Understanding the Benefits of Vibration Testing

November 15, 2012
• Introductions / History
• Benefits of Vibration Testing
• Overview of Vibration Testing
• Bearing Faults
• 9 Stages of Bearing Wear
• Traditional Bearing Analysis
• New Automated Bearing Diagnostics
• Comparison of Vibration Testing Methods
• Another type of vibration testing – screening tools
• When to use – diagnostic tester or screening
Introductions / History

Seminar series
**Reactive maintenance:**
“run to failure”
No actions taken until machinery fails.

Unplanned downtime, high labor costs, reduced production, high maintenance costs, machines drive staff.

**Preventive maintenance:**
“calendar-based”
Actions scheduled regardless of actual condition of equipment.

Fault free machines repaired unnecessarily, higher program costs.

**Predictive maintenance:**
“condition-based”
Actions taken only after fault found, monitored over time.

Equipment repaired when needed, increased production, reduced failures and maintenance costs.

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**The Bathtub Curve**
- **Break In**: Casualties increase as equipment breaks in.
- **Normal Operation**: Casualties stabilize as equipment operates.
- **Wear Out**: Casualties increase as equipment wears out.
- **Time**: Graph illustrates the lifespan of equipment with time.
Vibration Analysis
For diagnosing mechanical faults in rotating machines.

IR Thermography
For finding electrical hot spots in switchgear and motor controllers. Also used to find mechanical and process hot spots.

Motor Testing
For finding a wide variety of motor faults

Oil Analysis
For finding problems with lubricant; gearboxes and reciprocating machines

Ultra Sound
For locating air leaks
Benefits of Vibration Testing

- **Predictability**: give maintenance staff time to schedule required repairs and acquire needed parts.
- **Safety**: take faulty equipment offline before a hazardous condition occurs.
- **Revenue**: fewer unexpected and serious failures, helping to prevent production stoppages that cut into the bottom line.
- **Increased maintenance intervals**: life of equipment can be extended and maintenance can be scheduled by need.
- **Reliability**: fewer unexpected or catastrophic failures - problem areas can be anticipated before failure
- **Peace of mind**: builds confidence in maintenance schedules, budgeting, and productivity estimates.
In the world of mechanical maintenance, vibration remains one of the earliest indicators of a machine’s health. The P-F Curve, adapted from John Moubray’s book “Reliability Centered Maintenance II.”
Thermography and Vibration

Thermography is the measurement of temperature remotely to indicate equipment health and assigning a color based on the temperature.

- Electrical equipment
- Electrical circuits
- Mechanical equipment
- Heating/cooling equipment
- Building envelope
- Electronic
- Other
• Use IR Thermography to supplement bearing diagnostics
Overview of Vibration Testing

Transducer picks up vibration signals from bearing locations and transmits them to a data collection device.

- All rotating equipment generate a unique vibration signal or “signature”.
- These unique signals are usually captured in series, with the signal’s amplitude (y-axis) depicted over time (x-axis). This is called a time waveform.
• The waveform contains information about the machine where measured
• But the patterns of different events are overlapped and jumbled together

• Frequency analysis performed in the data collector simplifies the waveform
• Spectrum is the plot of the signal’s amplitude (y–axis) against frequency (x-axis)
Every machine component produces a unique type of vibration signal.

Signals displayed in the vibration spectrum often form characteristic patterns.

Pattern recognition is a key part of vibration analysis…but significant training and experience are necessary to read the patterns.

4 Common Faults are:
- Imbalance
- Misalignment
- Looseness
- Bearing Failures
Four common causes of vibration

1. Bearing failure
2. Misalignment
3. Unbalance
4. Looseness
Bearing Faults

- Replacing bearings based on calendar or running hours => bearings may be replaced too early or too late
- Scatter of bearing life ranges from hours to years
- Bearing faults can account for 60% of mechanical problems

Bearings fail due to:
- poor installation
- poor lubrication
- contamination
- wear/fatigue
- other faults
**Roller bearings:** A rolling-element bearing carries a load by placing round elements between the two pieces.

**Journal bearings:** simplest type of bearing, just a bearing surface and no rolling elements. The journal slides over the bearing surface.
Where to measure on machine

Motor
Coupling
Compressor
Low Range Data
Imbalance, Misalignment, Fan blades, Pump Impeller, Looseness, Foundation

High Range Data
First bearing fault indication, motor bars, gear mesh, turbine vanes
Overview of Vibration Testing

We can simplify it down to a 3 step process:

1. **Identify vibration peaks** as they relate to a source component on the machine.
2. **Look for patterns** in the data based on vibration rules
3. **Measure the amplitude** of the vibration peak to determine the severity of the fault.

Once the fault and severity are determined, a repair can be recommended and a work order generated.
• Bearing frequencies are non-synchronous
• The geometry of the balls, cage and races show up at different speeds – not a multiple of shaft speed
• In most cases, non-synchronous peaks are roller bearings
• Most vibration programs use bearing frequencies:
  1. Inner race
  2. Outer race
  3. Cage
  4. Ball Spin
Roller Bearing Faults

- Here is a vibration peak at 3.56X shaft speed
- This is probably from a roller bearing
9 Stages of Bearing Wear

- Early bearing wear first shows up in the high frequencies
- Nothing is seen in the low frequencies
- This data looks healthy

Stage 1
A peak shows up at 3.1X
This can’t be imbalance, misalignment, looseness, or from fan blades or pump impeller vanes.

Stage 2

Very small flaw
- Next, the peak at 3.1X grows in amplitude indicating that the bearing is getting worse.

Stage 3
Next, a harmonic of the 3.1 peak appears at 6.2, indicating that the bearing is getting worse.

Stage 4
- Sometimes, the bearing wear will cause looseness which shows up as increased harmonic peaks.

Stage 5
- As the bearing defect moves in and out of the load zone, modulation of the shaft is seen as 1X sidebands

**Stage 6**

**Moderate**

**Small flaw**
As bearings wear, they produce larger quantities of random vibration and impacts. This is first seen as a haystack around the base of the bearing tone.

Stage 7

Medium flaw

Serious
- Eventually, the random vibration raises the noise floor of the spectrum.

Stage 8

Friction = heat

Large flaw

Extreme
9 Stages of Bearing Wear

- Too late - Game Over!

Stage 9
Traditional Bearing Analysis

- First, look at complex time waveform to find impacting.
- Next, look up the bearing frequencies from a database of thousands of bearings.
- Then, overlay to identify possible bearing faults on the frequency spectrum.
- But, what if you don’t know or don’t keep track?
1. Normalize the Data
2. Synthetic Baseline
3. Automated Peak Extraction
4. Diagnostic Report
How does the Diagnostic Engine Work?

The technology behind the answer

**Step 1 - Data Normalization:**
- Normalization algorithm searches for a peak inside narrow window
- Sets nominal speed

- Rescales data from RPM to multiples of shaft rotation or orders
- Identifies vibration sources inside machine
**Step 2 - Synthetic Baseline**: screens data that has been collected derived from algorithms defining a healthy machine.

- Machine technical descriptions and data analyzed over 40 years
- Computes baseline noise level from machine type selected by user
- Computes other peaks from shaft speed and components
- Exceedances used for next diagnostic step

Peak at 7.29 X is above the baseline => Bearing
Step 3 – Pattern Recognition to determine machine faults

- Over 4700 rules for machine faults
- Based on analyzing patterns seen in rotating machinery
- Most common faults are imbalance, misalignment, looseness, roller bearings
- Example:

  9 Stages of roller bearing wear
Step 4 – Diagnosis with fault / severity / location / recommendation

- Motors (AC/DC, ¼ HP+)
- Fans and Blowers
- Belts and Chain Drives
- Gearboxes and Couplings
- Pumps (Centrifugal, Piston, Sliding Vane, Propeller, Screw, Rotary Thread/Gear/Lobe)
- Compressors (Piston, Centrifugal, Screw)
- Closed Coupled Machines and Spindles

How bad is the problem?

- Slight: No repair action is recommended. Retest the machine and monitor the condition after maintenance.
- Moderate: (Months, even up to a year) – No immediate repair action is required. Increase the frequency of measurements and monitor the condition of the machine.
- Serious: (Weeks) – Take maintenance action during the next planned downtime or maintenance period.
- Extreme: (Days) – Immediate action is required. Consider shutting down the equipment and taking repair action now to avoid failure.

How is the problem?

- Bearing Wear
- Imbalance
- Misalignment
- Looseness
- 200 Different Fault Calls
Comparison of vibration testing

Data collector =>
Data analyzer

Production Critical – top < 10%
Complex system – many variables
Reliability Team required
Data Collector / Analysis S/W

Vibration tester =>

Vital/Important – Costly repairs
Middle 60%
No support from Reliability Team
Basic machines – few variables
Maintenance Staff - part time

Vibration meter =>

Non vital – Expendable
Bottom 30% - Low priority

- Turbine Generators
- Diesel Generators
- Paper Machines
- Multi-machines
- Motors
- Pumps
- Fans
- Blowers
- Compressors
- Spindles
- Gearboxes
- Belts
Compare trends and reports

Data collector => Data analyzer

Vibration tester =>

Vibration meter =>

Trending

Report

Motor Imbalance

Motor Bearing Wear
Another Type of Vibration Testing

Simple vibration testing: Overall vibration/bearing measurements

- Vibration screening devices provide quick feedback of equipment condition.
- A single number for overall vibration to understand whether there is a problem, instead of analyzing vibration in-depth with a spectrum.
- If the machine vibration or noise is higher, this value will increase.
- Use vibration screening tools to make quick “go” or “no go” decisions by checking the value against a pre-set alarm level, comparing it to ISO Standards (ISO 10816) and trending the results over time.

<table>
<thead>
<tr>
<th>Vibration Velocity, mm/s</th>
<th>Class I: Small Machines</th>
<th>Class II: Medium Machines</th>
<th>Class II: Large Rigid Foundation</th>
<th>Class III: Large Soft Foundation</th>
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</thead>
<tbody>
<tr>
<td>0.01</td>
<td>GOOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td>GOOD</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0.03</td>
<td>GOOD</td>
<td></td>
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<tr>
<td>0.04</td>
<td>GOOD</td>
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<td></td>
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<tr>
<td>0.07</td>
<td>GOOD</td>
<td></td>
<td>Satisfactory</td>
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</tr>
<tr>
<td>0.11</td>
<td>GOOD</td>
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<td>1.77</td>
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</tbody>
</table>

Example:
- If the vibration velocity is 0.5 mm/s, it falls under the GOOD category in Class I: Small Machines.

Example:
- If the vibration velocity is 3.0 mm/s, it falls under the Unsatisfactory category in Class III: Large Soft Foundation.
Benefits of Vibration Screening Tools

Front line mechanical maintenance teams need:

• A quick screening tool to fit into existing rounds.
• Reliable and repeatable measurements of rotating equipment to make imperative go/no-go maintenance decisions.
• Ability to trend readings over time and notify a consultant or reliability engineer when something abnormal arises.
• Quick understanding of overall machine and bearing condition, to decide on repairs and repair equipment.
What does it measure?

Vibration Meter is a multifunction vibration checker which:

- Provides quantifiable results of bearing condition, overall vibration, temperature
- Assesses the severity on a severity scale
- Provides ability to upload the data to PC for later trending
Types of Vibration Testing

Crest Factor = Peak / RMS

Severity Scale

- GOOD
- SATISFACTORY
- UNSATISFACTORY
- UNACCEPTABLE

- No repair action is recommended.
- No immediate repair action is required. Increase the frequency of measurements and monitor the condition of the machine.
- Have a knowledgeable vibration technician conduct more advanced testing at the earliest opportunity. Consider taking maintenance action during the next planned downtime or maintenance period.
- Have a knowledgeable vibration technician conduct more advanced testing as soon as possible. Consider immediate shutdown of the machine to make repairs and prevent failure.

0.4 in/sec
Checks against machine categories

Chiller (refrigeration)
• Reciprocating • Centrifugal

Fans
• Belt-driven • Direct drive
• Vacuum blowers • Shaft-mounted integral
• Large forced and induced draft fans
• Axial flow fans (belt or direct drive)

Cooling tower drives
• Long, hollow drive shaft • Belt drive
• Direct drive

Centrifugal Pumps
• Vertical pumps • Horizontal pumps
• Boiler feed pumps

Positive Displacement Pumps
• Piston pumps • Gear pumps

Air compressors
• Reciprocating • Rotary screw • Centrifugal

Blowers
• Lobe-type rotary blowers
• Multi-stage centrifugal blowers

Generic gearboxes
• Single stage gearbox

Machine tools
• Spindles
Benefits of Trending with Vibration Meter

- Export measurements to Excel template on PC to trend overall vibration, CF+, and IR temperature.
- Looking at the number alone for the overall vibration or bearing condition might not be of much benefit.
- What is normal or what indicates a problem?
- Use the severity assessment and trending functionality to overcome this obstacle.
Benefits of Trending with Vibration Meter

- After operator rounds, trend with preconfigured Excel plot graphs and compare to ISO Standards (10816-1, -3 and -7).
- If there is an abnormality, it can be identified by using the trend charts.
- The user can now see a clear picture of the changing bearing condition and deteriorating health of the machine.
**Screening Tool**

- Maintenance teams need ability to spot and solve problems before they become bigger problems.
- Best way is with daily checks on machine condition and trend over time.
- Now you have a clear picture of changing bearing condition and deteriorating health of the machine.
- Is the machine OK or is it time to call in the big guns?

![Image of a person using a diagnostic tool](image)
When to use: diagnostic / screening tool

Diagnostic Tester

- Extensive setup, trending, analysis, on-site expert not needed to get machine condition answers
- Monthly or quarterly tests to diagnose machine condition
- Specific machine fault, severity and repair recommendation
- Watch trend of machine fault severity – It is time to take machine off line and replace the motor bearings.
Fluke 810 Vibration Tester

Fluke 805 Vibration Meter

Visit [www.davis.com/flukevibration](http://www.davis.com/flukevibration) for more information