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Condition monitoring - oil analysis & more

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Maintenance practices have evolved over the past 50 years through four distinct phases.

In this day and age, predictive maintenance and condition monitoring are necessities for any company that has machinery which is critical in achieving production goals. Oil analysis is a condition monitoring technique that has been in use for more than 50 years and has proved to be a highly effective management tool for monitoring the health of lubricated machinery and the lubricants themselves. However, oil analysis is not the only condition monitoring technique available to today's maintenance professional. Other techniques such as vibration monitoring, thermography and ultra-sonic analysis can also be used. This Technical Bulletin will look at the evolution of maintenance philosophies, the goals of a condition monitoring programme and how a combination of different analytical practices can be used to achieve these goals.

Maintenance philosophies

Maintenance practices have evolved over the past 50 years and have done so through four distinct phases.

1 Breakdown maintenance. This involves fixing things if, and only if, they break. This was common enough 50 years ago but with the current cost of equipment, labour and production, it is no longer a totally viable option. It should be pointed out, however, that all maintenance philosophies and condition monitoring techniques have their proper place, even breakdown maintenance. Each piece of equipment should be treated on its own merits and the most effective combination selected. The factory manager does not schedule to have every light bulb replaced on a calendar basis; light bulbs are replaced when they blow - that is breakdown maintenance and it is highly efficient and cost-effective in this case.

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Root cause failure analysis is the way of the future.

2 Preventive maintenance. This philosophy evolved because it was soon realised that breakdown maintenance was not the best way to look after most pieces of machinery in industry. Preventive maintenance involves the servicing, overhaul and replacement of items of plant based on a scheduled time interval such as operating hours/kilometres, or on a calendar basis. This was certainly a step in the right direction but it meant that units which did not require maintenance were fixed anyway. This caused problems as pieces of normally operating equipment were disturbed; there is a lot to be said for the maxim 'if it ain't broke, don't fix it'.

3 Predictive maintenance. Predictive maintenance evolved from preventive maintenance in an effort to avoid carrying out maintenance on items of plant that did not need it. This is also where condition monitoring techniques come into their own because this philosophy involves using as many non-destructive testing methods as is necessary to determine the health of a piece of equipment, and then making maintenance decisions based on these results. This practice originated in the aircraft industry during the early sixties and was known as maintenance 'on condition'.

4 Proactive maintenance. This naturally grows out of the other three philosophies and is concerned with the analysis of all maintenance and condition monitoring techniques to determine what causes failures and how these situations can be prevented in the future. Root cause failure analysis is central to this proactive maintenance and it is certainly the way of the future if organisations want to become world class players.

Types of failures

The different types of failure modes follow quite logically from the different maintenance philosophies. In order of increasing seriousness, they are:

1 Proactive failure: a pre-alert type of failure condition that has not yet resulted in material or performance degradation but, if the prevailing operating state persists, functional failure will occur.

2 Predictive failure: a condition where the first signs of material degradation are apparent by acceptable means of detection, but the operator has not perceived a change of machine performance ('on condition').

3 Preventive failure: a state of noticeable material degradation where serious deterioration in performance has occurred.

4 Breakdown failure: a condition of accelerated degradation in both material and performance, resulting in partial impairment of function.

5 Catastrophic failure: sudden and complete cessation of operation and total impairment of function - the 'sudden death' failure.

Condition monitoring can go a long way to reducing failures so that most will fall in the proactive or predictive categories.

Objectives

First and foremost a condition monitoring programme is there to save

Some machines will need more than one technique to identify a problem.

money, thereby increasing the profitability of the company. This is achieved through reducing maintenance costs and making these practices more effective, detecting abnormal wear situations and impending failures, increasing the availability and utilisation of equipment, optimising service and inspection intervals, and avoiding unnecessary overhauls and loss of production. Such a programme should allow the maintenance engineers to schedule downtime.

Levels of condition monitoring

There are also various levels of condition monitoring:

1. **Detection.** Is there a problem? What is the criticality of the situation?

2. **Diagnosis.** What is the problem? What condition monitoring techniques need to be used?

3. **Prognosis.** How serious is the problem? What does experience tell the maintenance professional?

In a plant some machines will be more critical than others and this will determine the level of maintenance on them. By using the correct condition monitoring technique, the important questions can usually be answered. Some machines will need more than one technique to positively identify a problem. When taking a critical machine out of production, the maintenance manager wants to be absolutely sure what needs to be fixed, that the right spares and personnel are available, and how long it will take.

What techniques are available ?

A wide range of condition monitoring techniques is available. Some of the more common ones are listed below, followed by a brief description of how they work.

1. **Oil analysis.** This technique involves the removal of a small sample of oil from an operating piece of machinery. The oil is subjected to a number of physical and chemical tests that determine the health of the machine, the health of the oil and the level of contaminants in the oil.

2. **Filter WDA (Wear Debris Analysis).** With filter analysis a small section of the filter medium is cut out and washed with a solvent to remove any wear debris or contaminants present. These can then be examined under a microscope or analysed chemically.

3. **Ferrography.** This is a form of in-depth WDA where the morphology of individual wear particles is studied and characterised with the aid of a microscope. This type of analysis is generally covered under oil analysis.

4. **Vibration monitoring.** This involves the measurement of oscillation of a body, machine or part of a machine around a fixed point; vibration is due to an excitation force that causes motion. These readings are subject to a wide variety of mathematical analyses in order to detect such problems as mass unbalance, bent shafts, misalignment, mechanical looseness, belt drive problems, journal bearing wear, gear wear and

AC induction motor problems. (See page 7.)

5 Thermography. This technique entails the use of infrared thermography whereby temperatures of a wide variety of targets can be measured remotely and without contact. This is accomplished by measuring the infrared energy radiating from the surface of the target and converting the measurement to an equivalent surface temperature. Thermography is used to monitor wherever excess heat can be generated when a component is defective, for example a bearing.

6 Ultra sonics. Acoustic emission or transmission and reflection of ultra high frequency sonic waves are used to detect and locate material defects. This technique can be used to detect bearing wear and is particularly useful for finding leaks.

7 Dye penetration. Cracks and surface irregularities can be easily picked up using a dye penetrant. A fluorescent dye is sprayed onto the surface to be examined, a developer or fixer is added and the component is examined under visible or ultra violet light to highlight the presence of any surface flaws.

8 Eddy currents. Surface defects can also be detected by eddy currents, which occur as a result of electromagnetic induction.

9 Radiography. Radiography uses X-rays in very much the same way that a medical X-ray would reveal a broken bone, to determine if any internal flaw or weakness exists within a mechanical component.

Which to use ?

Not all techniques can be used on all types of equipment. Some are highly complementary but others are not applicable at all.

Vibration analysis is not very effective with slow-moving, stationary equipment (the vibrational frequencies are very low) or mobile equipment which has a lot of extraneous vibration.

Oil analysis is not that effective for determining levels of wear or contamination where very large volumes of oil are concerned because the relevant readings are highly diluted, although it is a good test for the health of the oil.

In the case of a stationary gearbox, initial degradation of mechanical integrity will be picked up by oil

Not all techniques can be used on all types of equipment.

Component Categories	Condition Monitoring Techniques
Engines	Oil analysis, filter analysis, ferrography, ultra sonics.
Vehicular gearboxes	Oil analysis, ferrography, dye penetration.
Stationary gearboxes	Oil analysis, ferrography, dye penetration, vibration monitoring, thermography, radiography.
Compressors	Oil analysis, filter analysis, ferrography, vibration analysis
Fans, blowers and pumps	Oil analysis, ferrography, vibration analysis, thermography.
Hydraulic systems	Oil analysis, filter analysis, ultra sonics.
Switchgear and electrical systems	Thermography, oil analysis.

Correct sampling and measurement points are critical.

analysis well before vibration monitoring would pick it up. However, vibration monitoring will give a better indication of how long the gearbox will last before major repairs need to be carried out. In this situation the two techniques are complementary.

The table (below left) lists general component categories and the condition monitoring techniques which are best suited to them.

Steps to programme implementation

Before condition monitoring can happen, several preliminary steps need to be completed. First the need for and the feasibility of establishing condition-based maintenance must be determined. A review of equipment performance histories will determine the number and type of machines or systems that should be part of the programme. The review should note the criticality of each machine, types and frequencies of failures and the outlook for continued failures.

A manageable number of machines should be selected for inclusion in the programme. If personnel are inexperienced in using the techniques to be implemented, it makes sense to begin with a limited number of critical machines. This will provide the greatest payback in terms of savings, as well as belief in the system due to a high diagnostic 'hit rate'. The programme should be built slowly and the simplest technology should be used first.

Once the equipment to be included has been selected, the next step is to determine what, how, when and where to measure. Parameters that best indicate machine condition and failure progression must be chosen. Appropriate instruments, techniques and services which can be used to do the measuring must be selected. Decisions need to be made about how often to monitor and where on the equipment to take the measurements or samples. Correct sampling and measurement points are critical to avoid erroneous readings that will result in incorrect diagnoses.

Systems for establishing inspection schedules, handling data and training personnel should be developed. Individual responsibilities need to be defined and a structured means of communication should be in place to relay information about equipment condition and programme performance, from those responsible for monitoring and diagnosing, and those planning and scheduling repair activities to plant management. Traditional procedures such as scheduled maintenance, breakdown maintenance, construction work, inspections and stores activities should be integrated with condition and performance monitoring. The core of all these elements is a centralised information system.

The levels or limits (alarms) that represent abnormal operating conditions have to be set for all parameters that are to be monitored. Monitoring routes must be mapped out, machines given identification numbers and the sampling and measuring points marked on those machines.

Finally, baseline measurements must be taken to establish the initial condition of the machinery and to compare actual measurements to the standards set. Whilst baseline measurements are being taken, machines that are operating outside established limits will be identified.

These findings should be investigated and any faults diagnosed and corrected before machines are included in the programme. Once these preliminary steps have been taken, periodic monitoring can begin. Generally, periodic monitoring involves taking measurements on a scheduled basis, collecting, recording and trending data, then analysing the trended information to detect progressive problems, and identifying faults that require corrective action.

As the programme grows, greater knowledge acquired about the equipment leads to re-assessment of points monitored and original limits set. All relevant information about the machine needs to be gathered and should be readily available or integrated into existing software packages. Of all the techniques available, oil and vibration analysis are the most commonly used and are the two that complement each other the best

Oil and vibration analysis are the two techniques that complement each other the best.

What you will need

Dedicated staff who believe in the system are required for all the different monitoring tools, as well as for the analysis of data, follow-up work and the implementation of correct maintenance procedures. Everyone must buy in. Without this the condition monitoring programme will become a chain with a weak or broken link. Everyone is equally important and there must be a top-down management commitment. The experience of the people involved is also vitally important but unfortunately this only comes with time.

Detailed information is required on all equipment that is to be monitored; the exact details required will depend on the monitoring technique used. For example, with vibration monitoring, what is important is shaft speeds, the number of gear teeth, shaft layout and the type of bearing used. With oil analysis, the diagnosis is affected by the make and model of the component, the oil used and sump capacity. In the case of thermography, load and ambient temperature need to be known. All this information must be readily accessible.

As experience grows, so will the methodology used in analysing and diagnosing data. Case studies are very helpful and these should be kept handy when looking at data from similar machines. When a machine is opened to investigate a problem, photographs should be taken and combined with the case studies. It is important to learn from the failures that are experienced and to record all pertinent information. The diagnostician must have a thorough understanding of the machine and the levels it can tolerate before action is taken. For this reason it is crucial to have all parameters available to the diagnostician, such as the working environment, the duty cycle, hours to date, machine specifications and maintenance updates.

How to get the most out of a programme

1. Integrate condition monitoring with traditional procedures such as inspections and scheduled maintenance.

2. Regularly review and update alarm levels and limits.

Case studies are helpful and should be kept handy.

Vibration Monitoring

Oil analysis techniques and practices have been covered extensively in previous Technical Bulletins. For those Wearcheck customers who also use vibration monitoring, this technique will be looked at in a little more detail here.

As pointed out earlier, vibration is, very simply, the oscillation of a body about a reference point and is due to an excitation force that causes motion, e.g. a shaft moving (vibrating) about its average centreline position within a bearing, or a bearing moving about its average physical location.

Vibration can be measured with three types of monitoring systems, each with a specific purpose.

Machine protection systems are devices mounted permanently on the machine with an alarm and/or trip switch. They detect sudden gross changes in vibration and are intended to prevent the machine from further damage. They usually have no output or analysis capabilities.

Permanent monitoring systems are systems with sophisticated analysis and trending capabilities to monitor deterioration of bearings and other components.

Data logging systems are usually hand-held devices, which can be used to gather data from several machines and transfer them to a computer where trending and analysis can take place.

Typically, an accelerometer (measuring device) is mounted on a carefully selected point on the machine casing as close to the bearing as possible. The accelerometer converts the vibration of the machine into a dynamic electrical signal that can be fed into a data logger where it can be analysed directly or stored for later trending and analysis. The signal can be analysed in a number of ways to extract information about the condition of the machine. The interesting and important features are usually the overall vibration level as well as the spacing (frequency) at which repetitive signals occur.

Modern data loggers are powerful instruments and have many analysis and diagnostic features. However, the results are most commonly stored and later downloaded to a computer for subsequent analysis. Vibration data is normally gathered by walking a pre-planned route around the machinery and is performed on a regular basis such as every two weeks or monthly. Once the data has been loaded into the computer, a database is used to store the results for analysis and trending.

Monitoring frequencies

As with oil analysis, a measurement frequency needs to be determined in order to collect data on a regular and scheduled basis. The table below is a rough guide that should be adapted to suit each individual plant.

Some difficulty can be experienced in trying to set meaningful alarms or limits. The absolute alarms can be found in various standards but they tend to be vague and depend on many factors such as load, speed, temperature, stiffness, power rating, bearing type, ratio of rotor mass to casing mass, and transmission path. Very stiff systems or low speed machines produce low vibration levels, whilst flexible machines running at high speeds produce high vibration levels; these high levels do not necessarily indicate a faulty machine.

Vibration measurements need to be taken whilst the machine is running. Most equipment has scheduled idle periods so that the opportunity occurs for it to be examined and tested by other methods, of which visual examination is the most basic.

Critical machinery	One axial and two radial measurements at one to two week intervals or continuously
Necessary machinery	One axial and two radial measurements at two to four week intervals
Auxiliary machinery	One radial and one axial measurement at one to four month intervals

Commitment from top management is essential.

3 Keep case studies close at hand.

4 Regularly update machine information and make sure that this is readily available.

5 Commitment from top management is essential.

6 Stay up to date with the latest technology.

7 All personnel must buy into the programme; simple observations such as oil leaks can be invaluable.

8 Communication is vital; this can make or break a system, both in-house as well as with outside service providers.

In summary, a used oil analysis programme identifies machine component wear, predicts failures and prevents secondary damage and is a good complement to a vibration monitoring programme. A condition monitoring programme that combines both techniques will generally be quite effective in detecting and diagnosing machine faults.

While these techniques may not pinpoint the exact time of a probable failure, they can usually give maintenance staff enough advance warning to schedule repairs and minimise downtime. These predictive maintenance techniques are only extra tools to help detect, diagnose and prognose machinery and system faults. Always try and link different tools. If a problem cannot be solved with one, try another or a combination until a clear picture of what is going to happen has been achieved.

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