ADVANCED MAINTENANCE TECHNOLOGIES

Condition Monitoring and Total Reliability Management

© 1999-2013 IMPACT Engineering, Inc.
Overview

- What is Predictive Maintenance?
- What benefits can be achieved from a Predictive Maintenance program?
- What are the elements of an effective Predictive Maintenance program?
- What is required to achieve Total Reliability Management (TRM)?
Maintenance Methods

Total Reliability Management
Maintenance Methods

- Reactive (RM)
- Preventive (PM)
- Predictive (PDM)
- Pro-Active (PAM)
Reactive Maintenance

- Run machinery to failure
- If machinery is **running**, everything is **fine**
- Most common maintenance practice!

**Positive:**
- If it ain’t broke, don’t fix it
- May be cost-effective for small components

**Negative:**
- Unscheduled downtime
- High cost for major failures
- Personnel safety risk

© 1999-2013 IMPACT Engineering, Inc.
Preventive Maintenance

- **Scheduled/planned maintenance**: calendar, hours
- **Conservative**: based on historical estimates of expected life with additional safety factor

**Positive:**
- Prevents major failures
- Extends machinery operating life

**Negative:**
- Overhaul before useful life expended
- Unnecessary tasks often performed
- Induced failures

© 1999-2013 IMPACT Engineering, Inc.
Predictive Maintenance (PDM)

- Maintenance actions based on Condition Monitoring data

- Benefits:
  - Detect faults
  - Predict failure
  - Plan & schedule repairs
  - Eliminate unnecessary ‘Open/Inspect’ for Classification (ABS)

© 1999-2013 IMPACT Engineering, Inc.
# Condition Monitoring Technologies

## In-Service Condition Monitoring

<table>
<thead>
<tr>
<th>Vibration Analysis</th>
<th>Motor Current Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound Detection</td>
<td>Material Thickness</td>
</tr>
<tr>
<td>Thermographic Inspection</td>
<td>Recip. Engine Analysis</td>
</tr>
<tr>
<td>Lube Oil Analysis</td>
<td>Observations</td>
</tr>
</tbody>
</table>

© 1999-2013 IMPACT Engineering, Inc.
PDM Process

- Gather valid data.
  - Vibration, Ultrasound, Thermography, Maintenance History, Performance, Inspections

- Analyze data; convert to diagnostic information.
  - Spectral Plots, Alarm Levels, Experience, History

- Perform corrective action.
  - Alignment, Balancing, Lubrication, Structural

- Evaluate results.
  - Trend, Assess, Communicate, Plan

© 1999-2013 IMPACT Engineering, Inc.
What is Root Cause Failure Analysis (RCFA)?

- A systematic process of determining & eliminating fundamental problems which lead to failure

- It improves profitability through reduced cost of parts, labor, lost production and improved quality

- It is an essential part of a "world class" Reliability Maintenance program

© 1999-2013 IMPACT Engineering, Inc.
Pro-Active Maintenance (PAM)

Extends machine life, reduces maintenance cost by:

- Precision alignment & balancing
- New equipment performance verification
- Root Cause Failure Analysis

Results in immediate payback

© 1999-2013 IMPACT Engineering, Inc.
Changing Maintenance Practices

Switching from “Reacting to Breakdowns”,
and changing to “Elimination of Breakdowns”
where Predictive Maintenance is the Plan
and Preventive or Scheduled is the Exception.

© 1999-2013 IMPACT Engineering, Inc.
Maintenance Costs for General Industrial Rotating Machinery

Source: Hudachek & Dodd, ASME

© 1999-2013 IMPACT Engineering, Inc.
Condition Monitoring with Vibration Spectral Analysis

- Useful for all machinery
- Spectral characteristics identify faults
- Detects a wide variety of faults:
  - Mis-alignment
  - Imbalance
  - Looseness
  - Wear, Damage, etc.
Vibration Analysis Methods

- **Time Waveform** (amplitude vs. time)
- **Overall Level** (vibration)
- **Frequency Spectrum** (amplitude vs. freq.)
  - Fast Fourier Transform (FFT)
- **Selected Frequency Bands** (1 x SS, 2 x SS, etc.)
- **Phase Comparison** (relative position)
- **Trend Comparison**
Spectral Plot (FFT)

PISTON COOLING PUMP - #1
1C-10-1 -RP1 UPPER MOTOR BRN - RADIAL - PORT

ROUTE SPECTRUM

OVERALL = .5611 V-DG
PK = .5610
LOAD = 100.0
RPM = 1770.
RPS = 29.50

WAVEFORM DISPLAY

PK = .5415
PK(+) = .5738
PK(-) = .6107
CRESTF = 1.59

Order: 1.008
Freq: 1783.9
Spec: .550

© 1999-2013 IMPACT Engineering, Inc.
Imbalance: 1 X Shaft Speed (SS)
Looseness & Mis-alignment Spectral Plot

Route Spectrum

OVRALL = 0.2306 V-DG
PK = 0.2312
LOAD = 100.0
RPM = 1750.0
RPS = 29.17

Order: 1.039
Freq: 1818.7
Spec: 0.08320

© 1999-2013 IMPACT Engineering, Inc.
Ultrasound (UT) Detection

- Sound Energy above audible range: 40 kHz
- Transmitted through structure or air
- Mechanical friction and impacts produce UT
- Measured via contact transducer or microphone
- Sound is transformed to the audible range
- Amplitude and ‘quality of sound’ is noted
Major Applications

**Mechanical**: Bearings, Couplings, Gears ...

**Leaks**: Air, Steam, Vacuum, Gas ...

**Flow**: Steam Traps, Valves, Fuel Injectors ..

**Electrical**: Motor Controls, Switch Gear ..
Bearing & Coupling

UT Monitoring Benefits

- Monitor bearing lubrication quality.
  - *Under-lubrication causes many bearing failures*

- Elevated UT will be detected before significant increases in vibration

- Identify early stages of bearing faults
  - *Eliminate unexpected failure and damage*

- Excellent correlation with vibration data for advanced bearing fault detection
UT Sound Quality

- Good bearings & couplings produce smooth sound without distinct popping/clicking
- Faulty bearings produce popping/clicking sounds
- Dynamic loading increases amplitude values

<table>
<thead>
<tr>
<th>Typical Operating Speeds (rpm)</th>
<th>Typical or Normal UT Levels</th>
<th>High Friction (Lubrication Required)</th>
<th>Bearing Fault Present (Extreme Clicking/Popping)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 - 1,200</td>
<td>1 - 15 dB</td>
<td>15 - 25 dB</td>
<td>&gt; 25 dB (clicking)</td>
</tr>
<tr>
<td>1,800</td>
<td>10 - 25 dB</td>
<td>25 - 35 dB</td>
<td>&gt; 30 dB (clicking)</td>
</tr>
<tr>
<td>3,600</td>
<td>20 - 30 dB</td>
<td>30 - 45 dB</td>
<td>&gt; 40 dB (clicking)</td>
</tr>
</tbody>
</table>
UT Sound Clips

Good Brg. -- Bad Brg.

Bad Coupling Clicking / Rubs

Bad Spindle Brg. HFO Purifier

© 1999-2013 IMPACT Engineering, Inc.
Thermographic Infrared Image

Digital Camera

Infrared Camera

LI01: 175.4°C
LI02: 54.7°C

© 1999-2013 IMPACT Engineering, Inc.
CARMA®
Diesel Engine Condition Monitoring

- Real Time monitoring of:
  - Cylinder Pressure
  - Vibration
  - Ultrasound
  - Position of crank angle & rotation

- Data saved for later analysis and trending

- Cylinder performance and condition of components analyzed immediately.

© 1999-2013 IMPACT Engineering, Inc.
Sensor Setup

- Data manipulation
- Calculating power
- Trending
- Communication

© 1999-2013 IMPACT Engineering, Inc.
Analysis Process

The Result..

...Pressure, Vibration and Ultrasonic signals are displayed in reference to crank angle.

Consequently...

...pattern events can be correlated to piston, con-rod and crank position.
Corrective Maintenance

- **Shaft Alignment**
  - Mis-alignment is the ‘Root Cause’ for 50% of vibration/machinery problems

- **Dynamic Balancing**

- **Structural Resonance Testing & Corrections**

- **Immediate Payback**
  - Reducing vibration levels by 50% will increase bearing $L_{10}$ life by a factor of 8 ($3$).

© 1999-2013 IMPACT Engineering, Inc.
Shaft Alignment

- Misalignment causes vibration - reduces machinery component life.
- Alignment is often assumed, not obtained.
- Quality equipment and training essential!
  - Alignment investment pays for itself (Immediate Payback)

Methods
- Dial Indicators (Reverse Indicator Method)
- Laser/Optical

© 1999-2013 IMPACT Engineering, Inc.
Reverse Dial Indicator Method
Shaft Alignment

Vertical Pump

Horizontal Pump

© 1999-2013 IMPACT Engineering, Inc.
Vertical Machine Alignment

Dial Readings on Indicator S
0 o' 0
3 o' 1
9 o' 2 3 o'
6 o' 3

Dial Readings on Indicator M
0 o' 0
9 o' 1
3 o' 2
6 o' 3

© 1999-2013 IMPACT Engineering, Inc.
Laser/Optical Shaft Alignment

Ludeca Optalign™

© 1999-2013 IMPACT Engineering, Inc.
Dynamic Balancing
Total Reliability Management (TRM) Program Strategy

Maintenance strategy that effectively balances:

**Reactive** - On Demand / Run to Failure

**Preventive** - Interval Repairs

**Predictive** - Condition Monitoring

**Proactive** - Corrective & Root Cause Analysis
TRM Program Implementation

Phase I
- Baseline Diagnostic Evaluation

Phase II
- ABS Classification Submittal, Documentation
- ABS Program Training

Phase III
- Perform Proactive (Corrective) Maintenance

Phase IV
- Vessel purchases PDM tools for onboard analysis & Corrective Maintenance

© 1999-2013 IMPACT Engineering, Inc.
PDM Investment ‘Pay-Back’

Note: for Phase IV Program Implementation

Source: W. Woyshner, EPRI M&D Center

© 1999-2013 IMPACT Engineering, Inc.
Establishing an Effective TRM Condition Monitoring Program

**Strategic Plan:**
- Purpose
- Objective
- Methods

**Tactical Plan:**
- Procedure
- Training
- Resources

© 1999-2013 IMPACT Engineering, Inc.