Lifetime Reliability • Solutions

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The Lifetime Reliability Solutions
Certificate Course in Maintenance and Reliability
Module 1 – Introduction to Principles of Reliability and Precision Maintenance

Sessions 4
Detection of the Need for Maintenance

1. Introduction

An essential part of the maintenance of plant is the identification of the need for work to be carried out. Remember, maintenance is more than just "fixing things up"; it is the appropriate management of an asset for its lifetime.

Thus the philosophy that "*a stitch in time will save nine*" is very appropriate and is an important part of maintenance. Typically, the detection of need of maintenance has been one or other of;

- From a perceived change in observed condition or performance – Condition Checking
- Let it draw attention to itself – effectively breakdown maintenance
- From routine or periodic inspections – Planned Preventative Maintenance
- From a measured and trended change in the condition or performance – Condition Based Maintenance

This process contributes more fully to plant reliability when it is applied in conjunction with **Precision Skills** in maintenance. Precision Skills is the focus of the second part of this module.

2. Condition Checking

This procedure offers enormous potential but is frequently neglected or not recognised for what it offers. This is where plant operators, or others who visit and are close to plant on a regular basis, observe and report upon what they **See, Hear and Feel** in relation to the plant. They may use some rudimentary instrumentation to assist in this. In this role the plant operator is seen to be the first line condition monitoring personnel.

On plants where this role is formally recognised and feedback is expected, and is acted upon, there is a very significant lift in the reliability of the plant.

Note the three essential elements here;

- The role is formally recognised; this may involve some appropriate training
- Advise or feedback is expected and a process exists for this
- The information is acknowledged and is acted upon. The outcome is fed back.

Condition checking will not be so effective if plant housekeeping is not good. It is not possible to observe fluid leaks, coupling or belt debris, or witness marks of machine movement if the machine is dirty. If a machine runs roughly or noisily it will not be possible to detect an increase in roughness – a relatively subtle change from smooth to rough is very readily identified with the human touch.

Some modification in guarding may be needed to permit access for feeling bearings or observing debris from couplings.

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Under maintenance regimes such as TPM plant operators and maintainers are formed into teams and the operator is trained and expected to carry out the basic routines of preventative maintenance and inspections, with support from the maintenance staff. This concept of teamwork, or partnership, has been reported to work very effectively when all the elements given above are in place, and are used rather than given lip service. Increasingly this concept is being used more widely although not necessarily under a TPM regime.

3. Breakdown Maintenance and Planned Preventative Maintenance

These were discussed in Session 2 and are not amplified further for the sake of this discussion.

4. Condition Based Maintenance.

The principal techniques of Condition Based Maintenance, or Condition Monitoring, are;

- Vibration Measurement and Analysis
- Oil Condition and Wear Debris Analysis
- Thermography
- NDT, particularly thickness testing
- Performance, eg flow measurement

At most sites where vibration condition monitoring is routinely conducted there will usually be a thermography and an oil analysis programme operating as well. However, until recent times there has been little effort to correlate the findings of all methods into a combined condition report. This is now changing with more emphasis being given to 'integrated condition monitoring' where an alarm in one method gives cause to look for evidence of a fault in the other methods. Better quality forecasts of remaining life are the result of good quality integrated programmes.

These techniques are based upon the measurement of some physical parameter, many of them dynamic. We shall focus now on the means of making these measurements.

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Measurable Parameters in Dynamic Systems

1. Introduction.

Human beings interact with the environment through the five physical senses of sound, sight, touch, smell and taste. These senses enable us to be aware of danger, help us to make right judgements in our movements, enable us to communicate, to enjoy food and to sense when something is foul or unhealthy.

Historically these have been the foundation of our relationship with machinery also and this relationship continues perhaps more strongly than ever. Every time we drive our car we are listening to the familiar noises it makes and the responses it gives. Even the slightest change in those sounds or responses can lead us to be aware of trouble.

In the world of industrial machinery there continues to be a significant dependence upon sound in particular and the other senses to a lesser degree. In a review of condition monitoring fault reports raised over a period of several years in the late 1970's, this author recalls that approximately 30% were raised from direct observations by the technician, not as the result of any measurements. It is likely that this is still the case although today, the persons reporting the faults may not be part of a formal condition monitoring programme.

While condition monitoring by the human senses continues to be a vital part of our relationship with machinery, it is very subjective. If we use a screwdriver to listen to a bearing, the condition assessment of a group of people listening to the same thing may vary greatly. In general terms our senses are uncalibrated to enable any structured form of data management and inadequate to detect faults before they have progressed to a serious degree.

Therefore, with the march of technology we have developed some useful sensors to enable precise measurement of a number of physical parameters in machinery.

A sensor, or **transducer,** may be defined as "*A device for converting the variation in one quantity (e.g. vibration, pressure) into variations in another (e.g voltage, current).*"
For example, a microphone converts sound (very small pressure variations) into voltage which is proportional to sound pressure.

The purpose of this Session is to briefly review the variety of sensors commonly used for condition monitoring purposes, to understand how the outputs of the sensors are managed and how we can use this information to help with the continuing goal of improved reliability.

2. Measurable Parameters.

The table below shows the wide range of physical parameters and the types of machine where they may give meaningful information for condition monitoring and diagnostic purposes.

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Table A.1 — Examples of condition monitoring parameters by machine type

Parameter	Machine Type								
	Electric motor	Steam turbine	Aero gas turbine	Industr-ial gas turbine	Pump	Comp-ressor	Electric gen-erator	RIC engine	Fan
Temperature	•	•	•	•	•	•	•	•	•
Pressure		•	•	•	•	•		•	•
Pressure (head)					•				
Pressure ratio			•	•		•			
Air flow			•			•		•	•
Fuel flow			•	•				•	
Fluid flow		•			•	•			
Current	•						•		
Voltage	•						•		
Resistance	•						•		
Input power	•				•	•	•		•
Output power	•	•	•	•			•	•	
Noise	•	•	•	•	•	•	•	•	•
Vibration	•	•	•	•	•	•	•	•	•
Oil pressure	•	•	•	•	•	•	•	•	•
Oil consumption	•	•	•	•	•	•	•	•	•
Oil (tribology)	•	•	•	•	•	•	•	•	•
Torque	•	•				•	•	•	
Speed	•	•	•	•	•	•	•	•	•
Length		•							
Angular position		•	•	•		•			
Efficiency (derived)		•	•	•	•	•		•	
• indicates condition monitoring measurement parameter applicable									

A very simple and common machine in industry is the electrically driven pump. If we consider such a machine in normal operation there will be a number of parameters that we can measure using commonly available transducers. We can use the information from these sensors to learn a lot about the condition and performance of the pump.

These are some possible sensor types:

Sensor type.
Vibration – Seismic (casing or bearing)
Vibration – Relative (shaft to bearing)

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Liquid Pressure
Temperature – direct measurement
Temperature – non-contact
Motor Current
Liquid Flow
Oil Condition

3. Transducer Outputs.

Some of these parameters are, by nature, reasonably steady values that we will refer to as 'DC' for direct current. For example, a temperature measurement system would be expected to read out a value that told us the temperature in degrees Centigrade and, while that may vary in amplitude a little, it would normally be a fairly stable value.

Other parameters will by nature be dynamic and the sensor output will be essentially 'AC' or alternating current. An obvious example would be the motor current.

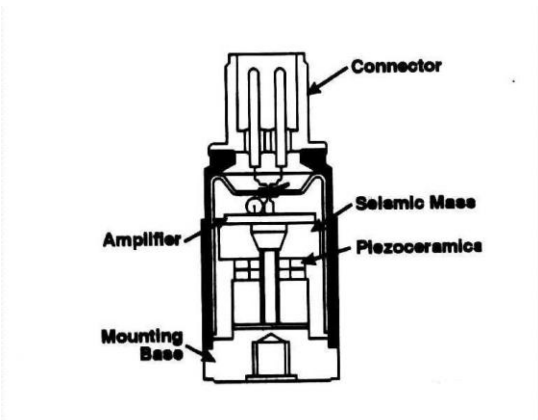
We will now consider briefly some of the more common types of sensor.

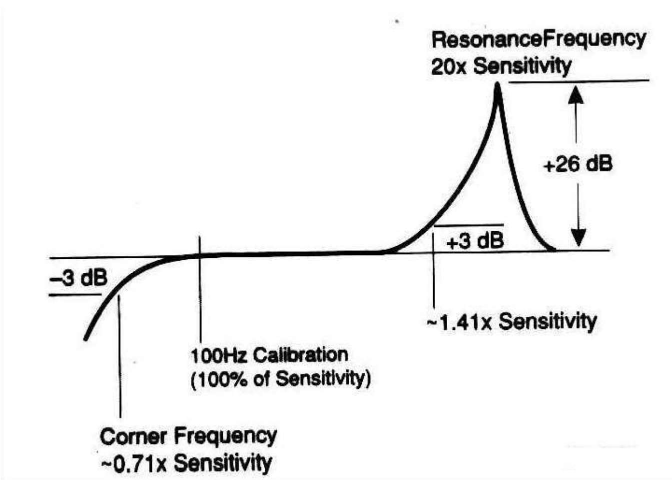
4. Common Sensors.

4.1 Vibration Transducers – Seismic.

The most common sensor for vibration is the accelerometer that, as the name suggests, produces an output proportional to acceleration.

The Accelerometer is a simple force-measuring device comprising a mass coupled to a pressure-sensitive (piezoelectric) crystal. It is a seismic device so that motion of the sensor causes forces from the inertia of the mass to be transmitted to the crystal that, in turn, produces a measurable change in charge output. This can be amplified to give an output in terms of mV per unit of acceleration.





The modern accelerometer is a highly reliable, reasonably robust piece of equipment and is almost universally used for machine casing vibration measurements. It has the big advantage that electronic integration is very easy to arrange and therefore the output can be conditioned to read velocity or displacement with a minimum of components.

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The useable frequency range of an accelerometer is very wide. A common industrial accelerometer, such as shown above, gives a very flat and repeatable response from 1 Hz to 10 kHz and this is ideal to cover most machinery measurement requirements.

At the high frequency end there is a further useful characteristic. The sensitivity actually increases as the mass-spring assembly in the accelerometer approaches resonance. This feature enables an increase in sensitivity of around 20 times the linear range to detect the very small amplitudes of energy emitted from the very early stages of bearing failure.

Therefore, most bearing fault detection instruments use this particular feature as the means of identifying bearing faults in the very early stages. (These techniques will be dealt with in a separate section later on in the Course).

Most accelerometers used for condition monitoring have a sensitivity of 100 mV/g. With typical supply voltages, these accelerometers can measure 50 to 80 g peak before saturation. The evidence of saturation is a ‘ski-slope’ at the low frequency end of the spectrum. A lower sensitivity accelerometer is needed when this condition is in evidence.

Sensor mounting is an important consideration for repeatability and signal integrity. Australian Standard AS 2775 is a useful reference in relation to the variety of mounting methods.

In ideal practise, only two methods are widely used; magnetic attachment and some form of screwed or locked platform mounting. However, in the real world some form of probe may still be used – mainly for reasons of access, but this is to be discouraged.

Magnetic attachment has frequency limitations and, even under ideal conditions, should not be used where frequencies above 2000 Hz are required to be measured. Increased response to about 3000 Hz can be obtained by using flat magnetic washers glued to the machine and a flat-faced magnet on the accelerometer. The washers must, of course, be made from non-corrosive magnetic material.

Screwed platform mounting provides measurement across the full frequency range as well as perfect repeatability of location. However, platforms take time to install and are therefore only used where the frequency or repeatability requirements are outside the capability of magnetic attachment. Glued platforms may not be successful on some machine surfaces.

The drawings on the following page are taken from AS 2775 and show several classic transducer mounting arrangements.

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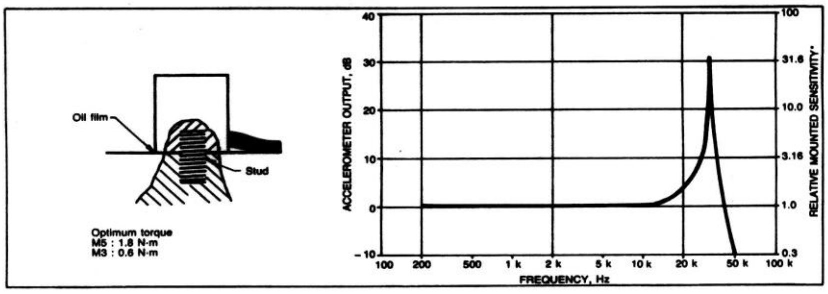
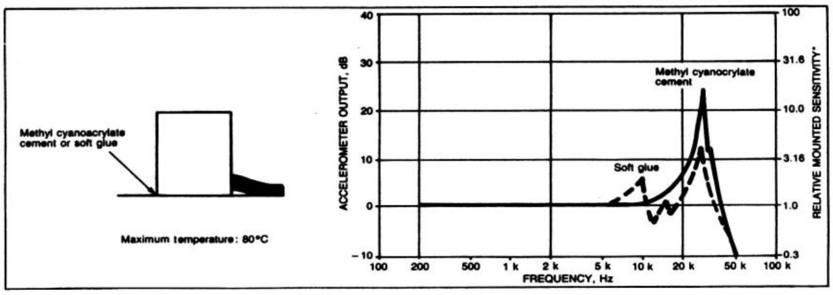
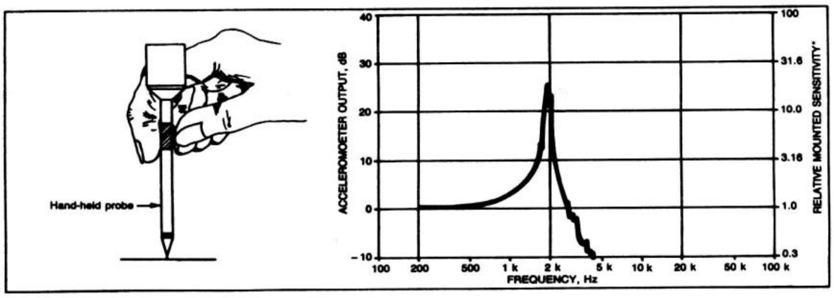


TEST WITH OIL FILM AND STUD



TESTS WITH METHYL CYANOACRYLATE CEMENT AND SOFT GLUE



TEST WITH HAND-HELD PROBE

4.2 Vibration – Shaft Relative.

These sensors are commonly known as ‘Proximity Probes’ because they measure the proximity of one surface to another. They are based on the eddy current principle and are essentially a ‘gap’ measuring device. The displacement they read is therefore relative to movement between the mounting of the probe and the surface that it is observing.

The most common application is for protection of high speed turbo machinery. High speed machines use white-metal, oil film bearings where a reduction or loss of oil film thickness can mean catastrophe. Proximity probes are mounted in pairs 90 degrees apart at each bearing to observe the displacement of the shaft. The diagram on the next page shows a typical comprehensive protection system for a turbo-generator.

Note that the word ‘protection’ has been used rather than condition monitoring. The essential purpose of these systems is to detect small changes in the movement of a shaft in its bearing that may indicate a potential failure of the bearing. The kinetic energy in the

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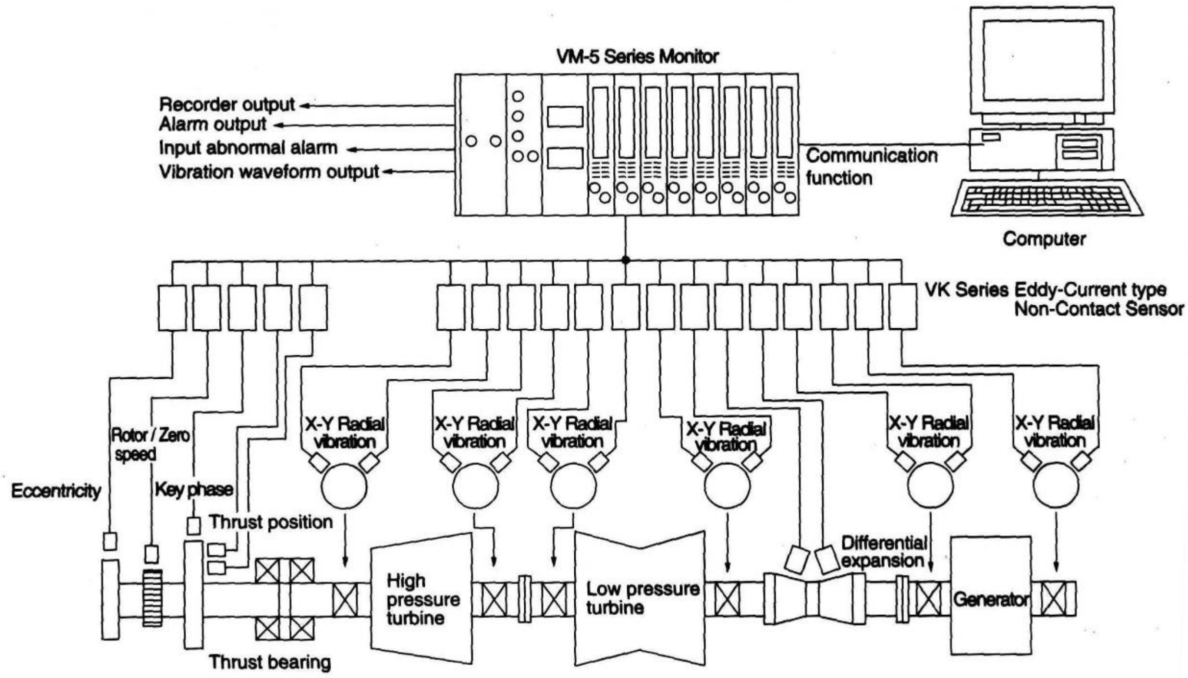
rotating elements combined with small operating clearances means that a bearing failure could be both highly dangerous as well as hugely expensive.

The information gained from the proximity probes is useful for condition monitoring purposes and trends can be observed of changes in machine balance or alignment that can lead to corrective action.

Application of the eddy-current displacement sensors to steam turbine and generator



A typical proximity probe has a linear range of approximately 2.0 mm and is therefore usually set at about 1.0 mm from the surface it is observing. The output constant from the driver is typically 8 volts/mm. A probe of this kind can potentially read a change in gap of less than one micrometre but from a practical point of view the surface roughness of the shaft as well as electrical and magnetic anomalies are always going to interfere with the reliability of such small measurements.

The diagram below shows a typical response curve for a proximity probe and its driver and how the information is presented to the monitoring system.

The instrument panel usually is fitted with BNC sockets – one per proximity probe – and the vibration monitoring technician can plug into these outputs and sample the DC (gap) voltage as well as the AC (shaft motion) signal. If the technician has a two-channel machinery analyser it is possible to produce a diagrammatic ‘orbit’ or Lissajous Diagram of each pair of probes. If the tacho reference is also sampled via a third input then phase can also be measured. Changes in any of these parameters can give vital clues to potentially severe changes in condition.

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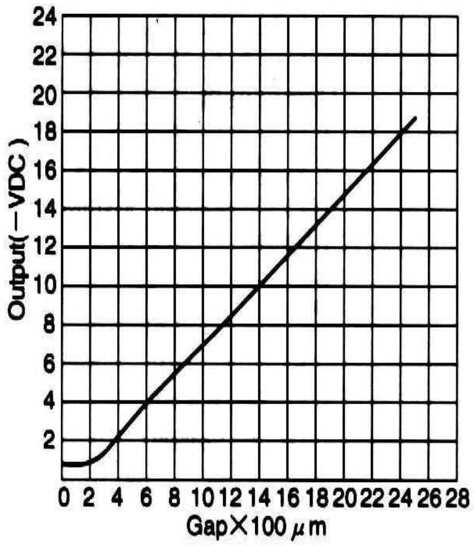

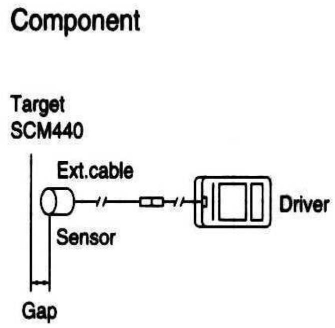

4.3 Pressure Sensors.

There are numerous types of pressure sensors available and it is beyond the scope of this course to go into the detail of all of these. An excellent reference for further information is the publication titled 'Guide to the Measurement of Pressure and Vacuum' prepared by The Institute of Measurement and Control, London. ITA have a copy available for perusal.

The most common types of electronic pressure transducers for process control are the diaphragm/strain-gauge type and the capacitance type. Outputs from both are typically 4-20mA to provide a DC pressure value. A typical specification sheet is attached for the Druck PTX 1400 Industrial Pressure Transmitter, which is a strain-gauge type. Note that these devices are unsuited for dynamic pressure measurements as the Over-Pressure ratings are limited.

For investigative work it is often required that the dynamics of a fluid system (liquid or gas) be measured. For this purpose, piezo-electric pressure sensors are available that have quite a high frequency AC response and can accurately measure the shock-wave transients caused, for example, by reciprocating pumps or compressors. They are unable to measure steady pressures (DC values) because the nature of piezo is that there must be continuous excitation to produce a signal.

An example of where piezo-quartz transducers would be used is the measurement of combustion pressure in reciprocating engines. They can be made to withstand very high over-pressure values such as might be expected in such test environments. Characteristically these transducers are not robust enough for continuous duty and are only used for investigative work. The mortality rate is quite high for pressure systems with high transient peak amplitudes continuing over long periods.

4.4 Temperature – Direct Measurement.

Temperature sensors are usually designed to be very much DC devices as typically temperatures do not vary dynamically.

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The most common industrial devices are Mineral Insulated Thermocouples (known simply as thermocouples) and Platinum Resistance Temperature Detectors (known as RTD's). They come in various configurations but are essentially based on the fact that certain metals change resistance with change in temperature.

Thermocouples can be manufactured to almost any shape and length from mineral insulated 'cable' and examples are shown on the coloured sheet at the end of theses session notes. Typical accuracies are shown there for different combinations of metals.

RTD's are more accurate devices and a little more expensive. Any application requiring very fine temperature measurement resolution would use RTD's. However, they are also slower to respond to temperature changes so that accuracy is gained at the expense of sensitivity.

4.5 Temperature – Non-Contact.

In recent years portable non-contact thermometers based on infra-red emission have become cheaper in price and are now widely employed in condition monitoring. Used with care they can be very accurate and repeatable. A copy of a brochure describing a typical instrument is given at the end of these notes.

The more sophisticated use of the same technology is thermography whereby temperature can be measured over large surface areas in real time. Thermography in fact is able to offer a significant AC component and sometimes that can be useful in the study of rotating elements of machinery. Thermography is dealt with in more detail in a later session.

4.6 Motor Current.

The current transformer or clamp will produce an AC signal that is predominantly a 50Hz sine wave. However, there can be modulations of the current due to rotation of the machine and potential electrical irregularities, such as a broken rotor bar.

In the 1990s Motor Current Spectrum Analysis (MCSA) was being promoted as the ideal condition monitoring tool for electric motors and all sorts of claims were made for the wonderful things you could do with it. Numerous technical papers were published and diagnostic procedures described.

In reality MCSA is difficult to apply to machines that do not have current transformers fitted because the installation of a current clamp is necessarily invasive and an electrician is required to make the installation, etc, etc. Therefore, when it is applied it is generally only onto large motors where reliability is critical and current transformer taps are available on the control panel.

4.7 Liquid Flow.

The measurement of flow is very much a DC value but it should be noted that water hammer is effectively a dynamic phenomena of liquid flows the effects of which can best be studied by AC pressure wave analysis.

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There are literally scores of different devices for measuring flow. Some of the more common devices used in the mining and industrial scenes are these:

- **Orifice plate method.** The small amplitude pressure changes at selected tapping points upstream and downstream can be applied to a standard formula to provide accurate flow calculation. The main problem with orifice plates are that the range of flows for any given plate is limited to a ratio of about 5:1.

- **Electromagnetic Flowmeter** (commonly known as a Magflowmeter). These devices measure the current generated in an electro-conductive liquid (most liquids) as it passes through a magnetic field. They are relatively expensive but highly accurate because they take account of the total flow profile. Especially used for slurries and acids and other products that would be difficult to measure with lower cost invasive methods.

- **Coriolis Meter.** These devices are complex but are able to accurately measure mass flow whereas most other meters just measure volume. Therefore they are particularly useful where density variations must be taken into account. Maximum size about 150 mm diameter.

- **Vortex Flowmeter.** Works on the basis that the wavelength of a vortex created by an obstacle in the flow is always the same and only the amplitude varies. The amplitude of the disturbance can be measured by a strain gauge, ultrasonic sensor or peizo elements and reasonably accurate flow measurements determined.

- **Ultrasonic Flowmeters.** These come in two forms; **transit-time** which is a highly accurate method for clear or near-clear liquids, and **Doppler,** which is a far less precise method useful for liquids that have suspended solids or bubbles. The big advantage of ultrasonic flow measurement is that it is non-invasive and, with appropriate knowledge and skill, very good results can be achieved. At the end of these notes is a paper written by Max Wishaw giving some notes arising from his experience in the use of these instruments.

4.8 Oil Sampling.

Most oil sampling is done manually and the samples taken away for laboratory analysis. However, there are some on-line sensors available for special purposes.

Perhaps the simplest is the magnetic switch in the return oil line. The idea is that ferrous particles being carried in the flow from wear or fatigue somewhere in the machine are collected on the magnetic plug and close a circuit to give warning of trouble. These have been used on aircraft gas turbines for many years and have proven to be very reliable indicators.

More sophisticated on-line analysers are now becoming available to look for wear particles, water, fuel dilution and the like. Many such devices are available as portable instruments to be able to provide quickly and simply some information about oil condition in the field and whether more advanced analysis is needed.

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5. Process Control.

Over the past 30 years or so there have been huge advances in process control and automation. In the 1960's control rooms had lots of operators, tables and chairs and log books. On the walls were large chart recorders printing out a few key process variables. All process changes were done in the plant by operators with valve spanners.

Today the process plant is run by computers monitoring numerous variables and continuously making changes to operate the plant within pre-set boundaries.

Some condition monitoring variables have not yet made it into the control room, especially vibration and oil condition. Most condition monitoring data such as vibration, oil and thermal imaging is still collected by walk-around technicians. Historically the reason has been that these are seen as 'maintenance' data inputs and were not of interest to operators.

However, there is evidence that operators are being expected to take an increased interest in the mechanical performance of the machines in their charge. We believe that this is a healthy trend and LRS is very much committed to training operators and tradespersons to better appreciate the health of machinery by using the measurable parameters as we have discussed in this session.