



Condition Based Maintenance

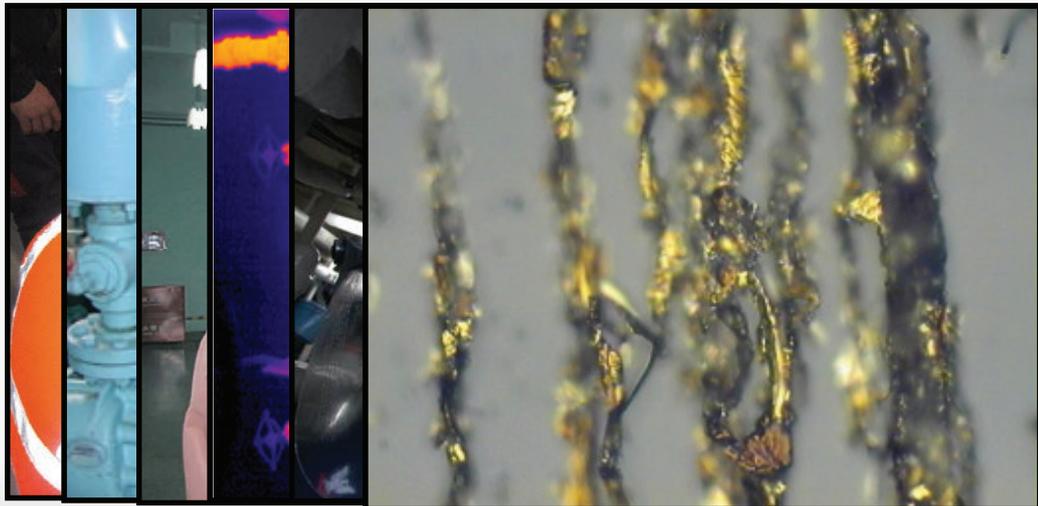
The key elements and successful implementation

Tommy Glesnes
Managing Director
AMPs AS



Condition monitoring

- Let's take a look at vibration monitoring; airborne and structure-borne ultrasound; motor diagnostics (MCSA, ESA and MCA); thermography, oil analysis and wear particle analysis.





Vibration monitoring

Let the vibration warn us of problems



Vibration analysis



- Vibration analysis has been successfully used for many years to detect the nature and severity of the fault.
- The challenge is to *measure and analyze the vibration correctly*.

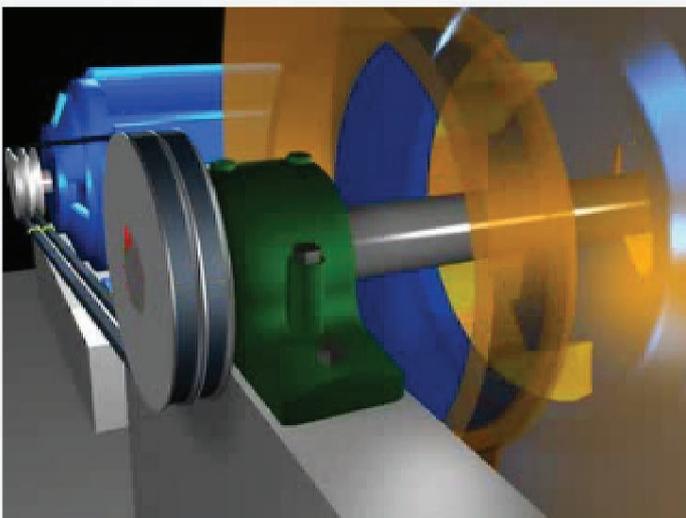
Vibration analysis



- Machines always generate vibration.
- The vibration can be related to the rotating components.
- When the vibration changes you know that the condition has changed.*

* As long as the speed/load has not also changed.

Vibration analysis



- If the fan is not balanced, or the pulley is eccentric, then the vibration will change in a predictable way.

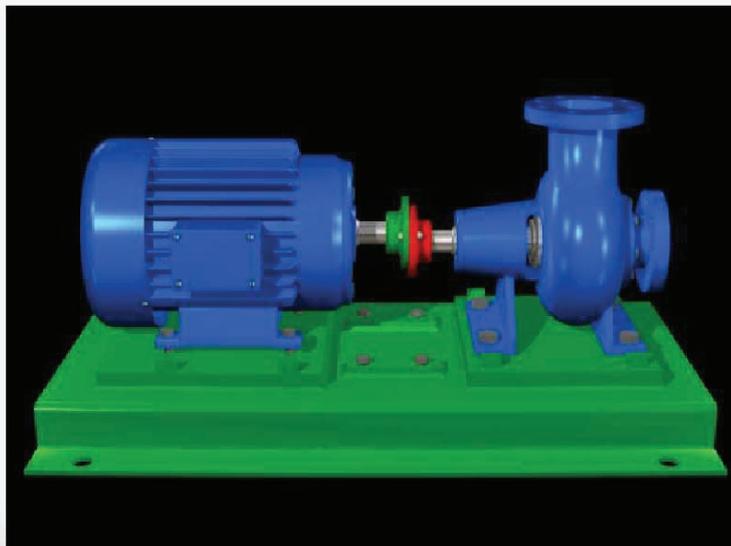
Vibration analysis



- If the bearings are worn, or there is a crack in the outer race, or there is excessive clearance, then again the vibration will change in predictable ways.

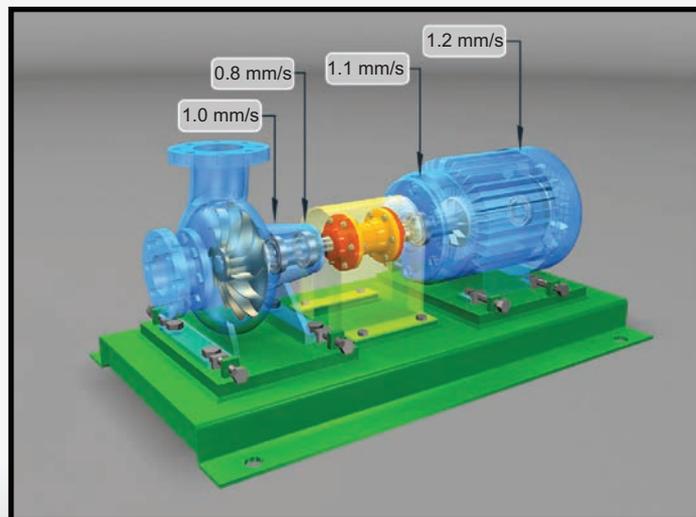
Vibration analysis

- And if two machine components are coupled together and there is wear in that coupling, or the shafts are not aligned properly, then the vibration will change in predictable ways.

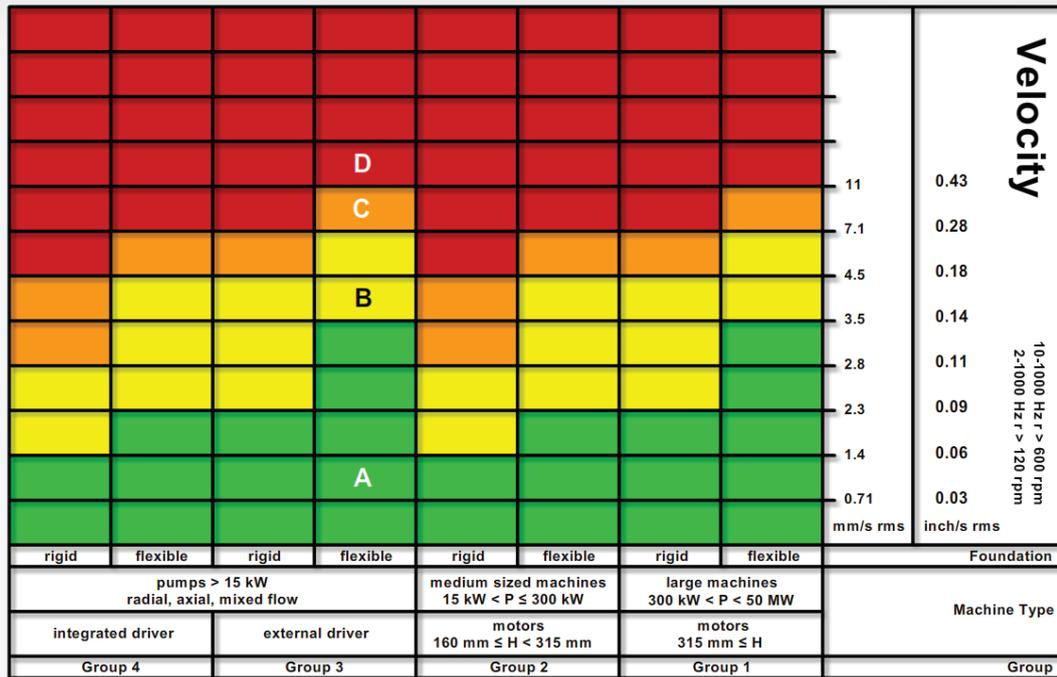


Overall level readings [Keeping it simple]

Overalls: The vibration summed into a single value



Vibration analysis: Overalls compared to alarms



A New machine condition

B Unlimited long-term operation allowable

C Short-term operation allowable

D Vibration causes damage

UNIT

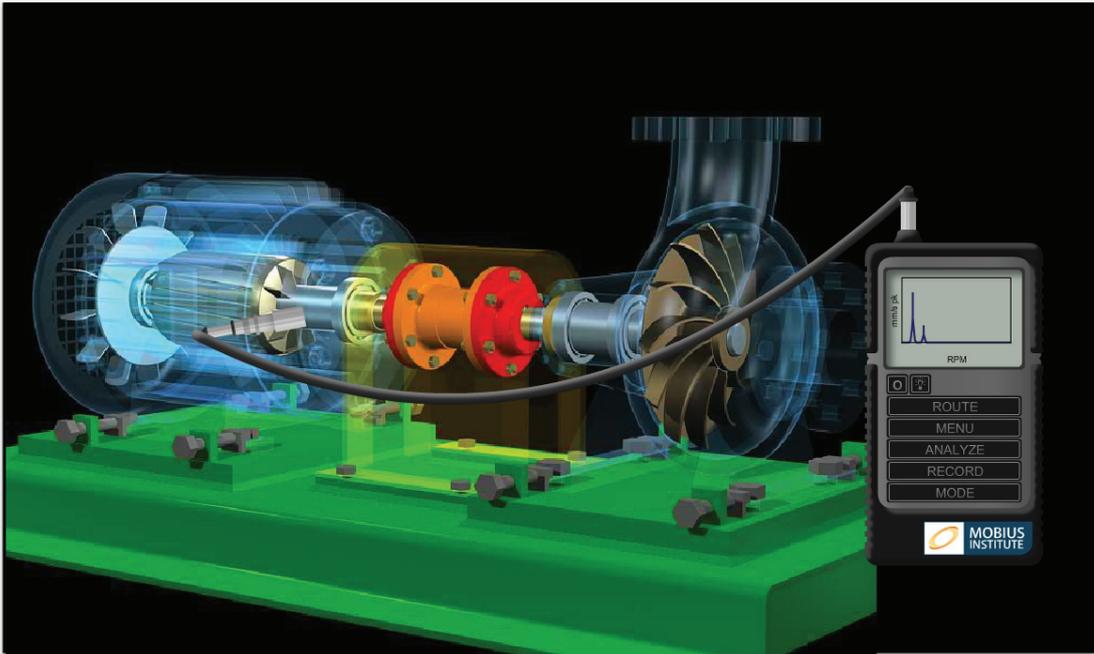
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Vibration spectra [Focusing on frequency]



Vibration analysis: Spectrum analysis

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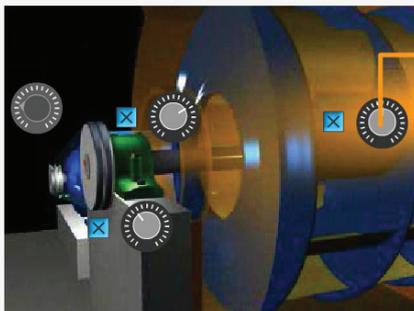


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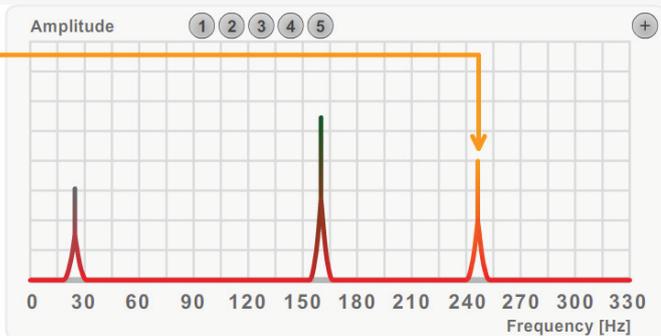
Vibration analysis: Spectrum analysis

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- The FFT process converts the time waveform into a spectrum.
- The spectrum highlights the frequency of each major vibration source.



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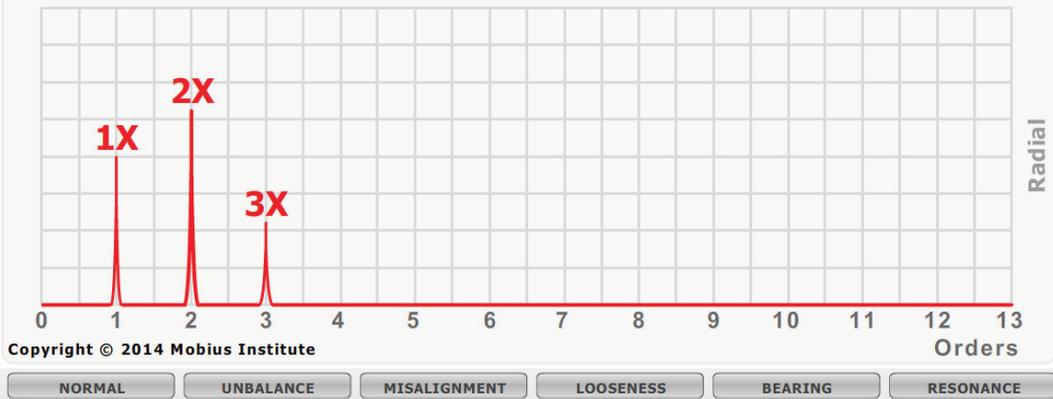


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Vibration analysis: Spectrum analysis

- The spectrum changes in predictable ways.
- We look for peaks and patterns.

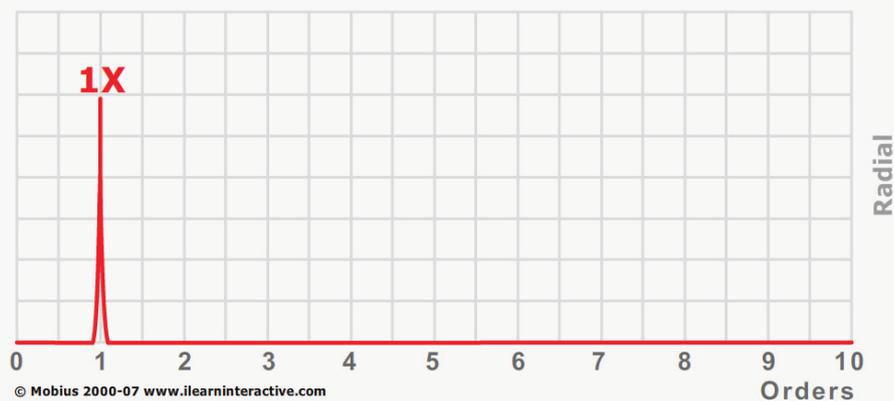
Parallel Misalignment



Unbalance

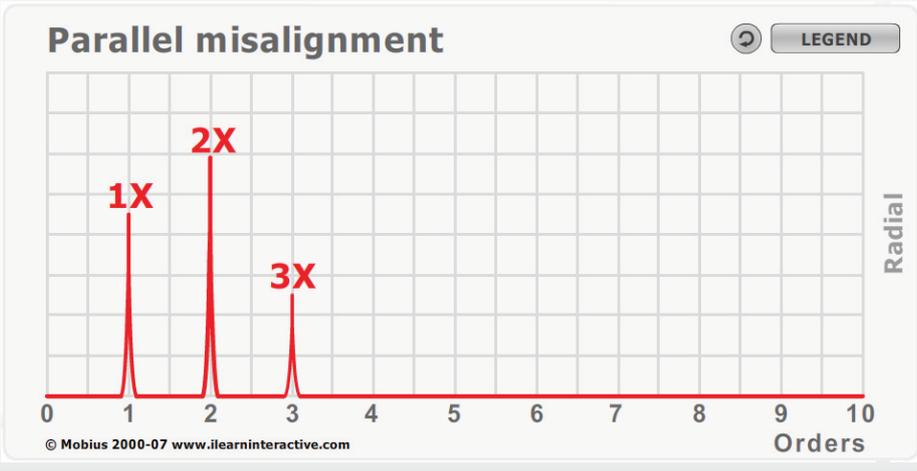
- Unbalance is common, especially in fans
- We see high vibration at the frequency that corresponds to running speed

Imbalance (static)

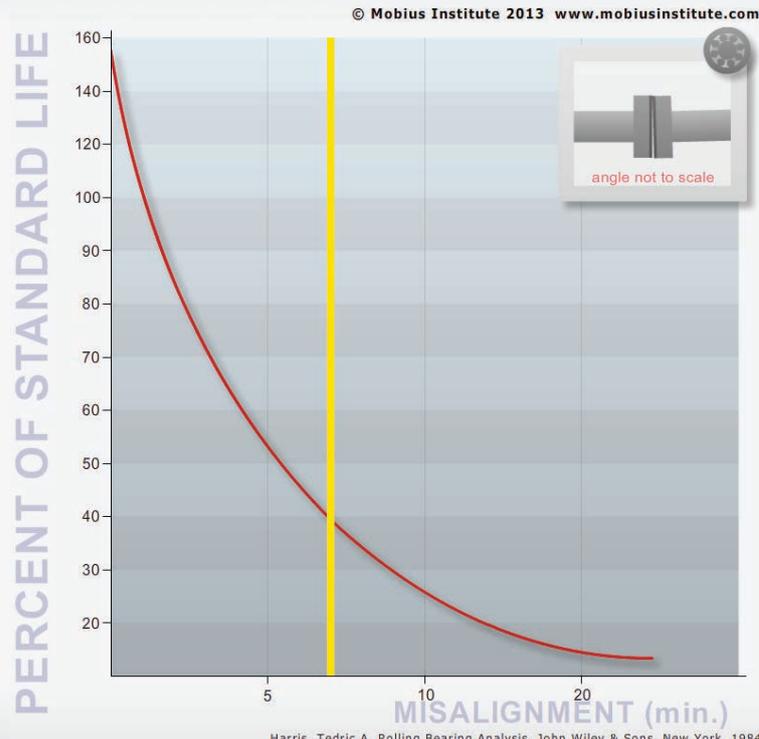


Misalignment

- Misalignment is also common – mostly because of poor alignment practices.
- We can have angular misalignment and/or offset misalignment – usually both.



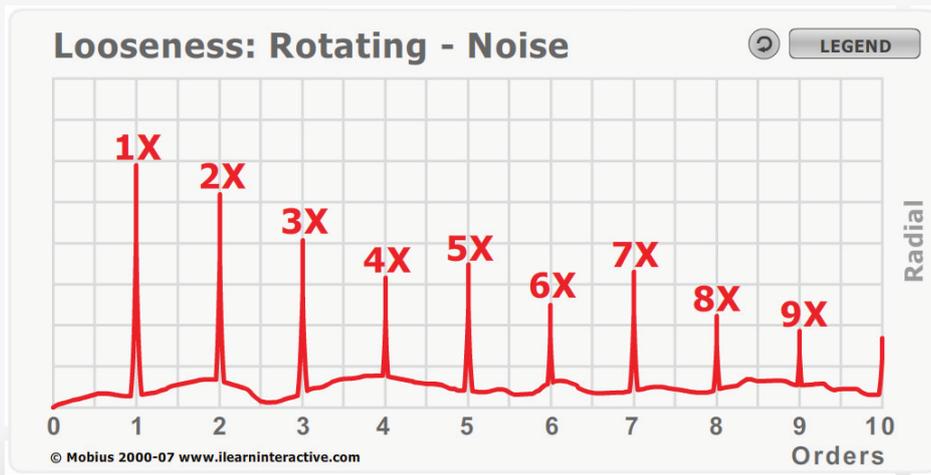
Defect elimination: Precision alignment



Harris, Tedric A. Rolling Bearing Analysis. John Wiley & Sons, New York, 1984

Looseness

- Looseness within the bearing, or looseness that causes rough vibration, can be detected because we witness a series of peaks called "harmonics".



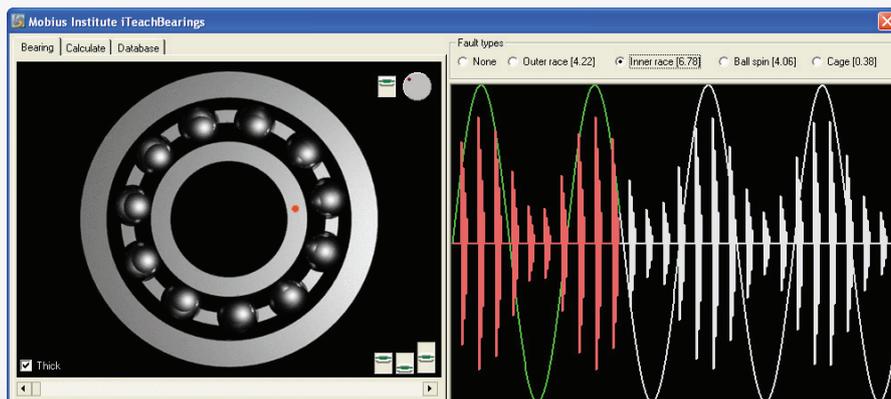
High frequency detection
[Focusing on high frequency]

High frequency techniques

Enveloping
Demodulation
Shock Pulse
PeakVue
HFD
SEE
SWAN

Detect the earliest signs of failure

- One of the keys to a successful vibration program is to detect bearing defects early.
- We should also do what we can to detect and eliminate the root causes.
- *Fortunately*, bearing vibration has unique characteristics.



Vibration analysis [pros]

Provides great detail on nature and severity
Provides a very early warning
Covers a wide range of fault conditions

Vibration analysis [cons]

Requires training to perform correctly
Sensor must make contact
Equipment is expensive
Testing machine correctly is time consuming
Analysis takes time
Accuracy is difficult to achieve

Airborne and structure-borne ultrasound

Listen for tell-tale signs of trouble



Selected images from **SDT North America** and **UE Systems**.
Sounds and video from SDT North America

Ultrasound



- The operator wears headphones and listens to the sounds.
- Many of the faults being detected are based on qualitative techniques.
- It therefore takes some time to become familiar with the tools.



Ultrasound



- The instruments also have a readout of the amplitude which can also be used as a gauge: how “loud” is it, and has it changed from last time.

Ultrasound: Mechanical applications

- Ultrasound can be used to listen to the bearing in order to hear the earliest signs of failure and for signs of poor lubrication.

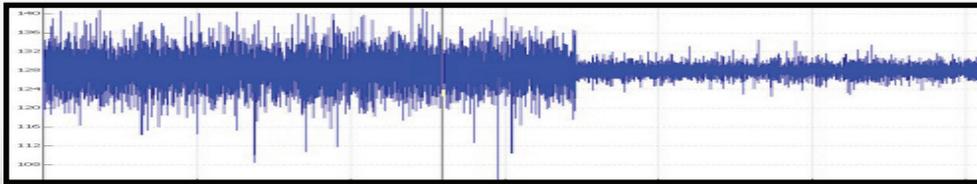


In this case a feed pump is tested and the bearing appears to be OK

Ultrasound: Lubrication



- The sound changes as the grease hits the bearing.



Ultrasound: Leak detection

- In this example you can see the technician searching for a leak. Waving the instrument from side to side enables the technician to locate the leak.



Liquid "bubble amplifier" assists in the detection process

Ultrasound [pros]

Very versatile: mechanical, electrical, process

Inexpensive entry point

Directional sound

Good support for vibration and IR

Good for Operator Driven Reliability



Ultrasound [cons]

Subjective – *what does the sound mean?*

Qualitative, not quantitative

Can lull you into false sense of security



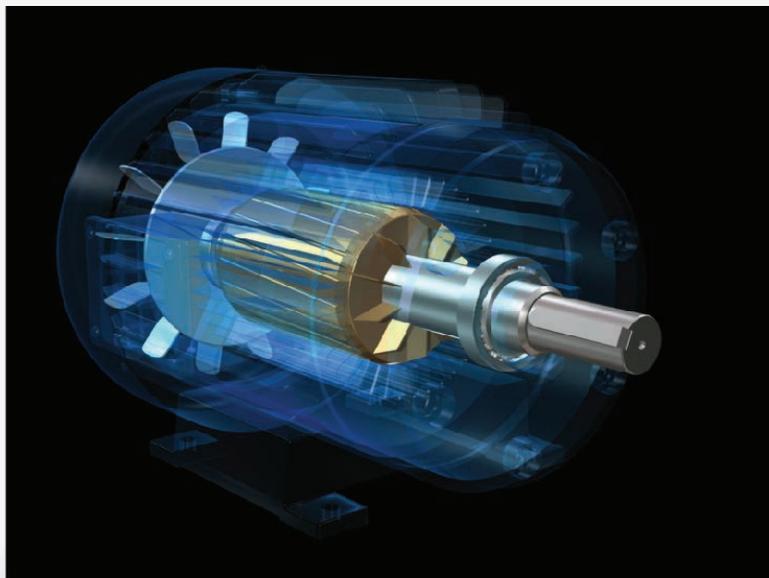
Electric motor diagnostic testing: [MCSA, ESA, and MCA]

An introduction to static and dynamic motor diagnostic testing



Electric motor diagnostic testing

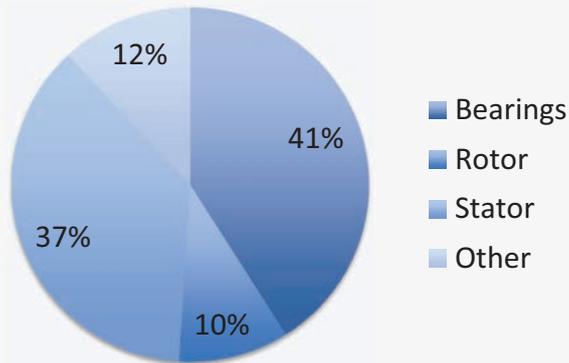
- It is possible to check if the windings, insulation, rotor, stator, power supply, and connectors are free of defects.



Electric motor diagnostic testing

- A study conducted in 1985 by the Electric Power Research Institute (EPRI) in association with GE found that motors failed 41% due to bearing failures, but 47% of the time due to rotor and stator failures.

Motor failures



1985 EPRI/GE Study EL4286 Volume 1 Project 1763-2

Electric motor diagnostic testing

- Vibration analysis (and ultrasound) can be used to detect common mechanical faults associated with electric motors in addition to faults associated with the rotor and stator.



Motor Current Signature Analysis (MCSA)

- Motor Current Signature Analysis (MCSA) involves measuring the current on one phase of the motor with a current clamp (or the flux) while the motor is running and analyzing that signal with a vibration analyzer.



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Motor Circuit Analysis (MCA)

- Motor Circuit Analysis (MCA) systems test the motor when it is *off-line*. They treat the motor as a circuit; measuring resistance, inductance, and capacitance.



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Motor testing [pros]

Understand the condition of the rotor, stator, connections, insulation and power supply
On-line and off-line tests can be performed
Motor can be tested remotely

Motor testing [cons]

Have to assess safety issues (on-line tests)
Requires training
Assess ROI – likelihood of motor failures

4 Used oil analysis

An overview of how to analyze lubricants to determine the fitness of the lubricant, contamination of the lubricant, and condition of the machine

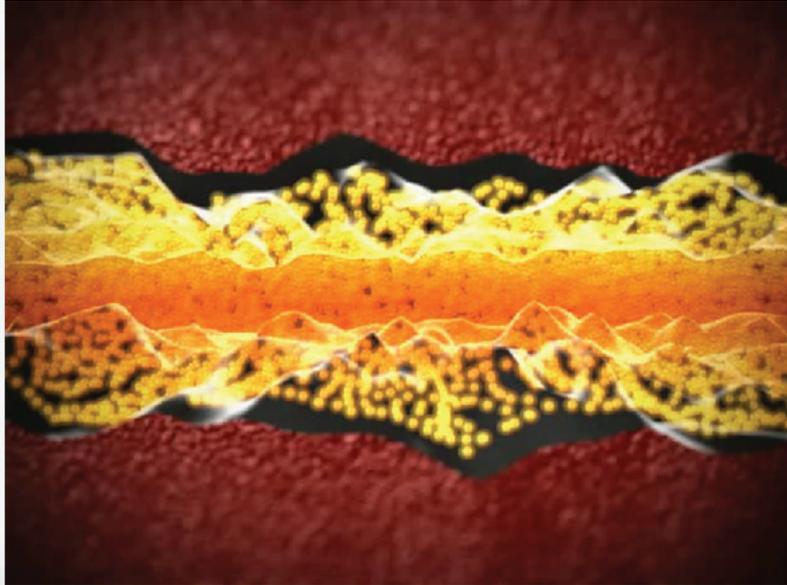
Oil analysis

- Bearings and gears cannot reach their maximum design life unless the lubricant:
 - Has the correct viscosity,
 - Has the correct additives,
 - Is clean of contaminants.



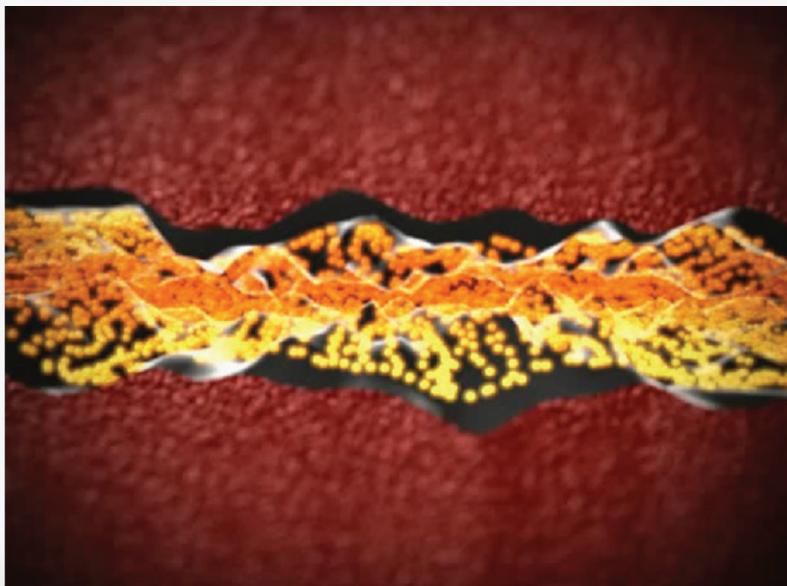
Oil analysis

- The lubricant is put in place to keep surfaces apart, and to providing cooling.



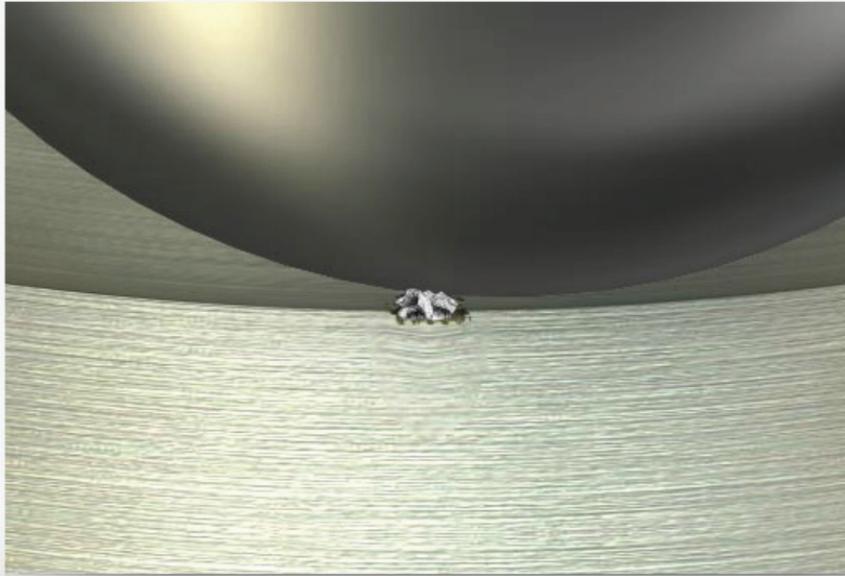
Oil analysis

- Wear will increase if there is insufficient lubricant.



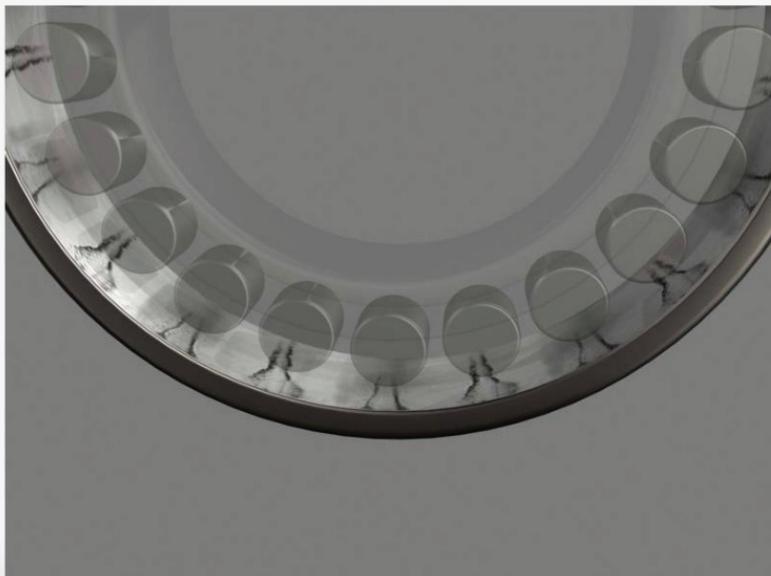
Oil analysis

- Hard contaminants can damage the surface of gears and bearings.



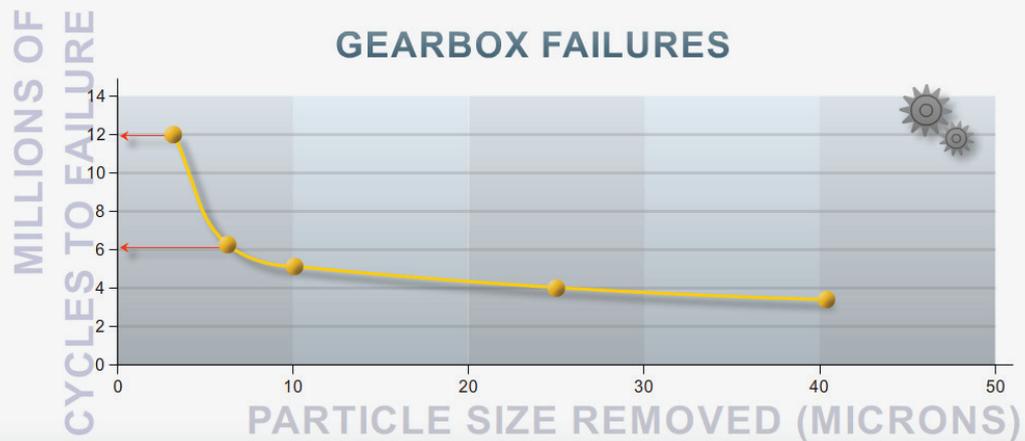
Oil analysis

- Water contamination can also damage the surfaces, leading to premature failure. It will also damage the lubricant.



Oil analysis

- A study by Dr. P. B. Macpherson showed that the greatest impact of filtration was when particles down to 3 μm were removed



Ref: A study by Dr. P. B. Macpherson

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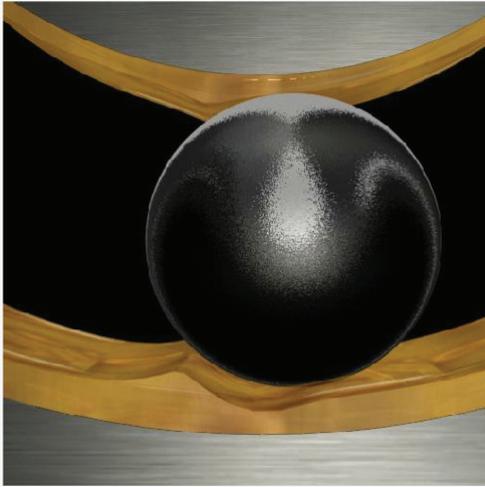
Oil analysis



- Oil analysis has been in active use for many years.
- Kits and mini-laboratories can be purchased for on-site testing, and/or oil samples can be sent off-site for testing and analysis.
- Tests are performed on lubricating oils (combustion engines and non-combustion rotating machinery) and hydraulic oil.

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Oil analysis



- There are three goals with oil analysis:
- **Check the chemistry** of the lubricant – make sure that it is able to do the job correctly.
- **Check for contamination** – make sure that water, or other liquids or particulates cannot affect the lubricant or your machine.
- **Check for wear** – determine the presence, nature, source, and severity of wear.

Oil analysis [pros]

- Understand the condition of the lubricant
- Detect contamination of the lubricant
- Detect wear of the components

Oil analysis [cons]

Requires investment to take samples correctly

Cost associated with oil lab service

Complicated test results

Must understand limitations



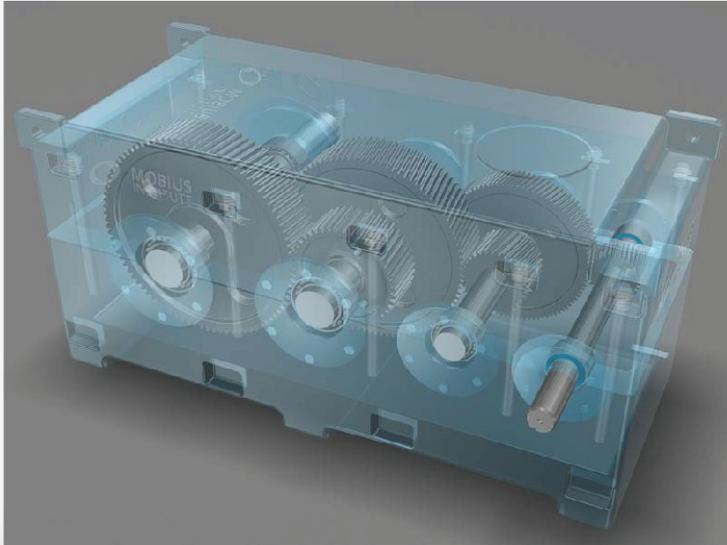
Wear debris analysis

Checking the lubricant and hydraulic fluids for wear particles or particles associated with contamination



Wear particle analysis

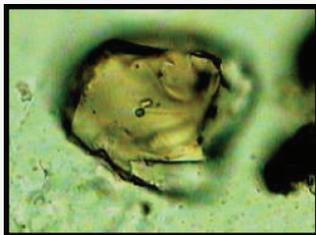
- Wear debris analysis is a very important tool for gearboxes, oil lubricated bearings, diesel engines and other oil lubricated components, plus hydraulic fluids.



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Wear debris analysis: Identifying particles

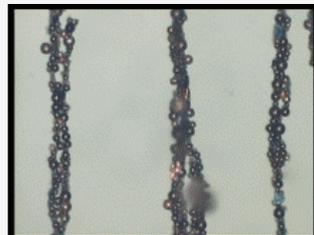
- The following images taken from filtergrams and ferrograms demonstrate of what can be seen under a microscope.



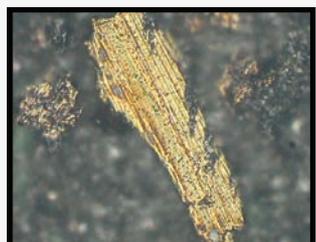
Silica Crystal



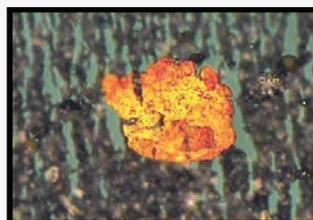
Cutting Wear



Spherical particles



Severe sliding



Bearing wear

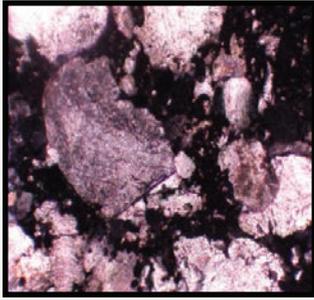


Gear wear

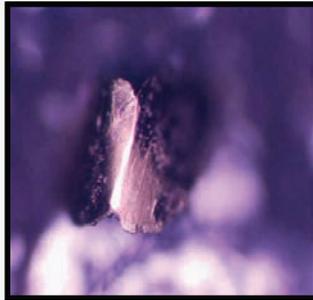
Samples from www.oiltest.com.au

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Wear debris analysis: Identifying particles



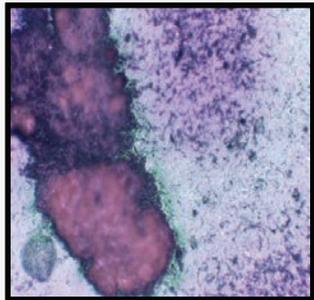
Fatigue Chunks



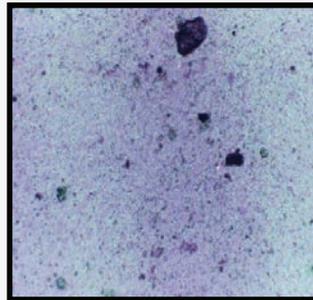
Non-Ferrous Bearing Wear



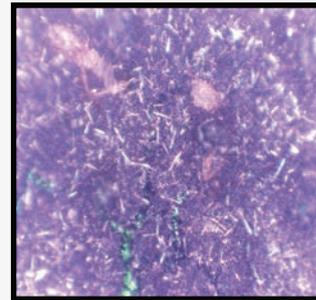
Gear Spalling



Red Oxides \ Corrosion



Coal Ingress



Filter Failure - Fibres & Contamination

Samples from www.oiltest.com.au

Wear particle analysis [pros]

Understand the condition of bearings, gears
and hydraulic components

Detect sources of contamination

Can be performed inexpensively

Wear particle analysis [cons]

Requires investment to take samples correctly
Cost associated with oil lab service
Complicated test results



Infrared (IR) analysis (thermography)

A very quick overview of the infrared analysis technology



Special thanks to João Pais from "Specman", Portugal for a number of the thermal images in this section.

Thermography [pros]

Very versatile: mechanical, electrical, process

Affordable*

Easy to use*

Works well with vibration and ultrasound



Thermography [cons]

Not as simple to use as people think

Understanding the technology

Understanding the equipment/process

Understanding thermal properties

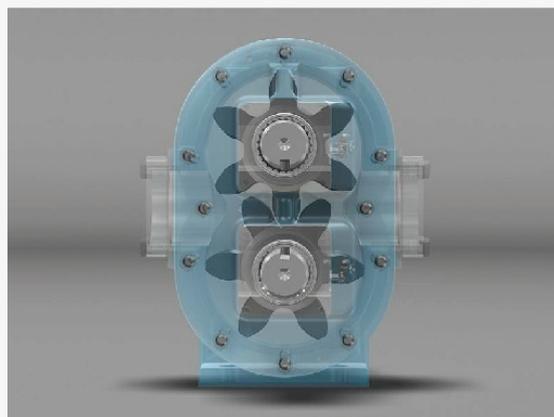
Mechanical: Late stage fault detection

Be careful around electrical components



Conclusion

Wrapping up condition monitoring



- Understanding the strengths and weaknesses of each technologies, and understanding the failure modes of your equipment enables you to achieve the greatest results.
- But never forget why you are doing it; to avoid failure (and the consequences) and ideally to improve reliability.

Combining technologies

Integrated condition monitoring

Combining technologies

- Different technologies have overlapping capabilities.

	Pumps	Electric Motors	Diesel Generators	Condensers	Heavy Mobile Equip't	Circuit Breakers	Valves	Heat Exchangers	Electrical Systems	Transformers	Tanks / Piping
Vibration Analysis	✓	✓	✓		✓						
Lube / Fuel Analysis	✓	✓	✓		✓						✓
Wear Particle	✓	✓	✓		✓						
Bearing Temp Analysis	✓	✓	✓		✓						
Performance Monitoring	✓	✓	✓	✓				✓		✓	
Ultrasonic Noise	✓	✓	✓	✓			✓	✓	✓	✓	✓
Infrared Thermography	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
NDT (Thickness)				✓				✓			✓
Insulation Resistance		✓	✓			✓			✓	✓	
Motor Current Analysis		✓									
Polarisation Index		✓	✓						✓		
Electrical Monitoring									✓	✓	
Visual Inspection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Combining technologies

- There is overlap between the technologies
 - Some overlap and provide confirmation
 - Wear particle analysis and vibration in gearboxes
 - Ultrasound and thermography in steam trap faults
 - Vibration and motor current analysis
 - Some provide earlier warnings than others
 - Bearings emit high frequency vibration before they increase in temperature
 - Some provide indication of root cause
 - Ultrasound with lack of lubrication
 - Oil analysis and contamination

Combining technologies

- Some provide a unique indication of the fault
 - Ultrasound can detect corona and leaks
 - Thermography provides an indication of insulation problems (tanks, steam pipes, etc.)
 - Vibration can detect unbalance
 - Oil analysis provides an indication of lubricant condition

Combining technologies

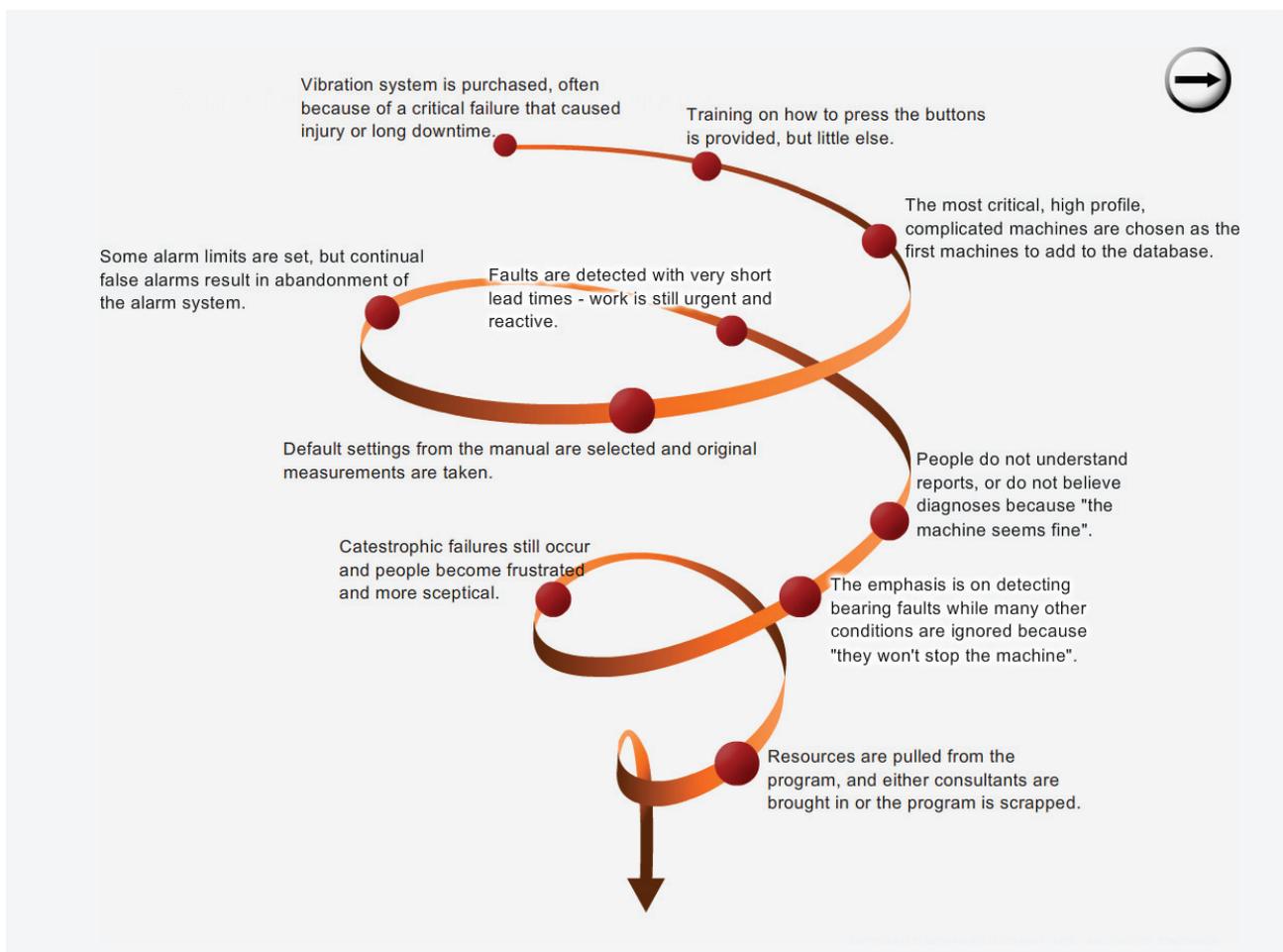
- It is also important to consider the issue of detection versus diagnosis versus prognosis
 - Detection:
 - How do we detect that a failure is occurring?
 - Question: How early should the detection be made?
 - Diagnosis:
 - How do we determine what is wrong and therefore what correction will be required?
 - Question: How important is the accuracy of the diagnosis?
 - Prognosis:
 - What will happen in the future?
 - Question: Consider financial, safety, risk, and probability

7 Program setup

How to set-up and manage the program for success

Running a successful program

- Too many programs are run in an ad-hoc way
 - Buy some instrumentation
 - Follow some basic guidelines to set it up
 - Arbitrarily decide what to test
 - Arbitrarily decide where to test it
 - Arbitrarily decide on test schedule (test more often if critical)
 - Training focuses more on button-pressing than “theory”
 - Take proper training and certification *later*
 - *Reports are technical*



Make believers [philosophy]

You will be a fish swimming upstream unless the planners, maintenance, and operations **believe in the philosophy.**

Suggestion:

Teach people about age-related versus random failures



Make believers [technology]

You will be a fish swimming upstream unless the planners, maintenance, and operations **believe in the technology** – they won't believe your diagnosis and recommendation.

Suggestion:

Teach people about the technology



Make believers [plant floor]

You will be a fish swimming upstream unless the “plant floor” believes in, **and does not feel threatened,** by the technology and philosophy.

Suggestion:

Provide “toolbox talks” to demystify and create buy-in



Make believers [leadership]

You will be a fish swimming upstream unless senior management believe in the philosophy ***even when there are not many failures.***

Suggestion:

Provide “manager briefings” and communicate regularly about the benefits



Understand the machine

Don't become wall-chart analysts.

Understand how the machines work and how they fail - and how that changes the vibration, temperature, sound, and lubricant.

Suggestion:

Learn about the machines

Understand the instrument

Don't use the default settings.

Understand what the options mean, how to set them and when to use them.

Suggestion:

Learn about the technology

Write clear reports

Condition monitoring is pointless unless you provide **actionable information**.

Suggestion:

Tell people what's wrong, what has to be done and when it has to be done



Certification

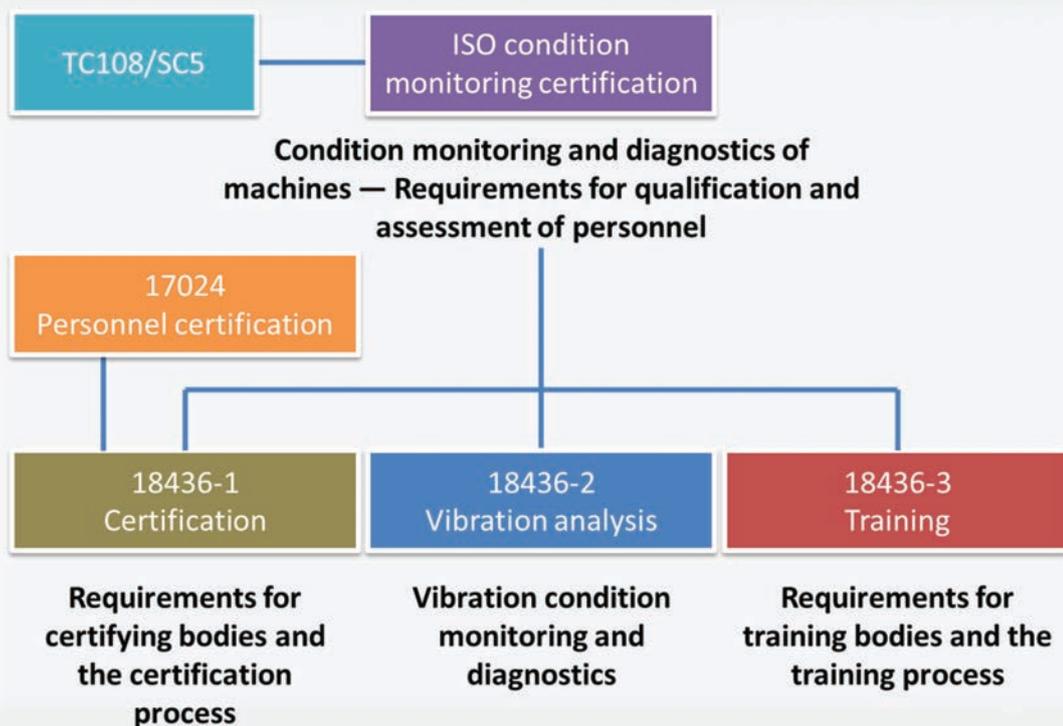
Becoming qualified



Background

- There are five relevant standards when it comes to certification in vibration analysis:
 - Three relate specifically to condition monitoring training and certification
 - ISO 18436-1:2012 - Certification
 - ISO 18436-2:2014 - Vibration analysis
 - ISO 18436-3:2012 - Training
 - One relates to the certification of competence in any field
 - ISO/IEC 17024: 2012 - Personnel certification
 - And one relates to quality management:
 - ISO 9001:2008 - Quality management systems

Background





Background

- Note that there are other condition monitoring certification standards where we offer certification:
 - Infrared thermography 18436-7:2008
 - Ultrasound 18436-8:2013
- And other standards where will be offering certification in the future:
 - Field lubricant analysis 18436-4:2014



Benefits of certification

- Provides evidence of:
 - Training
 - Experience
 - Competence
- Provides a universal benchmark across all condition monitoring groups, even in different countries
- Provides a framework for training
- Has proven to be aspirational – vibration analysts striving to learn more and achieve recognition in their professional field
- Enables a company to identify those with the aptitude, interest and drive to perform the challenging vibration analysis tasks
 - Including program management
- (Provides some evidence that attendees paid attention during class)

Benefits of certification

- Certification gives peace of mind knowing that your employees meet a knowledge standard that is recognised globally as the minimum required for Condition Monitoring personnel who perform specific tasks.
- It ensures that they have retained information that is needed for day-day decision making, increasing efficiency of time and reducing the risk of errors.
- When employing new personnel or promoting others to supervisory roles, the four levels of Certification gives an indication of the technical skills of the people under consideration.

To become certified

- In order to become certified *in vibration analysis*:
 - Must meet experience requirements:

Requirements	Category I	Category II	Category III	Category IV
Experience	6 months	18 months	36 months	60 months

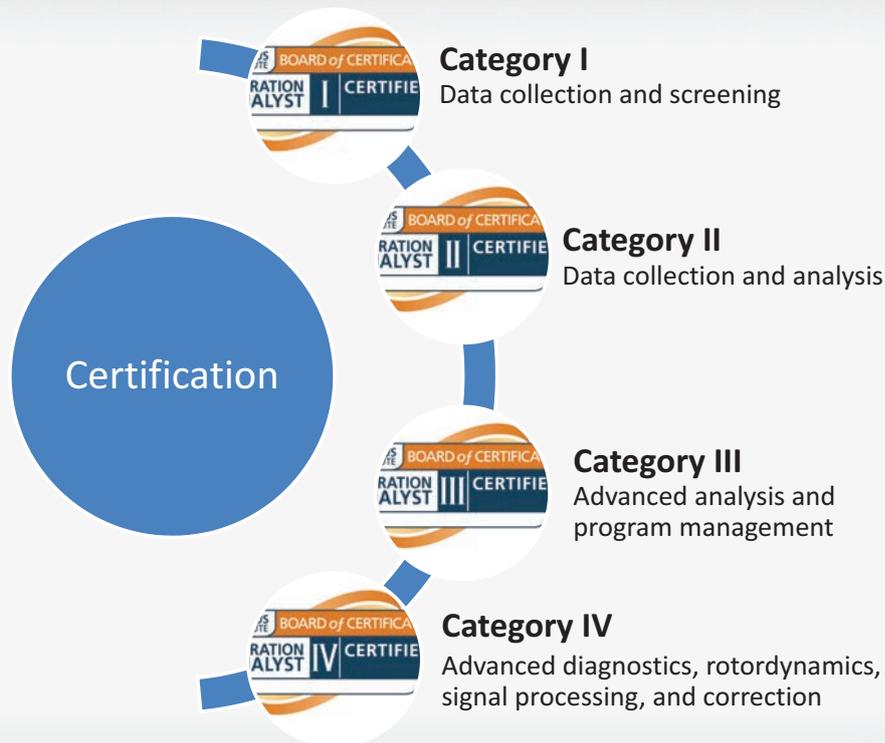
- Must meet training requirements:

Requirements	Category I	Category II	Category III	Category IV
Training	30 hours	+ 38 hours	+38 hours	+64 hours

- Must pass an exam:

Requirements	Category I	Category II	Category III	Category IV
Exam	60 Q's 2 hours	100 Q's 3 hours	100 Q's 4 hours	60 Q's 5 hours

Certification



Certification

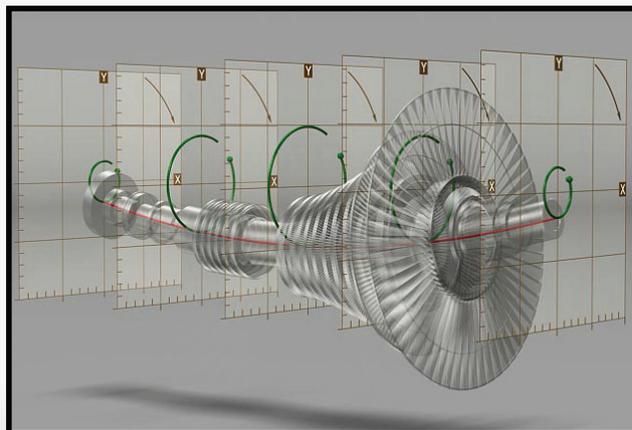
- **Category I**
 - Person primarily collecting data and previewing the data for quality purposes
 - Sometimes is the eyes and ears of the analyst
- **Category II**
 - Is probably also collecting data
 - Performing vibration analysis
 - Most common fault conditions
 - Understanding of dynamics and more complex topics
 - Should be using waveforms, phase, and enveloping
 - Correction: basic balancing and alignment
 - Should *not* be responsible for the design of the program

Certification

- **Category III**
 - The program manager
 - Tuition for junior analysts
 - Oversight of Category I and II analysts
 - Can solve most common fault conditions
 - Must understand waveforms, phase, enveloping
 - *Introduction to Category IV topics*

Certification

- **Category IV**
 - Superheroes of the vibration world!
 - Structural dynamics, rotordynamics, journal bearings, orbits, modal analysis, ODS, signal processing
 - Correction: Balancing, alignment, vibration control, resonance



Conclusion

Conclusion



- Understanding the strengths and weaknesses of each technologies, and understanding the failure modes of your equipment enables you to achieve the greatest results.
- But never forget why you are doing it; to avoid failure (and the consequences) and ideally to improve reliability.

Thank you!
That concludes this presentation



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