

5. INTRODUCTION TO CONDITION MONITORING

INTRODUCTION

Condition monitoring pertains to providing information on the condition of plant so that it can be maintained properly. By having such knowledge of machine condition, we can predict incipient failures and stop the plant for maintenance in a planned manner so that the minimum loss of output occurs and so that the maintenance can be carried out as efficiently as possible.

Our process plants are maintained predominantly by two methods:-

Breakdown maintenance - Machines can be run until they fail, and then repaired. This obviously crude method of operation can be very expensive in terms of lost output and machine destruction, and it may also be dangerous.

Preventive Maintenance - A better method is to stop machines at regular intervals for maintenance in order to reduce the chance of unplanned stoppages - i.e. breakdowns. A rare practice in traditional industrial maintenance is service replacement - replacement of components at a set frequency or after a specified life, regardless of condition.

The problem in planning preventive maintenance or in implementing service replacement is to decide about the appropriate maintenance interval for the machine, because the actual running time before maintenance (or replacement) is really needed, is not constant, but varies from one occasion to another, due to differences in the operation of the machine owing to the behaviour of its components.

- Too frequent maintenance wastes production time and increases the risk of trouble arising from human errors in reassembly on the other hand.
- Too long an interval results in an unacceptable number of machine failures during operation.

A compromise between two extremes can be established by experience, but machine failures will continue to occur. The golden means in terms of maintenance strategy will be carrying out preventive maintenance at what may be irregular intervals, but determining these intervals by the actual condition of the machine at the time. For such condition based maintenance to be possible, it is essential to have knowledge of the machine condition and its rate of change with time. The main function of condition monitoring is to provide this knowledge.

The knowledge may be obtained by selecting a suitable parameter for measuring deterioration, and recording its value at intervals. Assessing the trend of this measurement can give a useful lead information well in advance warning of incipient machine failure. This is known as trend monitoring.

ADVANTAGES OF CONDITION MONITORING

To understand the gains to be made from condition-based maintenance let us consider the typical failure curve (Fig.1) which can be divided into three regions:-

- Region-1 EARLY LIFE - FAILURES ARE DUE TO INFANT MORTALITY
- Region-2 USEFUL LIFE - FAILURES ARE RANDOM
- Region-3 WEAR-OUT STAGE - FAILURES DUE TO WEAR AND TEAR

Figure 5-1

It is this last region - the wear-out stage - in which condition monitoring offers the greatest potential. Given an effective maintenance program incorporating condition monitoring, one will be much more efficient at:-

- Detecting, repairing, replacing, marginal operating units only.
- Replacing limited - life items, prior to wear out and damage to other units in the system.
- Detecting and removing foreign matter (for example, dirt, oil and moisture) which can contribute to reduced component life span.

Often incipient wear out failures result in below par operation. Hence, success in detecting and repairing such potential failures not only prevents failure, but also:-

- Helps to produce required quality - less rejects and scrap.
- Helps to improve employee safety through reduced number of on-line failures.
- Helps to ensure plant operation at optimum efficiency and in so doing minimizes energy usage.
- Gives satisfaction through timely deliveries.

Efficient condition monitoring of a plant can also give other less obvious benefits. For example the effect of updating the plant output - a gleam in every production manager's eye - can be more accurately predicted. Also condition monitoring judiciously applied during commissioning allows weak spots to be quickly identified, and an early indication gained of whether or not the plant will achieve its rated output.

Benefits which can be derived from monitoring the condition of plant and machinery are:-

- ◆ Increased plant availability resulting in greater output from the

- capital invested.
- ◆ Reduced maintenance costs.
- ◆ Improved personnel safety.
- ◆ More efficient plant operation, and more consistent quality, obtained by matching the rate of output to the plant condition.
- ◆ More effective negotiations with the equipment manufacturers, backed up by systematic measurements of plant condition.
- ◆ Better customer relations following the avoidance of inconvenient breakdowns which would otherwise have occurred.
- ◆ The opportunity to specify and design better plant in the future.

To obtain these benefits, an industry must be prepared to:-

- ◆ Put in managerial efforts needed to organise the condition monitoring activities.
- ◆ Be prepared to meet its cost for 1-2 years i.e. until the benefits become apparent.

Factors affecting industrial application:

Overall economic benefit is usually the most important consideration affecting a company's decision to apply condition monitoring, and in particular the benefits arising from the reduction of output losses and maintenance costs. There are, however, a number of other factors which favour the use of condition monitoring, but a few may be unfavourable.

Circumstances which favour the successful application of condition monitoring are:-

- ◆ Where a safety risk is particularly likely to arise from the breakdown of machinery.
- ◆ Where accurate and advanced planning of maintenance is essential.
- ◆ Where operators cannot be expected to detect faults in expensive equipment whose breakdown may result in serious damage.

Circumstances in which condition monitoring is unsuitable are:

1. Where an industry is operating at a low level of activity so that plant and machinery is often idle. If the plant is operating part of the time, there is generally plenty of opportunity for inspection and maintenance during idle periods.
2. Where skilled operators have close physical contact with their machines and can use their own senses for subjective monitoring. Machine tools and ships can be examples of this situation, but any trends towards the use of less skilled operators or supervisory engineers, favours the application of condition monitoring.

Selecting the Level Condition Monitoring Activity:

Monitoring the condition of plant, machinery and equipment can result in a number of benefits, but its economic advantages are a major factor in any decision to adopt it.

To determine the level of condition monitoring activity appropriate to a particular industry, it is first of all necessary to assess the potential economic savings. These arise mainly from:

1. A reduction in the loss of production due to breakdowns.
2. A reduction in maintenance costs.

These will determine the possible level of expenditure and the level of application. The experience of current users of condition monitoring suggests that its use can eliminate 75% of unscheduled breakdowns in a typical plant. On this basis the possible annual gross savings by reducing production losses due to breakdowns may be estimated from:-

$$D \times O \times 75\%$$

D = Average number of days production lost per year due to breakdowns.

O = Average daily added value output of the organisation.

Added value output can be calculated from

**Total sales revenue minus
Cost of raw-materials and energy bought in.**

Additional annual gross savings arise from reduction of maintenance costs, due mainly to saving in labour costs on breakdown maintenance. Based on the experience of existing users, a possible average figure for this saving is:-

$$\text{Breakdown maintenance Labour cost} \times 50\%$$

If a figure for breakdown maintenance labour cost is not available, an alternative method of assessing the saving is:-

$$A \times L \times B \times 50\%$$

where,

A = Total annual cost of maintenance

L = % of A which is for labour

B = % of A which is for breakdown work.

In most cases L & B are usually about 30%. So a more approximate of the gross saving is:-

$$A \times 30\% \times 30\% \times 50\%$$

i.e. A x 5%

The total potential gross savings are therefore:-

$$(D \times O \times 75\%) + (A \times 5\%)$$

Selecting machines and components for monitoring:

Machines or components for which condition monitoring is particularly effective will be those which, on breakdowns, give rise to high costs. The costs will arise mainly from the following:

1. The loss of productive earning capacity.
2. The direct cost of damage occurring at the breakdown.

Selection of machines by loss of productive earning capacity:

Whatever the size of plant or factory, it is useful to obtain, or draw up, a flow diagram of the production process which shows how the various machines may be linked together in terms of the flow path of the product.

The diagram will indicate where there are critical machines in which failure can cause a disruption of the production process, and these machines will be the first choice for monitoring.

Machines giving rise to high losses in productive capacity will tend to be those which:-

1. Are in continuous operation.
2. Have minimum parallel or standby capacity.
3. Have minimum intermediate product storage capacity on either side of them.
4. Are involved in a critical product transfer or transport function.

Selection of machines on a basis of failure damage:

Any machines in the plant which are prone to high level of consequential damage, or machines which are very expensive or difficult to replace, will be particularly suitable for application of condition monitoring. **Machines in which the direct cost of failure damage** is likely to be high will tend to be those which:-

1. Operate at high pressures, temperatures or voltages.
2. Handle dangerous working fluids.
3. Contain high inertia and high speed components.
4. Are arranged in very compact layouts.

Apart from any economic aspects, any machines which involved a safety hazard will be worth monitoring for this reason alone.

The safety hazard may arise because:

- a. The machine explodes as a consequence of failure.
- b. Dangerous materials are released as a consequence of failure.

c. The machine is used for transporting personnel.

General Scope of monitoring methods:

Condition monitoring is not new in that engineers, in-charge of machines, have always used their own senses to obtain a general indication of machine condition.

Simple monitoring methods using the senses of the engineer in charge:-

Sight	Leaks Smoke or casing colour change, indicating overheating.
Smell	Overheating Leaks
Hearing	Abnormal noise, indicating some malfunction.
Feel	Abnormal vibration, indicating some malfunction, high casing temperatures, indicating overheating.

General Assessment of machine performance.

A great improvement in assessing the existence of a problem can be obtained, however, by the use of simple instrumentation to give numerical readings. These numerical readings eliminate the errors of personal opinion, and can be compared with data from the machine manufacturers for normal operation, and with previous readings on the same instrument.

Simple instrumentation is usually fitted to most machines, and can give some numerical indication of the existence of a problem in the machine. Typical examples are:-

Pressure gauges
Temperature indicators
Tachometers
Ammeters

Warning lights and other alarms set to operate at some particular measured value can also indicate that a problem exists.

In spite of the large number of techniques and the amount of instrumentation that is available, there are really only four basic methods of condition monitoring, and these are:

1. Visual monitoring

Machine components are visually inspected to determine their condition.

2. Vibration monitoring

The condition of moving components in a machine is assessed from the amount and nature of vibration which they generate.

3. Thermal Monitoring

The condition of the components are assessed based on the temperature levels.

3. Wear-debris monitoring

The condition of critical component surfaces, subject to loading and relative movement, is assessed from the wear debris which they generate. They are usually oil washed components, and the collection and analysis of debris is done by testing the lubricating oil.

4. Performance monitoring

The condition of a machine or component is assessed by measuring how well it is performing its intended duty.

With each of the above methods of monitoring, the existence of a problem is usually detected from the general level of measurement and its rate of change. While the nature of the problem can generally be determined from a more detailed analysis of the measurements obtained. This analysis is outlined in Table-1.

TABLE--1

Monitoring Method	Detection of existence by measurement of level	Determination of the nature of the problem by analysis of the measurement		
Visual Monitoring	Overall appearance	Colour	Shape	Texture
Performance Monitoring	Rate of output	Uniformity of rate of level	Quality	Uniformity of output quality
Vibration Monitoring	Overall Vibration level	Frequency content	Single wave form	Single statistics.
Wear debris Monitoring	Amount of debris	Size distribution	Shape of the debris	Chemical composition of the debris.

The various techniques, within the four main categories of monitoring method, are given below as a guide to their general selection:

Visual Monitoring

Direct

- Microscopes - magnification
- Boroscopes - improved access
- Stroboscopes - makes moving parts appear stationary

Recorded

- Photographs - to record surface condition
- Radiographs - to see internal parts
- Thermographs - to see surface temperature
- Surface prints - to record surface damage
- Surface casts - to record surface damage
- Witness indents- to indicate surface wear
- Dye penetrants - to detect surface cracks

Performance and trend monitoring

Machine Performance assessment by comparison of inputs and output components. The behaviour to be assessed depends on the type of component:

Stationary and	Strain measurement
Stressed	Crack detection Sentinel holes in pressure vessels
Bearings	Temperature measurement Shaft position/clearance
Seals	Leak detection.
Friction devices	Temperature measurement
Wearing Surfaces	Dimensional measurement Wear depth indicators. Component position measurement.
Pipes and valves	Pressure drop/flow relationship
Heaters & coolers	Temp. drop/flow relationship.

Vibration monitoring:

Shafts and symmetrical components

Shaft vibration measurements to check operation of rotors and journal bearings

Natural/critical frequency checks response to excitation to indicate cracks and stiffness changes.

Bearing housings and casing.

General vibration and noise level for overall machine condition. Spectral analysis to indicate the component likely to be defective.

Discrete frequency monitoring and special techniques such as shock pulse and kurtosis, spectrum

analysis and signal averaging to look for specific machine and component defects.

Wear debris and contaminant monitoring.

Direct detection of the debris in the oil in the machine optical methods.

Electrically conducting filters.

Inductive and capacitive methods.

Collection of the debris in the machine for regular examination.

Existing filtration system.

Special filters.

Magnetic plugs.

Regular sampling of the lubricant for an analysis of its contents.

Elemental (spectrometric) analysis.

Magnetic particle separation.

Automatic particle counting.

Reference:

1. Condition Monitoring Manual;
Michael Neale, HMSO; UK.