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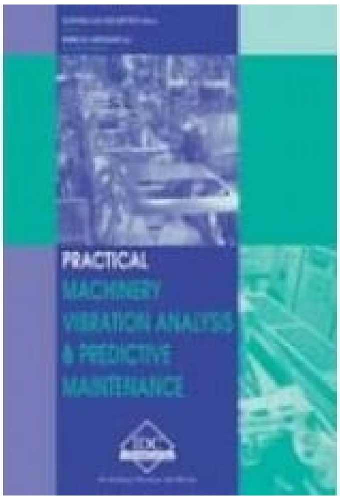
VB-E - Machinery Vibration Analysis and Predictive Maintenance



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Short Description

This manual provides a detailed examination of the detection, location and diagnosis of faults in rotating and reciprocating machinery using vibration analysis. The basics and underlying physics of vibration signals are first examined. The acquisition and processing of signals is reviewed followed by a discussion of machinery fault diagnosis using vibration analysis, and rectifying the unidentified faults.

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The manual concludes with a review of the other techniques of predictive maintenance such as oil and particle analysis, ultrasound and infrared thermography. The latest approaches and equipment used together with current research techniques in vibration analysis are also highlighted.

Table of Contents
Download Chapter List

First Chapter
Chapter 1: Predictive Maintenance Techniques: Part 1 – Predictive Maintenance Basics

1

Predictive Maintenance Techniques: Part 1 – Predictive Maintenance Basics

1.1 Maintenance Philosophies

If we were to do a survey of the maintenance philosophies employed by different process plants, we would notice quite a bit of similarity despite the vast variations in the nature of their operations. These maintenance philosophies can usually be divided into four different categories:

- Breakdown or Run to Failure Maintenance
- Preventive or Time Based Maintenance
- Predictive or Condition Based Maintenance
- Pro-Active or Prevention Maintenance

These categories are briefly described in the figure below:

Figure 1.1

Maintenance Philosophies

1.1.1 Breakdown or Run to Failure Maintenance

The basic philosophy behind Breakdown Maintenance is to allow the machinery to run to failure and only repair or replace damaged components just before or when the equipment comes to a complete stop. This approach works well if equipment shutdowns do not affect production and if labour and material costs do not matter.

The disadvantage is that the maintenance department perpetually operates in an unplanned 'crisis management' mode. When unexpected production interruptions occur, the maintenance activities require a large inventory of spare parts to react immediately. Without a doubt, it is the most inefficient way to maintain a production facility. Futile attempts are made to reduce costs by purchasing cheaper spare parts and hiring casual labour that further aggravates the problem.

The personnel generally have low morale in such cases as they tend to be overworked, arriving at work each day to be confronted with a long list of unfinished work, and a set of new emergency jobs that occurred overnight.

Despite the many technical advances in the modern era, it is still not uncommon to find production plants that operate with this maintenance philosophy.

1.1.2 Preventive or Time Based Maintenance

This philosophy behind Preventive Maintenance is to schedule maintenance activities at predetermined time intervals, based on calendar days or runtime hours of machines. Here the repair or replacement of damaged equipment is carried out before obvious problems occur. This is a good approach for equipment that does not run continuously, and where the personnel have enough skill, knowledge, and time to perform the preventive maintenance work.

The main disadvantage is that scheduled maintenance can result in performing maintenance tasks too early or too late. Equipment would be taken out for overhaul at a certain number of running hours. It is possible that, without any evidence of functional failure, components are replaced when there is still some residual life left in them. It is therefore quite possible that reduced production could occur due to unnecessary maintenance. In many cases there is also a possibility of diminished performance due to incorrect repair methods. In some cases, perfectly good machines are disassembled, their good parts removed and discarded, and new parts are improperly installed with troublesome results.

1.1.3 Predictive or Condition Based Maintenance

This philosophy consists of scheduling maintenance activities only when a functional failure is detected.

Mechanical and operational conditions are periodically monitored, and when unhealthy trends are detected, the troublesome parts in the machine are identified and scheduled for maintenance. The machine would then be shut down at a time when it is most convenient, and the damaged components would be replaced. If left unattended, these failures could result in costly secondary failures.

One of the advantages of this approach is that the maintenance events can be scheduled in an orderly fashion. It allows for some lead-time to purchase parts for the necessary repair work and thus reducing the need for a large inventory of spares. Since maintenance work is only performed when needed, there is also a possible increase in production capacity.

A possible disadvantage is that maintenance work may actually increase due to an incorrect assessment of the deterioration of machines. To track the unhealthy trends in vibration, temperature, or lubrication, requires the facility to acquire specialised equipment to monitor these parameters and provide training to personnel (or hire skilled personnel). The alternative is to outsource this task to a knowledgeable contractor to perform the machine monitoring duties.

If an organization had been running with a breakdown or preventive maintenance philosophy, the production team and maintenance management must both conform to this new philosophy.

It is very important that the management supports the maintenance department by providing the necessary equipment along with adequate training for the personnel. The personnel should be given enough time to collect the necessary data, and be permitted to shut down the machinery when problems are identified.

1.1.4 Pro-Active or Prevention Maintenance

This philosophy lays primary emphasis on tracing all failures to their root cause. Each failure is analysed and proactive measures are taken to ensure that they are not repeated. It utilises all of the predictive / preventive maintenance techniques discussed above in conjunction with Root Cause Failure Analysis

(RCFA). RCFA detects and pinpoints the problems that cause defects. It ensures that appropriate installation and repair techniques are adopted and implemented. It may also highlight the need for redesign or modification of equipment to avoid recurrence of such problems.

As in the predictive based program, it is possible to schedule maintenance repairs on equipment in an orderly fashion, but additional efforts are required to provide improvements to reduce or eliminate potential problems from occurring repeatedly.

Again, the orderly scheduling of maintenance allows lead-time to purchase parts for the necessary repairs. This reduces the need for a large spare parts inventory, because maintenance work is only performed when it is required. Additional efforts are made to thoroughly investigate the cause of the failure and to determine ways to improve the reliability of the machine. All of these aspects lead to a substantial increase in production capacity.

The disadvantage is that extremely knowledgeable employees in preventive, predictive, and prevention / pro-active maintenance practices are required. It is also possible that the work may require outsourcing to knowledgeable contractors who will have to work closely with the maintenance personnel in the RCFA phase. Pro-Active Maintenance also requires procurement of specialised equipment and properly trained personnel to perform all these duties.

1.2 Evolution of Maintenance Philosophies

Machinery maintenance in industry has evolved from Breakdown Maintenance to Time Based Preventive Maintenance. Presently, the Predictive and Pro-Active Maintenance philosophies are the most popular.

Breakdown maintenance was practiced in the early days of production technology and was reactive in nature. Equipment was allowed to run until a functional failure occurred. Secondary damage was often observed along with a primary failure.

This led to Time Based Maintenance, also called Preventive Maintenance. In this case, equipment was taken out of production for overhaul after completing a certain number of running hours, even if there was no evidence of a functional failure. The drawback of this system was that machinery components were being replaced even when there was still some functional lifetime left in them. This approach unfortunately could not assist to reduce maintenance costs.

Due to the high maintenance costs when using Preventive Maintenance, an approach to rather schedule the maintenance or overhaul of equipment based on the condition of the equipment was needed. This led to the evolution of Predictive Maintenance and its underlying techniques.

Predictive Maintenance requires continuous monitoring of equipment to detect and diagnose defects. Only when a defect is detected, the maintenance work is planned and executed.

Today, Predictive Maintenance has reached a sophisticated level in industry. Till the early eighties justification spreadsheets were used in order to obtain approvals for Condition Based Maintenance programs. Luckily, this is no longer the case.

The advantages of Predictive Maintenance are accepted in industry today, because the tangible benefits in terms of early warnings about mechanical and structural problems in machinery is clear. The method is now seen as an essential detection and diagnosis tool that has a certain impact in reducing maintenance costs, operational vs. repair downtime and inventory hold-up.

In the continuous process industry, such as oil and gas, power generation, steel, paper, cement, petrochemicals, textiles, aluminium and others, the penalties of even a small amount of downtime are immense. It is in these cases that the adoption of the Predictive Maintenance is required above all.

Through the years, Predictive Maintenance has helped improve productivity, product quality, profitability and overall effectiveness of manufacturing plants.

Predictive Maintenance in the actual sense is a philosophy - an attitude that uses the actual operating conditions of the plant equipment and systems to optimise the total plant operation.

It is generally observed that manufacturers embarking upon a Predictive Maintenance program become more aware of the specific equipment problems and subsequently try to identify the root causes of failures. This tendency lead to an evolved kind of maintenance, called Pro-Active Maintenance.

In this case, the maintenance departments take additional time to carry out precision balancing, more accurate alignments, detune resonating pipes, adhere strictly to oil check / change schedules *etc*. This ensures that they eliminate the causes that may give rise to defects in their equipment in the future.

This evolution in maintenance philosophy has brought about longer equipment life, higher safety levels, better product quality, lower life cycle costs and reduced emergencies and panic decisions precipitated by major and unforeseen mechanical failures.

Putting all this objectively one can enumerate the benefits in the following way:

- Increase in machine productivity :

By implementing Predictive Maintenance it may be possible to virtually eliminate plant downtime due to unexpected equipment failures.

- Extend intervals between overhauls:

This maintenance philosophy provides information that allows scheduling maintenance activities on an “as needed” basis.

- Minimise the number of “open, inspect and repair if necessary” overhaul routines:

Predictive Maintenance pinpoints specific defects and can thus make maintenance work more focused, rather than investigating all possibilities to detect problems.

- Improve repair time :

Since the specific equipment problems are known in advance, maintenance work can be scheduled. This makes the maintenance work faster and smoother. As machines are stopped before breakdowns occur, there is virtually no secondary damage, thus reducing repair time.

- Increase machine life:

A well-maintained machine generally lasts longer.

- Resources for repair can be properly planned:

Prediction of equipment defects reduces failure detection time, thus also failure reporting time, assigning of personnel, obtaining the correct documentation, securing the necessary spares, tooling and other items required for a repair.

- Improve product quality:

Often, the overall effect of improved maintenance is improved product quality. For instance, vibration in paper machines has a direct effect on the quality of the paper.

- Save maintenance costs:

Studies have shown that the implementation of a proper maintenance plan results in average savings of 20 - 25% in direct maintenance costs in conjunction with twice this value in increased production.

1.3 Plant Machinery Classification and Recommendations

1.3.1 Maintenance Strategy

The above maintenance philosophies have their own advantages and disadvantages and are implemented after carrying out a criticality analysis on the plant equipment. Usually the criticality analysis categorizes the equipment as:

- Critical
- Essential
- General-purpose

The *critical* equipment are broadly selected on the following basis:

- Whether their failure can affect plant safety.
- Machines that are essential for plant operation and where a shutdown will curtail the production process.
- Critical machines include unduplicated machinery trains and large horsepower trains.
- These machines have high capital cost, they are very expensive to repair (e.g., high-speed turbomachinery), or take a long time to repair
- Perennial "bad actors" or machines that wreck on the slightest provocation of an off-duty operation.
- Finally, machinery trains where better operation could save energy or improve production.

In all probability, the Pro-Active and Predictive Maintenance philosophy is adopted for critical equipment. Vibration monitoring instruments are provided with continuous, full-time monitoring capabilities for these machines. Some systems are capable of monitoring channels simultaneously so that rapid assessment of the entire machine train is possible.

The *essential* equipment are broadly selected on the following basis:

- Failure can affect plant safety.
- Machines that are essential for plant operation and where a shutdown will curtail a unit operation or a part of the process.
- They may or may not have an installed spare available.
- Start-up is possible but may affect production process.
- High horsepower or high speed but might not be running continuously.
- Some machines that demand Time Based Maintenance, like reciprocating compressors.
- These machines require moderate expenditure, expertise and time to repair.
- Perennial "bad actors" or machines that wreck at a historically arrived time schedule. For example, centrifugal fans in corrosive service.

In many cases, the Preventive Maintenance philosophy, and at times even a less sophisticated Predictive Maintenance program is adopted for such equipment. These essential machines do not need to have the same monitoring instrumentation requirements as critical machines. Vibration monitoring systems installed on essential machines can be of the scanning type, where the system switches from one sensor to the next to display the sensor output levels one by one.

The *general-purpose* equipment are broadly selected on the following basis:

- Failure does not affect plant safety.
- Not critical to plant production.
- Machine has an installed spare or can operate on demand.
- These machines require low to moderate expenditure, expertise and time to repair.
- Secondary damage does not occur or is minimal.

Usually it is acceptable to adopt the Breakdown Maintenance philosophy on general-purpose equipment. However, in modern plants, even general-purpose machines are not left to chance.

These machines do not qualify them for permanently installed instrumentation or a continuous monitoring system. They are usually monitored with portable instruments.

1.4 Principles of Predictive Maintenance

Predictive Maintenance is basically a condition driven Preventive Maintenance. Industrial or in-plant average life statistics are not used to schedule maintenance activities in this case. Predictive Maintenance monitors mechanical condition, equipment efficiency and other parameters and attempts to derive the approximate time of a functional failure.

A comprehensive Predictive Maintenance program utilises a combination of the most cost-effective tools to obtain the actual operating conditions of the equipment and plant systems. On the basis of this collected data, the maintenance schedules are selected.

Predictive Maintenance use various techniques such as Vibration analysis, Oil and Wear debris analysis, Ultrasonics, Thermography, Performance evaluation and other techniques to assess the equipment condition.

Predictive Maintenance techniques actually have a very close analogy to medical diagnostic techniques. Whenever a human body has a problem it exhibits a symptom. The nervous system provides the information - this is the detection stage. Furthermore, if required, pathological tests are done to diagnose the problem. On this basis, suitable treatment is recommended.

Figure 1.2

Predictive Maintenance

In a similar way, defects that occur in a machine always exhibit a symptom in the form of vibration or some other parameter. However, this may or may not be easily detected on machinery systems with human perceptions.

It is here that Predictive Maintenance techniques come to assistance. These techniques detect symptoms of the defects that have occurred in machines, and assist in diagnosing the exact defects that have occurred. In many cases, it is also possible to estimate the severity of the defects.

The specific techniques used depend on the type of plant equipment, their impact on production, or other key parameters of plant operation. Of further importance are the goals and objectives that the Predictive Maintenance program needs to achieve.

1.5 Predictive Maintenance Techniques

There are numerous Predictive Maintenance techniques, including:

1. Vibration Monitoring - This is undoubtedly the most effective technique to detect mechanical defects in rotating machinery.
2. Acoustic Emission - This can be used to detect, locate and continuously monitor cracks in structures and pipelines.
3. Oil Analysis - Here, lubrication oil is analysed and the occurrence of certain microscopic particles in it can be connected to the condition of bearings and gears.
4. Particle Analysis - Worn machinery components, whether in reciprocating machinery, gearboxes or hydraulic systems, release debris. Collection and analysis of this debris provides vital information on the deterioration of these components.
5. Corrosion Monitoring - Ultrasonic thickness measurements are conducted on pipelines, offshore structures and process equipment to keep track of the occurrence of corrosive wear.
6. Thermography - Thermography is used to analyse active electrical and mechanical equipment. The method can detect thermal or mechanical defects in generators, overhead lines, boilers, misaligned couplings and many other defects. It can also detect cell damage in carbon fibre structures on aircrafts.
7. Performance Monitoring - This is a very effective technique to determine the operational problems in equipment. The efficiency of machines provides a good insight on their internal conditions.

Despite all these methods, it needs to be cautioned that there have been cases where Predictive Maintenance programs were not able to demonstrate tangible benefits for an organization. The predominant causes that lead to failure of Predictive Maintenance are inadequate management support, bad planning and lack of skilled and trained manpower.

Upon activating a Predictive Maintenance program, it is very essential to decide on the specific techniques to be adopted for monitoring the plant equipment. The various methods are also dependent on type of industry, type of machinery and also to a great extent on availability of trained manpower.

It is also necessary to take note of the fact that Predictive Maintenance techniques require technically sophisticated instruments to carry out the detection and diagnostics of plant machinery. These instruments are generally very expensive and need technically competent people to analyse their output.

The cost implications, whether on sophisticated instrumentation or skilled manpower, often lead to a question mark above the plan of adopting Predictive Maintenance philosophy.

However, with management support, adequate investments in people and equipment, Predictive Maintenance can yield very good results after a short period of time.

1.6 Vibration Analysis - A Key Predictive Maintenance Technique

1.6.1 Vibration Analysis (Detection Mode)

Vibration analysis is used to determine the operating and mechanical condition of equipment. A major advantage is that vibration analysis can identify developing problems before they become too serious and cause unscheduled downtime. This can be achieved by conducting regular monitoring of machine vibrations either on continuous basis or at scheduled intervals.

Regular vibration monitoring can detect deteriorating or defective bearings, mechanical looseness, and worn or broken gears. Vibration analysis can also detect misalignment and unbalance before these conditions result in bearing or shaft deterioration.

Trending vibration levels can identify poor maintenance practices, such as improper bearing installation and replacement, inaccurate shaft alignment or imprecise rotor balancing.

All rotating machines produce vibrations that are a function of the machine dynamics, such as the alignment and balance of the rotating parts. Measuring the amplitude of vibration at certain frequencies can provide valuable information about the accuracy of shaft alignment and balance, the condition of bearings or gears, and the effect on the machine due to resonance from the housings, piping and other structures.

Vibration measurement is an effective, non-intrusive method to monitor machine condition during start-ups, shutdowns, and during normal operation. Vibration analysis is used primarily on rotating equipment such as steam and gas turbines, pumps, motors, compressors, paper machines, rolling mills, machine tools and gearboxes.

Recent advances in technology allow a limited analysis of reciprocating equipment such as large diesel engines and reciprocating compressors. These machines also need other techniques to fully monitor their operation.

A vibration analysis system usually consists of four basic parts:

- Signal pickup(s), also called a transducer
- A signal analyser
- Analysis software
- A computer for data analysis and storage

These basic parts can be configured to form a continuous on-line system, a periodic analysis system using portable equipment, or a multiplexed system that samples a series of transducers at predetermined time intervals.

Hard-wired and multiplexed systems are more expensive per measurement position. The determination of which configuration would be more practical and suitable depends on the critical nature of the equipment, and also on the importance of continuous or semi-continuous measurement data for that particular application.

1.6.2 Vibration Analysis (Diagnosis Mode)

Operators and technicians often detect unusual noises or vibrations on the shop floor or plant where they work on a daily basis. In order to determine if a serious problem actually exists, they could proceed with a vibration analysis. If a problem is indeed detected, additional spectral analyses can be done to accurately define the problem, and to estimate how long the machine can continue to run before a serious failure occurs.

Vibration measurements in analysis (diagnosis) mode can be cost-effective for less critical equipment, particularly if budgets or manpower are limited. Its effectiveness relies heavily on someone detecting unusual noises or vibration levels. This approach may not be reliable for large or complex machines, or in noisy parts of a plant. Furthermore, by the time a problem is noticed, a considerable amount deterioration or damage may have occurred.

Another application for vibration analysis is as an acceptance test to verify that a machine repair was done properly. The analysis can verify whether proper maintenance was carried out on bearing or gear installation, or whether alignment or balancing was done to the required tolerances. Additional information can be obtained by monitoring machinery on a periodic basis, for example, once per month or once per quarter. Periodic analysis and trending of vibration levels can provide a more subtle indication of bearing or gear deterioration, allowing personnel to project the machine condition into the foreseeable future. The implication is that equipment repairs can be planned to commence during normal machine shutdowns, rather than after a machine failure has caused unscheduled downtime.

1.6.3 Vibration analysis - Benefits

Vibration analysis can identify improper maintenance or repair practices. These can include improper bearing installation and replacement, inaccurate shaft alignment or imprecise rotor balancing. As almost 80% of common rotating equipment problems are related to misalignment and unbalance, vibration analysis is an important tool that can be used to reduce or eliminate recurring machine problems.

Trending vibration levels can also identify improper production practices, such as using equipment beyond their design specifications (higher temperatures, speeds, or loads). These trends can also be used to compare similar machines from different manufacturers, in order to determine if design benefits or flaws are reflected in increased or decreased performance.

Ultimately, vibration analysis can be used as part of an overall program to significantly improve equipment reliability. This can include more precise alignment and balancing, better quality installations and repairs, and continuously lowering the average vibration levels of equipment in the plant.