Condition Monitoring
(Why, what, when, where, who & The Need to do Better)

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Production

Pumps, motors, fans, compressors, mills, lathes, or whatever generally have moving and stationary parts. Between them you need something to reduce friction and wear. Often this is a lubricant.

How good it is affects efficiency.

How well it and the bearings are maintained affects productivity.

Knowing how these are doing is condition monitoring.

Condition Monitoring

To assess the status of the equipment AND to be able to quantify important parameters for trending.

Sight – level, flow & pressure gauges

Touch – temperature & vibration

Sound – audible noise & ultrasound

Taste - analysis

Smell – sniffers & DGA

Condition Monitoring

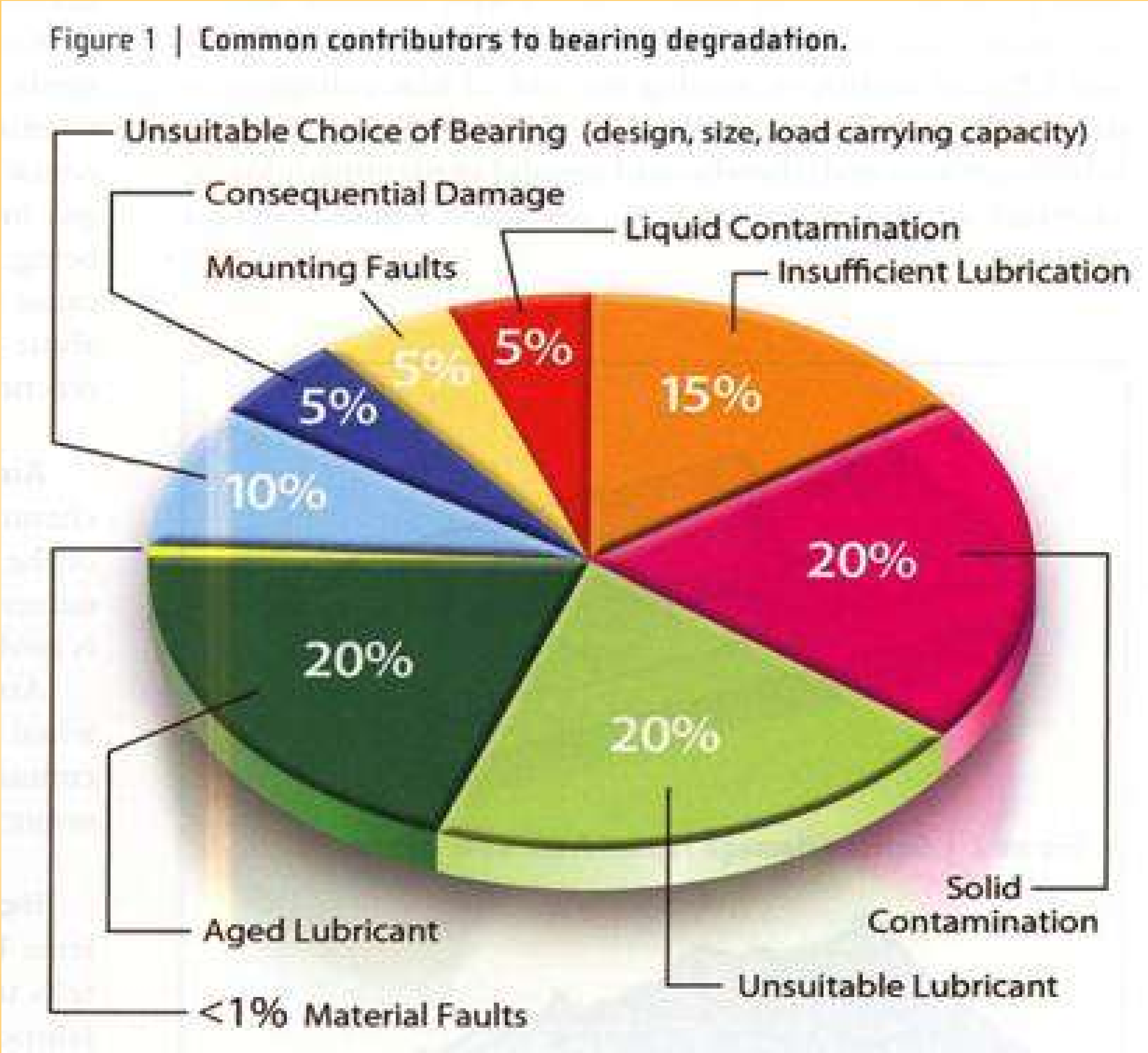
The tests for condition monitoring are not just for the lubricant and even those for the lubricant can be quite different from those used for production, quality assurance and/or product development.

The reason is that in the field you have to be able detect contamination, wear and possibly environmental issues. Contamination can be from water, particles, air, cross contamination, etc.

Condition Monitoring - Why

Misalignment, unbalance, loose support bolts, failing impellors, worn bearings, failing bearings, lubrication issues, electrical problems, plugging filters, wrong oil levels, leaks, etc.

Proactive measures can sometimes prevent the problems in the first place.



Ref: 'Lubricant management for non-circulating sumps', M. Johnson, TLT, August 2009 pp 16-23

Condition Monitoring - What Else?

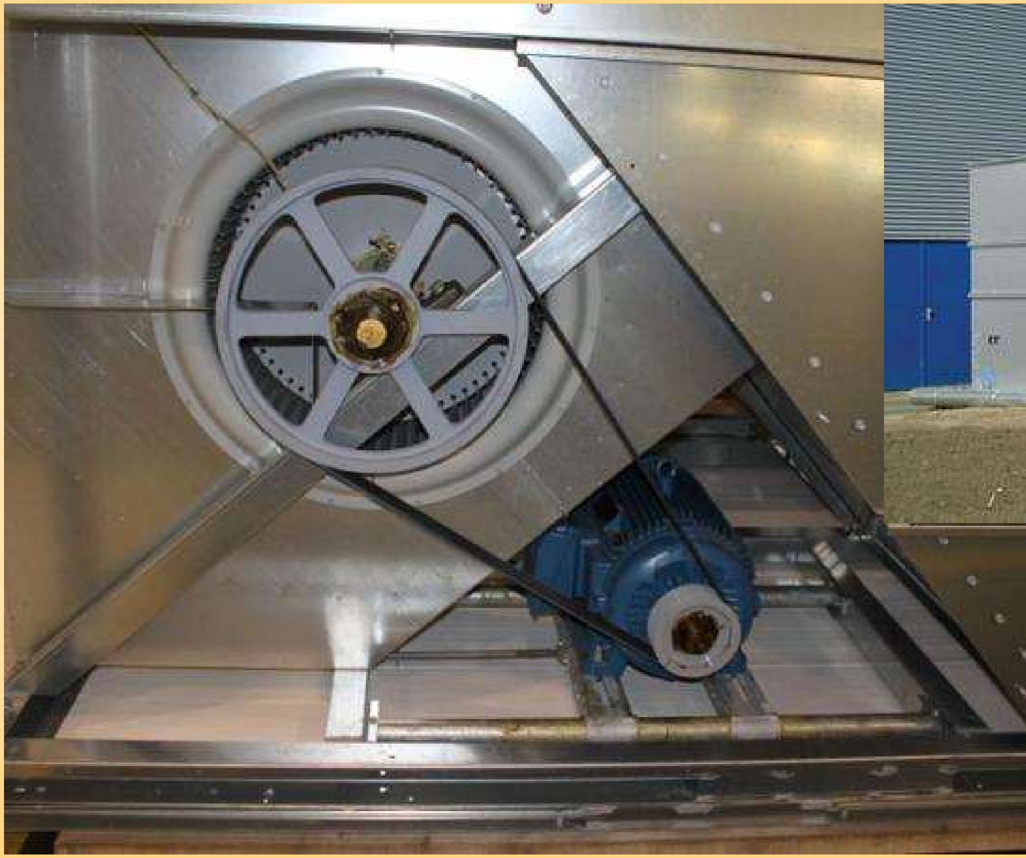
Failure mode, effects and criticality analysis (FMECA) is an extension of failure mode and effects analysis (FMEA) by including a criticality analysis. It is used to chart the probability of failure modes against the severity of their consequences.

The "Right" Stuff

Achieving real benefits requires true consideration of the five R’s of lubrication.

- **right lubricant**
- **right amount**
- **right place**
- **right time**
- **right way**

Condition Monitoring - Where



Ref: www.baltimoreaircoil.eu

Mishap Severity Categories (MIL–STD–882)

Category 1: Catastrophic -Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation.

PAS55
(Publically Available Specification)

PAS55

4.6 Performance assessment & improvement

4.6.1 Performance & condition monitoring
4.6.2 Investigation of asset-related failures, incidents & nonconformities
4.6.3 Evaluation of compliance
4.6.4 Audit
4.6.5 Improvement actions
4.6.6 Records

What Next?

Final resolution might require the use of one or more of the five main nondestructive testing techniques;

- **Magnetic particle**
- **Liquid penetrants**
- **Ultrasonics**
- **Radiography and/or**
- **Eddy current**

Brown’s First Law Of Applied Tribology

(Power Generation)

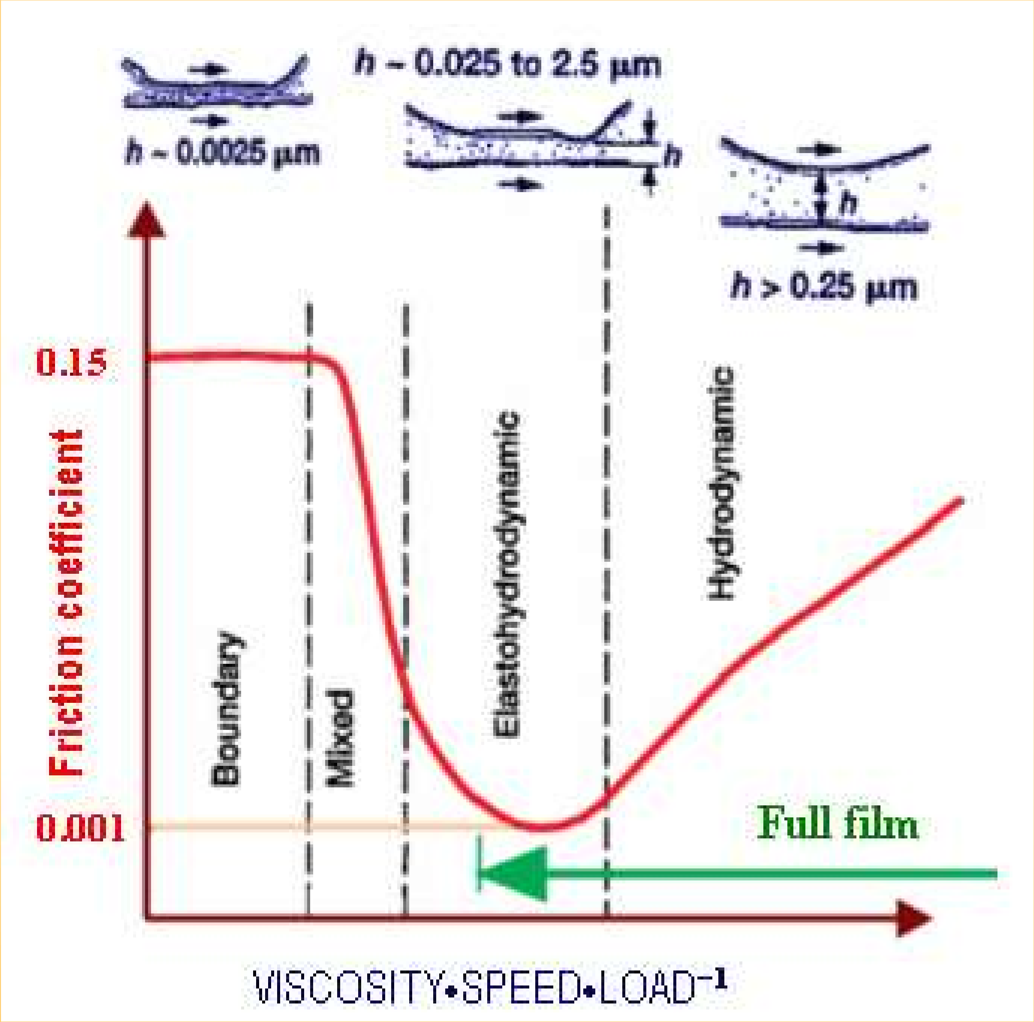
If it's running,
It's wearing

If it's not running,
It's probably worn!

Corollary 1: if not the above then it may be on standby in case something else wears out.

Corollary 2: if the equipment is not economical to run, this is probably because of a loss of efficiency as a result of wear.

Moving Surfaces - Stribeck Curve



Rolling Element Bearings Lives - Now

New life theory (ISO 281:2007) takes into account the viscosity ratio of actual vs. required, type of bearing, type of loading and cleanliness of the oil.

$$L_{naa} = a_1 \, a_{ISO} (C/P)^3$$

L_{naa} = *adjusted rating life in millions of revolutions*

a_1 = *life adjustment for reliability (i.e. 10% failure)*

a_{ISO} = *life adjustment factor based on new life theory*

C = *Basic load rating*

P = *Equivalent dynamic bearing load*

Rolling Element Bearings Lives - Now

Life Modification Factor a_{ISO}

Among other things considers the influence of:

- ***Fatigue limit of the bearing material by the fatigue load limit C.***
- ***Grade of contaminations by the factor $e_{c.}$***
- ***Lubrication conditions by the viscosity ratio κ.***

Note: *ISO 281:2007 does not cover the influence of wear, corrosion and electrical erosion on bearing life.*

Ref: www.cwbearing.com

Adjustment Factor for Contamination

Very clean - Debris size the order of the film thickness	*1*
Clean – typical of bearings greased for life and sealed	*0.8*
Normal – typical of bearings greased for life and shielded	*0.5*
Contaminated – typical of bearings without integral seals, coarse filters and/or particle ingress from surroundings	*0.5 .. 0.1*
Heavily Contaminated	*0*

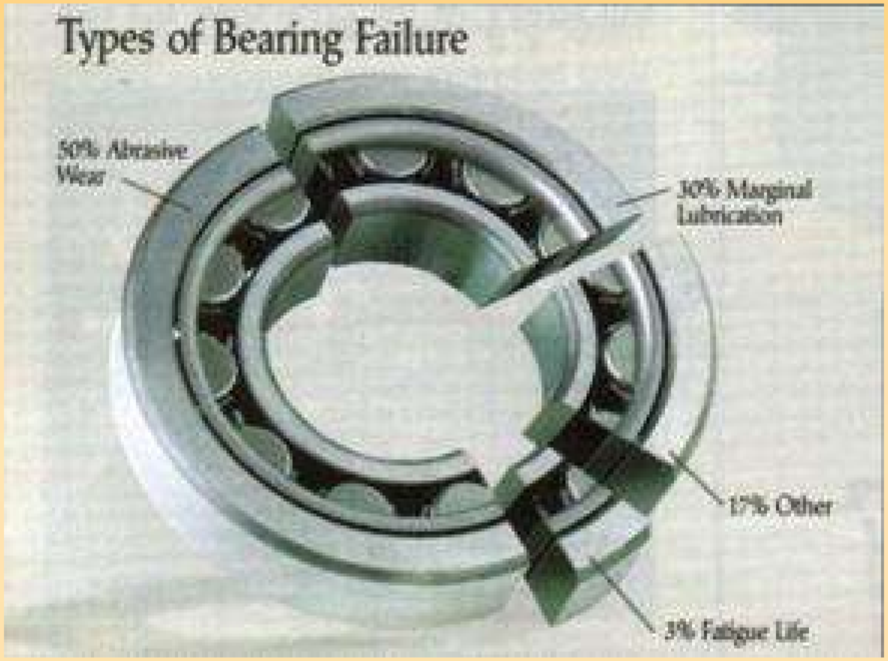
Rolling Element Bearings

Unfortunately the leading causes of failures are reported to be improper lubrication and improper mounting.

'These are preventable.'

Hafner, E.R., 'Proper Lubrication-The Key To Better Bearing Life, Part 1: Selecting The Correct Lubricant', Mech. Eng., pp 32-37, October 1977

Rolling Element Bearings



In real life it has been reported contaminants cause 50% of bearing failures.

Rolling Element Bearings

Remaining causes are;

Marginal lubrication	**30%**
Other	**17%**
Fatigue life	**3%**

It was reported that they typically fail at 20% of their catalogue life. Again this is a real waste.

Ref: NSK as reported in Machinery & Equipment MRO, p13 June 1999

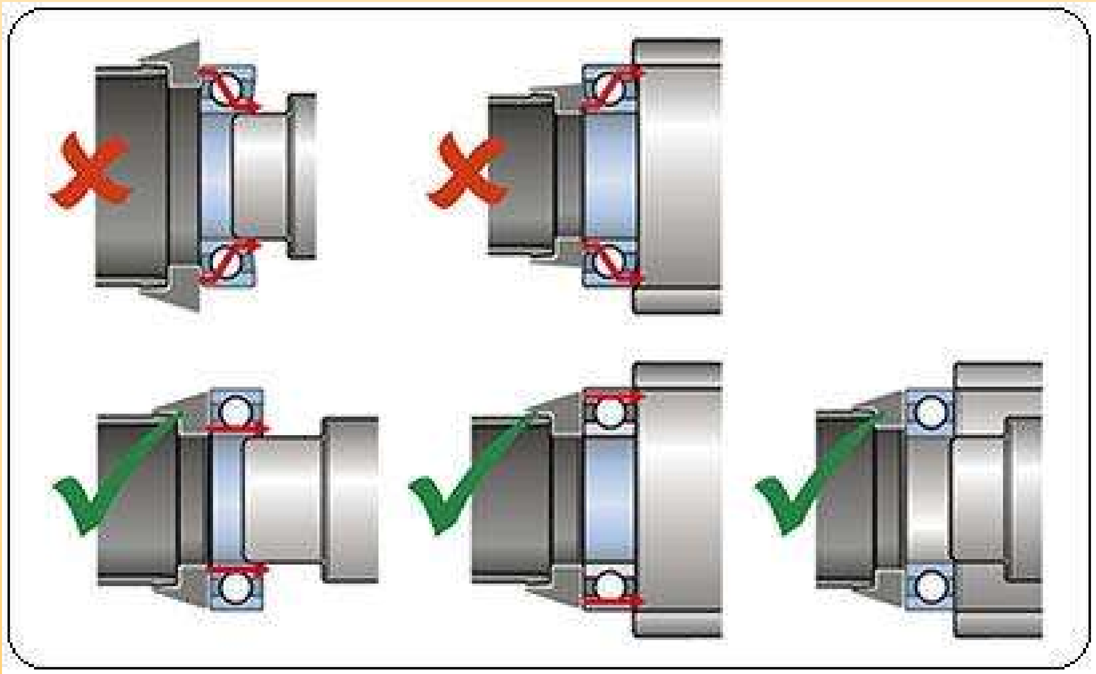
Proactive – Do They Have the Right Tools?

Proper sized adapter ring, impacts sleeves and a soft tipped hammer.

Ref: www.mapro.skf.com/products/

Proactive – Do They Have the Right Training?

Mounting forces must not pass through the rolling elements



Ref: www.mapro.skf.com/products/

Proactive – How Do You Compare?

Ref: IAEA-TECDOC-1551 Implementation Strategies and Tools for Condition Based Maintenance at Nuclear Power Stations

Visual – Sight Gauges – some are just ok

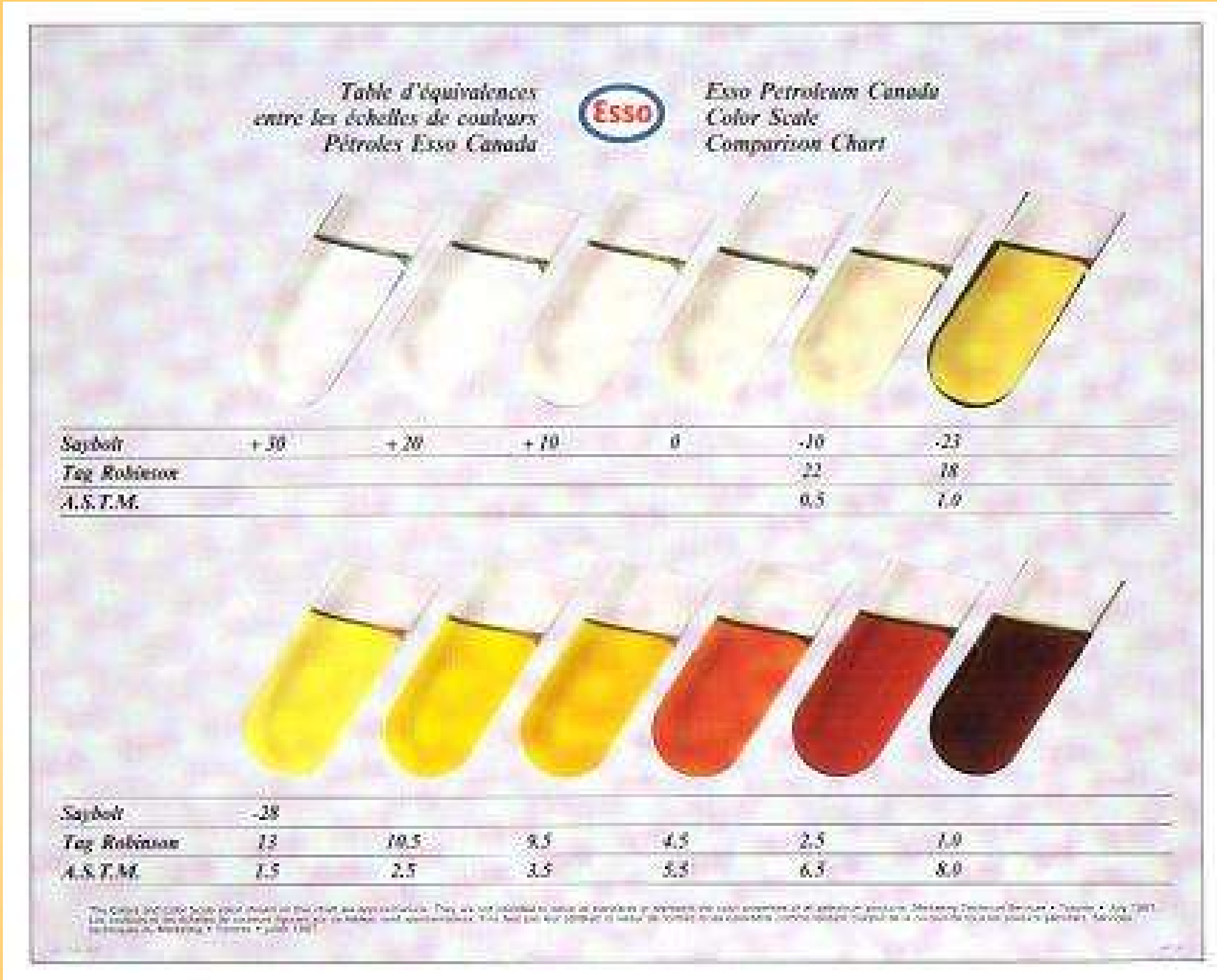
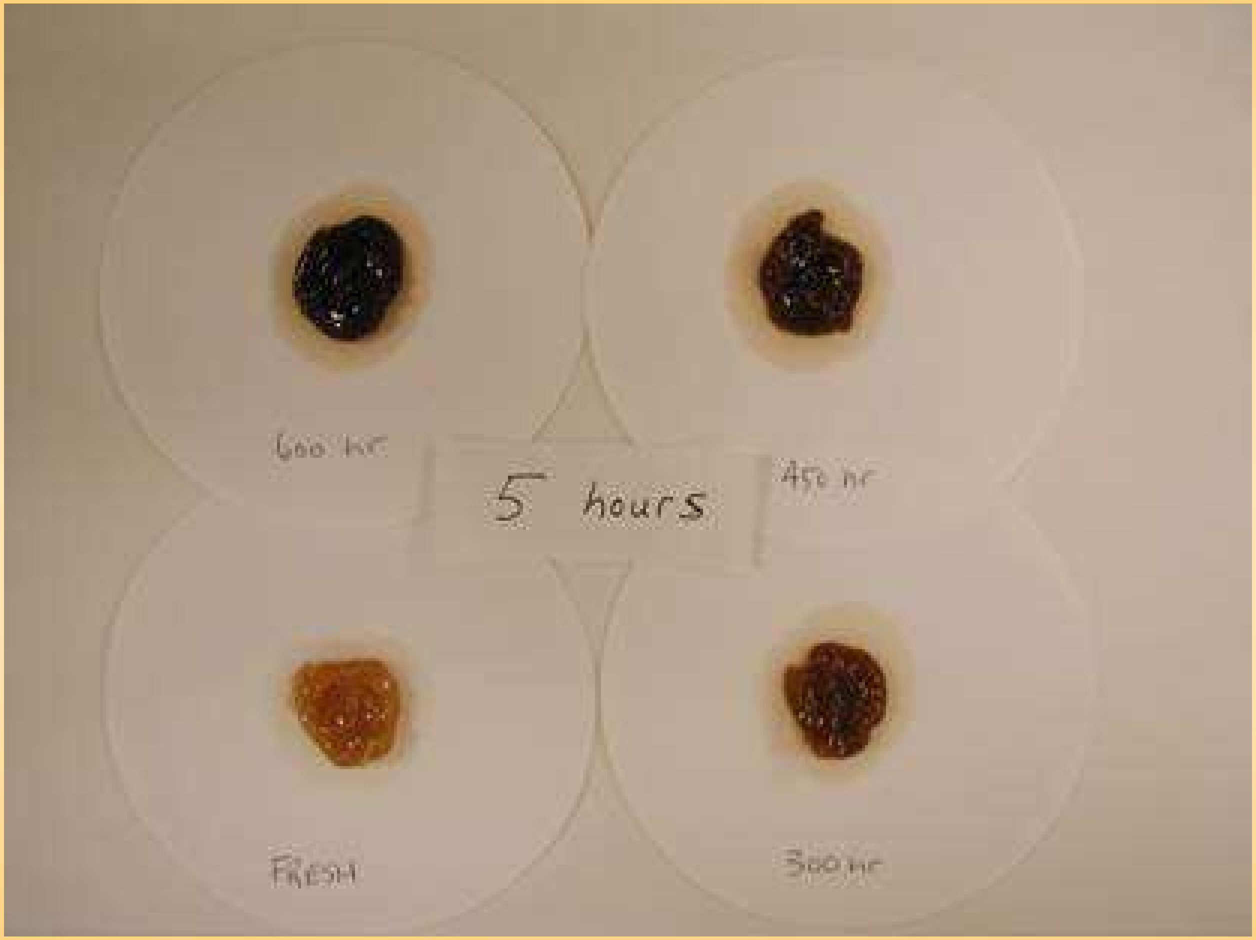


Table d'équivalences
entre les échelles de couleurs
Pétroles Esso Canada
Esso
Esso Petroleum Canada
Color Scale
Comparison Chart
Saybolt +30 +20 +10 0 -10 -23
Tag Robinson 22 18
A.S.T.M. 0.5 1.0
Saybolt -28
Tag Robinson 13 10.5 9.5 4.5 2.5 1.0
A.S.T.M. 1.5 2.5 3.5 5.5 6.5 8.0

Visual – Pressure Gauges – some are okay

Visual – Pressure Indicators – some are not so good

Blotter



Fresh And Three Aged Samples – Color Change

(Left For 5 Hours At Room Temperature)

‘New’ Tests

R/S Rheometer

‘New’ Tests

Ruler Test Equipment

‘New’ Tests

Spectroil Q100 Oil Analysis Spectrometer

Standard includes 22 elements.

Wear Metals: Al, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Mo, Ni, Ag, Sn, Ti, V & Zn

Contaminants: B, Ca, K, Si & Na

Additives: Ba, B, Ca, Cr, Cu, Mg, Mo, P, Si & Z

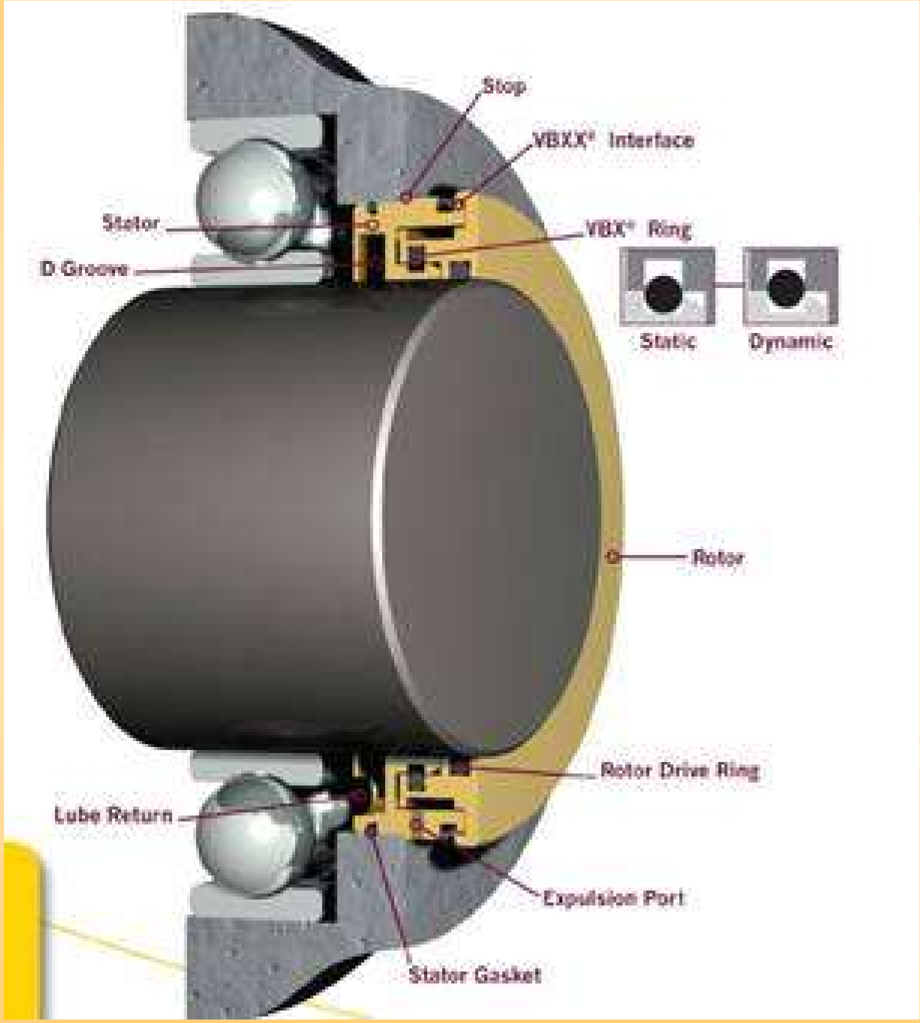
Additional 13 can be added: Sb, Bi, As, In, Co, Zr, W, Sr, Li, Ce, Nb & Rh

Major Causes Of Premature Engine Bearing Failure

	%
Dirt	**44.9**
Misassembly	**13.4**
Misalignment	**12.7**
Insufficient Lubrication	**10.8**
Overloading	**9.5**
Corrosion	**4.2**
Other	**4.5**

Ref: Clevite AM-208-**8**

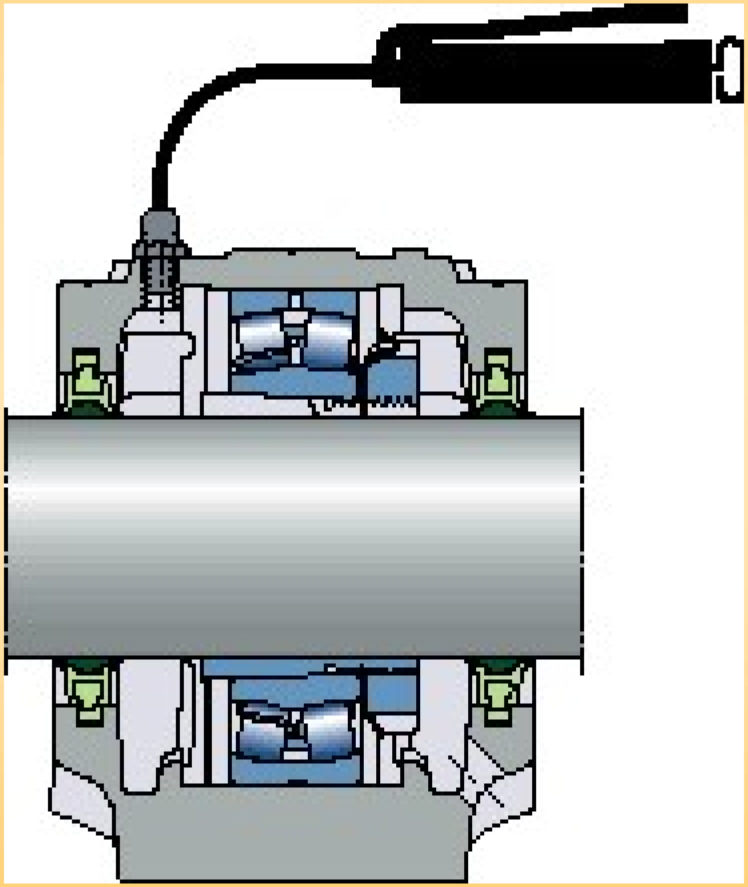
Better Seals – What is being used?



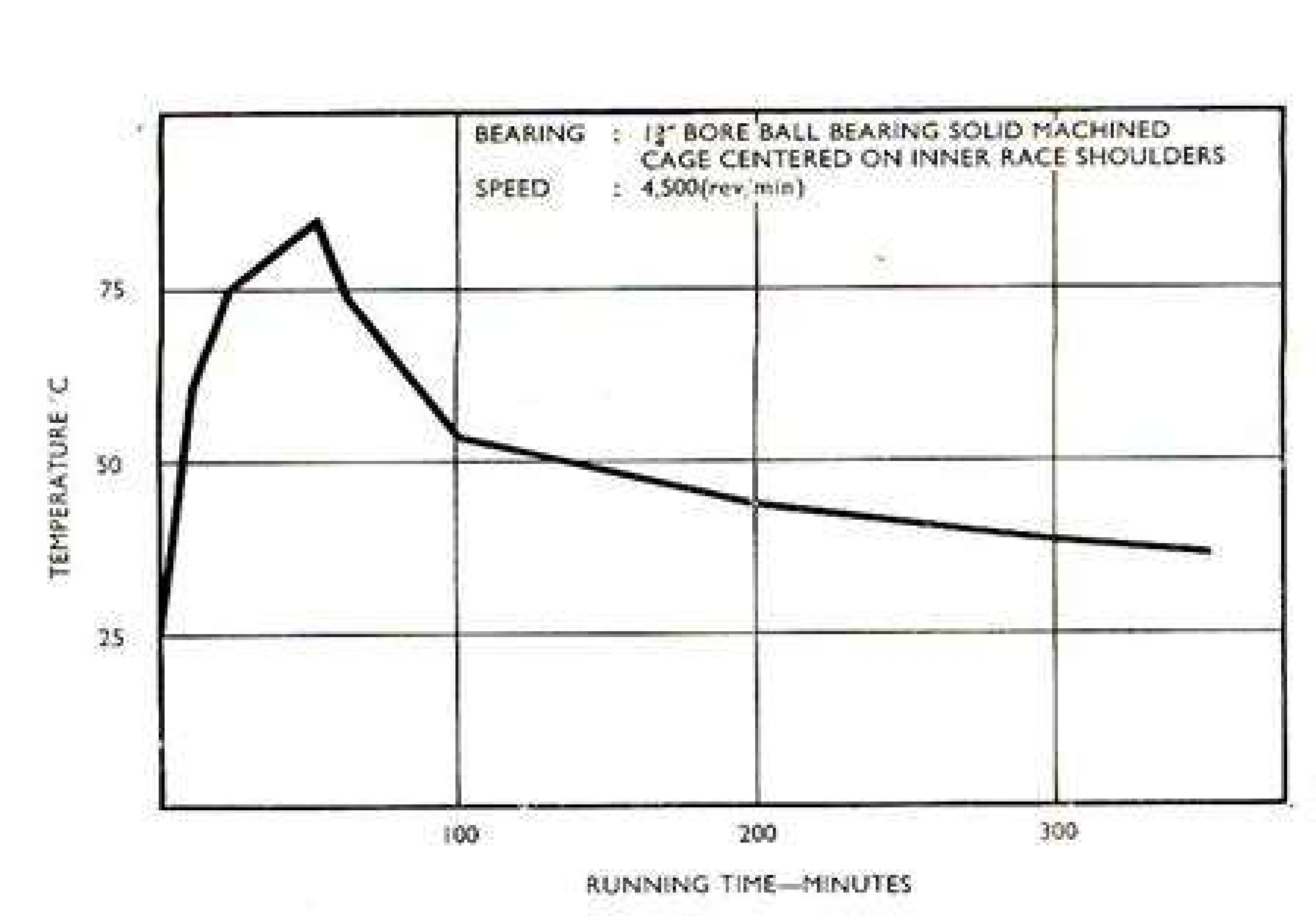
Fluid Additions – Condition Monitoring?

Ref: Des-Case

Greasing Bearings



‘Normal’ Temperature Rise



Ref: Harris, A.F., ‘The Lubrication of Rolling Bearings’, p. 118, Shell Int’l Petroleum Co. Ltd., 1972

Lube Causes of High Bearing Temperatures

- **Over-greasing the bearing, which forces the balls to push through excess grease as they rotate, leading to a sharp temperature rise.**

- **Too little grease in the anti-friction bearing, or too little oil in the sleeve bearing.**
- **Too low, or too high temperature, of the oil cooling water for the sleeve bearing.**

Ref: ‘Motor Bearings’, Global Cement Magazine October 2007

Lube Causes of High Bearing Temperatures cont'd

- **Friction of the bearing sealing (bad shaft seals leading to loss of grease or oil).**

- **Using a low-temperature grease which does not provide adequate viscosity at normal operating temperatures.**

- **Mixing incompatible greases, which can reduce the consistency of the grease and possibly the overall viscosity.**

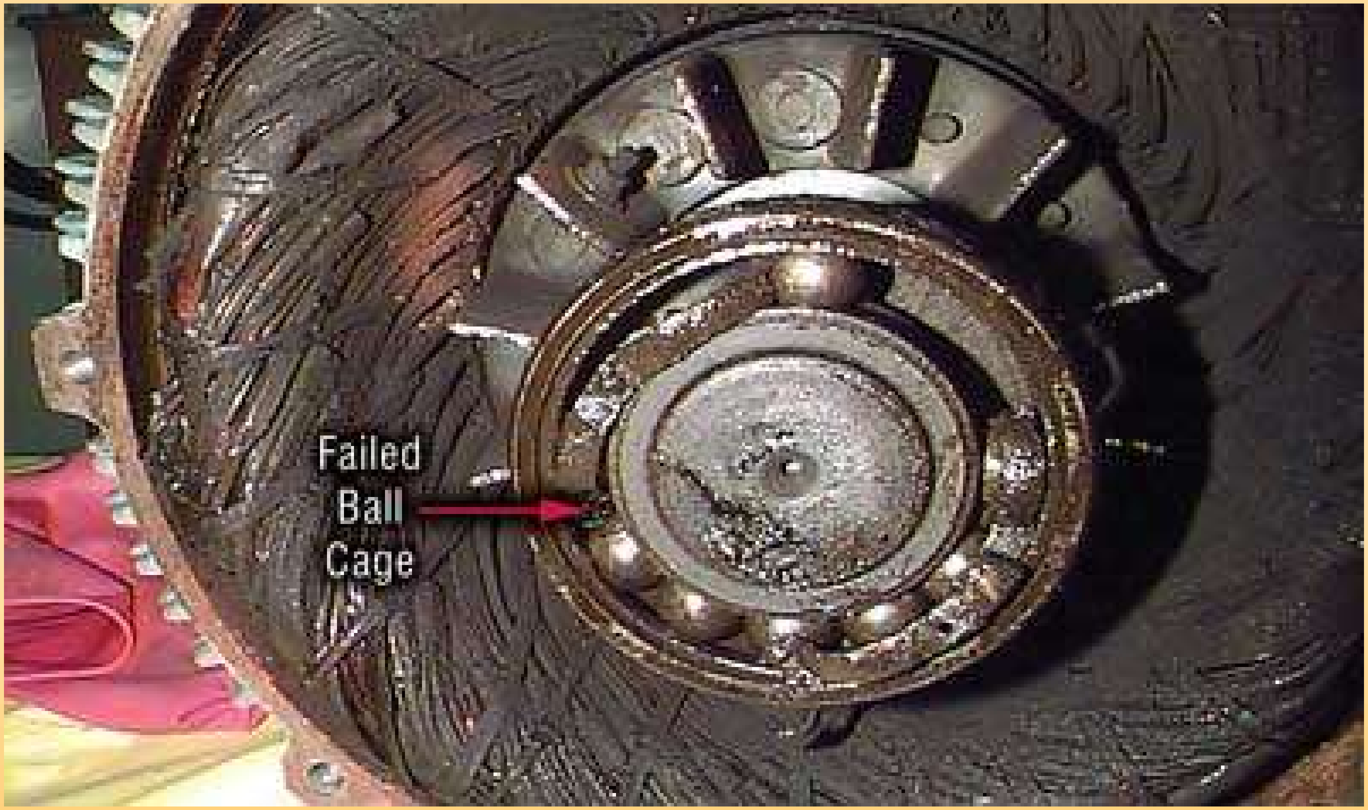
Ref: 'Motor Bearings', Global Cement Magazine October 2007

Reducing Motor Bearing Failures

Shell Canada found that at one of their refineries, 91% of the problems with motors were the bearings.

They were able to achieve a 90% reduction in such failures, mainly by better control of lubrication.

Over Greasing

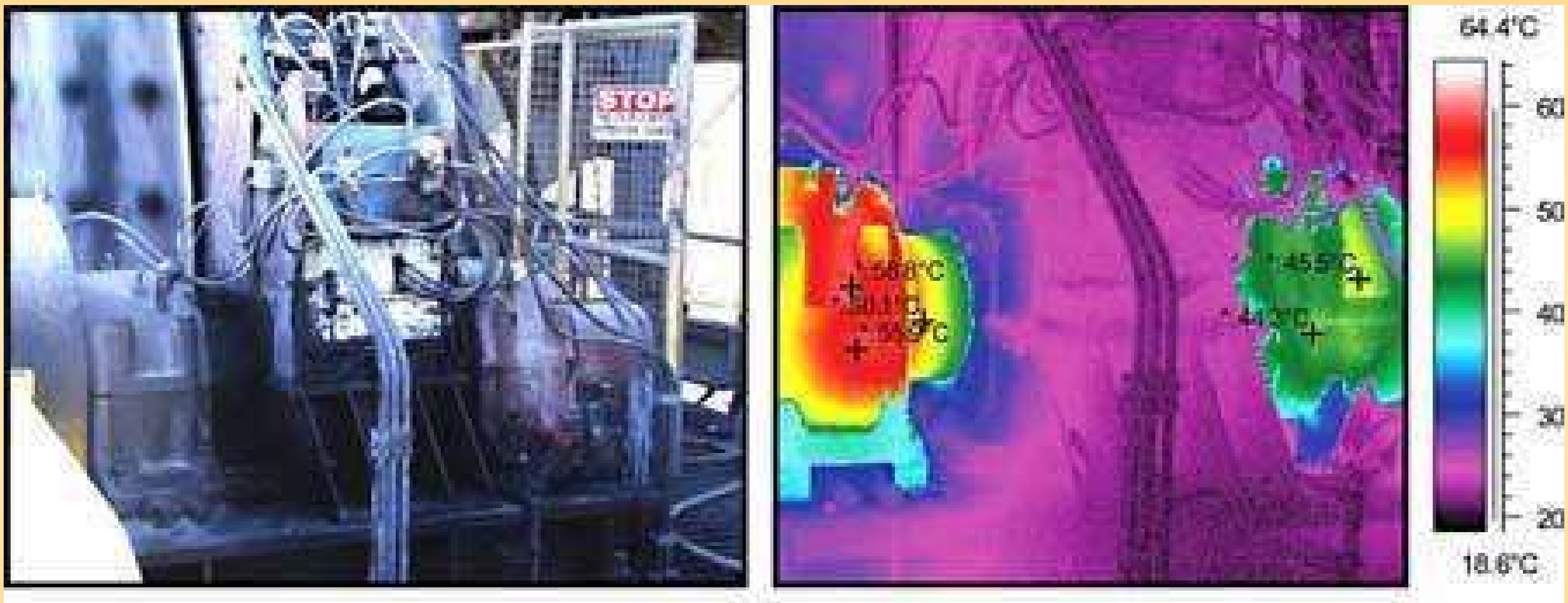


Preventing Over Pressurization

Provides for pressure-specific shut-off (for example, 20 psi).
At the given shut-off pressure, the grease flow will stop.

$0.35 each

Thermography

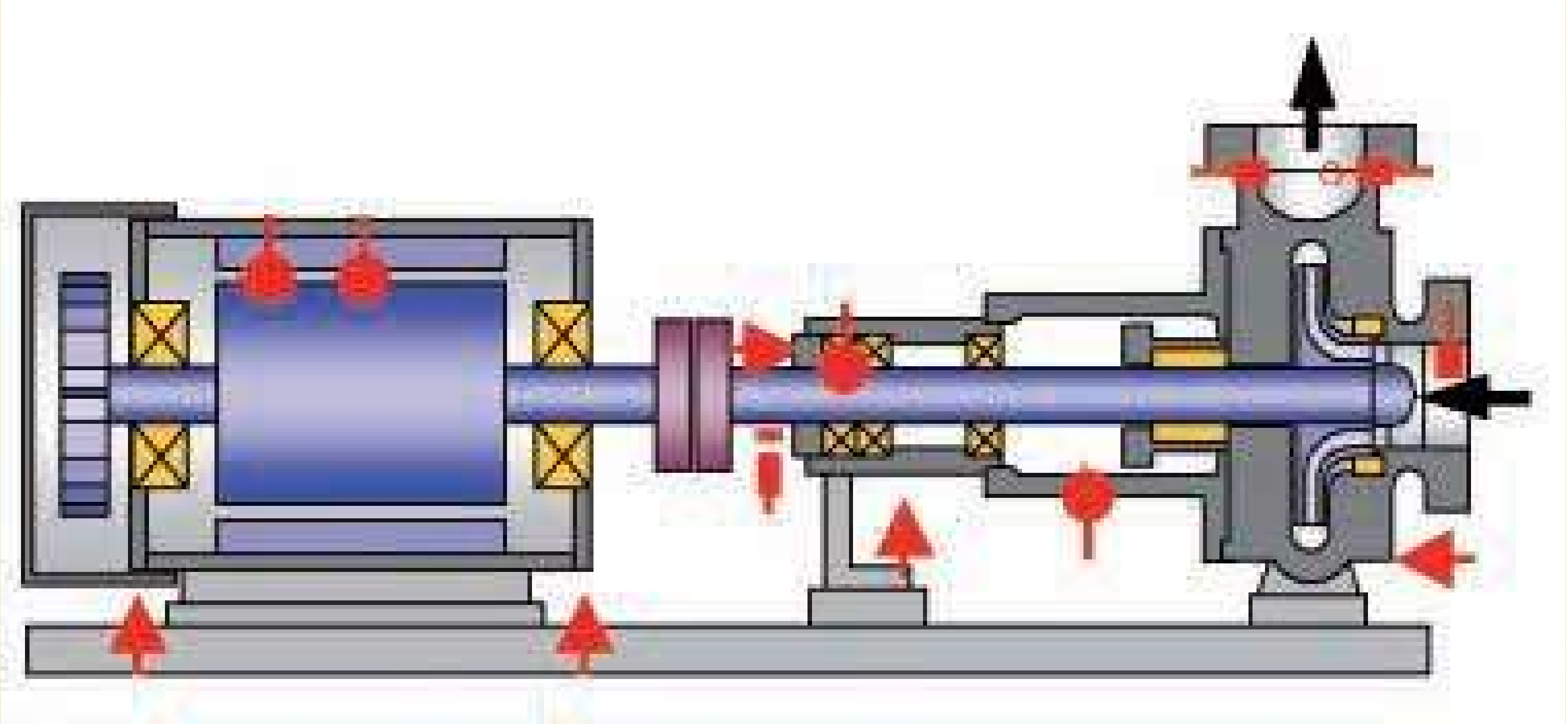


Ref: www.reliableplant.com/Articles/Print/28638

When Is Enough?

Courtesy: EA Grease Caddy

Vibration Analysis – Where & What?



For monitoring use the same place every time.

Ref: www.pruftechnik.com

Approximate Bearing Frequencies And Harmonics

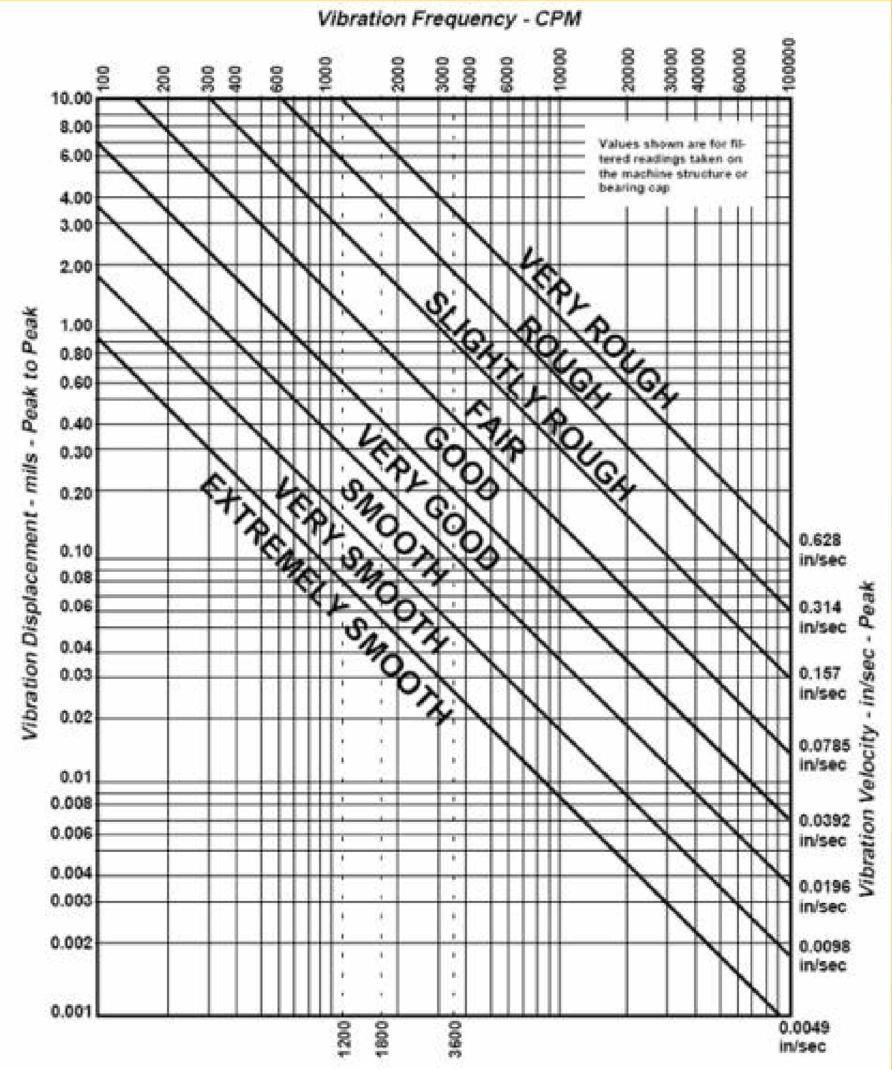
Ball Pass Frequency Outer Race (BPFO)
= # of rollers x shaft speed x 0.4

Ball Pass Frequency Inner Race (BPFI)
= # of rollers x shaft speed x 0.6

Fundamental Train Frequency (FTF)
= speed x 0.4

Ref: :http://www.reliableplant.com/Read/27324

Vibration Severity

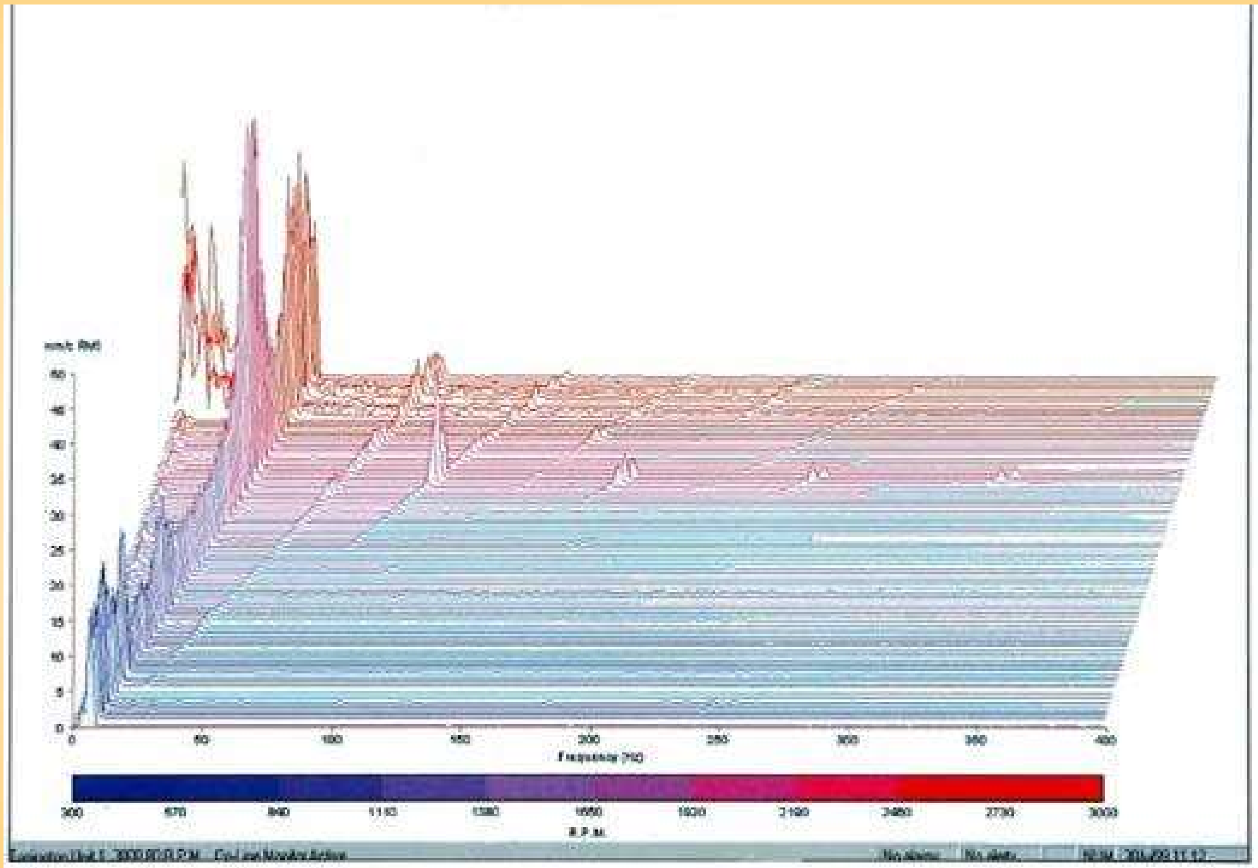


Ref: : www.irdmechanalysis.com

Vibration Analysis

Ref: : www.irdmechanalysis.com

Vibration Analysis - Example



Ref: : www.irdmechanalysis.com

What to Test and When

This is best based on your specific equipment, lubes, skill sets and criticality but there are still good guidelines readily available.

Example: ASTM D6244 Standard Practice for In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment

For gear/circulating oils, hydraulic oils, diesel engine oils, turbine type oils, air compressor oils, EHC (PO_4 esters) EHC Mineral Oils.

What Else?

Examine all removed parts including bearings and filter elements to refine the maintenance intervals and to learn what is happening.

For filter elements have both low and high pressure alarms. A differential pressure that does not increase is cause for checks.

Periodically look inside reservoirs to check fluid levels, look for foam, look for deposits and to look for any plunging returns.

Are we getting better?

Still failures.

Less training and fewer skilled crafts.

More outsourcing.

More ‘penny’ control.

Less innovation.

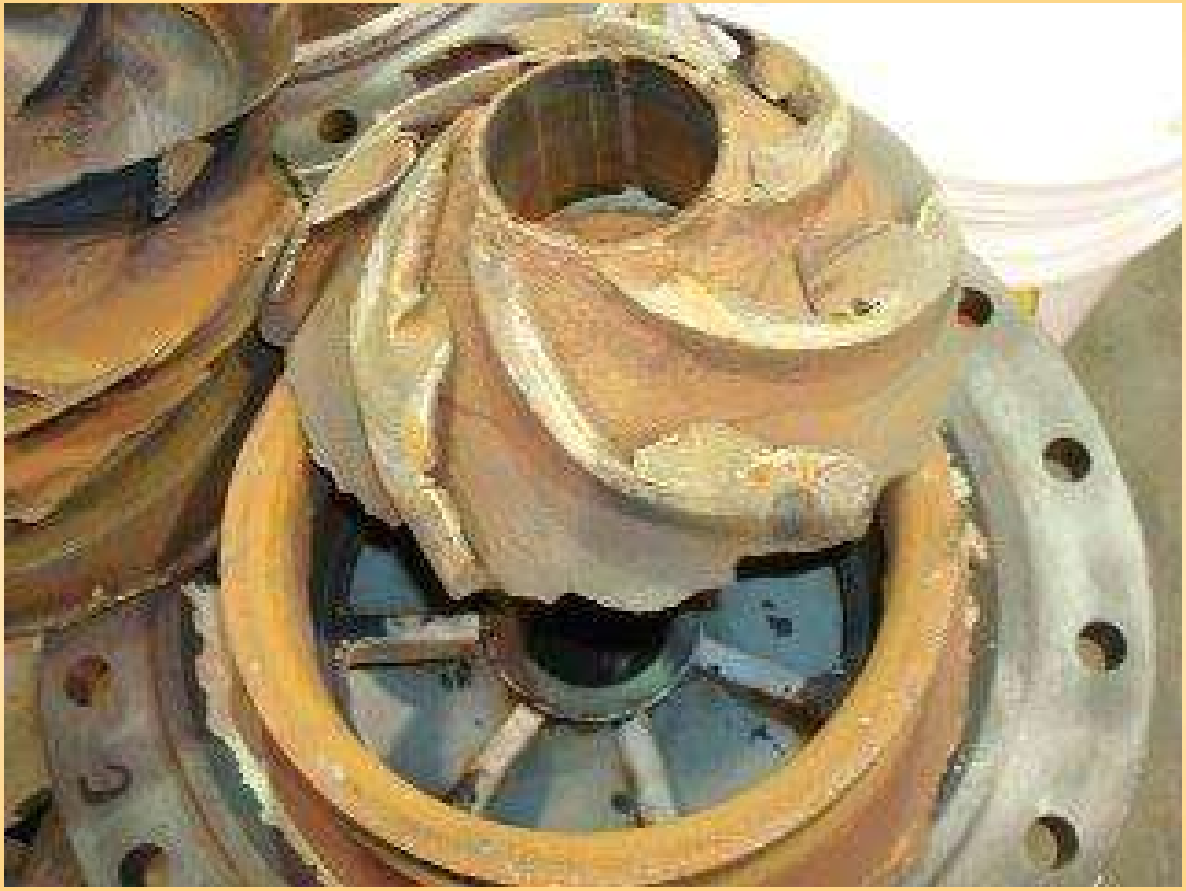
Less directed training.

Plus, counterfeit part issues.

Wind Turbines – expensive candles

Needs re knowing forces, lube requirements, maintenance and condition monitoring

Port Hope – water pumps



What happened, why and what warning signs were missed?

Be Proactive

- What is in your mechanics tool box?
- Do they have the training to do the job correctly the first time? How do you know?
- Can they get the right tools?
- What is being done for condition monitoring and why?
- What was learnt from the successes and failures?
- Do you have true life cycle cost accounting?

Summary

1. **Except for gross overloading, most equipment problems will give some indication of distress 'long' before there is significant consequential damage.**

2. **An effective condition monitoring program generally requires the integration of a number of techniques and staff.**

3. **Trend plotting can be extremely helpful to show degradation and the effectiveness of production and maintenance actions.**

Summary cont'd

4. There has to be realistic measures in place to foster effective condition based maintenance and continuous improvement.

5. Personnel have to provided with skills and tools required to do the job.

Thank you