elevate Actionable Device Diagnostics
Agenda

• What is Vibration?
• How do we measure it?
• What are we looking at?
• What does it all mean?
• How do Vibration and Lubricant Analysis work together?
• Questions / Open Discussion
Agenda

• What is Vibration?
• How do we measure it?
• What are we looking at?
• What does it all mean?
• How do Vibration and Lubricant Analysis work together?
• Questions / Open Discussion
What is Vibration?

- A textbook definition
  - Vibration is the motion of a body about a reference position caused by a force
What is Vibration Analysis?

• Before we actually get into the “what”, let’s talk about the “why”
The why of Vibration Analysis…

"Of all the parameters that can be measured non-intrusively in industry today, the one containing the most information on machinery health is the vibration signature."

Art Crawford
Acknowledged expert in the field of vibration analysis
The why of Vibration Analysis...

- Track progressing stages of **Bearing Failure**
- Identify/correct **Imbalance** and **Misalignment**
- Identify/correct **Resonance**
- Identify **Mechanical Wear** in couplings, bearings, support structures, etc.
- Detect other defects such as:
  - **Lube failure** / soft foot / broken rotor bars
  - Pump cavitation, and many more...
Agenda

• What is Vibration?
• How do we measure it?
• What are we looking at?
• What does it all mean?
• How do Vibration and Lubricant Analysis work together?
• Questions / Open Discussion
How do we measure it?

- A pre-requisite
  - Vibration “Fundamentals”
- Definitions
  - Frequency units
    - Hz
    - CPM (RPM)
    - Multiples of an arbitrary frequency
      - Harmonics
    - Multiples of the operating frequency
      - Orders
Vibration Fundamentals

Vibration Measuring Units

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>$a$</td>
</tr>
<tr>
<td>Velocity</td>
<td>$a / 2\pi f$</td>
</tr>
<tr>
<td>Displacement</td>
<td>$a / 4\pi^2 f^2$</td>
</tr>
</tbody>
</table>

- Acceleration: $G$'s or in/s$^2$ (180 deg phase lead)
- Velocity: inches/sec (90 deg phase lead)
- Displacement: .000" or Mils

90° 90°
Vibration Fundamentals

<table>
<thead>
<tr>
<th>Displacement</th>
<th>Mils (um)</th>
<th>Peak-to-Peak / Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>In/Sec (mm/s)</td>
<td>Peak / RMS</td>
</tr>
<tr>
<td>Acceleration</td>
<td>G’s (mm/s(^2))</td>
<td>RMS</td>
</tr>
</tbody>
</table>

1 mil = 0.001” = 25.4 um
Measuring Vibration

- Transducers, Sensors, Probes...oh my...
- Translation of mechanical vibration (movement) into a representative electrical signal
- Three units of measurement, three types of measurement devices
Measuring Vibration

- Accelerometers
  - Measure acceleration…
  - Piezoelectric device
  - ICP most common
Measuring Vibration

- **Velocity Probes (Velometers)**
  - Measure velocity…
  - Mostly piezoelectric
  - ICP
  - Have a built-in integrator
  - Mechanical in the past
Measuring Vibration

- Displacement Probes (Eddy Current Probes)
  - Measure displacement...
  - Non-contact
  - Induces eddy current
Measuring Vibration – Typical Applications

Radial Shaft Vibration & Position

Radial Casing Vibration

Axial Shaft Vibration & Position
How do the probes perform over a range?

Useful Operating Ranges

- **Relative Amplitude**
  - 100000000
  - 10000000
  - 1000000
  - 100000
  - 10000
  - 1000
  - 100
  - 10
  - 0.1
  - 1

- **Hz**
  - 0.1
  - 1
  - 10
  - 100
  - 1000
  - 10000
  - 100000
  - 1000000
  - 10000000
  - 100000000

- **Proximity Probe**
- **Velocity Transducer**
- **Accelerometer**
What units should we use?

- **Acceleration**
  - accentuates HIGH frequencies,
  - and attenuates LOW frequencies.

- **Velocity**
  - “flat” treats all frequencies equally.

- **Displacement**
  - accentuates LOW frequencies,
  - and attenuates HIGH frequencies.
How do I pick a probe?

Types of Bearings

Journal Bearings
- Stationary Signals
- Relative Low Frequency

Rolling Element Bearings
- Modulated Random Noise
- Pulsating signals
- High Frequency

Use Proximity probes

Use Accelerometers
What is the output of a probe?

Machine Vibration Signal

Time Signal
Where do we put the probes?

For detail study of vibration dynamics of machine – vertical, horizontal and axial at each bearing location

For monitoring – one point per bearing and add axial when there is a thrust bearing or axial potential faults eg. misalignment
Agenda

- What is Vibration?
- How do we measure it?
- **What are we looking at?**
- What does it all mean?
- How do Vibration and Lubricant Analysis work together?
- Questions / Open Discussion
What are we looking at?

- How do we make sense out of a raw-data waveform?
- What is a spectrum?
- How is a spectrum calculated?
- What can we do with a spectrum?
Going from Time to Frequency

Transducer

Overall Energy

Waveform

FFT

Spectrum
Going from Time to Frequency
Pros and Cons of Time and Frequency

**Time Signal:**
transient signals, repeat frequencies, beats and sine waveform good visible
→ but:
Individual Frequencies of the Vibration Spectrum almost not visible

**Amplitude Spectrum:**
good visibility of the dominant frequencies of the vibration signal
→ but:
 transient Signals, shocks with repeat frequency and beat signals almost not visible

FFT
Fast Fourier Transformation
Agenda

- What is Vibration?
- How do we measure it?
- What are we looking at?
- What does it all mean?
- How do Vibration and Lubricant Analysis work together?
- Questions / Open Discussion
“Rubber, meet Road”

- Monitoring
- Diagnostics
Not an atypical monitoring idea

![Graph showing vibration amplitude over time with fault limit and alert limit. The lead time to failure is highlighted.]

Lead Time to failure

Integrity  Commitment  Accountability  Teamwork  Customer Centric  Results Driven

Puffer-Sweiven Confidential

33
Diagnostic Tips

• Each machine fault generates a specific vibration pattern

• The frequency of the vibration is determined by the machine geometry and operating speed

• A single vibration measurement provides information about multiple components
Not an atypical spectrum

What does this mess mean?

Many distinct peaks
So what does this mean?

Specific peaks typically correlate to:
- **Specific** machine faults
- **Related** to machine speed
Is it a balance problem?

Imbalance typically appears at the turning speed of the machine.
An alignment problem?

Misalignment typically shows up at either 1 or 2 x turning speeds
A looseness problem?

Looseness shows up as multiples of turning speed
A bearing problem?

Bearing wear shows up at specific peaks related to the geometry of the bearing.
Lubrication faults…

• You can find “Lack of Lubrication” fairly effectively
  • Noisy waveform
  • No real harmonically related spectral data
  • Autocorrelated waveform shows little or no correlation
Missing Cage / Lubrication Issue

Analyze Waveform
20-Feb-06 11:59:47
(PkVue- HP 500 Hz)
RMS = 7.17
PK(+) = 23.48
CRESTF = 3.27
DCoff = 0.0

Alert=6 g's
Lubrication had very little effect on level

Analyze Spectrum
20-Feb-06 11:59:47
(PkVue- HP 500 Hz)
RMS = 3.21
LOAD = 100.0
RPM = 941. (15.68 Hz)

Freq: 381.25
Ordr: 24.31
Spec: .02942

Little Periodic activity
Autocorrelated Waveform

140 - 3RD STAGE BROWN STOCK WASHER
221-07-02 -MIA MOTOR INBOARD AXIAL

Analyze ACorr(Wf)
20-Feb-06 11:59:47
(PkVue- HP 500 Hz)

RMS = .0593
LOAD = 100.0
RPM = 941. (15.68 Hz)

PK(+) = .6267
PK(-) = .1570
CRESTF= 10.56

No consistent periodic activity
Lubrication had very little effect on noise level

<table>
<thead>
<tr>
<th>Time in Seconds</th>
<th>Correlation Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>1.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Puffer-Sweiven Confidential

Integrity     Commitment     Accountability     Teamwork     Customer Centric     Results Driven

43
This is what caused the signature
Agenda

- What is Vibration?
- How do we measure it?
- What are we looking at?
- What does it all mean?
- How do Vibration and Lubricant Analysis work together?
- Questions / Open Discussion
Vibration and Lubrication Analysis Together

- Complementary
- Lubrication will typically lead vibration
- Generally, Lubrication Analysis will indicate very incipient problems that can then be monitored with Vibration
- Vibration Analysis will confirm the fault
- Should we really let it get this far?
Agenda

- What is Vibration?
- How do we measure it?
- What are we looking at?
- What does it all mean?
- How do Vibration and Lubricant Analysis work together?
- Questions / Open Discussion
Questions / Open Discussion
THANK YOU!