# Machine and Lubricant Condition Monitoring for Extended Equipment Lifetimes and Predictive Maintenance at Power Plants

by:
Malte Lukas and Daniel P. Anderson
Spectro Incorporated
Littleton, Massachusetts, USA

**Abstract**
Predictive maintenance has gained wide acceptance as a cost cutting strategy in modern industry. Condition monitoring by lubricant analysis is one of the basic tools of a predictive maintenance program along with vibration monitoring, performance monitoring and thermography.

In today's modern power generation, manufacturing, refinery, transportation, mining, and military operations, the cost of equipment maintenance, service, and lubricants are ever increasing. Parts, labor, equipment downtime and lubricant prices and disposal costs are a primary concern in a well run maintenance management program. Machine condition monitoring based on oil analysis has become a prerequisite in most maintenance programs. Few operations can afford not to implement a program if they wish to remain competitive, and in some cases, profitable.

This paper describes a comprehensive Machine Condition Monitoring Program based on oil analysis. Actual operational condition monitoring programs will be used to review basic components and analytical requirements. Case histories from several power plants will be cited as examples of cost savings, reduced equipment downtime and increased efficiencies of maintenance programs through a well managed oil analysis program.

## 1.0 INTRODUCTION

Modern oil analysis was pioneered in the years after World War II by railroads, but it wasn't long thereafter that the U.S. Armed Forces widely adopted these methods, primarily for early detection of failure in aircraft gas turbines. The experience gained in the military for aircraft gas turbine lubricant monitoring and other "oil-wetted" systems may be applied to the modern power station. Military use also spurred the development of small, rugged, easy-to-use, field deployable, yet accurate instruments. These recent advances in instrumentation and computerization have made on-site oil analysis, even in remote and non-laboratory environments and without highly trained personnel, readily available and affordable.

Historically, maintenance departments perform equipment maintenance based on one of three strategies. They are, *Run to Failure*, *Preventive Maintenance* or *Predictive Maintenance*.

The *Run to Failure* strategy is based on fixing or replacing equipment "as required". It has no periodic maintenance schedules, and repairs are initiated only when the equipment no longer functions. It applies to those systems which cost less to repair or replace than it would cost to have them in a program of preventive or predictive maintenance. The "run to failure" or "fix when fail" strategy was effective prior to World War II when equipment was fairly basic, easy to repair and relatively inexpensive by today's standards. It is seldom applied to today's modern machinery.

A *Preventive Maintenance* strategy is based on performing periodic tear-downs, inspections and parts replacements. Maintenance actions are based on manufacturer's recommendations and experience from past equipment failures. Parts, lubricating oil, hydraulic fluids and filters are replaced based on operating hours or distance traveled. This approach was first introduced by the aircraft industry after World War II and required components to be replaced at set time intervals regardless of their condition. It is a very effective maintenance strategy, but may also be a very costly one. Quite often, perfectly serviceable equipment is torn down and rebuilt, or major components are replaced based only on the fact that a specific service cycle has been completed. Lubricating oils and hydraulic fluids are also discarded without regard to the possibility that they may have useful service life remaining.

*Predictive Maintenance* strategies have become the basis of modern mining maintenance programs. An effective program makes use of periodic tests based on oil analysis, vibration monitoring and performance monitoring. The condition of the system, based on testing, thus allows maintenance to be geared to the specific needs of each piece of equipment. Impending failure can be detected and repaired in its early stages, and equipment is scheduled for proper maintenance without unexpected downtime. Lubrication oil and filters are replaced only when they are exhausted and no longer effective.
An effective predictive maintenance program makes use of machine condition monitoring based on oil analysis, vibration monitoring, and performance monitoring. This paper deals primarily with oil analysis. However, it stands to reason that the more information that is available, the better the diagnosis that can be made on the condition of a system. The following discussion shows how the type of predictive maintenance program implemented and the type of monitoring necessary depends on the application and possible failure modes.

Many industrial predictive maintenance programs use vibration monitoring on fixed and stationary equipment. In some cases, an abnormal vibration spectrum will be the first indication of a problem in a piece of equipment. In other cases, oil analysis will give an earlier indication of abnormality. For example, a rotational imbalance would first be observed by vibration analysis. Only after a period of time in operation would the excess stress on the bearings result in a greater quantity of wear debris being present in the lubricating oil. On the other hand, an abrasive wear situation, in which abrasive contaminant particles have gotten into the lubricating oil, would first be detected by oil analysis. Only after a significant amount of wear has occurred, would a problem be indicated by vibration analysis.

Performance monitoring refers to observing and trending a number of different operating parameters which, in many cases, are quite easy and inexpensive to obtain, such as temperatures, pressures, flow rates, oil consumption, etc. In a simple bearing, temperature may be the only parameter that is measured. However, in a complicated machine such as a large diesel engine, quite a few measurements are possible, which include fuel consumption, inlet and outlet coolant and oil temperatures, air intake pressure, exhaust pressure and exhaust temperature.

## 2.0 OIL ANALYSIS

An effective predictive maintenance program based on condition monitoring through oil analysis must determine both machine condition and lubricant condition. Lubricating oil may be used as a diagnostic medium which carries wear debris away from the wearing surfaces. Analysis of the wear debris can, therefore, provide important information about the condition of the internal parts of a machine or engine. On the other hand, the condition of the lubricant itself is important to know. Does the lubricant meet specification? Is the viscosity correct? Is the oil contaminated with water, particulates or chemical compounds?

A modern condition monitoring program based on oil analysis takes the form shown in Figure 1. A sample, or in some cases several oil samples, are taken from a piece of equipment at a predetermined sampling interval and sent to the laboratory for analysis. Based on the analysis, a diagnostic report is made and a recommendation is sent to the personnel responsible for the equipment. The report may show that everything is normal, warn of a possible problem or make a specific maintenance recommendation. The entire process, from sample taking to the diagnostic report, should take less than 24 hours to be effective. In a modern oil analysis program, the data generated and collected by the laboratory is also used to provide periodic maintenance summaries. These reports can be statistical in nature and provide an insight to management personnel on the effectiveness of the program, efficiency of the maintenance department, repair status of equipment, recurring problems, and even information on the performance of different lubricants.

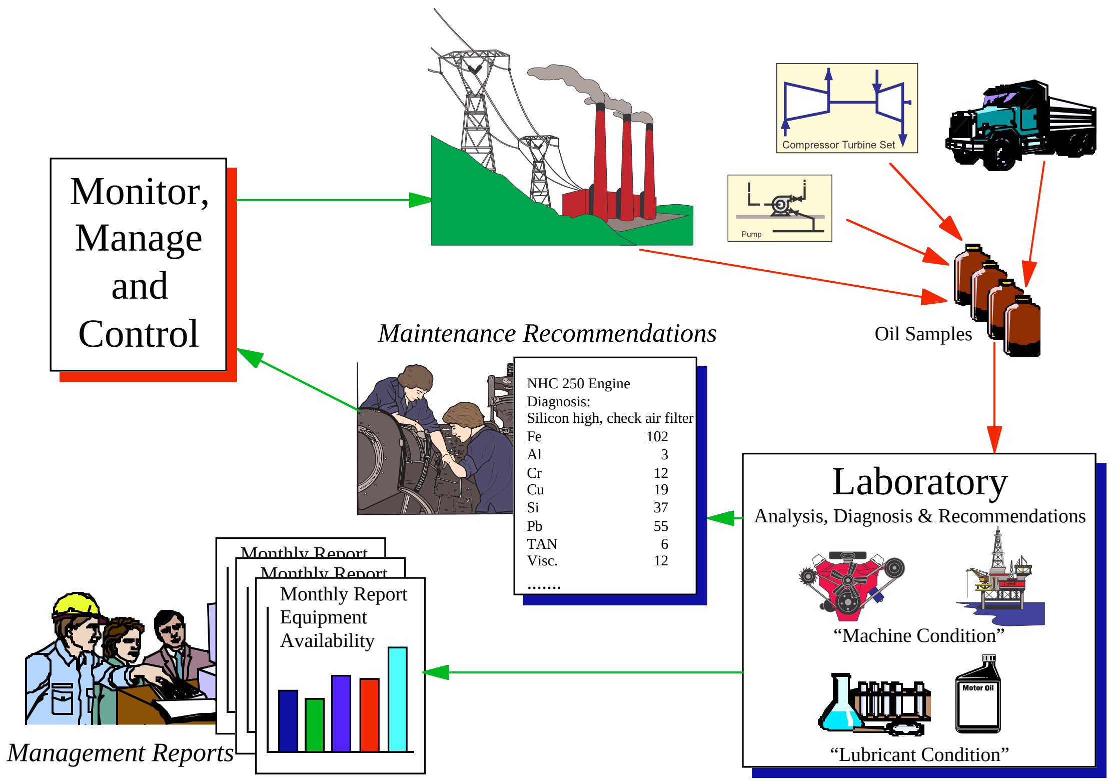


Figure 1, Oil Analysis Program, Flow Diagram

Condition monitoring by oil analysis can be broken down into two main categories: Debris Monitoring and Lubricant Condition Monitoring. Debris monitoring measures the trace quantities of wear particles carried away from the wearing surfaces by the lubricant. Lubricant condition monitoring determines if the lubricant itself is fit for service based on physical and chemical tests. These techniques, when combined with statistical trending and data based management techniques, provide a complete program of machine condition monitoring by oil analysis.

## 2.1 Debris Monitoring

Debris monitoring pertains primarily to the detection, and sometimes also the analysis, of metallic wear particles. The most common techniques and devices applied to this category of condition monitoring include atomic emission spectroscopy (AES), atomic absorption spectroscopy (AAS), X-ray fluorescence spectroscopy (XRF), ferrography, magnetic plugs, magnetic chip detectors, and microscopic examination of filter debris.

Debris monitoring is the backbone of oil analysis condition monitoring programs. It is effective in the sense that tests can be applied to determine that a system is nearing, or has reached, a failure mode. Further damage can thus be contained or avoided through immediate shutdown and repair.

Spectroscopy is the most widely applied technique for debris monitoring. It provides a quantitative, multi-elemental analysis of wear debris in lubricating oil. The elemental concentration of as many as 20 elements are reported in parts per million (ppm). Wear metals such as iron, aluminum, chromium, copper, tin, lead, silver, titanium and nickel are detectable, as well as lubricant additives such as calcium, barium, zinc, phosphorus, magnesium, boron and molybdenum. Certain contaminants such as silicon, sodium and potassium are also routinely detected. Trends are used to determine the mechanical health of a system. Concentration trends are established through routine monitoring to indicate if a continuing wear condition exists, the rate of wear, and as a consequence, the immediacy of the wear problem.

There are several types of spectrometers used for debris monitoring. These include, rotating disk arc emission (RDE), atomic absorption (AAS), X-ray fluorescence (XRF) and inductively coupled plasma (ICP) emission spectrometers. Each has its own advantages and disadvantages.

### 2.2 Lubricant Condition Monitoring

The second part of an oil analysis program is lubricant condition monitoring. Through periodic sampling of the lubricant, the laboratory can determine the effectiveness and remaining life of the lubricant based on degradation and/or contamination analysis.

Many oil analysis laboratories perform one or more ASTM approved tests to determine oil condition. These are both physical and chemical tests. Some typical tests for oil condition are:

- Viscosity
- TBN (total base number)
- TAN (total acid number)
- Water content (Karl Fischer)
- Total solids content

Viscosity can be measured rather quickly and accurately with the right equipment, but the remaining tests are rather time consuming and awkward to perform.

TBN, TAN and Karl Fischer water content are titrations which require a fair amount of time and also use solvents which are somewhat toxic and costly to dispose of.

Total solids content can be determined a number of different ways (by blotter, centrifuge, filtration and weighing or thermogravimetric analysis), none of which are equivalent. Of these tests, the only one that is easy to perform is the blotter test, the interpretation of which is something of an art.

In recent years Fourier Transform-Infrared (FT-IR) spectroscopy has been applied to used lubricating oil analysis. FT-IR analysis is quick and inexpensive to perform and is an excellent screening tool.

ASTM tests can be performed in cases where a definitive answer is required. FT-IR analysis quantifies the presence of various types of chemical bonds. Differences between the infrared spectra of the sample and the unused lubricant indicate chemical changes in the used oil as well as various types of contamination. A thirty second analysis provides information on oil contaminants include water, blowby products (soot), coolant chemicals (ethylene glycol) and unburned fuel and degradation based on nitration, oxidation, and sulfation.

## 3.0 TURNKEY USED OIL ANALYSIS LABORATORIES

Configuration and instrumentation of a laboratory will vary based on the machines being monitored and the sample work load. A full-service laboratory is shown in Figure 2, but the basic minimum components consist of an emission spectrometer, a Fourier Transform-Infrared spectrometer (FT-IR) and a viscometer. Each instrument sends its results to a data based laboratory information management system for data storage, evaluation and reporting.

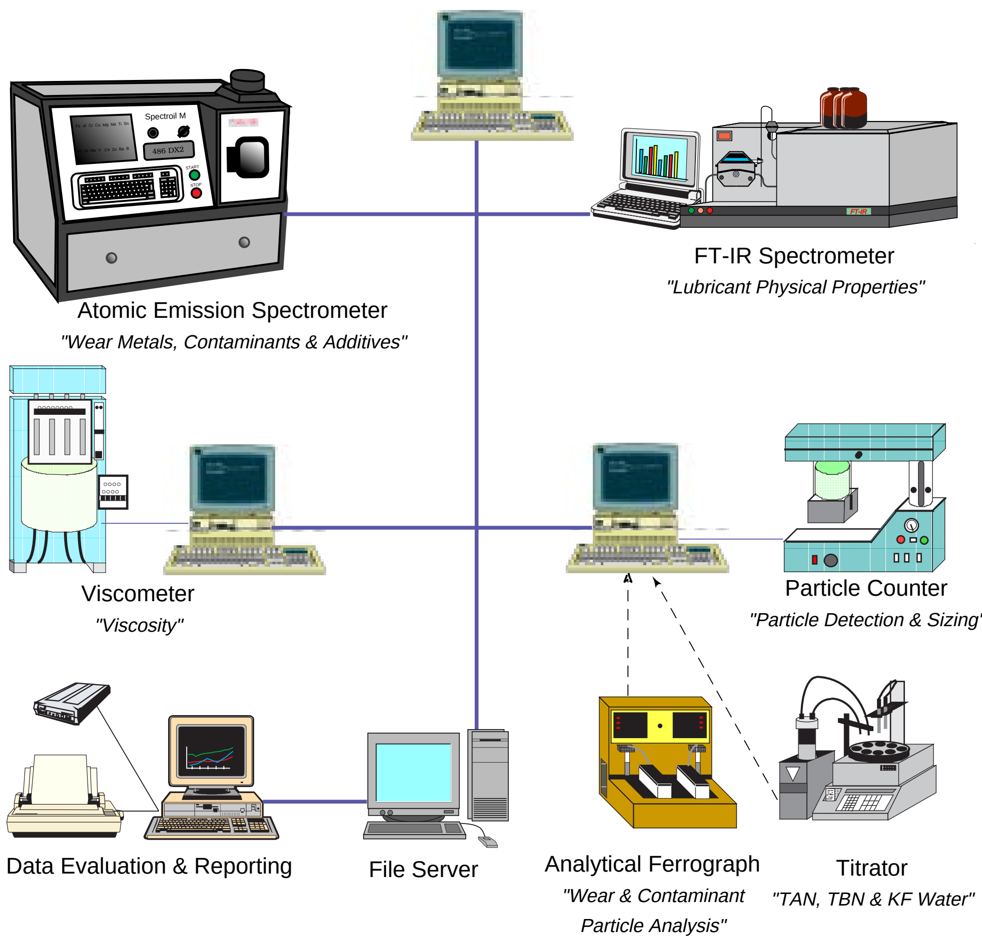


Figure 2, Full-service turnkey used oil analysis laboratory

A rotating disc emission (RDE) spectrometer is the basic instrument recommended for routine measurement of the elemental concentration of wear metals, contaminants and additives. It provides simplicity of operation, sensitivity to larger particles, freedom from diluting samples, and requires no gas or cooling water while completing analysis of approximately 20 elements in less than a minute. An atomic absorption spectrometer (AAS) is seldom used unless the sample volume is extremely low and cost per sample is not a consideration. An inductively coupled plasma (ICP) spectrometer is recommended only where absolute accuracy of results is important, such as quantification of additive elements in a lubricating-blending plant.

FT-IR spectrometers for used oil analysis have dedicated programs which extract lubricant degradation and contamination parameters from the measured spectrum of the used oil sample. The technique is fast, less than a minute per sample, and provides data on oxidation, nitration, sulfation, soot, fuel dilution, water and glycol contamination and in some cases, additive depletion. As a fast trending technique, it has become a standard instrument in many high sample volume used oil analysis laboratories.

A viscometer is the third required instrument in the basic turnkey used oil analysis system. Viscosity is the single most important physical characteristic of a lubricant since it determines load carrying ability as well as flow and heat flow characteristics. Manual viscometers are inexpensive and work well in low sample volume requirements. Automatic viscometers are readily available for various degrees of automation and unattended operation.

In the basic system, measurements from each analytical instrument are sent to a central computer file where the results are incorporated into a history file for each unit (specific machine or sampling point on a machine). When tests are complete, the computer calls up the file of each unit and compares the results to a criteria matrix with allowable limits and to past analyses. In an automatic evaluation mode, records for samples with all data within limits are passed directly to the history file and a report with no recommended action is sent to the maintenance personnel. Samples with "out of limit readings" are flagged for review by the laboratory expert, who can then send a report with a maintenance recommendation to the maintenance personnel via telephone, telefax or printed copy.

This basic used oil analysis laboratory can be expanded as the analytical requirements of the laboratory or the sample work load increase. Ferrography, which magnetically separates the wear particles in an oil sample and arranges them according to size on a microscope substrate, gives important supplemental information on ferrous particles too large to be measured by routine spectrometric methods.

Total Acid Number (TAN), Total Base Number (TBN), and Karl Fischer water determination are three frequently performed ASTM tests for oil degradation and contamination. An automatic titrator is sometimes supplied with a turnkey system if more definitive information than that supplied by the FT-IR spectrometer is required.

Particle count measurement is sometimes recommended, primarily for use with hydraulic systems or other clean lubricating oil systems such as those for turbines and compressors.

With this added equipment, the used oil analysis laboratory combines the analytical speed required for large sample volumes with the additional capabilities of providing specialized ASTM based tests. It contains instruments and operating software designed specifically for used oil analysis with turnaround times of 24 to 48 hours to provide data trends used for effective machine condition monitoring. With expanding needs, a local area network (LAN) can be used to share information and additional tests can be added to match specific machinery monitoring needs.

## 4.0 CASE HISTORIES

The following are a series of actual predictive maintenance examples based on oil analysis case histories. They show the effectiveness and versatility of well managed and properly applied condition monitoring programs based on oil analysis.

### 4.1 Cost Avoidance by Reducing Unexpected Bearing Failures

The Southern California Edison Mohave Generating Station implemented a full condition monitoring program in the early 1990's. At that time they set up and placed into operation their own on-site oil analysis laboratory. Confirmed cost benefits were realized within the first year of operation.

Bearing failures and replacement costs were targeted as an immediate application for oil analysis. Over a four year period, they were able to decrease the cost of general use roller and ball bearings by more than a factor of four. The costs savings were documented as bearing expenditures which were reduced as follows:

| Year | Bearing Costs |
|---|---|
| 1992 | $415,000 |
| 1993 | $264,000 |
| 1994 | $209,000 |
| 1995 | $100,000 |

Condition monitoring also reduced the replacement cost of mill and PA Fan motor bearings from $320,000 to $30,000.

The Mohave Generating Station has 40 Dynacore centrifuge rotors in operation to remove water from coal slurry prior to burning. In 1991 they experienced 35 feed pipe bearing failures. Today, failures have been almost completely eliminated as a result of their oil analysis program. The actual failure rate history over since the implementation of oil analysis has been as follows:

| Year | No. Bearing Failures |
|---|---|
| 1991 | 35 failures |
| 1992 | 17 failures |
| 1993 | 4 failures |
| 1994 | 3 failures |
| 1995 | 1 failure |

### 4.2 Cost Avoidance by Reducing Power Outages

Unscheduled shutdowns resulting in power outages are always costly. A recent case history exemplifies the potential cost of unexpected failures of machinery that result in power outages.

Oil analysis started to indicate an increasing trend in the copper wear metal from a circulating water pump thrust bearing. The trend was confirmed through ferrographic analysis of the most recent oil sample. Based on the laboratory recommendation, the pump was scheduled for a premature bearing replacement. The corrective action prevented a major outage had it gone undetected. If the bearing failed, the generator would have run at half load for at least eight hours. Based on reduced load operation of 350MW at $15/MW for eight hours, the savings were a minimum of $42,000 plus cost avoidance due to secondary damage.

### 4.3 Supporting Warranty Claims through Condition Monitoring Records

How often is a warranty claim met with .... “Your lubricant and/or fuel and/or maintenance is at fault, not our machinery."  Just such a case was recently documented, but with different results.

New haul trucks had been purchased by a mine.  They were the same capacity as others in the fleet, but equipped with a newer engine.  In fact, this was the first mine haul application for this engine.

From the first week in operation, excessive smoking indicated problems which were immediately confirmed through condition monitoring. Excessive wear was taking place and piston rings and cylinder life did not reach 5000 hours.  Factory service was requested and warranty claims submitted.

The actual “failings” of maintenance, fuel and improper lubricants were cited by the factory representative. Condition monitoring records were produced as well as a graphical display of the data.  The information immediately showed that these “failings” did not exist and also provided specific insight into the actual root of the problem.

The manufacturer of the engines had investigated many different piston ring configurations in response to the constant demand for ever more fuel-efficient engines.  Unfortunately, what had proved fuel-efficient in line haul trucking proved to be trouble in the high torque-loading operation of mine haul trucks.  The warranty claims were granted.

### 4.4 Cost Avoidance by Detecting Lubricant Mix-Up

A serious recurring problem in maintenance procedures is the use of an incorrect lubricant.  A condition monitoring program can readily identify such problems through the analysis of the lubricant additive package and lubricant physical property analysis.

The most common occurrence of lubricant mix-ups occur when an oil system is "topped off" to replace the oil that has been lost due to use or leakage.  Usually a small amount of incorrect oil in a large closed loop system presents few immediate problems.  This is, however, not the case in certain diesel engines as illustrated by this example.

Table 1 is a summary of the last four oil analyses for a medium speed diesel engine from a locomotive. Only the most significant analytical data is shown.

Table 1, Spectrometric Results for an EMD Medium Speed Diesel Locomotive

| Date | Fe | Cu | Ag | Mg | P | Zn |
|---|---|---|---|---|---|---|
| 9/30 | 19 | 10 | 0 | 0 | 0 | 3 |
| 12/23 | 21 | 10 | 0 | 0 | 9 | 3 |
| 3/23 | 27 | 13 | 2 | 107 | 75 | 90 |
| 6/11 | 25 | 30 | 10 | 220 | 110 | 123 |

The data clearly shows that after the first two samples, an incorrect oil was used to top-off the reservoir.  The three additive metals magnesium (Mg), Phosphorus (P), and zinc (Zn) appear in the third analysis and increase in the fourth, a clear indication that the oil formulation has changed.  In this type of engine, an incorrect oil which contains a zinc based additive package can result in severe wear problems. Several components such as bearings and wrist pins have silver coatings which corrode and wear in the presence of zinc. The early stages of the corrosive action cause by the zinc additive is indicated by the increase in the iron, copper and silver wear metals. A recommendation based on the analysis was made to drain and flush the system and to observe correct top-off oil requirements. Without oil analysis, the wear problem could have resulted in a bearing failure and a major overhaul costing over $150,000.

## 4.5 Contamination Example on a Pump Turbine

Pump turbines are used in many parts of the world to generate electrical power. Water is pumped to an elevated reservoir at night when power is relatively inexpensive. During peak power requirement periods, the water is allowed to flow downhill to turn a turbine which is coupled to a generator. These are reliable systems. However, condition monitoring based on oil analysis can be very effective at predicting a possible failure in the very early stages of the problem and prior to secondary damage or catastrophic failure.

Alert Samples Industry Average

A pump storage system of an electric utility was part of a condition monitoring program when the laboratory detected an increase in “coarse” wear particles in the upper guide bearing assembly of the turbine. Although the normal analysis using an emission spectrometer was acceptable, the laboratory requested more frequent sampling based on the data for iron and babbit metals obtained with a large particle detection system option to the emission spectrometer. The original and the next three analyses using the standard emission spectrometer and the large particle detection (Rotrode Filter Spectroscopy, RFS) technique are shown in Figure 3. Although the normal emission spectrometric analysis does not show a trend, the RFS analysis definitely does.

Ferrographic analysis on the last two samples verified the presence of large cutting wear particles, Figure 4, causing the laboratory to issue an ALERT.

However, the presence of spheres on the ferrogram was the eventual indicator which lead to the source of the wear problem. Tilting pad bearings such as those used on the turbine do not generate spheres in a wear mode. Weld beads were suspect and it was eventually verified that the turbine had not been protected during overhead construction work. Weld debris including weld beads, and not a defective component, were the cause of the wear trend.

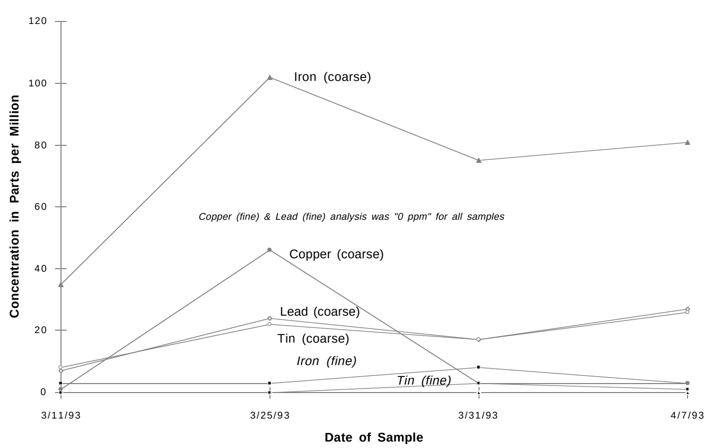


Figure 3, Pump Turbine Guide Bearing Wear Trend

Figure 4, Ferrogram Showing Cutting Wear and Weld Beads

Although the wear was not critical, the oil was cleaned as a precaution and more frequent oil analysis monitoring was recommended. The wear trend if undetected by oil analysis may or may not have lead to a catastrophic failure. The thought of failure is not a pleasant one, especially in view that such a failure can require a multi-million dollar overhaul.

**4.6 Slinger Ring Problem in Journal Bearing**

The previous case history dealt with oil analysis from plain journal bearings common to many large industrial motors and turbines. A variation of this bearing, found in high horsepower motors is the ring oiled sleeve. The rings (slingers) sit on the shaft and rotate with it, splashing oil on top of the shaft. In forced lubrication systems, these slinger rings become redundant. However, in the event of an emergency shutdown, the forced feed lubrication is lost, and these slingers act as a safety device during coast down to prevent lubricant starvation.

Slingers are generally made of clock brass or general duty bearing bronze. They are considered “soft” material compared to the carbon steel shaft. On occasion, the slinger rings can stick, causing them to wear abnormally against the rotating shaft. As this happens, they release a large amount of nonferrous copper alloy wear particles into the circulating oil.

Abnormal slinger wear was suspected in an extruder main drive motor by the predictive maintenance engineer at a large petrochemical complex. The 6,000 HP motor has a force-feed lubrication system which started to be monitored regularly through oil analysis. The oil analysis data detected serious wear from the slingers, Figure 5, and it was confirmed by ferrographic analysis.

The lubrication system was placed on a monthly sampling cycle. As the wear trends increased, the oil analysis laboratory recommended an oil change based on the April 30 analysis. It was assumed that the concentration of debris within the system would be reduced, thereby minimizing the risk of damage to other components in the lubrication cycle until a detailed inspection of the bearing could be carried out at the next scheduled maintenance overhaul.

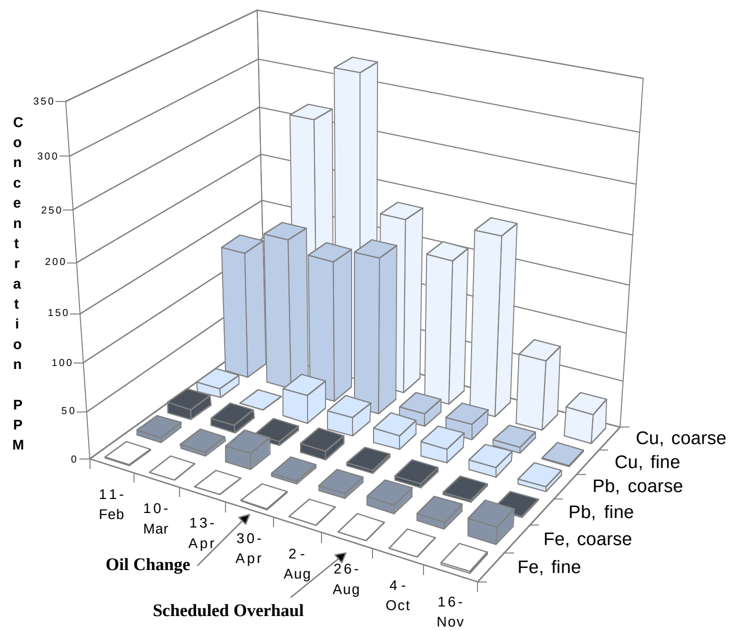


Figure 5, Wear Trend in Extruder Drive Motor

During the scheduled overhaul in October, the slingers were found to have substantial wear. The debris from the wear contributed substantially to scoring of the babbit liner on the sleeve section, Figure 6. A decision was made to reinstall the bearing, change the oil and continue monitoring on a regular monthly basis. Replacement slingers were machined in-house during the scheduled overhaul. An unscheduled shutdown and resulting disruption of the process line was avoided. The condition monitoring engineers also approached the motor manufacturer regarding design changes to reduce abnormal slinger wear.

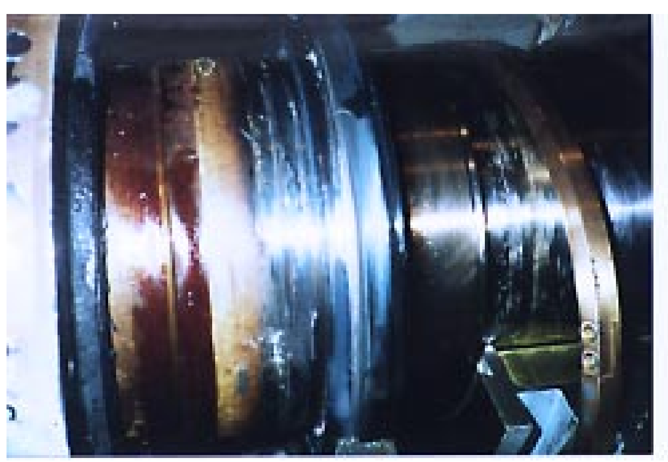

Figure 6, Slinger Ring Assembly Showing Abnormal Wear

## 5.0 CONCLUSION

It is never too late to implement a machine condition monitoring program. The benefits of the program can be realized in a very short period of time. Figure 7 is a typical summary of the types of problems that will be encountered in most instances. A number of serious or critical problems will be identified almost immediately. These will require immediate attention to avoid secondary damage, unexpected downtime or a major overhaul. A surprising number of imminent problems will also be identified. These are the future unplanned failures and should be scheduled for action and/or repair during the next scheduled maintenance shutdown.

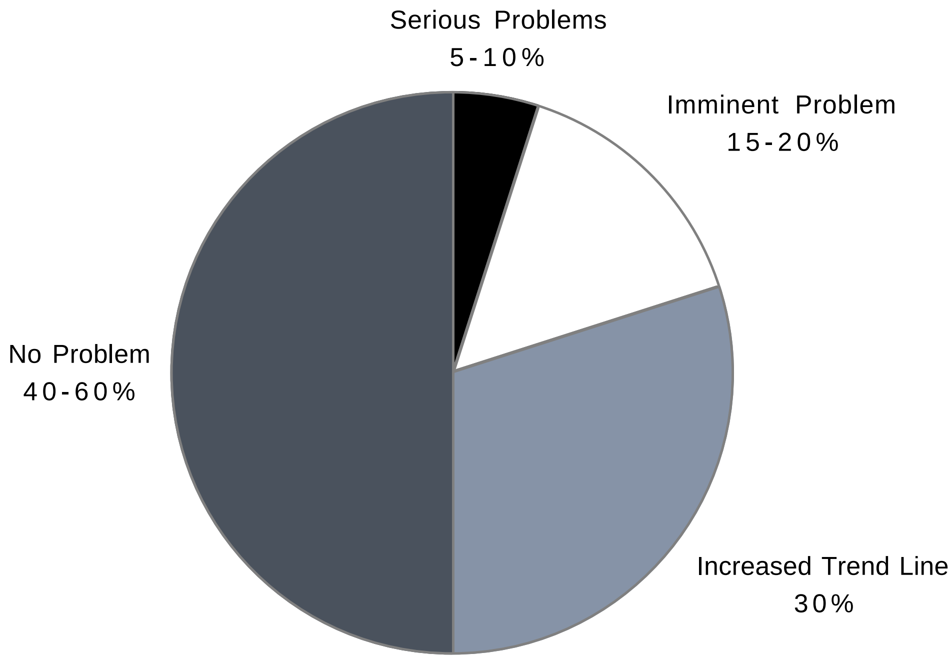


Figure 7, Summary of Problems in a Maintenance Program

The objectives of a predictive maintenance program based on condition monitoring through oil analysis is to identify potential failures in their early stages when repairs can still be initiated and costly secondary damage is avoided. A second objective is to monitor the quality of lubricants and to reduce lubricant usage through extended oil change intervals. The net benefits are reduce maintenance costs, increase equipment availability and life, reduce lubricant usage and improve safety. They can be summarized as follows:

1. *REDUCE MAINTENANCE COSTS* - This is the most apparent advantage, but sometimes the most difficult to document. Several problems can be avoided through an oil analysis program:

a. Total Equipment Loss. A serious mechanical failure can result in the total destruction of that piece of equipment. An obvious example could be the failure of the main bearing in a turbine.

b. Secondary Damage. The failure of a minor component can often result in much more extensive damage to the equipment. For example, if detected early enough, the replacement of a defective bearing can prevent the catastrophic damage and cost associated with a crankshaft replacement.

c. Over-Maintenance. A system of routine, scheduled maintenance will inevitably result in work that is performed before it is necessary. An on-condition maintenance system based on oil analysis can prevent this.

d. Maintenance-Generated Failures. The potential of human error exists whenever a piece of equipment is overhauled. A mistake such as the failure to tighten a bolt can result in equipment damage and failure when, in many cases, the equipment need not have been overhauled in the first place.

2. *INCREASE EQUIPMENT AVAILABILITY* - A power plant must make effective use of its equipment in order to fulfill its function. Profitability or effectiveness is lost every time a piece of equipment is in the shop due to secondary damage or unnecessary maintenance.

3. *REDUCE LUBRICANT USAGE* - The analysis of oil for degradation and contamination provides an indicator of its ability to lubricate. If the reserve alkalinity, detergent, and extreme pressure qualities have not degraded and the contamination is low, the oil change interval can be extended, conserving both money and natural resources.

4. *IMPROVE SAFETY* - When considering aviation, not much more need be said, especially in the case of single engine aircraft. Other equipment such as diesels, compressors, or generators, may also pose potential safety hazards in the event of a major destructive failure.

It is almost impossible in today's competitive environment to operate a mine without some kind of predictive maintenance program. Condition monitoring based on oil analysis is a proven technique which leads to more efficient use of equipment and maintenance savings. Some basic principles that must be followed in implementing such a program to fully realize its benefits are:

1. *Well Defined Purpose* - You must clearly state what is to be accomplished. In most cases it is to save maintenance costs and improve equipment availability.

2. *Appropriate Tests* - Testing takes time and costs money. Many tests are possible, but the proper mix provides the necessary data and a certain amount of double checking.

3. *Careful and Timely Sampling* - An oil analysis program creates reports based on the analysis of the oil taken to the laboratory. An improperly taken or contaminated sample results in poor and erroneous data. Samples taken too infrequently can miss a potential problem, and those taken too frequently add to operating cost.

4. *Commitment to Act on the Information* - Everyone from the individual who takes the sample, the laboratory personnel and maintenance and management personnel must be committed to act on the information produced by the laboratory. It does no one any good , for example, if a mechanic ignores the information provided by the laboratory.