When is a vibration problem a problem?
ARIA Vibration Severity committee

March 2015
Vibration Severity Subcommittee

- Chairman – Bruce Evans
- Members - Matt Bourne, Paul Rand, Jason Tranter, John Manson, Guy Salathiel, Sabash Lallchand, Cameron Blackburn, Max Wishaw, Peter Todd, Ross Bowles, Jamie Draper, Keith DeCruz, Dare Petreski, Corne Stander and Fritz Neumann
- Approaching issue practically rather than academically or from an OEM standpoint.
- Hard to achieve consensus – much discussion and trialling still required.
Outline

1. Why do we need severity guidelines?
2. Aria committee progress
3. What exists now
4. Common methods which influence severity judgement
5. Arrium guidelines – how they work
6. Case Studies
7. Where to from here
The 3 Steps to Vibration Analysis

1. Detection
   
   *Is there a problem?*

2. Diagnosis
   
   *What is the problem?*

3. Severity Judgement
   
   *Is the problem a problem?*

**Focus of this presentation**
1. Why do we need severity guidelines?

Aim: “To produce a vibration severity guideline for use by vibration analysis technicians and consultants in making severity calls on the most common fault types on rolling element bearing machinery operating between 60 & 6000 rpm (1-100 hz).”
Use of Severity Guidelines

- Acceptance testing of new or overhauled equipment
- Assisting less experienced CM techs
- Offering a second opinion to experienced CM techs
- Assisting calls on less common faults
- Offering support for CM tech recommendations to maintenance
- Going further than the current ISO standards by adding guidelines for individual faults and faults which do not cause high vibration.
2. Aria committee progress

i. Machine categories

ii. Machine types

iii. Faults

iv. Severity levels

v. Possible severity parameters

vi. Survey
i) Machine Categories

- Severity level adjustments to be based upon just 2 criteria:
  1. mounting flexibility
  2. Shaft speed
     - Shaft speed particularly required for low speed shaft faults (< 10 hz)

- The following criteria will not be used to adjust severity levels:
  - Machine size (kW)
  - Criticality

- The following criteria will often require a note:
  - Machine type
  - Loading
ii) Machine Types

**Basic**
- Motors
- Pumps
- Fans
- Gearboxes
- Spindles/rolls

**Special variations**
- Agitators
- Mills
- Crushers
- Screens
- Reciprocating pumps
- Planetary gearboxes
- Compressors - screw
- Compressors - centrifugal
- Compressors - reciprocating
- Roots blowers

**Not to be included in guideline**
- Turbines - steam
- Turbines – gas
- Hydro machines
- Combustion engines
iii) Faults

- Generally cause high velocity vibration *
  - Unbalance/eccentricity
  - Coupling Misalignment
  - Looseness - static and rotating
  - Bent Shaft
  - Resonance
  - Blade Pass
  - Pump Cavitation

- Generally cause moderate velocity vibration *
  - Eccentric Air Gap
  - Gear Wear
  - Gear misalignment
  - Gear assembly phase error
  - Belt wear & looseness
  - Belt misalignment

- Generally do not cause elevated velocity vibration *
  - Rolling Element Bearing fault
  - Dry bearing (Lubrication fault)
  - Rub
  - Broken Gear Tooth
  - Broken Rotor Bars
  - Loose Rotor Bars
  - Gear hunting tooth
  - Skidding

All faults on low speed machines **

* When fault has reached a moderate severity level ie requires action

** Overall displacement levels useful for severity judgement for some faults eg ISO standards etc
iv) Severity Levels

- 5 severity levels to be adopted
- Names not agreed upon and can be varied according to site traditions

<table>
<thead>
<tr>
<th></th>
<th>Arrium</th>
<th>BlueScope</th>
<th>ISO 10816</th>
<th>DLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Target</td>
<td>Excellent</td>
<td></td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>4. Minor</td>
<td></td>
<td>Useable</td>
<td></td>
<td>Tolerable</td>
</tr>
<tr>
<td>3. Moderate</td>
<td>Poor</td>
<td></td>
<td>Zone C</td>
<td>Excessive</td>
</tr>
<tr>
<td>2. Major</td>
<td>Bad</td>
<td></td>
<td>Zone D</td>
<td>Extreme</td>
</tr>
</tbody>
</table>
v) Possible Severity Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall levels - um, mm/s, g's</td>
</tr>
<tr>
<td>Overall levels - demod/peak vue, true pk, crest factor, kurtosis, etc</td>
</tr>
<tr>
<td>Filtered band levels</td>
</tr>
<tr>
<td>Individual peak levels</td>
</tr>
<tr>
<td>Peak height above noise floor eg 20dB in demod</td>
</tr>
<tr>
<td>Levels vs fixed criteria</td>
</tr>
<tr>
<td>% change from baseline</td>
</tr>
<tr>
<td>% change from average + N std deviations</td>
</tr>
<tr>
<td>Rate of change</td>
</tr>
<tr>
<td>Presence/absence of symptom eg sidebands etc</td>
</tr>
<tr>
<td>Confirmation from other techniques eg wear debris, internal inspection etc</td>
</tr>
</tbody>
</table>
vi) Survey results

Survey developed to get feedback on alarming and severity judgement from real world analysts.

- 15 responses from experienced analysts so far

Preliminary conclusions:

1. Motors, pumps, fans and gearboxes common to all.
2. 80% use fixed alarms on overall levels and are influenced by ISO standards.
3. Only 20% use other alarms such as spectral bands, waveform alarms, rate of change alarms and statistically generated alarms – acknowledge their usefulness but find them not worth the effort required to set up in their software.
4. Furthermore, 93% look at spectra regardless of overall levels in order to detect faults as well as manually judge the severity of faults.
5. Wide range of approaches to judging bearing defect severity including “educated gut feel”. There is no agreement in this area.
6. For experienced analysts, severity guidelines would be most useful for less common faults and for faults on slow speed shafts (especially <200 rpm).
3. What exists now

i. ISO and AS standards

ii. IRD severity chart

iii. Spectral severity charts
ISO & AS vibration severity standards

Table 2: Recommended Vibration Severity Criteria

<table>
<thead>
<tr>
<th>Range classification</th>
<th>Velocity range (m/s)</th>
<th>Quality Judgement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.02</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>0.045</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>Satisfactory</td>
</tr>
<tr>
<td></td>
<td>1.12</td>
<td>Unacceptable (See Note 2)</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>Unacceptable</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td>Unacceptable (See Note 2)</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>Unacceptable (See Note 2)</td>
</tr>
<tr>
<td></td>
<td>7.1</td>
<td>Unacceptable</td>
</tr>
<tr>
<td></td>
<td>7.1</td>
<td>Unacceptable</td>
</tr>
<tr>
<td></td>
<td>11.2</td>
<td>Unacceptable</td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>Unacceptable</td>
</tr>
<tr>
<td></td>
<td>25.0</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td></td>
<td>45.0</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td></td>
<td>71.0</td>
<td>Unacceptable</td>
</tr>
</tbody>
</table>

Notes:
1. The limiting values given in the table above are fair average values for comparison purposes; they are not meant to be limiting values for establishing machine conditions or for assessing the need for maintenance as for condition monitoring.
2. For the full definition of this term, reference to Clause 10 should be made.

Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts

Part 1: General

Part 2: Large land-based steam turbine generator sets in excess of 50 MW
How bad is 5mm/s by ISO?

It depends...

1. What year is it?
2. What country are you in?
3. Does the measurement apply to 10hz to 1khz freq?
4. How big is the machine?
5. How fast is it going?
6. How is it mounted? (What is the first natural freq at the measurement location?)
7. Does it have a flexible coupling?
8. Is it a pump?
9. If so then how critical is it?
10. Is it a fan?
11. Has it just increased by 25% of the zone B/C level?
12. Is it in the axial direction? If so is there a thrust brg?
13. What is the displacement level?
## Is 5mm/s a problem by ISO? Fan Example

<table>
<thead>
<tr>
<th>Standard</th>
<th>Equipment Type</th>
<th>Rigid Mount</th>
<th>Flex Coupling</th>
<th>Speed (rpm)</th>
<th>Phase</th>
<th>Category</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 10816-3 (2009)</td>
<td>Fan only</td>
<td>⬤</td>
<td>⬤</td>
<td></td>
<td></td>
<td>BV-3</td>
<td>Below alarm &amp; shutdown levels</td>
</tr>
<tr>
<td></td>
<td>Motor only</td>
<td>⬤</td>
<td>⬤</td>
<td></td>
<td></td>
<td>Group 2</td>
<td>Zone D</td>
</tr>
</tbody>
</table>

**Motor & Fan**

- Rigid mount: ⬤
- Flex coupling: ⬤
- Speed: 1500 rpm
- Category: Category 2
- Zone: Zone D

**Fan only**

- Rigid mount: ⬤
- Flex coupling: ⬤
- Speed: 1500 rpm
- Category: Group 2
- Zone: Zone D

**Motor only**

- Rigid mount: ⬤
- Flex coupling: ⬤
- Speed: 1500 rpm
- Category: Group 2
- Zone: Zone D
Is 5mm/s a problem by ISO? Pump example

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 10816-3 (2009)</td>
<td>Motor only</td>
<td>18kW</td>
<td>Rigid mount</td>
<td>Direct drive</td>
<td>1500 rpm</td>
<td>Non-critical</td>
<td>Group 2</td>
<td>Zone D</td>
</tr>
<tr>
<td>ISO 10816-7 (2009)</td>
<td>Pump only</td>
<td>18kW</td>
<td>Rigid mount</td>
<td>Direct drive</td>
<td>1500 rpm</td>
<td>Non-critical</td>
<td>Category 2</td>
<td>Unrestricted long term operation</td>
</tr>
</tbody>
</table>

- Routine measurement
- Factory acceptance test
- In situ acceptance test

Pass - Allowable operating range
Fail - Not allowable
IRD Mechanalysis Severity chart (1978?)

- 11.2 mm/s rms
- 5.6 mm/s rms
- 2.8 mm/s rms
- 1.4 mm/s rms
- 0.7 mm/s rms
- 0.35 mm/s rms
- 0.17 mm/s rms
- 0.09 mm/s rms
Other Spectral Severity charts

Blake (1964)

Petrochem


DLI Engineering (1988)
DLI spectral chart

DLI Machinery Vibration Severity Chart

- **Extreme**
  - > 18mm/s rms
  - > 250µm p-p

- **Excessive**
  - > 7mm/s rms
  - > 100µm p-p

- **Tolerable**
  - > 2.5mm/s rms
  - > 45µm p-p

- **Acceptable**
  - > 1mm/s rms
  - > 15µm p-p

- **Good**
  - < 1mm/s rms
  - < 15µm p-p

**Spectral peak threshold - mm/s rms**

- 30 Hz
- 1kHz

**ie Low freq faults have lower alarms**
Eg gearbox output shafts etc

**ie High freq faults have lower alarms**
Eg some mesh freqs, rotor bar freqs & high bearing harmonics etc
4. Common methods which influence severity judgement

i. The 10% method (and variations)

ii. The wait for clarity method

iii. The P-F’d method

iv. The “I’ll deal with it later” method

v. The reliability culture
i) The 10% Method* 
(* with variations for 15%, 5% and 3%)

Severity levels are adjusted such that no more than 10% of equipment being tested requires action.
3% method example

- As used by well known commercial oil lab

Abnormal: 3%
Caution: 2%
Normal: 95%

Arrium set alarms
ii) The wait for clarity method

1. If vibration level is increasing but reason for increase is not clear then nominate severity as “Minor” and continue to monitor.
2. If vibration level increases further but reason is still not clear then go back to 1.
3. Eventually the reason will become clear...
4. Often after failure and internal inspection.
iii) The P-F’d method

- **P = Potential Failure**
  - Point where impending failure can be detected
  - Vibration: 1-9 months
  - Wear debris in oil: 1-6 months

- **F = Functional Failure**
  - Thermography: 3-12 weeks
  - Audible noise: 1-4 weeks
  - Hot to touch: 1-5 days
  - Motor relays
iv) The "I'll deal with it later" method

I’ll deal with it later

- Contaminated Oil
- Wear debris
- Oil degradation
- Water in oil
- Bearing Defect
- Incorrect Viscosity
- Oil additives
- Misalignment
- Unbalance
- looseness
- Lubrication
- Inspection defect
The Reliability Culture

**Reactive**
- Fix it when it’s not broken
- Operate to failure

**Preventive**
- Fix it before it breaks

**Predictive**

**Proactive**
- Fix it so it doesn’t break

**Relevant Severity levels**
- Major
- Moderate
- Minor

**Increasing reliability**
- None

Abuse it

Operate to failure

Fix it when it’s not broken

Fix it before it breaks

Fix it so it doesn’t break
How should we set severity levels?

- Is it reasonable to go by fairly rigid standards?
- To what extent should severity be adjusted based upon:
  - Overall poor plant condition
  - Pushback from maintenance and operations
  - Culture of management
  - Lack of CM skill and experience
5. Arrium severity guidelines

- Developed by OneSteel (now Arrium) in early 2011.
- Not sanctioned by Aria but part of the severity guidelines ideas for consideration.
Arrium Severity parameters

1. Overall levels
   - Overall velocity – mm/s rms
   - Overall displacement – um pk-pk
   - Change in overall velocity
   - Overall acceleration – g’s rms
   - Overall demod/pk vue

2. Spectrum levels
   - Maximum peak in velocity – mm/s rms

3. Waveform levels
   - Peak amplitude in waveform – g’s pk

Faults generating high vibration
- Bearing & lube faults - Minor severity only
- All faults
- Gear tooth faults
Overall levels
Velocity & displacement

Only applicable to faults which generate high vibration:
- Unbalance/eccentricity
- Coupling Misalignment
- Looseness - static and rotating
- Bent Shaft
- Resonance
- Blade Pass

> +1 mm/s = minor
> +2 mm/s = moderate
< 600 rpm
Spectrum examples

The highest peak relating to the fault determines the severity.

1. **Unbalance**

   - 1x
   - 2x
   - 3x
   - 4x

2. **Looseness**

   - 1x
   - 2x
   - 3x
   - 4x
   - 5x

- 6 mm/s
- 4 mm/s
- 2 mm/s
- 1 mm/s

- 5 mm/s
- 3 mm/s
- 1.5 mm/s
- 0.5 mm/s
## Unbalance Example

**ARIA Vibration Fault Severity Project**

**Fault:** UNBALANCE/ECCENTRICITY/BENT SHAFT

<table>
<thead>
<tr>
<th>Basis of severity judgement</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Overall levels</th>
<th>Velocity</th>
<th>Displacement</th>
<th>Acceleration</th>
<th>Demod/Peak Vue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>&lt; 1.4 mm/s rms</td>
<td>62 um p-p</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Good</td>
<td>&gt; 2.8 mm/s rms</td>
<td>127 um p-p</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Minor</td>
<td>&gt; 2.8 mm/s rms</td>
<td>127 um p-p</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt; 4.5 mm/s rms</td>
<td>200 um p-p</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Major</td>
<td>&gt; 7.1 mm/s rms</td>
<td>320 um p-p</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Changes in levels</th>
<th>Velocity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>&gt; +1 mm/s rms</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt; +2 mm/s rms</td>
<td></td>
</tr>
</tbody>
</table>

**Spectral - maximum peak amplitude**

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Displacement</th>
<th>Acceleration</th>
<th>Demod/Peak Vue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>&lt; 1 mm/s rms</td>
<td>62 um p-p</td>
<td>n/a</td>
</tr>
<tr>
<td>Good</td>
<td>&gt; 2 mm/s rms</td>
<td>127 um p-p</td>
<td>n/a</td>
</tr>
<tr>
<td>Minor</td>
<td>&gt; 2 mm/s rms</td>
<td>127 um p-p</td>
<td>n/a</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt; 4 mm/s rms</td>
<td>200 um p-p</td>
<td>n/a</td>
</tr>
<tr>
<td>Major</td>
<td>&gt; 6 mm/s rms</td>
<td>320 um p-p</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Relevant peaks**

1x

1x

**Comments:** Displacement levels apply to shaft speeds < 600 rpm
Bearing fault example

**ARIA Vibration Fault Severity Project**

**Fault**  
Bearing fault

**Bearing fault**

**Contributor**
Bruce Evans
**Date**  
04-Oct-13

**Basis of severity judgement**
Spectral peak amplitudes

### Overall levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Velocity</th>
<th>Displacement</th>
<th>Acceleration</th>
<th>Demod/Peak Vue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Good</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Minor</td>
<td>&gt; n/a</td>
<td>n/a</td>
<td>1 g rms</td>
<td>n/a</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt; n/a</td>
<td>n/a</td>
<td>Avg + 2 sid dev</td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>&gt; n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

### Changes in levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Velocity</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>&gt;</td>
<td>n/a</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;</td>
<td>n/a</td>
</tr>
</tbody>
</table>

### Spectral - maximum peak amplitude

<table>
<thead>
<tr>
<th>Level</th>
<th>Velocity</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>&lt;</td>
<td>NIL</td>
</tr>
<tr>
<td>Good</td>
<td>0.1 mm/s x rpm/1000</td>
<td></td>
</tr>
<tr>
<td>Minor</td>
<td>0.3 mm/s x rpm/1000</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>1 mm/s x rpm/1000</td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NB For shaft speeds above 2000 rpm use 2000 rpm in calculation*

**Relevant peaks**
Bearing Defect Frequencies (non-integer multiples of running speed), Erg Freq harmonics + 1x or FTF sidebands

**BPOR**
3. Bearing fault
Input shaft 1500 rpm
Minor=0.1\times rpm/1000
=0.1\times 1.5
=0.15 mm/s

Moderate Fault

4. Bearing fault
Output shaft 300 rpm
Minor=0.1\times rpm/1000
=0.1\times 0.3
=0.03 mm/s

Major Fault
Arrium Spectrum Alarm Summary

200 um pk-pk

MODERATE Severity Levels

Moderate alarm - Overall velocity

- Unbal/misal/bent shaft /blade pass/resonance
- Looseness
- Gear misal/ assembly phase error
- Motor air gap
- Pump cavitation
- Belt fault
- Rub
- Broken rotor bar
- Bearing fault/Gear wear
6. Case Studies
Gear wear/misalignment example – 550 rpm

- Overall levels:
  - 1.8 mm/s rms
  - 10 um pk-pk
  - Zone A by ISO

- 400kW

- 1.46 mm/s

- 2xGM

- 3xGM

- 1x sideband
  - 0.17 mm/s

- GM

- 0.17 mm/s

- 1x sideband

- GM

- Moderate

- Moderate (just)
Fan Bearing example – 1400rpm

Overall level
2.8 mm/s rms
Below alarm & shutdown levels by ISO

BPFO
1.9 mm/s
7. Where to from here

- Do survey - link to be sent. Please participate.
- Try Arrium severity guidelines for yourself – link to be sent.
- Contributions on severity judgement criteria for individual faults – see Aria web site.
- Aria Severity Guidelines to be published if we can get sufficient agreement.