Condition Monitoring of Lubricants- Experiences at Tata Steel

G.R.P. Singh, Head Fluid Power, Maint. Expert Group, Tata Steel.

ABSTRACT

It has long been accepted that condition-based maintenance is the most effective and cost-efficient approach to maximizing the life of industrial machinery. Vibration and lubricant analysis are two key components of any successful condition-monitoring program and can be used as both predictive and proactive tools to identify active machine wear and diagnose faults occurring inside machinery. When these techniques are conducted independently, only a portion of machine faults are typically diagnosed. However, practical experience has shown that integrating these two techniques in a machine condition-monitoring program provides greater and more reliable information, bringing significant cost benefits to industry.

Compared to vibration analysis, lubricant analysis has certain advantages, as they can provide direct and early information on wear modes and the machine’s condition. In fact, in many instances it has been proven to be a leading indicator of active machine wear, compared to vibration analysis. In addition, lubricant analysis has certain advantages in monitoring low-speed machinery (less than 5 rpm), where it is usually difficult to apply vibration analysis techniques. However, wear debris analysis cannot effectively uncover all manners of failure mechanisms on its own. For this reason, both lubricant analysis and vibration analysis are necessary and vital parts to an effective program.

INTRODUCTION

The lubricating oil circulating round within an operating engine or machine is similar to the blood circulating within the living human body. Just as samples of the blood can be extracted and examined in a quest to identify the health state of the blood owner, samples of lubricating oil circulating round within a machine can also be indicative of the health of the machine.

The advantage of monitoring lubricant is that the lubricant is highly likely to carry the evidence of faults from a variety of positions within the machine to some point where a monitor can be fitted or from where a sample can be drawn.

Lubricant Analysis can be used for following two purposes:
1) Monitoring the condition of a Lubricant
2) Monitoring the condition of an Equipment

Used Lubricant analysis is both proactive and predictive. The operational life of most industrial machinery is directly related to the contamination and chemistry of the lubricants. By monitoring, reporting and recommending the correction of contamination problems, oil analysis is possibly the most valuable proactive condition monitoring technology available for improving equipment reliability.

Following are the aims of Condition Monitoring of Lubricants

1) Determine Lubricant Condition / Quality
2) Identify and quantify contaminants
3) Optimize lubrication change interval
4) Verify equipment abnormal condition
5) Enhance scheduling of repairs
6) Enhance trouble-shooting
7) Monitor / Verify maintenance activities
8) Develop complete profile history

9) Aides in the equipment performance and replacement evaluation

LUBRICANT CONDITION MONITORING TECHNIQUES

1) Monitoring the condition to assess usability

For systems containing less than 250 litre, analytical testing is not justified and change periods are best based on experience. For systems containing more than 250 litre, regular testing should be carried out to determine when the lubricant is approaching the end of its useful service life. A combination of spot testing and laboratory testing is recommended.

A) Spot testing:

- visual test
- odour test
- viscosity comparison
- blotting test
- crackle test

Visual Test

Appearance when taken	Appearance after 1 hr.	Reason	Action to be taken
Clear	Clear	None	None
Opaque(1)	Clear	Foaming	Cause of foaming to be sought (2)
	Clear with separated water layer	Unstable emulsion(3)	Check centrifuge function (4)
	Opaque	Stable emulsion	Check centrifuge function, Send for Lab test (5)
Dirty	Solids separated (6)	Contamination	Check filter or Centrifuge, Send for Lab test(5)
Black (with smell)	No change	Oil oxidized	Send for Lab test (5)

1) Both foams (mixture of air and oil) and emulsions (mixture of water and oil) render the oil opaque. 2) Foaming is generally mechanical in origin, being caused by excessive churning, impingement of high-pressure return oil on the reservoir surface etc. Foam can be stabilized by the presence of minor amount of certain contaminants, e.g. solvents, corrosion preventives, grease. If no mechanical reason can be found for excessive foam generation, it is necessary to change the oil. 3) Steps should be taken to remove the water as soon as possible. Not only is water liable to cause lubrication failure, but it will also cause rusting; the presence of finely divided rust tends to stabilize emulsions. 4) The usual reason for a centrifuge failing to remove water is that the temperature is too low. The oil should be heated at 80 deg C before centrifuging. 5) It is not always possible to decide visually whether the oil is satisfactory or not. In doubtful cases it is necessary to have laboratory analysis. 6) In a dark oil, solids can be seen by inverting the bottle and examining the bottom.

Odour Test – Oxidized or biodegraded oil has bad smell

Viscosity comparator – Compares the viscosity with new oil

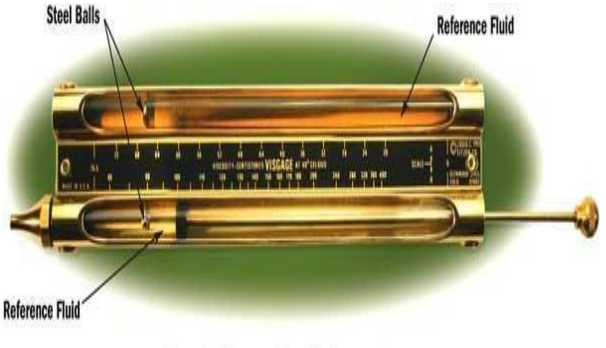


Figure 2. Visgage - a Viscosity Comparator

While there are many laboratory techniques for determining the viscosity of hydraulic and lubricating fluids, many maintenance programs depend on information gathered on-site by less sophisticated instruments. One such instrument uses the falling ball viscosity measurement concept. Its principle of operation is based on comparing the viscosity of the test fluid with a reference fluid of known viscosity.

Blotting test – To check the Water and Dirt presence
Crackle test – To check the Water presence

There are a number of ways to measure the presence of water in oil, but most of them are complicated, expensive or difficult to use in the field. An easy way to detect the presence of free and emulsified water, the most dangerous forms of water in oil, is with the hot-plate crackle test. For years, oil analysis laboratories have screened samples with the crackle-test, performing more expensive analysis only when the crackle test is positive.

In this test, a hot plate is held at 320°F (130°C) and a small drop of oil placed in the center. Any moisture present in the oil is reflected in the number of bubbles observed as the water vaporizes. Depending on the lubricant, relatively few small bubbles indicate approximately 500 to 1,000 ppm (0.05 to 0.1 percent) water. Significantly more bubbles of a larger size may indicate around 1,000 to 2,000 ppm water, while an audible crackling sound indicates moisture levels in excess of 2,000 ppm. The Crackle Test is sensitive only to free and emulsified water.

B) Laboratory Testing of Physical properties of Oil

Test	Type of oil	Action level
Kinematic VISCOSITY at 40’ C	Lub Oil	15% increase from new oil value (1)
Kinematic VISCOSITY at 100’ C	Automotive Grade	15% increase from new oil value (1)
Water by distillation % volume	All	200 ppm
Flash Point	Auto / Hyd	180 deg C min
TAN (Total Acid Number)	All	1 + TAN of new oil (2)
TBN (Total Base Number)	Automotive	4.0 Minimum
Sediment (% wt)	All	0.01 Maximum

1) Change oil if viscosity has increased by 15% as a result of degradation. Where increase or decrease is caused by contamination with miscible liquid or topping up with wrong grade of oil, much greater changes can be tolerated and limits have to be chosen to suit particular cases. 2) Acidity develops as a result of oxidation; the oxidation reaction is auto-catalytic so that once it has started it proceeds at an increasing rate. The acids formed are not corrosive to material of construction, but measurement of acidity gives a useful guide to the condition of the oil.

2) Monitoring the condition of an Equipment

This involves monitoring the wear particles & contaminants in the lubricant and determining their concentration, thereby monitoring the condition of the equipment.

There are three techniques which are widely used.

1) Particle Counting
2) Spectroscopy
3) Ferrography

Particle Counting determines the number of wear particles and contaminants in different size categories. The two most common standards for determining oil quality cleanliness levels are ISO 4406 and NAS 1638. Table given below summarizes important differences between the two standards. ISO 4406 is the more common standard in the hydraulic oil industry and uses cumulative counts, for example number of particles greater than 5 micron. The NAS 1638 standard uses differential counts, for example number of counts between 5 and

15 micron. Note that in both systems an increase in one code level represents a doubling of particle counts.

Standard	Counts	Sizes (micron)
ISO 4406	Cumulative	2, 5, 15
NAS 1638	Differential	5, 15, 25, 50, 100

IS0 –4406 was formulated in the year 1987. The ISO code used two sizes of greater than 5 micron and greater than 15 micron because it was felt that

- The concentration at the smaller sizes (≥5 μ) would give an accurate assessment of the SILTING condition of the fluid. These particles reduce the service life of the components and the systems.
- While the population of the particles ≥15 μ would reflect the presence of WEAR catalysts. These particles have direct effect on the functionality of the system. It may result even into a break down.

Example :
400 particles>5 micron/ml
65particles > 15 micron/ml
ISO16/13

ISO Contamination Numbers :

No. of particles per 100 ml		
More than	**Up to**	**Range No.**
8,000,000	16,000,000	24
4,000,000	8,000,000	23
2,000,000	4,000,000	22
1,000,000	2,000,000	21
500,000	1,000,000	20
250,000	500,000	19
130,000	250,000	18
64,000	130,000	17
32,000	64,000	16
16,000	32,000	15
8,000	16,000	14
4,000	8,000	13
2,000	4,000	12
1,000	2,000	11
500	1,000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5
8	16	4
4	8	3
2	4	2
1	2	1

Over a period of time many developments have taken place in the field of hydraulics and measurements of particles/ calibration of test equipment/ methods.

The changes in hydraulics have taken place in the following areas:

- To design high pressure systems to achieve overall smaller size of components and systems.
- To design close toleranced components to give better control and repeatability
- To design heavily energized polymer/PTFE sealing systems/ super finished functional surfaces to reduce friction and hence give better efficiency and control**.**

It is necessary to minimize the no. of particles equal to or larger than component operating clearances to effectively control abrasive, fatigue and adhesive wear. Based on these clearances the critical particle size that must be controlled is typically 1 –5 microns to maximize component life.

The silt particles have been redefined in a new range called >= 2 micron and accordingly new ISO code having 3 scale numbers was proposed (1998) in place of the erstwhile 2 scale numbers.

Example:

Range number	**Micron**	**Actual particle count range (per ml)**
18	**2+**	**1300-2500**
16	**5+**	**320-640**
13	**15+**	**40-80**

NAS Classification measures particles above 5 micron only and does not consider particles of 2 to 5 micron size.

Size Range	**00**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5-15	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**16000**	**32000**	**64000**
15-25	**22**	**44**	**89**	**178**	**356**	**712**	**1425**	**2850**	**5700**	**11400**
25-50	**4**	**8**	**16**	**32**	**63**	**126**	**253**	**506**	**1012**	**2025**
50-100	**1**	**2**	**3**	**6**	**11**	**22**	**45**	**90**	**180**	**360**
Over 100	**0**	**0**	**1**	**1**	**2**	**4**	**8**	**16**	**32**	**64**

CM20 Particle Counter

Spectrometric Elemental Analysis

Spectroscopy detects different elements (wear particles and contaminants) and quantifies their concentration in parts per million (ppm).

Monitoring of 22 elements associated with metal wear, lubricant contamination and additive depletion can be done. Wear metals include: iron, copper lead, tin, chromium, aluminum, silver, nickel, magnesium and vanadium. Lubricant contaminants include: silicon, boron, aluminum, sodium lead, potassium. Additive depletion includes: phosphorous, zinc, calcium, barium, boron, sodium, molybdenum, magnesium and silicon. Spectroanalysis testing is an effective method for monitoring small particles. Severe wear particles larger than 10 microns cannot be detected accurately.

ICP (Inductively Coupled Plasma) Atomic Emission Spectroscopy is being used at Tata Steel for Spectrometric Elemental Analysis.

In this, oil sample is sprayed into an argon plasma torch. The spectral colors of the emitted light and its intensity are then measured to indicate the amount of various elements that are present.

Example: Elemental Spectroscopy of used oil sample from the engine of HEMM.

ELEMENTS	TYPICAL SOURCES
Iron (Fe)	Cylinders, Crankshaft, water
Aluminium (Al)	Dirt, Pistons
Silicon(Si)	Defoamants, Air
Lead (Pb)	Bearings, Grease, Paint
Phosphorous (P)	Additives, Coolants, Gears
Copper (Cu)	Bearing, bushing, Bronze
Sodium (Na)	Coolant, Additive, Dirt
Vanadium (V)	Catalysts, Fuel oils, Valves
Nickel (Ni)	Shafts, Gears, Rings

FERROGRAPHY:

Ferrography not only determines the concentration of wear particles and contaminants ranging in size from 1 to 250 microns, providing an early indication of abnormal wear, it also analyzes the wear particles to determine the wearing component, the cause and severity of wear.

Ferrography has two components:

1) Direct-Reading Ferrography
2) Analytical Ferrography

The Direct Reading Ferrography obtains two-(2) sets of readings:

- Direct Large (DL) >5um
- Direct Small (DS) ≤5um particles

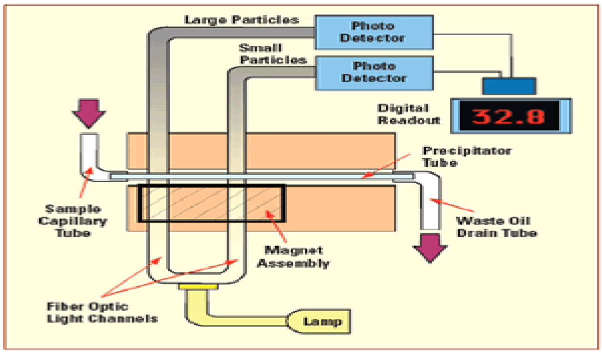
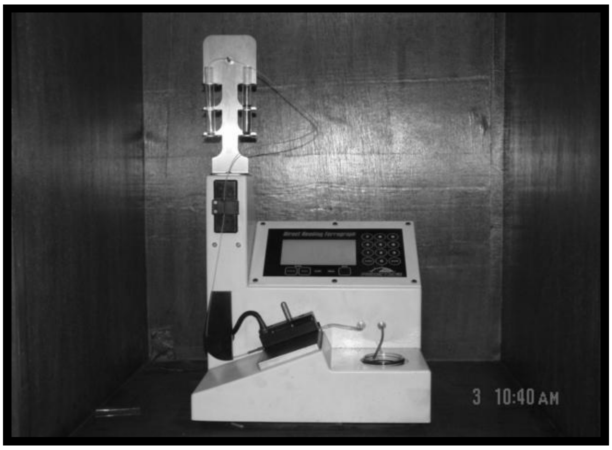


Fig. 3. Direct read ferrography measures large (DRL >5μ) and small (DRS <5μ) ferrous particles *(courtesy Analyst, Inc.)*



Direct Reading Ferrograph

When the ratio of DL to DS increases, it is an indication of a greater generation of large particles, which is a precursor to potential catastrophic wear.

Because direct read ferrography is relatively inexpensive and quick, it is a good screening tool for analytical ferrography. A ratio of DL to DS in excess of 5:1 calls for further investigation with analytical ferrography. Direct Reading Ferrography is also an excellent tool for trending ferrous wear particles.

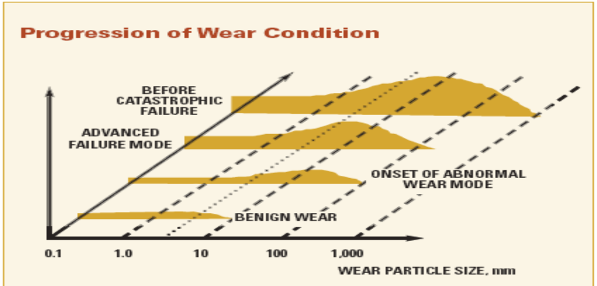
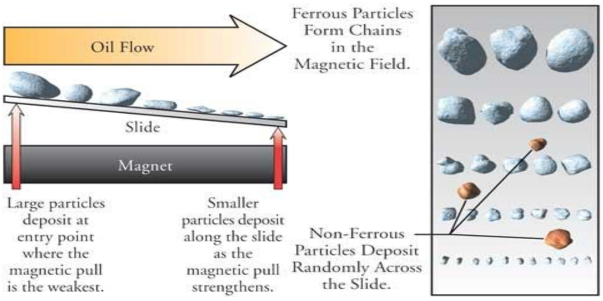


Fig 1. The goal of every predictive maintenance tool is to provide an early-warning system before equipment failure. As shown here, the earlier a warning comes, the better *(courtesy Predict)*.

In Analytical Ferrography, a Ferrogram is prepared by passing a diluted oil sample across a specially treated glass substrate, which is subjected to a strong magnetic field gradient. Due to the magnetic field, the ferrous particles align themselves in chains along the length of the slide with the largest particles being deposited at the entry point. Nonferrous particles and contaminants, unaffected by the magnetic field, travel downstream and are randomly deposited across the length of the slide.



The developed ferrogram is monitored under Ferroscope which is a bichromatic microscope, which indicates the size and shape of the particles.

Ferrogram Maker

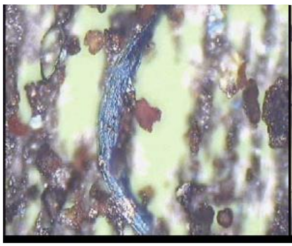
Importing image captured in the Ferroscope to computer for comparison

There are four Criteria for Evaluation

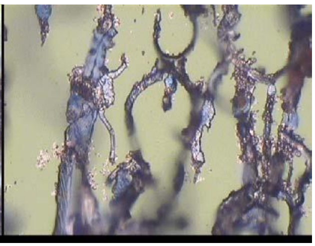
- Size
- Shape
- Composition
- Concentration

The size of the wear particle indicates the severity of wear.

Cutting Wear Particles (500X)

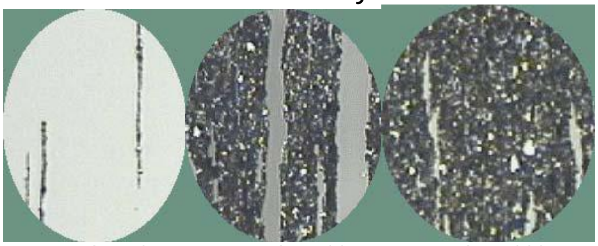


50 micron size particle MARGINAL



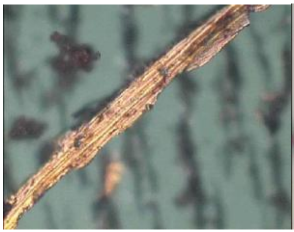
150 micron size particle CRITICAL

The Wear Particle Concentration (WPC) also indicated the severity of wear.



WPC = 10 **WPC = 100** **WPC = 1000**

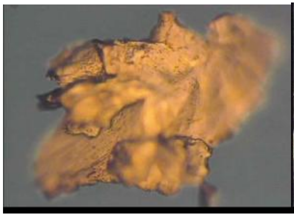
Different types of wear particles generated by specific kind of wear have distinctive shapes and characteristics, which reveals the cause of wear.



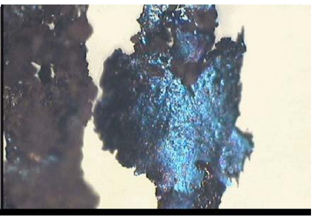
Flat elongated platelets
(Excessive load/speed on sliding surface)

Small sphere
(Rolling contact failure)

The particle composition / metallurgy aids in the identification of the wearing component. For example, Bearing wear particles of Copper and Steel look considerably different:



Reddish-Yellow color
(Copper Alloy)



Blue temper color on heat treatment
(Low Alloy Steel)

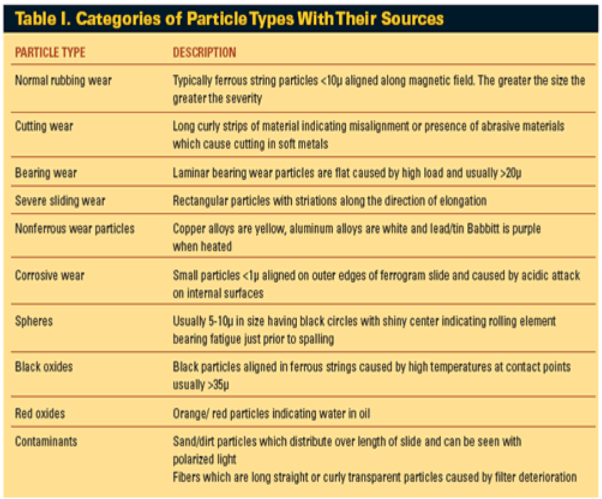


Table I. Categories of Particle Types With Their Sources

PARTICLE TYPE	DESCRIPTION
Normal rubbing wear	Typically ferrous string particles <10µ aligned along magnetic field. The greater the size the greater the severity
Cutting wear	Long curly strips of material indicating misalignment or presence of abrasive materials which cause cutting in soft metals
Bearing wear	Laminar bearing wear particles are flat caused by high load and usually >20µ
Severe sliding wear	Rectangular particles with striations along the direction of elongation
Nonferrous wear particles	Copper alloys are yellow, aluminum alloys are white and lead/tin Babbitt is purple when heated
Corrosive wear	Small particles <1µ aligned on outer edges of ferrogram slide and caused by acidic attack on internal surfaces
Spheres	Usually 5-10µ in size having black circles with shiny center indicating rolling element bearing fatigue just prior to spalling
Black oxides	Black particles aligned in ferrous strings caused by high temperatures at contact points usually >35µ
Red oxides	Orange/ red particles indicating water in oil
Contaminants	Sand/dirt particles which distribute over length of slide and can be seen with polarized light Fibers which are long straight or curly transparent particles caused by filter deterioration

Oil analysis is central to any successful predictive maintenance program.

Keep in mind that although atomic emission spectroscopy is an important predictive tool, it is limited by size of the particles detected.

Other techniques are required to measure large particle wear debris.

Central to wear debris analysis is analytical ferrography, the only common oil analysis tool that can justify equipment shutdown. Because it is time-consuming and relatively expensive ($35-$100), analytical ferrography is not commonly recommended for all samples.

Other tools, such as direct read ferrography and particle counts, need to be utilized as screening before running analytical ferrography.

Example: Used oil analysis for engine oil in a HEMM

Properties	Guidelines for rejection
K.Viscosity change @ 100 °C (ASTM- D 445)	+1 SAE Viscosity grade or 4 cSt from the new oil
Total base Number(TBN) (ASTM D-664)	2.5 min or ½ of new oil
Water Content (ASTM D-95)	0.2% max
Fuel dilution	nil
Potential Contaminants	
Silicone (Si)	15 ppm increase over new oil
Sodium (Na)	20 ppm increase over new oil
Boron (B)	25 ppm increase over new oil

Potassium (K)	20 ppm increase over new oil
Soot	1.5 % mass of used oil , Max.

Guidelines on Sample collection: Following are some of the guidelines on sample collection.

- Collect sample during normal operating condition
- Preferable to collect sample while equipment is in operation
- If not possible, collect sample within 15 minutes of the equipment being put out of operation
- Preferable to collect sample before in-line filters
- If collecting from tank, collect sample from the middle and not from the bottom

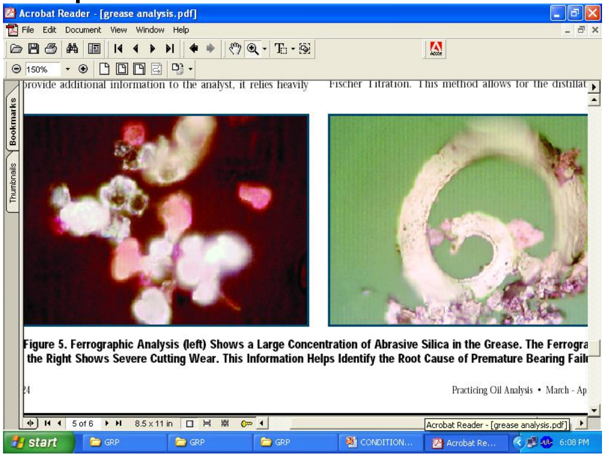
GREASE ANALYSIS:

The problem with grease analysis is integrity of the sample. The sample must be as representative as possible. A feature of grease analysis, as opposed to oil analysis, is that contaminants and wear debris are not uniformly distributed throughout the lubricant. This can lead to samples with huge variances in debris content. Generally the grease sample of interest is the grease doing the work at the contact interfaces, in the load zone of the bearing. This grease sample will have the most evidence of wear, contamination and degradation and in general will be the most representative, although It will likely also be the most difficult to obtain. The condition of the bearing is the focus; the condition of the grease is of secondary importance. Therefore, tests relating specifically to the grease are of little value. The engineer needs to know what contaminants are present and what they indicate in respect to the safe operation and reliability of the bearings. The tests focus on the presence of metallic elements and water.

Ferrographic Analysis of used grease:

While the quantitative estimation of wear debris is difficult in a used grease sample using elemental analysis, because of the difficulties of obtaining a representative sample, ferrographic analysis, which by its very nature is a qualitative technique, is ideal in determining the active wear mechanism and severity of the problem in grease-lubricated bearings. Ferrographic analysis on used grease is carried out be extracting the wear debris from the sample and analyzing it visually using an optical microscope, similar to the way ferrography is used for used oil samples. By looking at particle morphology, it is often possible with ferrographic analysis to identify the root cause of premature bearing failures, allowing appropriate corrective action to be taken.

Example:



provide additional information to the analyst, it relies heavily

Fischer Titration. This method allows for the distillat

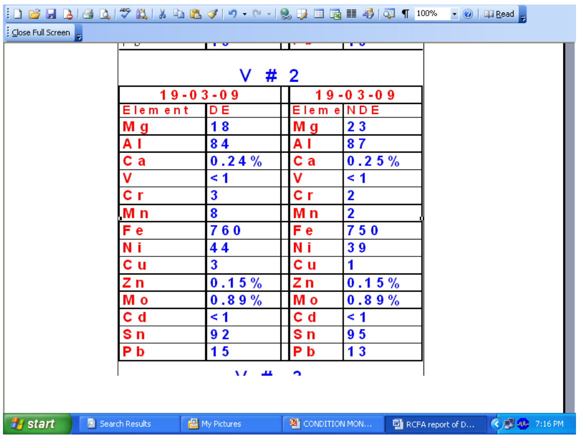
Figure 5. Ferrographic Analysis (left) Shows a Large Concentration of Abrasive Silica in the Grease. The Ferrogra
the Right Shows Severe Cutting Wear. This Information Helps Identify the Root Cause of Premature Bearing Fail

24

Practicing Oil Analysis • March - Ap

Spectrometric Analysis of used grease:

Spectrometric analysis of used grease can be done to find out which components are wearing by elemental analysis. But this test has limitation that it can not detect particles more than 10 micron and normally in case of severe wear, particles will be larger than 10 micron.

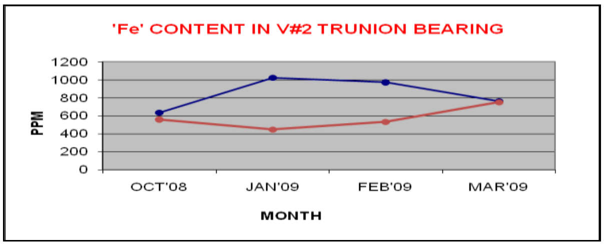


V # 2

19-03-09		19-03-09	
Element	DE	Eleme	NDE
Mg	18	Mg	23
Al	84	Al	87
Ca	0.24%	Ca	0.25%
V	<1	V	<1
Cr	3	Cr	2
Mn	8	Mn	2
Fe	760	Fe	750
Ni	44	Ni	39
Cu	3	Cu	1
Zn	0.15%	Zn	0.15%
Mo	0.89%	Mo	0.89%
Cd	<1	Cd	<1
Sn	92	Sn	95
Pb	15	Pb	13

This limitation was severely exposed in the case of trunion bearing failure at LD2. There was a failure of drive end located trunion bearing of Vessel#2 at LD#2 on 28.05.09. Because of some reason Ferrography analysis of the grease was stopped since September'08 and soap test was started.

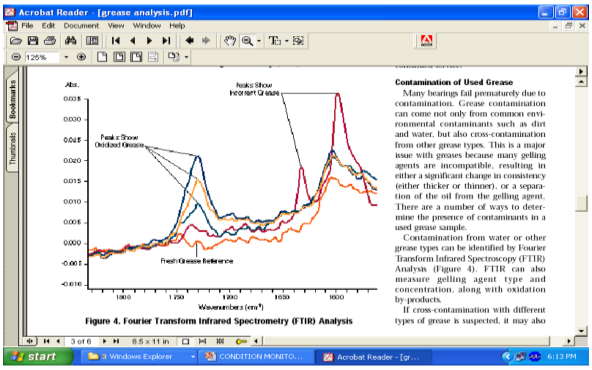
In soap test data, it was found that in vessel#2 bearings, though %Fe was found increasing, it was not alarming.



After the failure, Ferrography analysis was done with the sample collected on 24.04.09. Ferrography report is shown in the table below:

Though ferrography report clearly indicated the bearing problem, spectrometric analysis did not raise the alarm and bearing failed.

Contamination from water or other grease types can be identified by Fourier Transform Infrared Spectroscopy (FTIR) analysis.



Contamination of Used Grease

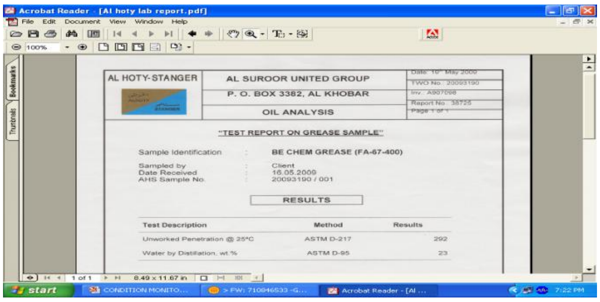
Many bearings fail prematurely due to contamination. Grease contamination can come not only from common environmental contaminants such as dirt and water, but also cross-contamination from other grease types. This is a major issue with greases because many gelling agents are incompatible, resulting in either a significant change in consistency (either thicker or thinner), or a separation of the oil from the gelling agent. There are a number of ways to determine the presence of contaminants in a used grease sample.

Contamination from water or other grease types can be identified by Fourier Transform Infrared Spectroscopy (FTIR) Analysis (Figure 4). FTIR can also measure gelling agent type and concentration, along with oxidation by-products.

If cross-contamination with different types of grease is suspected, it may also

Figure 4. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Some of the other properties of used grease like un-worked penetration and water content are measured to find out the suitability of the grease for further use. One such example is shown below.



AL HOTY-STANGER	AL SUROOR UNITED GROUP	Date: 16th May 2009
		TWO No.: 20093190
	P. O. BOX 3382, AL KHOBAR	Inv.: A907098
		Report No.: 38725
	OIL ANALYSIS	Page 1 of 1

"TEST REPORT ON GREASE SAMPLE"

Sample Identification : BE CHEM GREASE (FA-67-400)
Sampled by : Client
Date Received : 16.05.2009
AHS Sample No. : 20093190 / 001

RESULTS

Test Description	Method	Results
Unworked Penetration @ 25°C	ASTM D-217	292
Water by Distillation, wt %	ASTM D-95	23

Transformer Oil Analysis

Location	Observation	Recommendation.
LD Vessel # 2 Drive End Bearing sample grease collected on 24.04.2009	Few 1 mm and many 200-300 micron chunky bearing wear particles were observed. .	**Wear condition of bearing was bad.**

The analysis of insulating oils provides information about the oil, but also enables the detection of other possible problems, including contact arcing, aging insulating paper and other latent faults and is an indispensable part of a cost-efficient electrical maintenance program. Breakdown of one of the most crucial elements, the oil paper insulating system, can only reliably be detected by routine oil analysis.

By measuring the physical and chemical properties of oil, in addition to the concentrations of certain dissolved gases, a number of problem conditions associated with either the oil or the transformer can be determined. The following are some common tests performed on electrical insulating oils.

- Moisture Content
- Acid Number
- Dielectric Strength
- Power Factor

Dissolved Gas Analysis (DGA)
Dissolved gas analysis (often referred to as DGA), is used to determine the concentrations of certain gases in the oil such as nitrogen, oxygen, carbon monoxide, carbon dioxide, hydrogen, methane, ethane, ethylene and acetylene (ASTM D3612). The concentrations and relative ratios of these gases can be used to diagnose certain operational problems with the transformer, which may or may not be associated with a change in a physical or chemical property of the insulating oil. For example, high levels of carbon monoxide relative to the other gases may indicate thermal breakdown of cellulose paper, while high hydrogen, in conjunction with methane may indicate a corona discharge within the transformer.

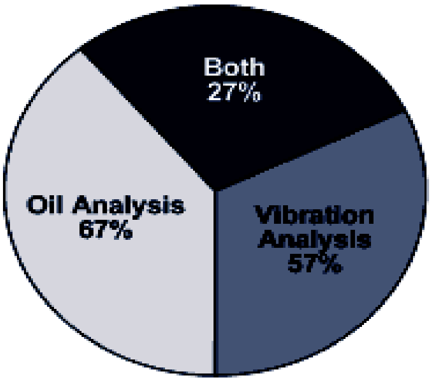
Integrating Vibration and Oil Analysis for Machine Condition Monitoring:

Compared to vibration analysis, oil and particle analysis have certain advantages, as they can provide direct and early information on wear modes and the machine’s condition. In fact, in many instances it has been proven to be a leading indicator of active machine wear, compared to vibration analysis. In addition, oil analysis has certain advantages in monitoring low-speed machinery (less than 5 rpm), where it is usually difficult to apply vibration analysis techniques. However, wear debris analysis cannot effectively uncover all manners of failure mechanisms on its own. For this reason, both oil analysis and vibration analysis are necessary and vital parts to an effective condition monitoring program.

For industries like power generation, petrochemical and steel industries, vibration analysis and oil analysis has historically been the technique of choice for monitoring the condition of large, critical pieces of rotating equipment. These industries have relied upon above to make effective maintenance decisions. In general, vibration analysis and oil analysis are the most effective techniques for monitoring the health of machinery. The two techniques are natural allies due to the complementary nature of their respective strengths. Unfortunately, the two techniques are rarely combined to form an effective union.

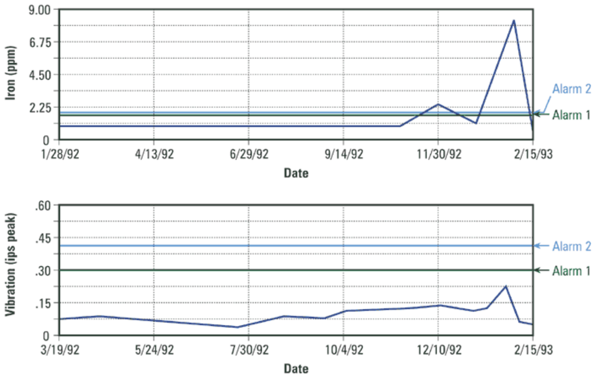
Vibration analysis activities typically reside in the condition monitoring or vibration monitoring group, while oil analysis usually resides with the lubrication team. Making matters worse, the oil analysis program usually consists of submitting occasional samples to a laboratory in exchange for results that frequently look more like chemistry than machine condition monitoring. And, too often, oil analysis is used to schedule oil changes while equipment condition assessments are left primarily to vibration analysis.

This is changing in many organizations. For example, **Palo Verde Nuclear Generating Station,** made a dramatic change in their approach to condition monitoring. They combined vibration analysis and oil analysis into a common group, brought their oil analysis on-site and began working as a team. Their results have been remarkable. In an assessment of bearing defects detected by technology, they found that oil analysis was responsible for 40% of the defects found, vibration analysis was responsible for 33%, and both techniques converged on the remaining 27% of the defects found. The loss of either technology would have reduced their detection resolution and their ability to control the root causes of machine failure. In one year, their predictive maintenance department documented approximately $3.7 million in savings.



Bearing Fault Detection
750 Machines

In the example shown below, it can be seen that Oil Analysis has given indication of bearing failure much in advance compared to Vibration Analysis (Iron ppm has increased the alarm level whereas vibration is still within alarm level).



In research conducted at Monash University, Melborne, Australia, the correlation between oil analysis and vibration analysis was found to be generally very good. However, there are instances when one technique indicates a fault while the other shows no change or even a contradictory result. For example, in applications where sliding wear is prevalent, one might detect increasing rates of wear generation and decreasing rates of vibration. This is caused by what the researchers termed a “lapping” effect. Essentially, the sliding wear slowly hones the surfaces smooth, reducing the overall vibrations until the point at which looseness and mechanical vibration are induced. The effect is intensified by the presence of abrasive dirt.

Conversely, the Australian researchers found that vibration analysis very effectively identifies the presence of a fractured gear tooth, but because the size of the debris generated is so large, wear particle analysis is ineffective. The debris falls to the bottom of the sump, never finding its way into a sample bottle until it is oxidized and leeches into the oil, a process that could take months. The Australian researchers concluded that both techniques are required to effectively monitor and diagnose the condition of plant machinery because each technique evaluates different and complimentary symptoms.

An example in which both techniques are required to effectively solve a problem is the case of a gearbox with increasing vibration at the gear mesh frequency. Inspection of the particle count and ferrous percentage revealed an increase in both categories, improving confidence that a problem existed. It was not until the oil's viscosity trend was assessed, however, that the true nature of the problem was revealed. A drop in viscosity from 220 cSt at 40°C to 70 cSt at 40°C was observed. A review of the work history showed that the oil was changed two weeks earlier. In all likelihood, the oil change was performed using the wrong oil leading to the wear and vibration. Without the combination of condition monitoring technologies, the root of the problem may have gone undetected.

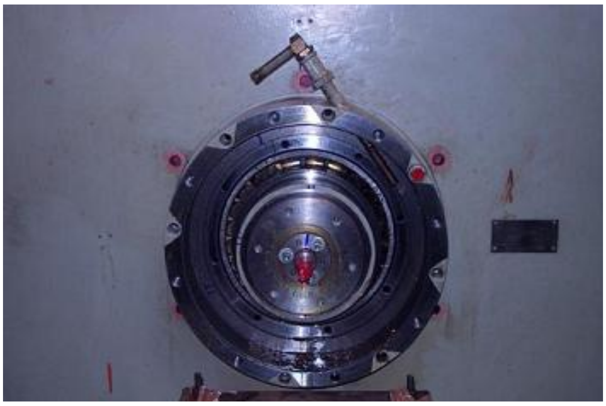
In general, we can make the following conclusions about combining oil analysis and vibration analysis in detecting and analyzing machine faults:

1. Both techniques are required to control the root causes of machine failure.
2. Often, one technique serves as the leading indicator of machine failure while the other serves as the confirming indicator.
3. Oil analysis is generally stronger in detecting failures in gearboxes, hydraulic systems and reciprocating equipment.
4. Vibration analysis is generally stronger in detecting failures in high-speed journal bearing systems.
5. Vibration analysis is often better at localizing the point of failure depending on the application.
6. Oil analysis is often stronger in determining which wear mechanism is inducing failure.
7. Both techniques are required to effectively determine the root cause of failure.
8. Correlation between oil analysis and vibration analysis is very good, but there are contrary instances.

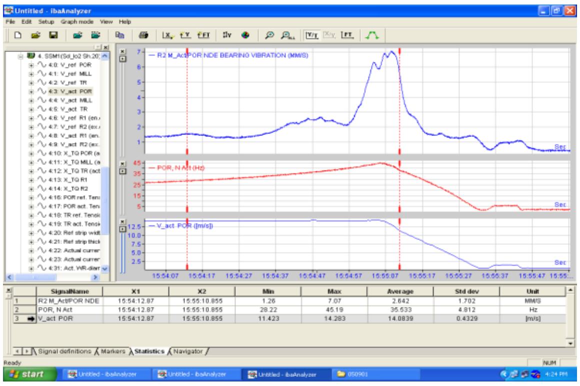
In conclusion, oil analysis and vibration analysis are natural allies in achieving machine reliability. They offer complementary strengths in controlling the root causes of machine failure and in identifying and understanding the nature of abnormal conditions.

At Tata Steel, Both Lubrication Group and Vibration Analysis Group are under one department MED (Mechanical). We are also trying to bring synergy in working of both the groups. One such example where Ferrography and Vibration Analysis were used in combination to find out bearing fault has been discussed in this paper.

CASE STUDY: BEARING PROBLEM IN SPM TR MOTOR NDE

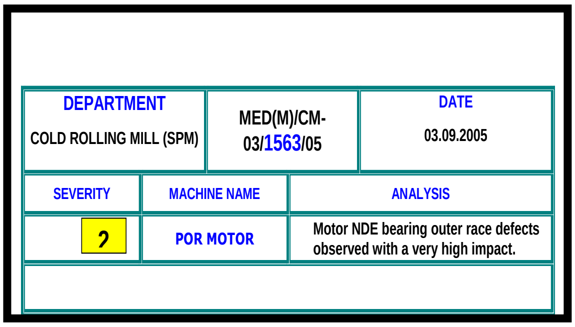


Vibration in Skin Pass Mill Motor non drive end bearing was increasing to the level of 7.26mm/sec at 45Hz Rotor speed. At lower Rotor speed Vibration Level was in the range of 1.5~ 2.0mm/sec.



	SignalName	X1	X2	Min	Max	Average	Std dev	Unit
1	R2 M_Act/POR NDE	15:54:12.87	15:55:10.855	1.26	7.07	2.642	1.702	MM/S
2	POR, N Act	15:54:12.87	15:55:10.855	28.22	45.19	35.533	4.812	Hz
3	V_act POR	15:54:12.87	15:55:10.855	11.423	14.283	14.0839	0.4329	[m/s]

Vibration Signature Analysis showed bearing defect.



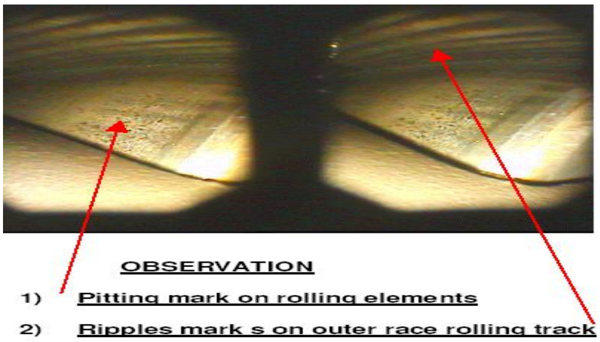
DEPARTMENT COLD ROLLING MILL (SPM)	MED(M)/CM-03/1563/05	DATE 03.09.2005
SEVERITY	MACHINE NAME	ANALYSIS
2	POR MOTOR	Motor NDE bearing outer race defects observed with a very high impact.

Multiple vibration peaks were observed at a high frequency, in the bands between 30000 to 120000 CPM, which can generally be attributed to a problem in the bearing.
Impacts in the Time waveform, which again is an indication of bearing problem.

Ferrography also showed large wear particles indicating progressive bearing damage.

SPM POR Motor Drive end	**DL 116.5 DS 74.9** **Few 50-60 micron and many 20-30 micron bearing wear particles were observed.**	**Wear particles more than previous sample.**
SPM-POR Motor Non Drive	**DL 189.4 DS 137. 5** **Three nos 110 - 130 micron and many 40-50 micron bearing wear particles were observed.** **Normal rubbing wear particles were high.**	**Wear particles more than normal.** **Check the sealing arrangement.** **Send sample after two week to monitor the trend of wear particle generation.**

Finally, Videoscopy was done and the pictures shown below revealed
- Flutes (Transverse grooves) across the outer race all along the circumference.
- Zigzag scoring marks on the rollers.



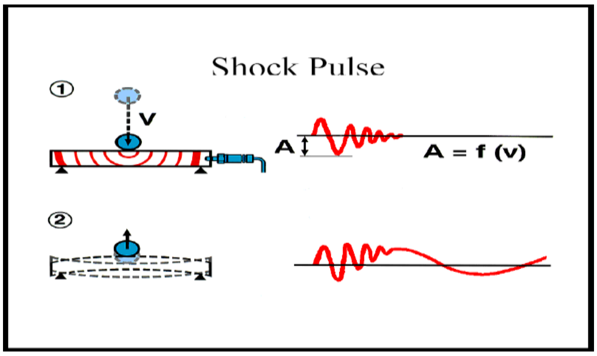
With the help of continued monitoring with Vibration Analysis and Ferrography, motor was made to run for another three months and bearing was changed in the Major Shutdown. After taking out the bearing, it was found that inner surface of the outer ring of bearing had fluting marks which is because of current passing through the bearing.

In this case both Vibration Analysis and Ferrography complemented each other and with continued condition monitoring, forced shutdown of SPM Motor was averted saving 4 days of shutdown of Skin Pass Mill. In fact, in this case, Ferrography was the lead indicator of progressing failure and increase in vibration showed up after some time.

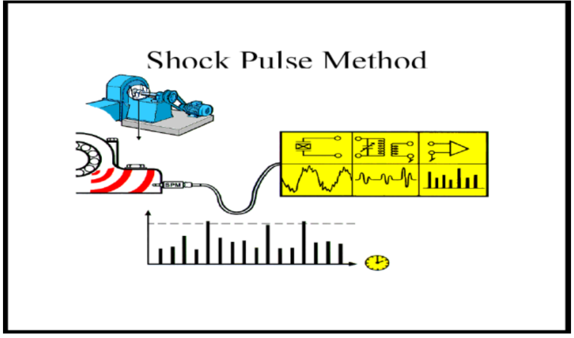
Condition Monitoring of Bearing Lubrication Condition:

Whether the bearing has sufficient lubrication or not, can be found out by two techniques:
1) Shock Pulse Measurement
2) Acoustic Emission Monitoring

1) Shock Pulse Measurement: The difference between SPM and Vibration Measurement can be illustrated by showing what happens when a falling metal ball strikes a metal bar. At the moment of impact, the colliding molecules will cause a pressure wave to spread through both bodies. The magnitude of this wave is a function of the speed of the colliding bodies. It is independent of their masses and shapes. The SPM method analyses the first stage event, the “shock pulse” traveling through the material of the bar.
The impact will then cause the bar to vibrate. This vibration is a function of the speed, mass, and shape of the bodies. Vibration measurement is used to measure the movement of the bar.



When hit by a shock wave, a shock pulse transducer responds at its own resonance frequency of 32 kHz. It will magnify the high frequency shock signal, while all machine vibration is filtered out.
The output of the shock pulse transducer is a rapid sequence of electric pulses, proportional to the amplitudes of the shock waves. Shock pulses are measured on a decibel scale (dBsv= decibel shock value).



The absolute shock pulse level of a bearing, measured in dBsv, is both a function of rolling velocity and of bearing condition. To neutralize the effect of rolling velocity on the measured value, the instrument has to be programmed with

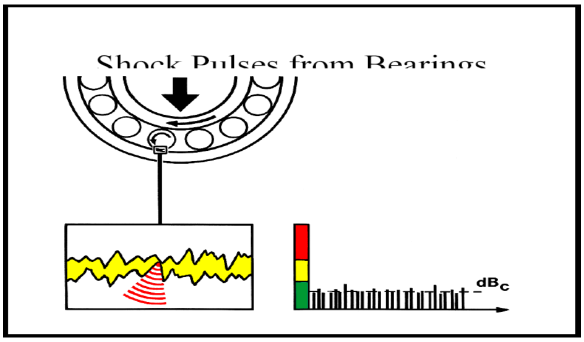
- shaft diameter (in millimeter or inch)
- rotational speed (in rpm).

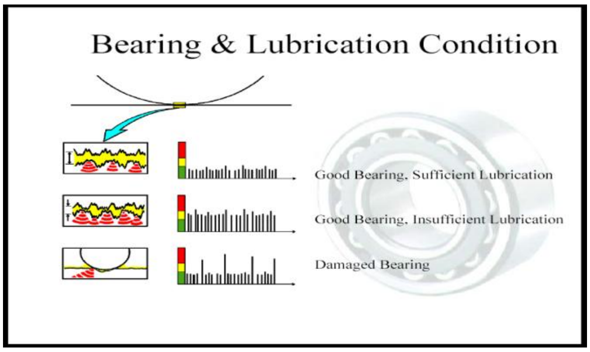
The instrument will then calculate the initial value dBi, the starting point of the condition scale for a particular bearing.

The instrument takes a sample count of the shock pulses occurring over a period of time and displays;

- the maximum value dBm for the relatively small number of strong shock pulses
- the carpet value dBc for the large number of weaker shock pulses.

The maximum value dBm defines the bearing's position on the condition scale. The difference between dBm and dBc is used for a finer analysis of the causes for reduced or bad condition.





An increase in dBc with dBm within limit shows insufficient lubrication.

2) Acoustic Emission Monitoring: Acoustic monitoring has for many years been successfully utilized to monitor the condition of electrical systems and identify leaks in vacuum, compressed air, steam and other fluid transfer operations. In recent years, more and more maintenance professionals have come to rely on this technology to also monitor the condition of mechanical components and even monitor bearing lubrication condition. The amount of noise produced by a lubricated bearing can be a useful indicator of the effectiveness of the lubricating film. Rolling element bearings typically employ an elasto-hydrodynamic lubricating film. In this type of lubrication,

the loaded surfaces elastically deform and the load is carried by a film of oil sufficiently thick to prevent the interacting surfaces from contacting one another. At a microscopic level, the finished surfaces in the bearings present irregularities or bumps often referred to as asperities. When they collide, it generates noise which can be measured by Acoustic Monitoring Device.

In a properly lubricated bearing, these collisions should be few and, thus, generate a relatively low noise level, but as the grease in a bearing is “used up”, the oil film begins to dissipate and the collisions become more frequent and create more noise. While it is certainly possible to hear this phenomenon with a stethoscope, the acoustic instruments allow it to be quantified and provide an objective interpretation of the sound levels. Based on the normal or base line noise levels for a particular bearing, limits can be established that alert the technician to the precise time the bearing requires re-lubrication and even indicate when to stop applying grease to prevent over-lubrication.

One such acoustic emission instrument is shown below. Distress readings are taken by the instrument. When bearings are found with value greater than 10, it is time to re-lubricate. The reduction in distress confirms the improvement. If there is no reduction in distress value after re-lubrication, it indicates bearing damage.

Identifying lubrication problems

Distress readings are taken every month. When items are found with a value greater than 10 its time to re-grease. The reduction in Distress confirms the improvement. No need to know speed, bearing type etc.

Instant “health” checking

3 of the 5 motors have a Distress>10. No need for calculations or previous machine knowledge - It's instant. Since re-greasing gave no improvement its clear there is permanent damage.

Confirming repair success

Benefits of Condition Monitoring of Lubricants:

Lubricant analysis can be a first line of defense against catastrophic equipment failure. Condition Monitoring of lubricant can detect minor changes in the lubricant before they cause damage to the equipment, can detect minor wear and corrosion problems before they cause major equipment damage and identify contaminants so corrective action may be taken to eliminate these contaminants before they cause equipment damage.

There are many examples where conditions monitoring of lubricants and corrective actions have given substantial benefits to the organization. At chiba Mill of Kawasaki steel company ltd., oil contamination control in hydraulic system resulted in a 97% reduction in hydraulic systems malfunctions over a period of 5 years. Piston pump average life increased from 12 months to 24 months.

Data given below shows, how bearing life is affected by both particle and water contamination. Substantial life improvement in bearing life can be achieved by monitoring both particle and oil contamination and controlling it within desired limit.

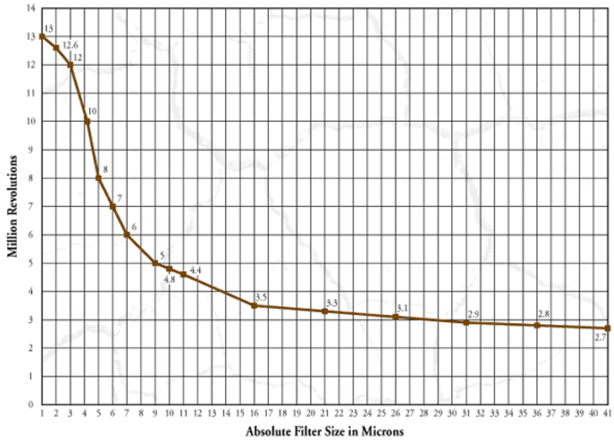


FIGURE 1. L_{50} BEARING LIVE VS. FILTRATION MESH SIZE

Source - SKF Ball Bearing Journal #242

Lubricant : SAE	
Wate Concentratio	Bearin Life
25	2.5
400	0.5
100	1.0

Source: TIMKEN

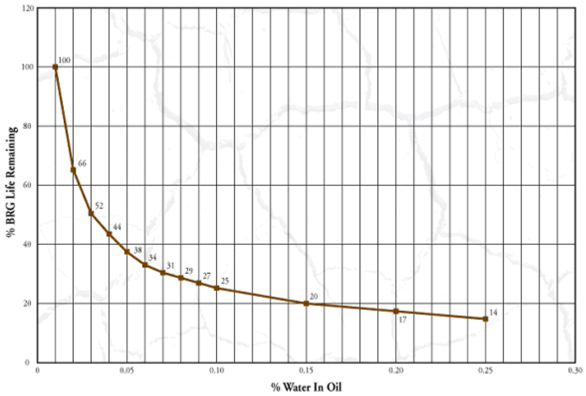
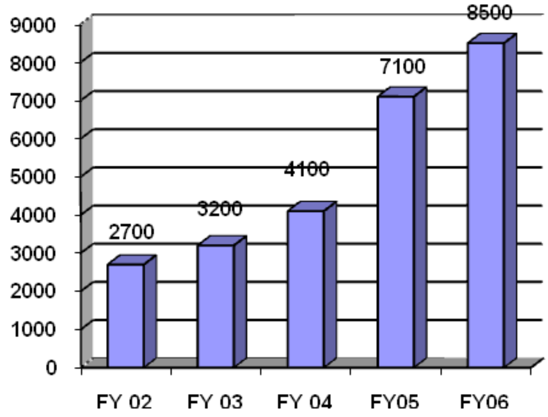


FIGURE 2. WATER CONTAMINATION VS. BEARING LIFE

Oil analysis programme at Tata Steel, West Bokaro, resulted in improvement in engine life as given below.



One of the paper mills (Weyerhaeuser) reported 80% reduction in bearing failures by improving oil cleanliness from 21/17 to 16/13 and and moisture level from 400-500 ppm to 100 ppm.

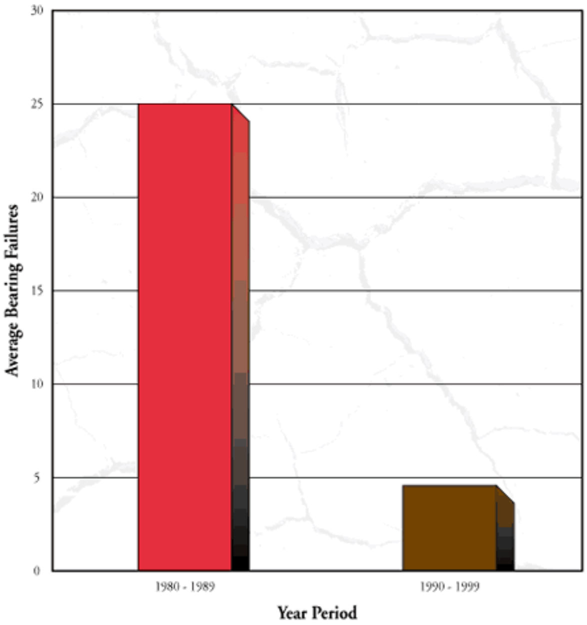


FIGURE 4. REDUCED BEARING FAILURES (AVERAGE NUMBER PER YEAR)

Companies have realized the importance of lubricant analysis as a means of reducing damage caused by wear or poor lubrication. Lubricant analysis helps to identify contamination, lubricant degradation, and abnormal machine wear. With the focus on enhanced asset reliability to avoid unscheduled machine downtime, condition monitoring of lubricant is growing to be an increasingly important aspect of every organization's predictive maintenance program.