

**Sensors &
Systems**

PROTECTING
YOUR
INVESTMENT

SENSORS

TURBINE SUPERVISORY GUIDE



**TECHNIQUES FOR THE
MONITORING & PROTECTION OF
POWER PLANT EQUIPMENT**



PROTECTING
YOUR
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SENSORS

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INTRODUCTION

For nearly 30 years Sensonics has been supplying Turbine Condition Monitoring solutions to the power generation industry worldwide. Involved in measurement definition through to supply and final system commissioning, our experience within the power sector is second to none.

We have produced this guide to capture the essence of that experience and to explain the basics of vibration and expansion measurement techniques relating to turbine and auxiliary plant equipment.

The guide starts with an introduction to the basic transducers available for plant mounting with associated options, and details the various measurement techniques used as standard throughout the power industry. This is followed by typical equipment protection configurations for safe plant shutdown. In the final part of this guide the system components are introduced and special measurement regimes discussed.

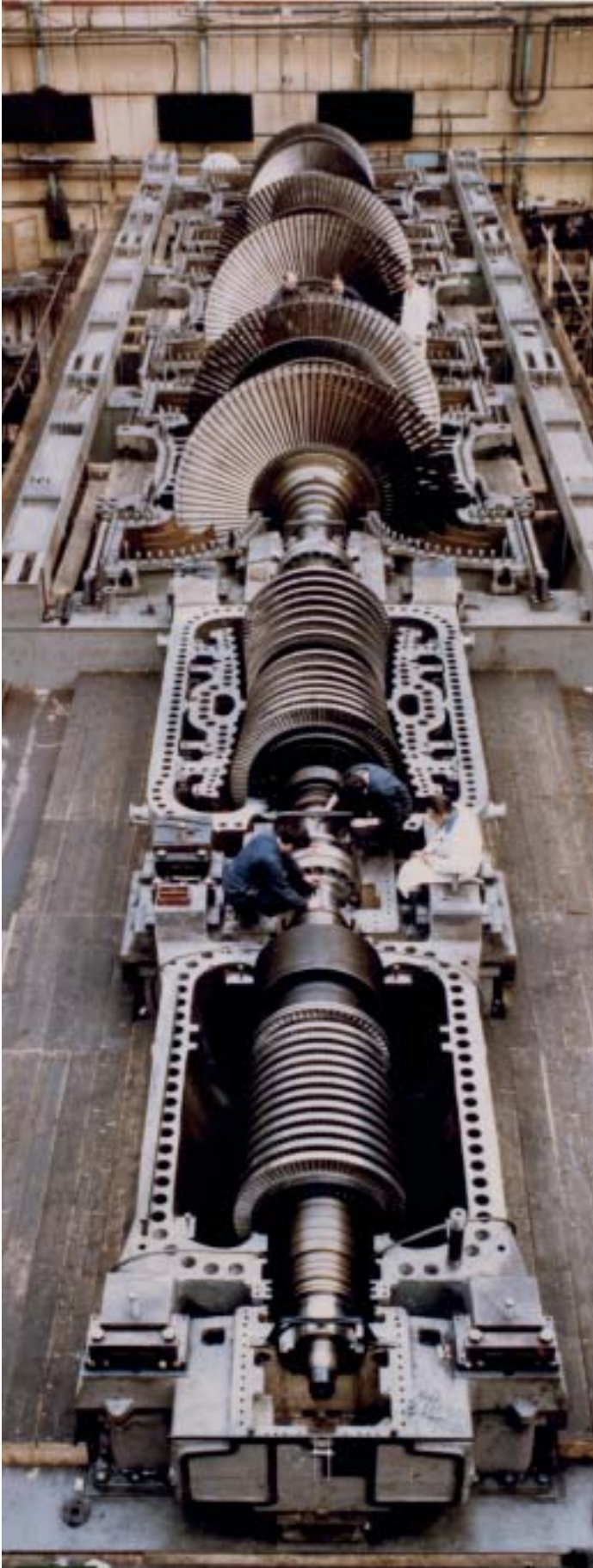
The guide aims to provide a balance of basic theory and practical advice but obviously cannot cover all measurement scenarios. For a detailed discussion on any measurement issues you may have, please feel free to contact Sensonics.

SENSONICS PRODUCTS & COMPETENCES

- Turbine Supervisory Systems
- Standalone Monitoring Solutions
- Accelerometer, Displacement & Seismic Transducers
- Nuclear Infrastructure Protection
- Structural Monitoring Solutions
- Turn-Key Design, Manufacture and Project Support
- ATEX & IEC61508 Capability
- Installation & Commissioning



OVERVIEW



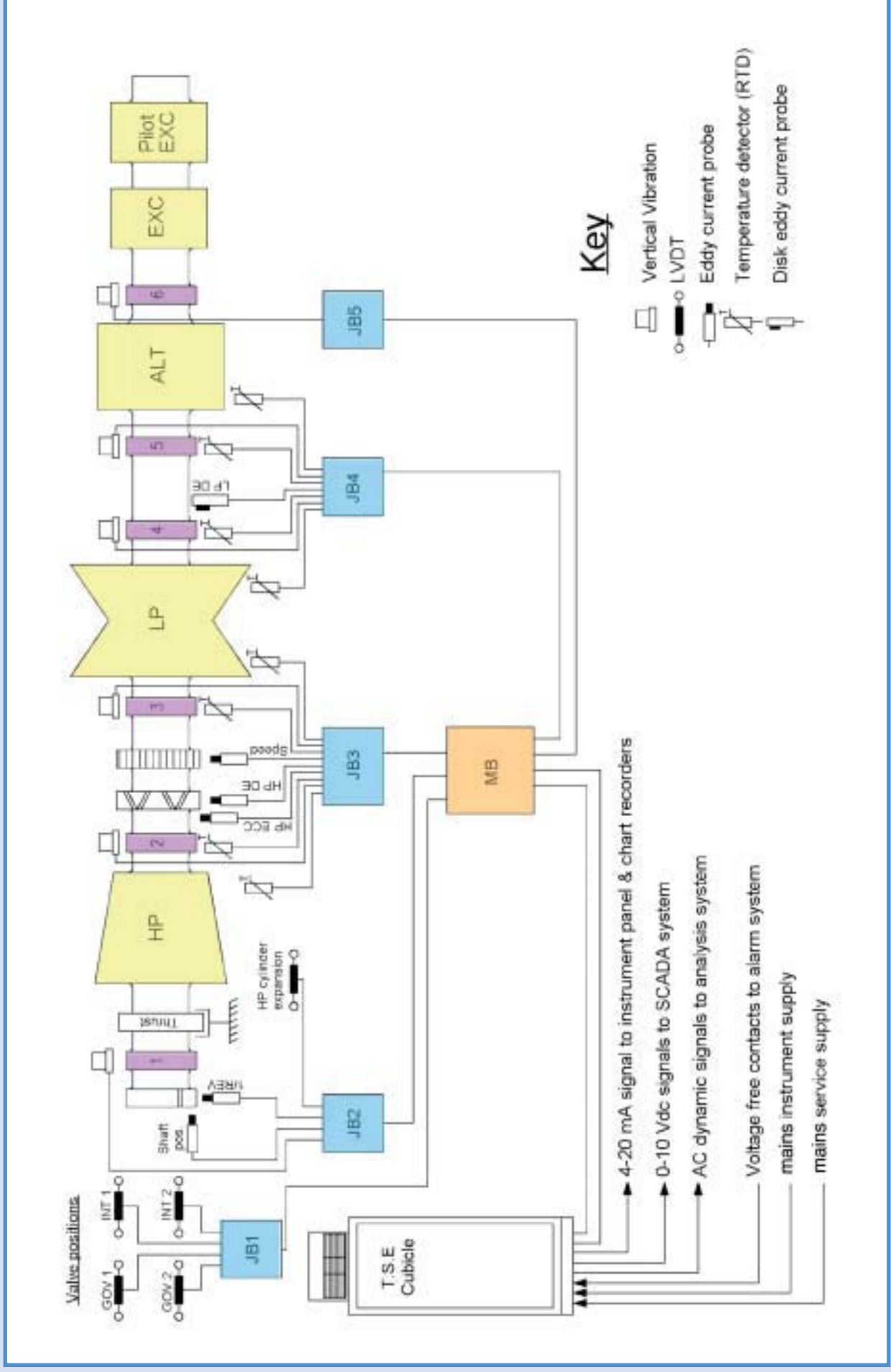
Turbine supervision is an essential part of the day-to-day running of any power plant. There are many potential faults such as cracked rotors and damaged shafts, which result from vibration and expansion. When this expansion and vibration is apparent in its early stages the problem can usually be resolved without any of the disruption caused when a turbine has to be shut down. By appropriate trending of the various measurement points and the identification of excessive vibration or movement, scheduled equipment stoppages or outages can often be utilised to investigate and resolve the failure mechanism.

It is for this predictive maintenance market that Sensonics produces a wide range of sensors and systems specifically for the power generation industry. With flexible and configurable equipment, we can tailor our supervisory equipment to your needs. In this brochure we aim to give a brief explanation of why turbine supervision is so essential and how Sensonics can provide the right solution to protect your turbine.

The diagram on page 5 illustrates a generic configuration of a set of Turbine Supervisory equipment. The steam turbine shown is fairly standard with an HP (high pressure) stage followed by a single LP (low pressure) rotor section; different turbine configurations depending on power rating, may have an intermediate (IP) section in addition to a number of LP's which finally drive the turbine generator. This type of configuration is illustrated in the adjacent picture. Although the equipment configuration does vary, the measurement techniques remain the same, with each turbine installation generating its own unique set of measurements. Typical measurement techniques include:-

- **Absolute vibration of bearing pedestals**
- **Shaft vibration relative to bearing**
- **Shaft eccentricity**
- **Differential expansion or shaft movement**
- **Valve position on steam inlet**
- **Casing expansion, both inner and outer**
- **Speed, including overspeed and zero speed**
- **Temperature**
- **Structural & foundation vibration monitoring**

Each of the measurement techniques are used to monitor the turbine during its operating cycle, some measurements may be configured to provide warning alarms as well as automated shutdown, although these systems tend to operate on a voted principle to ensure maximum system integrity.

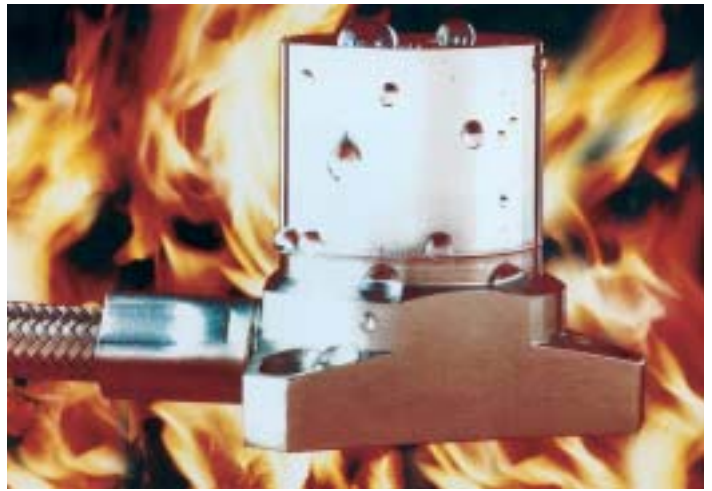


A TYPICAL TURBINE SUPERVISORY EQUIPMENT APPLICATION

TRANSDUCERS & SENSORS

The Accelerometer

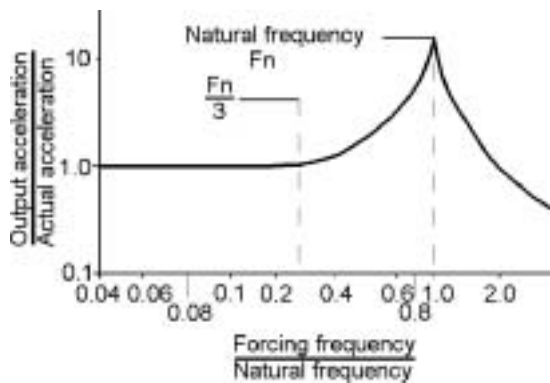
The accelerometer is based on the electrical properties of piezoelectric crystal. In operation, the crystal is stressed by the inertia of a mass. The variable force exerted by the mass on the crystal produces an electrical output proportional to acceleration. Two common methods of constructing the device to generate a residual force are compression mode and shear mode respectively. A residual force is of course required to enable the crystal to generate the appropriate response, moving in either direction on a single axis. A shear mode construction is illustrated below.



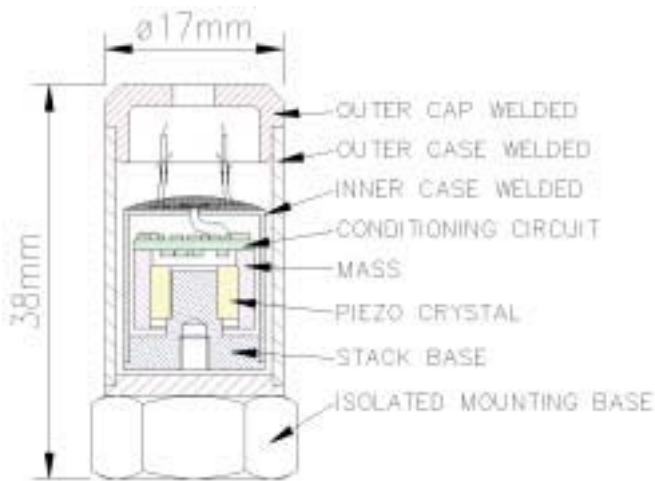
An accelerometer operates below its first natural frequency. The rapid rise in sensitivity approaching resonance is characteristic of an accelerometer, which is an un-damped single-degree-of-freedom spring mass system. Generally speaking, the sensitivity of an accelerometer and the ratio between its electrical output and the input acceleration is acceptably constant to approximately 1/5 to 1/3 of its natural frequency. For this reason, natural frequencies above 30KHz tend to be used.

The frequency response curve can be influenced by a number of factors, mainly the mass, the stiffness and the degree of system damping. The resonant peak of the accelerometer can be eliminated by increasing the damping. However, increasing the damping introduces a phase shift in the linear range whereas un-damped accelerometers have very little phase shift until near the natural frequency. It is therefore usual to have un-damped accelerometers with very high natural frequencies so that the linear range is extended as far as possible. Typical damping ratios are 0.01 to 0.05.

This resonant frequency in combination with the appropriate damping can be utilised to monitor bearing impact. Several manufacturers, including Sensonics have developed transducers that utilise the 'ringing' of the transducer to mechanical impulses to measure the health of roller bearings. This technique analyses the high frequency response of the transducer (at resonance) to determine an 'impact factor' normally in dB, which is directly proportional to the quantity and force of metal on metal impacts. This factor is normalised to an overall health measurement by consideration of bearing dimensions and rotational speed.



Typical accelerometer frequency response



Shear mode construction

Shear mode devices which apply a shear force to the inner and outer surfaces of a ring of crystal (as opposed to a perpendicular force to a disk of crystal), offer a distinct advantage over standard compression techniques. When mounting the device to the plant, normally through a stud & screw arrangement, the mechanical stresses within the transducer assembly change. Compression mode devices are particularly affected by these stresses, which produce low frequency effects, compounded if further integration is carried out. Sensonics shear mode range of transducers are unaffected by base strain and offer a true low frequency performance down to 0.4Hz.

Although the piezoelectric accelerometer is a self-generating device, its output is at a very high impedance and is therefore unsuited for direct use with most display, analysis, or monitoring equipment. Thus, electronics must be utilised to convert the high impedance crystal output to a low impedance capable of driving such devices. The impedance conversion electronics may be located within the accelerometer, outside of but near the accelerometer, or in the monitoring or analysis device itself.

Accelerometers with internal electronics are convenient and can use inexpensive conventional plugs and cable but they are limited to temperatures of typically 120°C. Locating the electronics in a cool location away from the accelerometer allows the transducer to tolerate higher temperatures.

Accelerometers are available in various output configurations. The industry standard drive utilises a 2-wire current source interface operating at a nominal bias voltage of +12Vdc typ., with an output sensitivity of 100mV/g. This configuration limits the dynamic range to around $\pm 70g$, which is suitable for most applications. Larger dynamic ranges can be achieved through lowering the sensitivity at the expense of signal to noise ratio, 10mV/g as an example, or utilising current output devices, which can provide $\pm 1000g$ depending on sensitivity requirements (10pC/g is typical).

Standard accelerometers are also available with velocity outputs in either metric or imperial format, although for these configurations the required measurement range must be understood if the correct sensitivity is to be selected (0-20mm/s, 0-50mm/s etc.). Since the integration function to convert the acceleration to velocity is carried out within the accelerometer, the low frequency performance is typically limited to around a few hertz. The limited complexity of the conditioning circuitry that can be included within the accelerometer combined with the integrated noise tend to be the limiting factors.

For direct integration with SCADA and PLC based systems, most manufacturers offer direct 4-20mA outputs covering a factory set range of either acceleration or velocity vibration. This can be an extremely cost effective solution (provided the required measurement range is again well understood) since no signal conditioning unit is required to drive the transducer or process the resulting measurement. The resulting current loop output is typically either a peak or an RMS representation of the vibration signal and therefore signal frequency analysis is not possible.

Velocity Transducer

The velocity transducer is inherently different to the accelerometer with a conditioned velocity output. This device operates on the spring-mass-damper principle, is usually of low natural frequency and actually operates above its natural frequency. The transducing element is either a moving coil with a stationary magnet, or a stationary coil with a moving magnet. A voltage is produced in a conductor when the conductor cuts a magnetic field and the voltage is proportional to the rate at which the magnetic lines are cut. Thus, a voltage is developed across the coil, which is proportional to velocity.

This type of transducer can provide sensitivities of up to 20mV/mm/s and is convenient because it generates a signal without an external power supply and the signal usually does not require further amplification.

The sensitivity vs. frequency response curve of a velocity pickup is limited at low frequencies by the optimum damping of the first natural frequency; at high frequencies its response is limited by the amount of motion necessary to overcome the inertia of the system, as well as by the presence of higher order natural frequencies.

For practical purposes, a typical velocity pick-up is limited to frequencies between approximately 10 and 1500 Hz. This has an advantage in certain applications where high frequency vibration (generated from steam noise for example) can saturate standard accelerometers with a built-in integration function.

It is possible to obtain moving coil type transducers which operate in any axis. The high specification units tend to be only available for operation in either the vertical or horizontal plane due to the arrangement of the sprung mechanism and orientation during factory calibration.

The ATEX Directive

The ATEX directive 94/9/EC defines the specification requirements of equipment intended for use in potentially explosive atmospheres. Equipments supplied to meet the directive are approved by an authorized external body, the manufacturer must also maintain a quality system to meet with the standard. Sensonics produce a wide range of ATEX approved accelerometers and eddy current proximity probes for various intrinsically safe applications.

The accelerometer is of particular concern when operating within a potentially explosive atmosphere because of the self-generating nature of piezoelectric devices and the high potential voltages that can be generated under shock conditions. For this reason the ATEX directive specifies complete encapsulation of the inner transducer body and limited capacitive capability within the electrical interface to minimize this effect. The inner crystal construction is voltage limited through the addition of diodes, as is the electrical interface. The construction of the device and the internal features will be specific to the approved temperature range and zone of operation.



The ATEX approved PZS4

THE EDDY CURRENT PROXIMITY PROBE

The principle of operation, as the name implies, depends upon the eddy currents set up in the surface of the target material - shaft, collar, etc. adjacent to the probe tip.

The Eddy probe tip is made of a dielectric material and the probe coil is encapsulated within the tip. The coil is supplied with a constant RF current from a separate Eddy Probe Driver connected via a cable, which sets up an electromagnetic field between the tip and the observed surface.

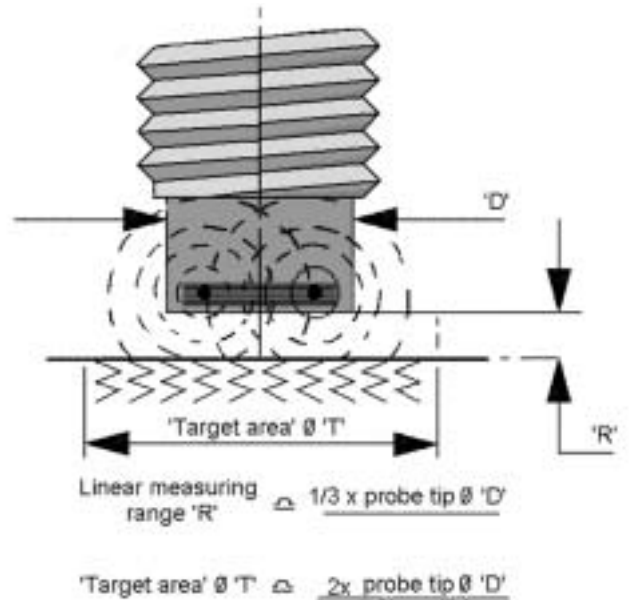
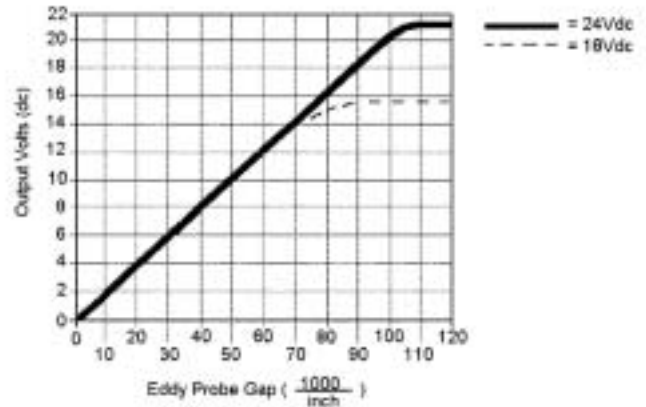
Any electrically conductive material within this electromagnetic field, i.e. the target material, will have eddy currents induced in its surface. The energy absorbed from the electromagnetic field to produce these eddy currents will vary the strength of the field and hence the energising current, in proportion to the probe-target distance. Such changes are sensed in the driver where they are converted to a varying voltage signal.

The whole probe, extension cable and driver system relies for its operation on being a tuned circuit and as such is dependent on the system's natural frequency. Thus each system is set up for a fixed electrical/cable length. Eddy probe systems are usually supplied with 2, 5, 9 or 14 metre total cable lengths.

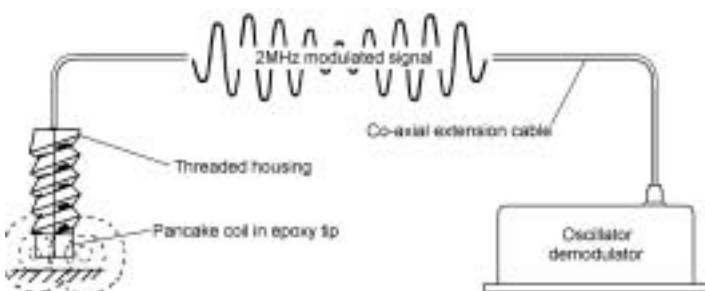
The probe types available are generally according to the API670 standard (see later discussion). Three main variants, straight mount, reverse mount and disc type probes make up the Sensonics range. The main difference between the straight and reverse mount is the location of the thread on the probe body and the fixing nut. Reverse mount tend to be used exclusively with probe holders, while straight mount are the more common and are used on simple bracketry or mounting threads where adjustment to the target is achieved through use of the thread on the probe body in conjunction with a moveable lock nut. The maximum measurement range available on this type of probe is typically 8mm.

The disc probe mounts the encapsulated coil on a metal plate with fixed mounting holes, making a very low profile assembly with a side exit cable. Larger coils can be mounted on this plate; for example, the 50mm diameter tip probe can provide a measurement range of beyond 25mm. However, care must be taken to ensure the target area is sufficient to obtain the required linear response. Note the relationship opposite – between linear range, probe tip and target area.

In rotating plant, the variations in shaft/bearing distance created by vibration, eccentricity, ovality etc. can thus be measured by probes mounted radially to the shaft. When the target is stationary the measured voltage can be used to set the probe/target static distance. Shaft speed can also be measured by placing the probe viewing a machined slot or a toothed wheel.



Eddy current probe empirical relationships



System overview

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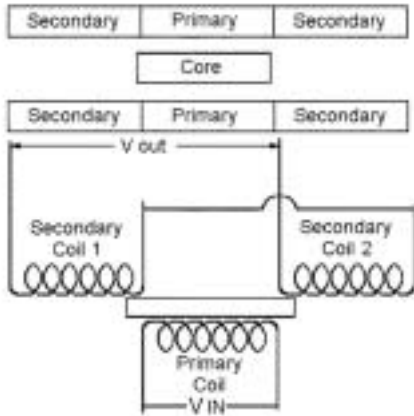


Typical straight probe with driver

THE LVDT

The LVDT is an electromechanical device that produces an electrical signal whose amplitude is proportional to the displacement of the transducer core.

The LVDT consists of a primary coil and two secondary coils symmetrically spaced on a cylindrical former.



Schematic of an LVDT

A magnetic core inside the coil assembly provides a path for the magnetic flux linking the coils. The electrical circuit is configured as above with the secondary coils in series opposition.

When an alternating voltage is introduced into the primary coil and the core is centrally located, then an alternating voltage is mutually induced in both secondary coils. The resultant output is zero, as the voltages are equal in amplitude and in 180° opposition to each other. When the core is moved away from the null position the voltage in the coil, toward which the core is moved, increases due to the greater flux linkage and the voltage in the other primary coil decreases due to the lesser flux linkage. The net result is that a differential voltage is produced across the secondary windings, which varies linearly with change in core position. An equal effect is produced when the core is moved from a null in the other direction but the voltage is 180° different in phase.

The LVDT can be operated where there is no contact between the core and extension rod assembly with the main body of the LVDT housing the transformer coils. This makes it ideal for measurements where friction loading cannot be tolerated but the addition of a low mass core can. Examples of this are fluid level detection with the core mounted on a float and creep tests on elastic materials. This frictionless movement also benefits the mechanical life of the transducer, making the LVDT particularly valuable in applications such as fatigue life testing of materials or structures. This is a distinct advantage over potentiometers which are prone to wear and vibration.

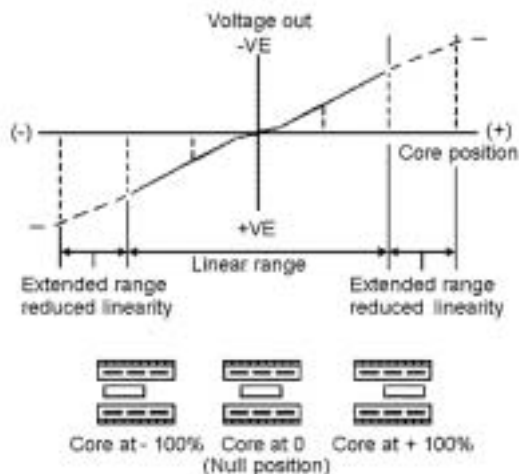
The principle of operation of the LVDT, based on mutual inductance between primary and secondary coils, provides the characteristic of infinite resolution. The limitations lie within the signal processing circuitry in combination with the background noise.

The principles of operation of the LVDT enables the transducer to be configured in a variety of housings depending on the degree of mechanical protection required. The use of rod end bearings, linear rolling element bearings and flexible conduit, helps the LVDT to survive even the most severe environments.

The LVDT principle can also be applied to the measurement of angular position; an RVDT (Rotary Variable Differential Transformer) converts the rotation of a shaft into a proportional electrical output signal. Although the transducer is capable of continuous rotation, a plot of angular rotation against magnitude and phase of the output signal over 360° would result in a complete sinusoidal wavelength response and therefore two null positions. To avoid ambiguity, just one of the null positions is chosen during calibration, providing a typical measurement range of $\pm 60^\circ$.

Some key characteristics of the Sensonics LVDT range are as follows.

- **Range** :2.5mm to 600mm
- **Core type** :Sprung, guided or free
- **Signal connection** :End or side exit connector or cable with option of conduit.
- **Mechanical conn** :Rolling, ball or rod end
- **Operating temp** : -40°C to +220°C
- **Specials** :Submersible (.100m depth)
:Short body to stroke ratio



Core displacement characteristics



A range of Sensonics LVDT devices

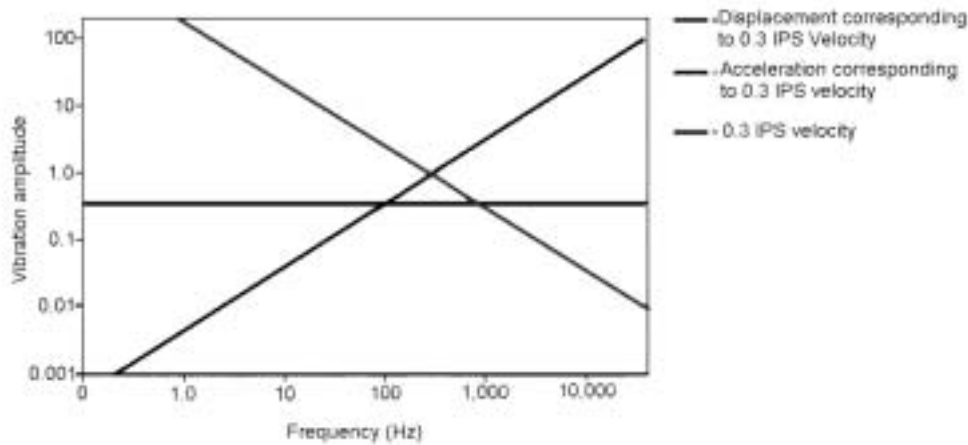
CHOOSING THE RIGHT TRANSDUCER

Each type of transducer has an area of measurement in which it is particularly useful. In the figure below, the relationship is clearly shown. Note that the velocity curve is constant. Acceleration (the first derivative of velocity) increases with frequency, while displacement (the first integral of velocity) decreases.

At 2000Hz (or 120000rpm) this example shows that measuring displacement would be impractical: the signal would be too low. A velocity pick up would be adequate, since the 0.3in/sec velocity produces a substantial voltage. However, the highest voltage level would be produced by an accelerometer.

Eddy Probe are used for low frequency measurements (typically dc to 1kHz), and the velocity pick-ups cover the mid-frequency band (10Hz to 2kHz). Accelerometers generally have the widest frequency range and certainly the highest (1Hz to 10kHz typically).

In practice, combinations of transducers are employed to supply different types of information simultaneously. For example, an Eddy Probe would be required to measure shaft vibration relative to a bearing housing, while an accelerometer (or velocity pick up) would measure the vibration of the housing itself and the bearing.



TRANSDUCER	ADVANTAGES	DISADVANTAGES
Eddy Current probes	Static and dynamic displacement measurements Immune to non-conductive materials such as plastic, wood oil and water Large linear ranges Non-contacting	Requires power supply Calibrated cable length between probe and driver unit
Velocity Transducer	Self-Generating Doesn't require an amplifier Can provide displacement data via integrator Good general purpose vibration transducer	Frequency response limits its lower frequency to 5-10Hz Moving parts make it prone to wear Phase response varies with frequency
Accelerometer	Wide frequency range High operating temperature (external electronics) No moving parts Can provide acceleration, velocity or displacement data	Requires charge amplifier Displacement information normally restricted to greater than 10Hz due to problems of double integration
LVDT	Infinite resolution Robust High temperature rating Adjustable zero and gain controls	Contacting Limited frequency response

MEASUREMENT TECHNIQUES

Absolute vibration

Absolute vibration monitoring is perhaps the primary method of machine health monitoring on steam turbines. The type of transducer used is seismic (ie vibration of turbine relative to earth) and can either be a velocity transducer or an accelerometer.

The choice of transducer has been the subject of debate for many years and often the final decision is purely subjective. A number of factors however should be taken into account.

The steam turbine is a fairly simple machine when considering vibration signatures. The frequencies of interest are normally from one-half to five times running speed (broadly 25 to 300Hz). The unique high frequency detection capability of the accelerometer is not often used.

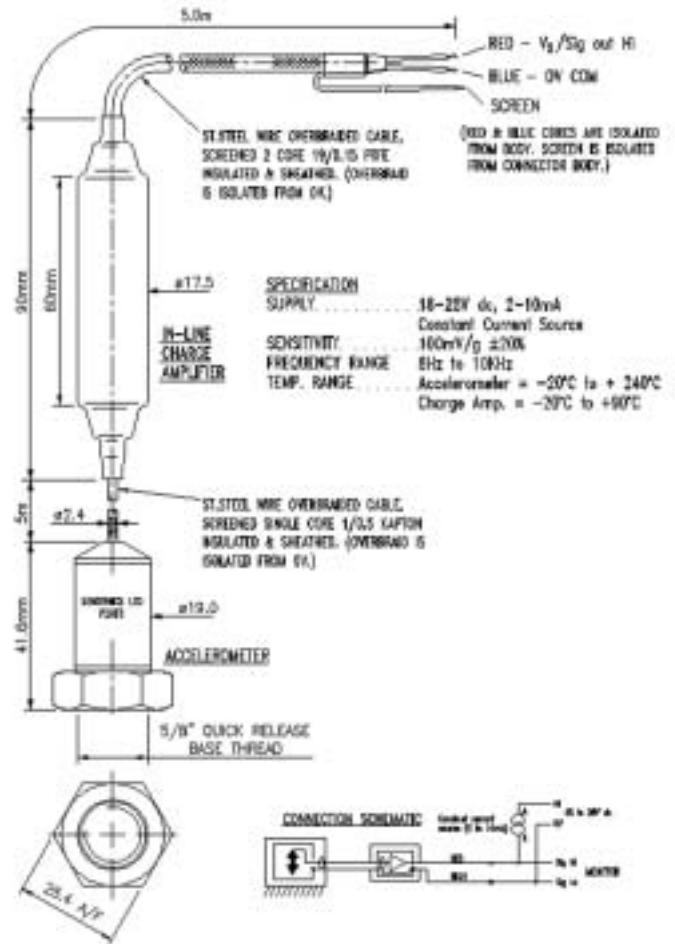


Pedestal vibration monitoring

Vibration monitoring is nearly always in terms of velocity or displacement and can therefore be obtained by an accelerometer or a velocity transducer. Particular care needs to be taken when double integrating an accelerometer signal to provide a displacement measurement. Problems usually occur below 10Hz when double integrating and 5Hz when single integrating. In the frequency ranges normally monitored on steam turbines this is not a problem. These measurement issues can be reduced by integrating the signal at source rather than after running the signal through long cables (ie having picked up noise on route). Accelerometers with built-in stages of integration are available to perform this task as discussed in the previous section.

Pedestal vibration is normally measured in the two axes perpendicular to the shaft direction where the bearing is under load, providing complete measurement coverage. In some instances the thrust direction is also monitored depending on turbine configuration.

Gas turbines demand high temperature transducers for absolute vibration monitoring (>400° typ). For this reason, a separate charge amplifier is normally utilised, located away from the high temperature environment.



Accelerometer with external electronics for high temperature applications

Difficulties can be encountered when monitoring the HP turbine pedestals using accelerometers. The high frequencies generated by steam noise can saturate the amplifier electronics. Filtering the signal prior to the charge amplifier will eliminate the problem but this must be incorporated into the amplifier circuit of an accelerometer with built in electronics.

In summary, the velocity transducer is simple and easy to fit to a turbine but has limited frequency and phase response (not a problem in the range 10 to 1000Hz) and requires periodic maintenance. The accelerometer on the other hand requires more careful installation but can then be left without maintenance.

The velocity transducer has the advantage over the accelerometer of being self generating and not requiring any power supply. On the other hand, the accelerometer has no moving parts and should not require frequent calibration.

ECCENTRICITY & SHAFT VIBRATION

Eccentricity monitoring can be subdivided into shaft vibration and bent shaft monitoring. Bent shafts normally result when the turbine is stationary and thermal arching or bowing of the shaft occurs or the shaft sags under its own weight. The Turbine is rotated slowly (barring) to prevent this happening or to straighten the shaft after it has occurred.

The accurate monitoring of the shaft, both when at full speed and when on barring is therefore vitally important but often requires two techniques to monitor them effectively. At shaft speeds above 300rpm, conventional detection circuits are used but below this speed, analogue meters and recorder traces fluctuate at the frequency being measured. Recorder traces become a blur of ink as the pen 'bands' at the frequency of the barring speed.

Detection circuits can be employed that hold the peak value of eccentricity so that a continuous line trace is obtained. In order to monitor gradually decreasing eccentricities, the peak hold function is discharged by 1% per rev using a tacho signal.

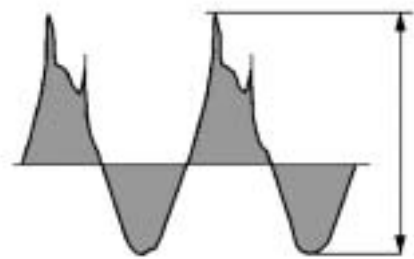
One of the difficulties encountered when using shaft displacement transducers be they the eddy current probe or the older inductive probes, is the problem of "runout". Runout is the error signal generated by mechanical, electrical or metallurgical irregularities of the shaft surface. These error signals are generally of a low magnitude in comparison to the vibration signal and are often at a much higher frequency.

The graphs illustrate that misalignment effects are readily ignored through utilising the peak to peak measurements of eccentricity. When higher frequency components are present (e.g hammer marks) the RMS value is more representative.

Sensonics have developed a dual path eccentricity module to specifically eliminate the effects of marks and dents on the shaft. The module utilises a speed signal derived from a second probe to actively tune the low pass elliptical filter response of the eccentricity unit to remove the high frequency components of the eccentricity waveform. This provides accurate peak measurements, particularly at low barring speeds and is effective through the full speed range.

To ensure that all the shaft vibration data is captured, probes mounted in the X and Y axis are normally used. Probes are invariably mounted at the 0° and 90° points or at the 315° and 45° points.

The eddy current probe measures displacement in the plane of its own axis only. Displacement vibration perpendicular to the probe axis is not measured.

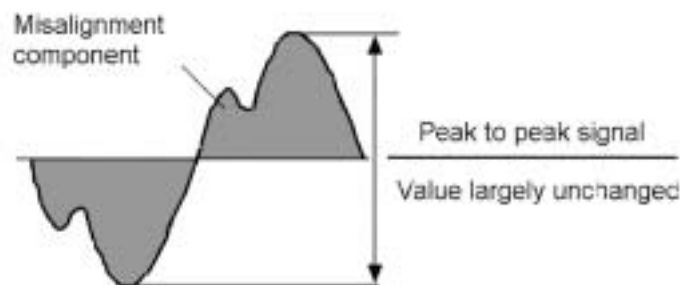


Measuring eccentricity with runout using RMS or peak to peak detection

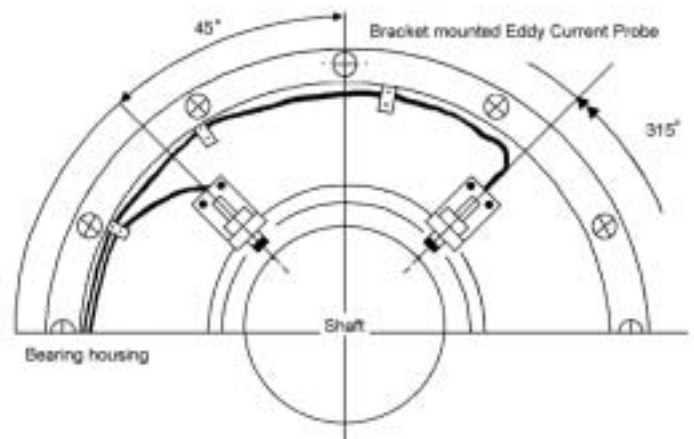


Typical probe mounting configuration

The 315° and 45° points are used to avoid the half joints of the bearings and to ensure that when bearings are removed the probes are removed along with them. This moves the probes away from possible mechanical damage when the turbine is being worked on.



Measuring lower frequency signals using RMS or peak detection



Eddy current probes monitoring vibration at 45° and 315° Points

ROTOR DIFFERENTIAL EXPANSION & SHAFT POSITION

The eddy current probe, as well as providing ac vibratory information, also provides dc information of the probe to target gap. This makes it ideal for measuring rotor to casing differential expansion via a non-contact method.

The eddy current probe and the measurement of differential expansion are governed by a series of empirical relationships.

The linear measurement range of an eddy current probe is approximately one third of its coil diameter as shown earlier. The ideal flat target area for an eddy current probe to “observe” is twice the coil diameter. Therefore the ideal target size for an eddy current probe is six times the linear measurement range.



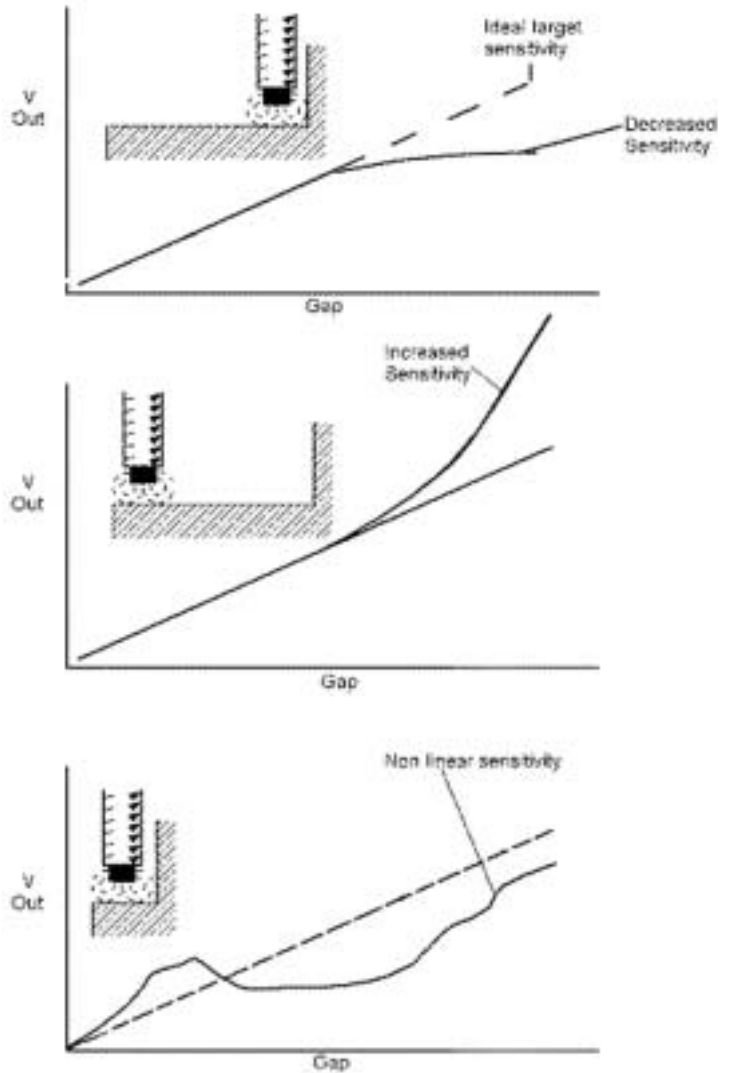
Probes monitoring differential expansion by observing a tapered collar

For differential measurement ranges of 25mm a target of 100mm is therefore required. This large target size is often impractical to fit. It is also often the case when retrofitting differential expansion systems that the existing collar is much smaller than that ideally required.

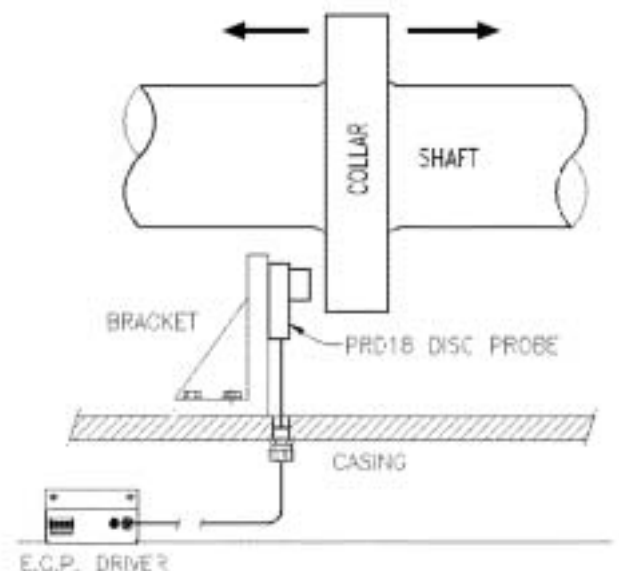
The illustrations opposite show the effect of a less than ideal target on the output of an eddy current probe.

To overcome this problem and obtain a linear output the probe electronics can either be calibrated in-situ or supplied pre-calibrated with a non-linear output. This non-linear output becomes linear when the probe is fitted in-situ. Eddy probe drivers are normally pre-calibrated to give a linear output when observing an ideal target.

The diagram opposite illustrates a disc type eddy current probe measuring movement against a flat collar, the limitations in terms of target area can clearly be seen.

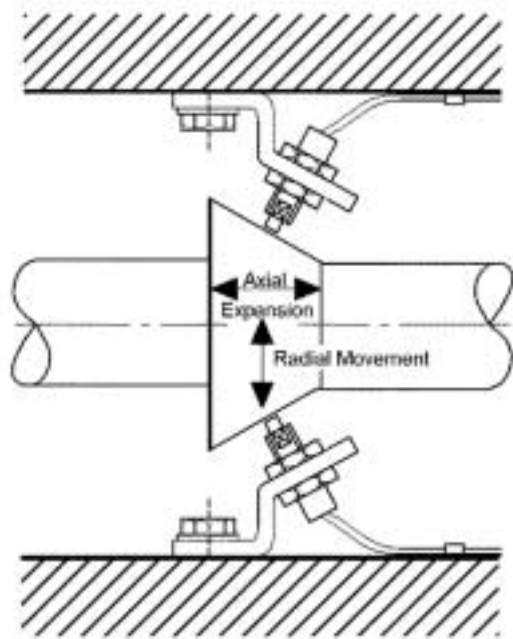


One option to overcome this limitation is to reduce the size of the probe and therefore obtain a more linear output against the fixed target area, in combination with measuring both sides of the collar. However, this push – pull technique does require some simple arithmetic within the signal conditioning units to generate the correct expansion measurement.



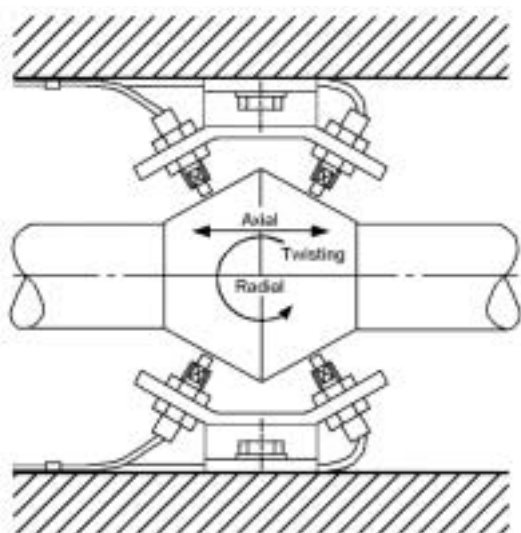
Another technique utilised in measuring differential expansion is to use tapered rather than flat collars. The use of tapered collars fitted to the turbine shaft enables longer linear ranges to be obtained. A 1 in 10 taper enables an axial expansion of 10 times the normal range of the probe to be measured.

A problem arises however if there is any radial movement eg if the shaft moves 100 micrometers within the bearings, this is incorrectly seen as 10 x 100 micrometers (ie 1mm) of differential expansion. To overcome this, two eddy probes are fitted. Thus two unknowns can be easily solved by two simultaneous equations through software manipulation.



Two probes monitoring expansion by observing a tapered collar

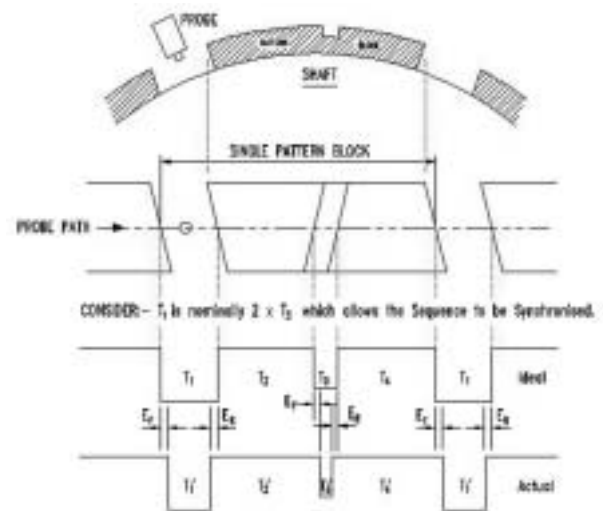
A further complication arises when the casing holding the eddy probes is subjected to twisting as can happen if slides start to stick (see below). A further two eddy current probes are then required to give a correct reading of differential expansion.



Four probes monitoring expansion by observing a tapered collar

It is also possible to measure differential expansion or axial movement with a small range probe using a mark space technique. This principle operates on detecting movement in special plates attached to the turbine shaft. The shaft target pattern consists of a number of pairs of 'teeth' and 'slots' surrounding the shaft and rotating with it. Each pair of teeth are tapered axially such that alternate teeth taper in the opposite directions, the narrow parallel slot between the teeth being at an angle to the shaft axis. There is a wider parallel slot between each pair of teeth to allow the system to identify each pair.

When the shaft rotates, the voltage pulses produced by the proximity probe and driver, have a tooth to slot pulse width ratio dependant upon the axial relationship between the shaft pattern and the probe position. The probe is mounted on a fixed part of the machine so variations in pulse width ratio are a measure of shaft axial position. The shaft pattern is illustrated below.



$$\text{Travel} = \text{Normalised Range} \times \frac{T_3 + T_4}{T_1 + T_2 + T_3 + T_4} + \text{Offset}$$

'Normalised range' is the total travel range divided by the pulse width ratio range determined from each travel extreme.

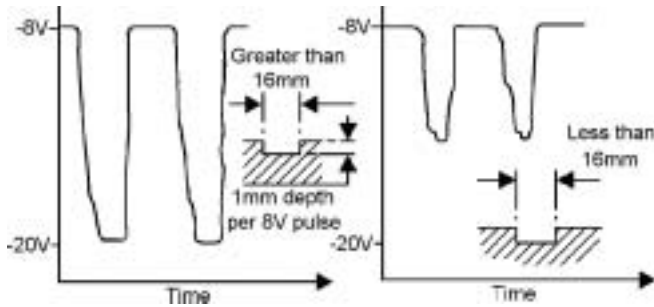
The Sensonics Sentry machine protection MO8612 module is suitable for this type of monitoring. The module exhibits a self-tracking threshold level, which ensures that the width of the signal pulses are measured at the optimum position within the pulse height. The unit is pre-programmed with specific plate patterns that can be selected to suit applications. The number of plates on the mark-space wheel is also an important parameter; when correctly set up this enables the module to minimise 'plate wobble' through the implementation of averaging algorithms. Customised patterns can also be entered into the module.

Since this technique measures axial movement based upon the ratio between detected pulses, it is immune to shaft movement in any other direction. This is a distinct advantage over the other techniques detailed in this section. A large expansion range can also be measured with a low cost probe through the fitting of the appropriate plate pattern, several centimetres if necessary, which would be impossible to achieve with a shaft collar.

SPEED - OVERSPEED - ZERO SPEED MONITORING

The eddy current probe as well as being used for shaft vibration and differential expansion can also be used as a speed monitoring transducer. The eddy current probe gives a large voltage output, which is independent of shaft speed.

A pulsed signal is obtained by observing a projection, a slot or series of slots. The size of the slot need only be 16mm wide by less than 0.25mm deep.



Effect of slot width on eddy probe output

The number of slots used is dependent on the minimum speed required. Most phase locked loops have a minimum operating frequency. This lower frequency is approximately 4Hz. In order to measure a minimum speed of say 1Hz ie 60 rpm, 4 pulses are required and at 30 rpm, 8 pulses are required. For monitoring of speeds above 240 rpm one pulse/rev is sufficient.

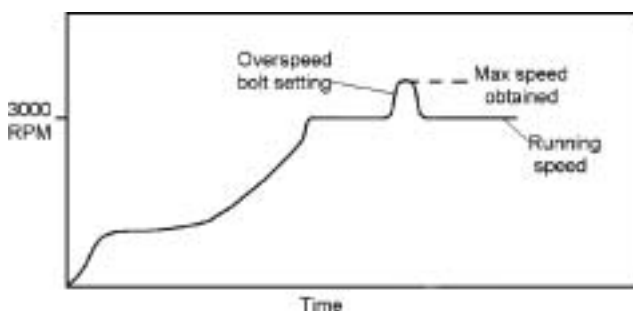
The eddy current probe can work using specially fitted speed wheels or by observing an already fitted gear wheel. Where gear teeth are less than 16mm thick then a lower voltage swing output signal is obtained as shown above.

Most speed monitors have a conventional 4 or 5 digit display and have a number of alarm set points. The update time of the display should be such as to give a steady reading but respond fast enough to speed changes.

An update time of 1 second is sufficient for on load and run-ups but is usually insufficient for overspeed testing. A speed monitor that has a faster update time when in overspeed mode is an advantage: typically 100 milliseconds.

When carrying out overspeed testing, to set the emergency stop valves, two speed readings are required:-

- The speed at which the turbine trips
- The maximum turbine speed reached.



Turbine speed profile

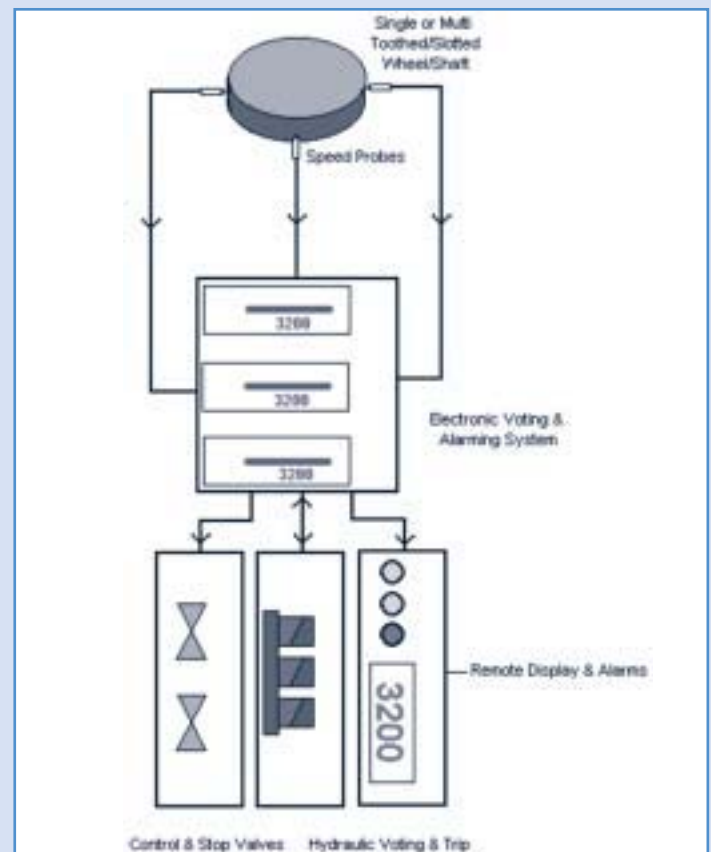
The speed at which the turbine trips is obtained by a display freeze on external contact closure. This contact closure is obtained by a micro-switch on the governor valves or some similar method.

The maximum turbine speed is obtained by a sample and hold circuit within the speed monitor. It is imperative however during the screen freezing or peak holding, that the recorder output follows the speed uninterrupted.

A zero speed facility can also be incorporated in a speed monitoring system or by a separate system entirely. A zero speed facility works by measuring the period between two pulses. When the period exceeds the selected zero speed time limit an alarm is initiated. Zero speed periods range from 1 second (60 rpm) to 300 seconds (0.2 rpm).

Alarm voting within speed trip systems is a common technique. Typically 2 out of 3 or 2 out of 4 voting methods are used, where multiple measurement heads around a single toothed wheel, generate individual trip alarms, which are further processed to generate a plant trip if any two signals are simultaneously valid. These type of systems also incorporate self test facilities that enable signal injection on individual speed channels for trip verification as well as testing the admissible trip combinations; A+C, A+D, B+C and B+D as an example for a 2 out of 4 system.

The test rack provides key switch facilities to enable on load testing. This provides an interlock mechanism, which prevents two channels from being selected at the same time. A typical 3-channel system is illustrated below:-



3-channel overspeed trip system

CASING & CYLINDER EXPANSION

These techniques require a larger measurement range than can be offered through standard proximity probe equipment, the necessary probe target is also not easy to achieve. This is where LVDTs are used to provide the expansion measurements required. A total range of 50mm usually suffices and the various mounting options available with LVDTs makes installation straightforward.

The movement of the turbine pedestals on the cylinder sole plates is a relatively easy measurement to make requiring an LVDT mounted on the turbine and the extension rod fixed or sprung onto the slides. The environment is not hostile although care must be taken to prevent mechanical damage to the transducer.

Turbine cylinder crabbing, movement of the cylinder in the horizontal plane on the cylinder sole plates, is monitored at the cylinder front and rear by two pairs of LVDT transducers mounted so that one pair is to the cylinder front outer corners and one pair to the rear corners. The outputs of a pair of LVDT transducers are summated and conditioned by an arithmetic unit to determine movement and to give a single output, which is displayed in the control room as cylinder crabbing.

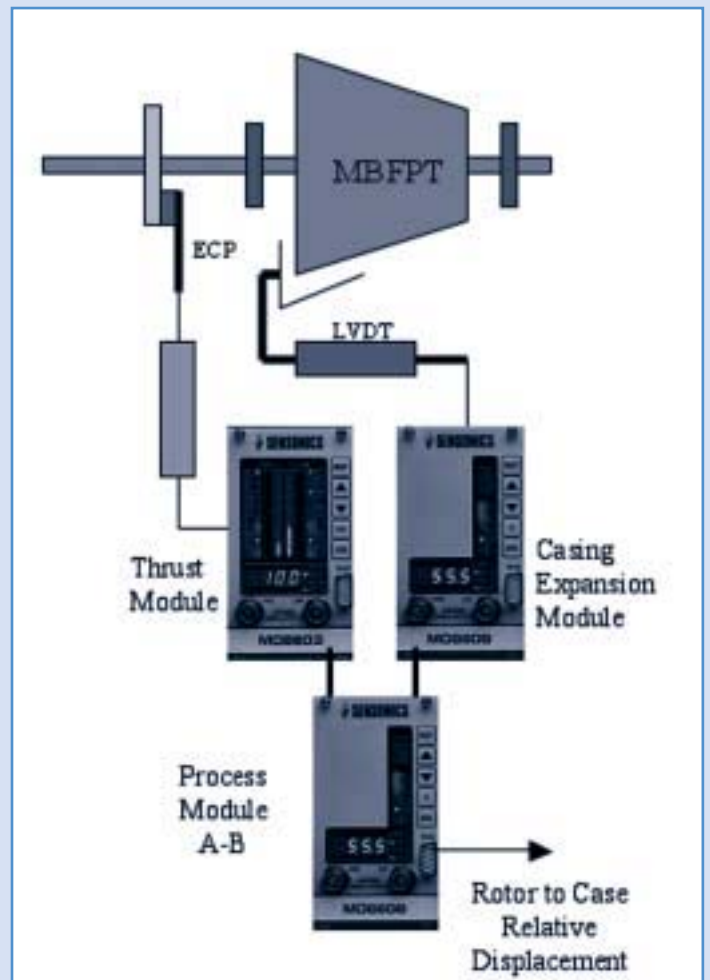


LVDT monitoring cylinder casing expansion

The inner to outer cylinder measurement requires a much higher degree of sealing within the transducer against moisture as the measurement is made inside each outer cylinder. The transducer body is mounted on a bracket. This is adjustable for initial setting up and calibration against the inside structure of the outer cylinder in such a position that the spring loaded core is held at approximately mid travel against a point on the inner cylinder. Expansion of either inner or outer cylinder with respect to the other, changes the relative position of the LVDT core, giving a change in output to the position monitoring instruments.

Rotor to casing expansion

It is also possible by a combination of two different techniques to monitor the rotor to casing expansion by measuring the rotor and casing movement separately with respect to the bearing pedestal and adding or subtracting to achieve the rotor to casing displacement. This is particularly relevant when the rotor differential expansion, carried out typically by a proximity probe, cannot be referenced to the casing through fixed mechanical connection. Sensonics Sentry range provides a solution through the use of an LVDT module for the casing expansion and a displacement module for the rotor expansion. An additional process module is implemented to calculate the relative displacement. This configuration is illustrated below.



Understanding the relative positions of the LP rotor and casing is extremely important, as contact of these parts can be catastrophic. This is most critical on run-up and run-down, where the expansion between the shaft and casing is occurring at different rates.

VALVE POSITION MONITORING

The Linear Variable Differential Transformer (LVDT) is ideally suited for valve position monitoring. In this type of application the LVDT is used to provide positional feedback to the governor control system to effect a closed loop system. The electrical properties of the LVDT therefore play a key role in determining the system response. Linearity is obviously key as well as a robust construction with flexible mounting options. AC type devices (as opposed to DC) are exclusively used for this type of application, which permit long cable runs and offset adjustment with gain control. The picture below shows a heavy industrial LVDT utilised in a valve position application.



Heavy industrial LVDT monitoring valve position

The usual LVDT's for this application have universal joints at each fixing point. This feature allows for any lateral movement as well as being a positive fixing.

Other options include rod end types, which tend to be spring-loaded but not suitable for this type of application since spring loaded LVDT's are subject to bouncing when the valve is "hunting" or oscillating.

Mounting of the LVDT is also critical to the application custom bracketry may be necessary to position the transducer, away from locations where high temperature steam leaks or vents occur. Although the Sensonics range of devices operate up to 180°C the life of the LVDT can be extended by minimising these temperature extremes.

The LVDT drive electronics would normally be mounted locally (up to 100 metres) either in a weatherproof housing or in a modular rack assembly. The use of external electronics has a number of advantages over internal electronics.

1. LVDT operating temperature increased to 220°C
2. Setting up is made easier as zero and gain controls are accessible.
3. Local 4-20mA output can be made available.

The LVDT is usually driven by a 3kHz oscillator which enables frequencies up to 300Hz to be monitored, permitting a fast closed loop response within the control system.

Drive electronics can also be combined with signal conditioning functions to provide various forms of positional information in addition to alarm triggering and process outputs. A twelve channel Sensonics Aegis system is illustrated below.



Aegis valve position monitoring system

The Aegis system offers a high integrity low cost multi-channel monitoring solution in a compact 3U, 19" rack format. The system utilises a common display to view positional information as well as to set up the dual level alarm trip facilities.

Each module excites an LVDT with a sinusoidal 3.0kHz waveform of fixed magnitude. The construction of the LVDT provides a feedback signal to the module via inductance in to the secondary windings from the primary dependant on stroke position. The centre of the stroke range is normally the null point. The module performs rectification of the secondary induced signal converting to relative displacement. The module is usually configured to show a percentage of the total stroke length required.

Calibration is achieved once the LVDT transducer is installed and the zero displacement point can be determined; this is then set on the module. The LVDT is then stroked to its maximum travel and the unit adjusted to display 100% displacement. It is also possible to display actual distance through the addition of a scaling factor.

The module also has a calibrate function which can be enabled remotely. Once in calibration mode the transducer signal is disconnected and replaced with the calibration signal which is common to all units within the rack. The calibration signal is normally set to be 50% of the stroke length, therefore the standard analogue outputs available (4-20mA, 0-5V) can be confirmed as mid range.

The rack also has a common reset facility to clear all latched alarms, which can be operated remotely in conjunction with the calibration function for alarm trip testing. As well as two sets of relay contacts per channel for the dual level alarms, (configurable for both positive and negative going alarms) each module also has a transducer integrity relay. This will indicate a fault if either the primary or secondary windings exhibit a continuity problem or short to earth.

AUXILIARY PLANT MONITORING

Fan & Pump Monitoring

The majority of rotary fan and pump systems can be broken down into three categories; direct coupled, gearbox coupled and belt coupled. Each of these systems will exhibit a unique set of failure modes between the motor and shaft interface. Faults at the blade or driven unit interface are common across the various configurations.

Unbalanced Fan or Pump

This is likely to be caused by a build up of debris on the blades over time and can put stresses on to other system components. Depending on the amount of imbalance, this generally results in high levels of vibration and can be detected using accelerometers fitted on both the fan/pump bearing and the motor bearing. The typical vibration frequency of the unbalance would be at the shaft rotating frequency. If the problem affects all blades then the frequency would be the shaft rotational speed multiplied by the number of blades.

Journal Bearing Defects

Like all bearings, sealed bearings will fail over time. Premature failure can be the result of insufficient or contaminated lubrication, as well as excessive operating temperatures. The failure will cause elevated levels of vibration at the shaft frequency and the vibration spectrum signature will normally be high in shaft frequency harmonics. The bearing will typically run at a higher temperature during the early stages of failure. Fitting a sensor offering both vibration and temperature detection is the ideal. Vibration can also be measured by monitoring the shaft transverse movement with proximity probes, if access to the bearing is difficult.

Roller or Ball Bearing Defects

As above, the same causes of failure apply, although for roller or ball bearings, manufacturing defects do play a larger role in premature failure mechanisms. Vibration monitoring again is the best method of detection, although the exact signature of failure is dependent not only on the rotational speed but also the bearing race dimensions and configuration. Usually these defects are best detected by using shock transducers mounted directly on the bearing housings.

Misalignment

This type of problem normally occurs following incorrect assembly of the system components. eg misalignment between the shaft, motor and driven unit. This is normally detected through bearing vibration monitoring, ideally utilising both horizontal and vertical mounted transducers. The typical vibration frequency would be 1, 2, or 3 times the shaft speed depending on the exact nature of the misalignment.

Gearbox Coupled Type

Apart from the bearing monitoring detailed above, gear tooth faults can also be detected at an early stage, using accelerometers mounted directly on the gearbox casing. The typical vibration frequency of a tooth fault can be detected at the shaft frequency multiplied by the number

of teeth, as well as harmonics of this. Although in some cases gear hunting problems can generate frequencies 1/10th to 1/20th shaft speed.

It is also important on gearbox monitoring to differentiate between tooth faults and shaft/bearing faults. For better diagnostics, a once per shaft revolution pulse is sometimes required.

Worn / Loose belts

Generates vibration frequencies of 2x, 3x & 4x the belt frequency, normally 2x being the dominant peak and amplitudes are usually erratic.

Eccentric Pulleys/Sheaves & Misalignment

These problems all cause high levels of vibration at the rotating frequency. If misalignment is the problem, the highest vibration is usually at the fan/pump end and in the axial direction (eccentric vibration is normally in line with the belt).

Belt Resonance

This is normally detected as a small peak of vibration of regular frequency and amplitude and should only be a problem if the frequency coincides with the motor or fan/pump rotating frequency.

Monitoring Solutions

A low cost, effective solution, for the protection and monitoring of single or multiple units is to have vibration transducers, temperature sensors and eddy current probes (for shaft vibration, eccentricity or thrust wear) feeding into a local unit with signal conditioning. The Sononics DN range of products is ideal for this type of application

- Din Rail Mountable
- Buffered Sensor O/P
- LCD Display
- Alert & Danger Alarms
- Integrity Alarm
- 4-20mA per channel



The DN2601 is capable of independently monitoring two channels of vibration, allowing user configurable alarm windows for the switching of internal contacts to raise a warning or to trip the fan or pump. The outputs can be used to log/view the pump/fan condition from a remote location (either by analogue current/voltage outputs or by a comms link).

The DN2604 offers both vibration and temperature monitoring in a single DIN rail mountable unit; this in combination with Sononics PZAT range of dual sensors (vibration and temperature) forms a very cost effective solution.

Speed measurement with Overspeed protection is available in the DN2608 module configuration.

INTRODUCTION TO API STANDARD 670

The American Petroleum Institute has developed a range of standards to assist users in the procurement of standardised systems of equipment for various applications. One standard particularly relevant to the monitoring of rotating equipment is the API Standard 670 covering Machinery Protection Systems, which has become heavily adopted by industry. The standard details the following measuring techniques:-

- **Casing Vibration**
- **Radial Shaft Vibration**
- **Shaft Axial Position**
- **Shaft Rotational Speed**
- **Piston Rod Drop**
- **Phase Reference**
- **Overspeed**
- **Critical Machinery Temperatures**

The standard also covers the transducer & monitoring equipment requirements as well as installation, commissioning and documentation. The majority of the above techniques have been discussed in previous sections.

The standard details a clear set of mechanical and electrical properties for both accelerometers and eddy current proximity probes. Adherence by manufacturers to these specifications assist the user in finding several sources for the same component (form, fit and function), as well as a robust product designed for the monitoring of heavy industrial machinery. Parameters detailed include; sensitivity, dynamic range, operating temperature range, accuracy, mechanical mounting options, connector and cabling standards, immunity to shock, etc. The Sononics range of vibration transducers and eddy current proximity probes both conform to the API 670 standard.

In terms of the monitoring system philosophy, the focus is of course on protection, detailing the appropriate measurement technique and associated system elements to form a multi-channel system with high integrity, minimising the effects of single point failures. The standard generally specifies that a single circuit board failure shall not affect more than two channels of measurement. The key concepts are as follows.

- **Integral display indicating measurement & status**
- **Monitoring resolution of 2% full scale**
- **Adjustments for alarm set points and scaling**
- **Channel fault monitoring**
- **Buffered transducer outputs**
- **Digital output of measured variables and channel configuration**
- **Isolated / non isolated 4-20mA per channel**
- **Alert and danger setpoints for each channel**
- **Relay for each setpoint with programmable delay**
- **Alarm defeat for system integrity testing**
- **Power supply protection**

Sononics 'Sentry' Machine Protection System conforms to the API 670 standard. A typical Sentry rack configuration is pictured below.



Sentry Machine Protection System

For each of the measurement options detailed opposite, not only is the equipment specification important but also the installation technique. The majority of the complexity and difficulty involves the transducer mounting and cabling. Each application is normally unique, the 670 standard details various standard approaches that can be implemented. Important elements to consider include access to the transducer for servicing or replacement, termination to a suitable local junction box, the selection of armoured cable with or without additional conduit for either isolation or mechanical protection, cable segregation, grounding techniques etc.

Protection Systems Incorporating Voting

To build on the good practice underpinned by the API 670 standard, some applications require extreme reliability and also safe failure in the event of a fault. Where the system has a direct impact on safety, IEC 61508 can be applied to determine the required 'Safety Integrity Level' or SIL rating. The rating can be between 1 and 4, with 4 being the most stringent. The 61508 standard defines a methodology for the protection system from concept through to decommissioning, the complete life cycle. To determine system suitability for such an application, the backbone of the analysis is a failure mode and effect analysis; carried out to determine the probability of a failure on demand as well the percentage of safe failure modes. This will determine the SIL rating.

Voted systems can provide enhanced system reliability in combination with a high degree of failure detection, therefore quite suitable for SIL rated applications, which may be a requirement because of a commercial impact (ie unnecessary shutdown) rather than safety alone.

Two out of three majority voting has already been discussed with respect to turbine overspeed protection. It is possible to implement more complex schemes through the logical combination of many measurement parameters, such as a turbine high vibration trip system where pedestal bearing vibration alarms are processed to only trip under a specific combination, thus reducing the effect of spurious events and transducer failures. Further voting can be added to the alarm processing hardware to ensure complete system robustness, any voted decision is positive detection of a system failure.

SPECIAL TECHNIQUES – ROD DROP

Rod Drop is an ingenious measurement technique for increasing the productivity of industrial plant by providing a reliable and accurate warning of rider band wear on reciprocating compressors, thus eliminating the need to shutdown the machine for inspection.

The Sensonics system consists of a special type of eddy current proximity probe (non-contacting displacement sensor) and a real time monitor module, which measures the vertical position of the rod and calculates the wear on the rider bands.

This measuring method is a well-proven technique; equipment to do this has been available for many years. The Sensonics system is different in that the probe used has a dramatically increased measurement range, which allows a different monitoring philosophy to be utilised.

Traditionally, rod drop monitoring systems have been confined to using standard eddy current probes with a measuring range of just 2mm, which is often not sufficient to cover the full range of lateral (or radial) movement of the connecting rod on most types of machine.

This has meant that monitoring system designers have had to utilise a 'snap shot' measuring technique where the vertical position of the rod is measured instantaneously at the same point on each cycle of the machine. This measurement is usually triggered by a pulse from a second eddy current proximity probe looking at a single 'phase reference' slot on the crankshaft. This measuring method relies on the assumption that the rods position is identical from one stroke to the next except for the gradual change in position caused by rider band wear.



A typical compressor with rod drop

Research has shown that this is often not the case and in fact each rod stroke cannot always be guaranteed to be repeatable, which is often a cause of inaccuracy in the calculated rod drop reading.

The Sensonics system uses a 4mm range probe (in the standard 8mm body) and is therefore able to measure the position of the rod throughout its 360° stroke (even where the rod is coated with ceramic). This in turn enables the monitor to calculate the true mean position of the rod more accurately and give a truly reliable measurement of the rider band wear. Due to the increased measurement range, the unit can also provide a peak to peak vibration measurement which can provide additional information on the machinery health.

The Sensonics system was first installed at a chemical plant in the UK, alongside numerous 'traditional' rod drop monitoring systems. Twelve months later the operating staff reported that the new system was 100% reliable and a vast improvement. They have since replaced their old equipment with the new Sensonics system.

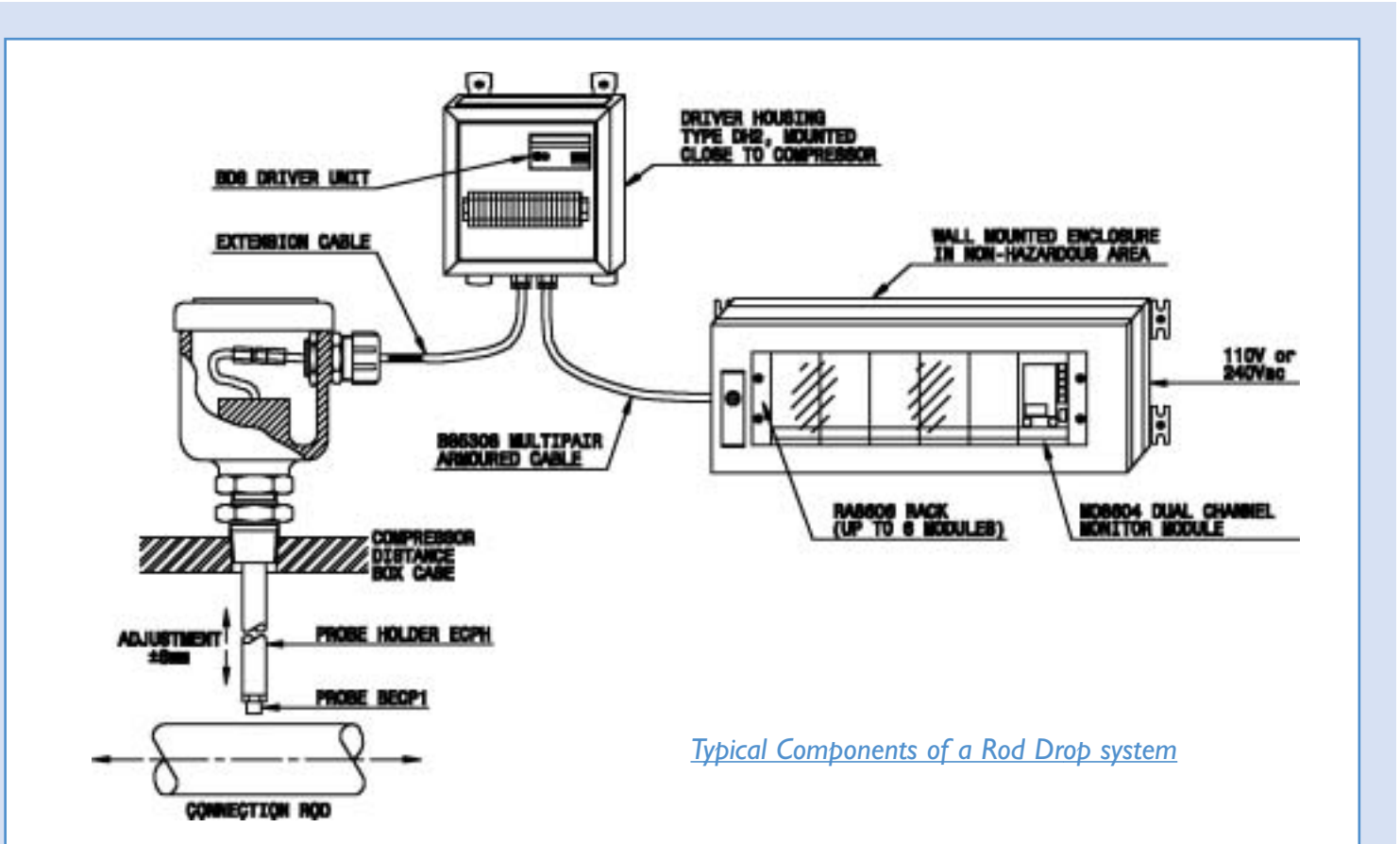
The system is not just for monitoring rod drop; casing vibration and valve temperature can also be incorporated for early warning of other types of mechanical fault.

Fitted through the distance box of the compressor, the small size of the probe means that the Sentry system can be economically retrofitted to installed machines of any make in the field with minimal modification. The whole system can be installed and commissioned from scratch in less time than it takes to strip the machine to take a traditional rider band wear measurement.

As illustrated opposite, compressor systems are complex machines and several techniques are normally utilised for machine health monitoring. An effective additional method to rod drop is to fit an impact sensor above the piston housing to detect transient vibration events generated from cracked parts, leaks or general machine wear.

Conventional vibration monitoring is excellent for detecting sinusoidal vibration events due to unbalance or bearing wear. However for reciprocating compressors, the transient shock and impact events are key, therefore simple RMS evaluation techniques cannot determine suitable trip levels for plant protection. The impact sensor in combination with a suitable monitor can count the number and magnitude of shock events providing a more reasonable metric to enable effective plant shutdown.

ROD DROP MONITORING SYSTEM



Probe type AECP04 This is the sensing element of the system, with a measuring range of 4mm, 1 off is required for each cylinder. Probes are supplied with 500mm unarmoured cable and integral connector.

Probe Holder type ECPH Aluminium body (standard) or ECPH stainless steel body (when required). 1 off is required for each probe. This item is fitted through the distance box of the compressor and holds the probe at the correct position over the surface of the rod. Adjustment of the probe position is possible from outside the distance box by the mechanism of the probe holder. The length of the insertion piece can be from 30mm to 300mm max.

Extension Cable type AEXC Connects the probe to the driver unit. As a 'tuned' system, extension cables are available in certain set lengths, choice of length is entirely dependent on the machine layout and positioning of the driver housing.

Driver Unit type AD8 This unit conditions and amplifies the signal from the probe.

Driver Housing type DH Series Basically a junction box that holds the driver unit. If the layout of the compressor allows, then 2 drivers can be housed in 1 box. Standard unit is painted steel, (SS an option) sealed to IP66 and supplied with stuffing glands for probe cables.

Interconnecting Cable to connect the drivers signals to the monitors. We recommend BS5308 armoured individually screened twisted pair cable. This is best supplied locally although Sensonics can provide it if required.

Zener Barriers for Intrinsically Safe applications. Note the barriers and monitors need to be mounted in non-hazardous areas.

Monitor Module type M08604 provides a display, outputs and alarms for compressor rod drop. Modules are dual channel and so one is required for every two probes or cylinders. Each module is programmed with a scaling factor for a particular compressor.

Rack type RA806 Standard 19" rack to hold up to 6 dual channel monitor modules. Can be panel mounted or to fit standard 19" enclosures.

Blank Panels type M08600 for spare positions in racks.

Sentry Set Up Software is used to configure the monitor modules (the most commonly used functions eg alarm levels, etc can be adjusted from the front panel of the monitor module without the need for the set-up software).

A Communications Cable is also provided to connect a laptop PC to the module for set up purposes.

SPECIAL TECHNIQUES – RUNDOWN MONITORING

Cracked rotor shafts have plagued nearly all turbine manufacturers (and of course their users) to a greater or lesser extent over the years, due to the costly and disruptive problems they cause. Vibration monitoring via pedestal vibration or eccentricity is not appropriate as it is not good when it comes to detecting cracked shafts at the early stage required.

In order for a crack to be detected by vibration monitoring alone the size of the crack will be approaching 20 to 30% and by this point the shaft will have to be scrapped. This late diagnosis can however be avoided so that future planning can take into account predictions of the shaft's life-span.

A more sophisticated technique than simply monitoring the overall or frequency components of shaft vibration must be adopted to detect shaft cracks at such an early stage.

When a crack appears in a shaft it affects the stiffness of that shaft. The stiffness of the shaft is dependant upon the width of the crack. When the crack is at the top, the weight of the rotor forces the crack to close and when the crack is at the bottom, the weight of the rotor causes it to open. Therefore during one revolution of a shaft with a crack in it, the stiffness varies according to the crack's position.

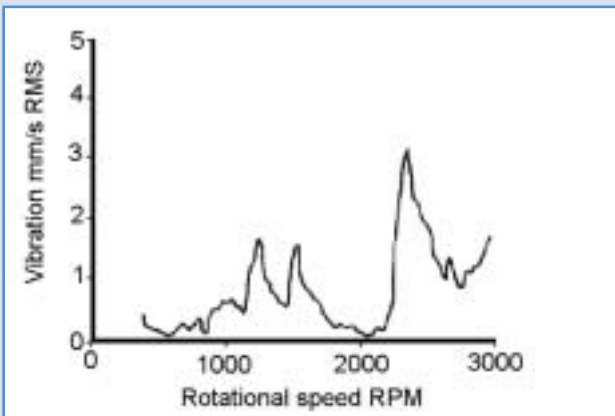
The varying stiffness as the shaft rotates means that the deflections are not proportional to the forces causing them. This varying stiffness/deflection causes harmonics of the running speed to be generated.

When one of these harmonics coincides with a rotor critical, as it is in the case of a run-up or run-down, the vibration response at that frequency changes. A run-down spectra of a cracked shaft will therefore show a change in response at a frequency corresponding to one of the known critical speeds when the rotor is actually spinning at one-half, one-third etc of that critical speed.

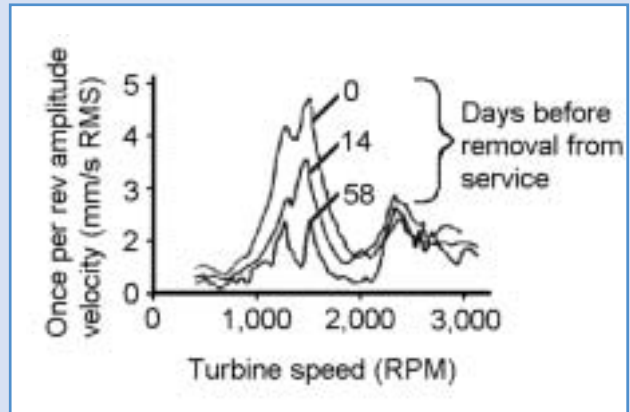
This allows a crack to be spotted when it is a fraction of the size of a crack spotted using vibration monitoring alone and therefore long before the shaft has to be replaced. Trending of vibration data is an extremely valuable tool for machine health monitoring. Not only does it indicate problems but it enables estimates to be made as to when the problem will become serious enough for the machine to be taken out of service.

Trending of vibration data however requires the machine trend data to be taken when machine conditions are identical. The diagrams below show that even when there are relatively small changes in the turbine load, the vibration spectra are markedly different.

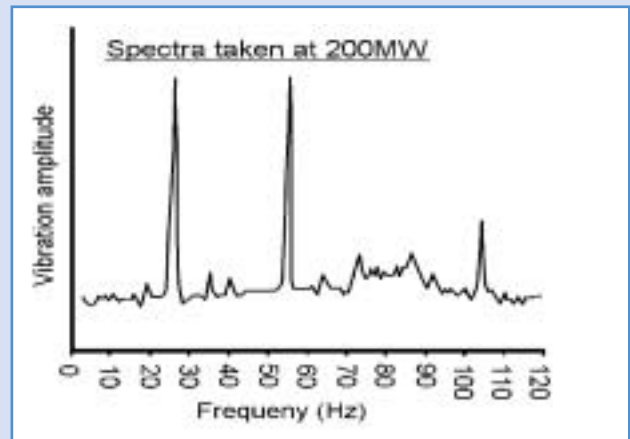
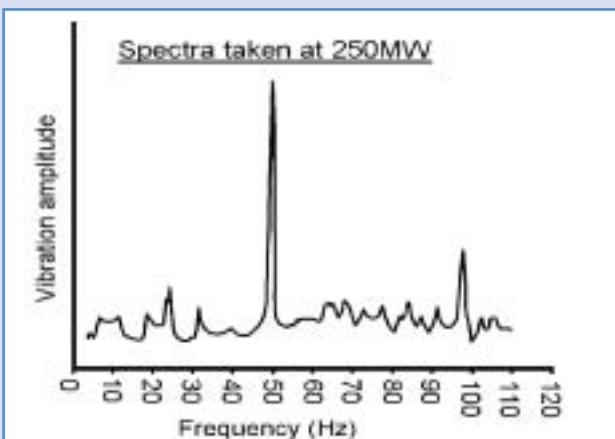
Trending also becomes difficult when the vibration signature of the machine is constantly changing, due not only to generator load but a number of factors including steam conditions. Conditions between a number of run-downs do however remain constant so comparison between rundown signatures provides valid trending data.



Typical run-down plot of vibration



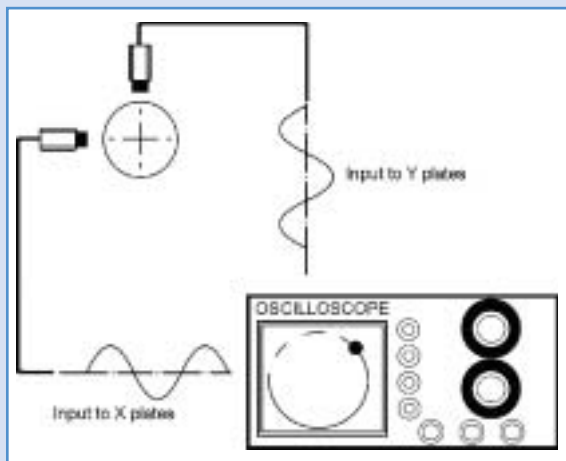
Run-down plot from a turbine with cracked rotor



spectrum from steam turbine at two different loads

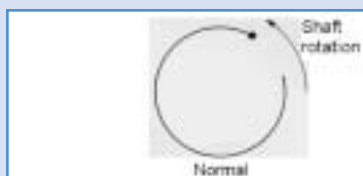
SPECIAL TECHNIQUES – ORBIT ANALYSIS

When two eddy probes are looking at a stationary shaft at 90 degrees to each other and displayed on the X and Y plates of an oscilloscope, an illuminated dot will appear on the CRT. This dot represents the centre-line of the shaft and will be seen to move in relation to the position of the shaft. At slow roll the shaft centre-line will appear as a discrete dot but as the speed is increased, the centre-line of the shaft is represented as a continuous circle known as a Lissajous figure. This is the actual shaft movement within the bearings. If this Lissajous figure is projected onto the screen with a phase reference on the Z axis input then it is known as an orbit.



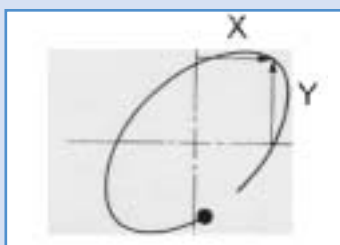
The orbit and its resultant shape under various conditions can be used to augment machinery surveillance and analysis. Certain machine conditions produce certain orbit shapes, thus a knowledge of the orbit can lead to detection of machine conditions. As the orbit is a direct display of the output from eddy probes any run-out be it electrical or mechanical will also be displayed. For meaningful orbit displays, then run-out should be minimised. The conditions that cause classical orbit shapes are as follows:-

- Shaft-Unbalance**
- Oil Whirl**
- Shaft Pre-load**
- Oil Whip**
- Shaft Bow**
- Shaft Rubbing**



Shaft Unbalance

An orbit which is essentially circular is usually generated by an unbalanced condition. It is the phase reference marker that indicates the high spot at any particular time and the dimensions of the orbit on the display that give an indication of the magnitude of unbalance.

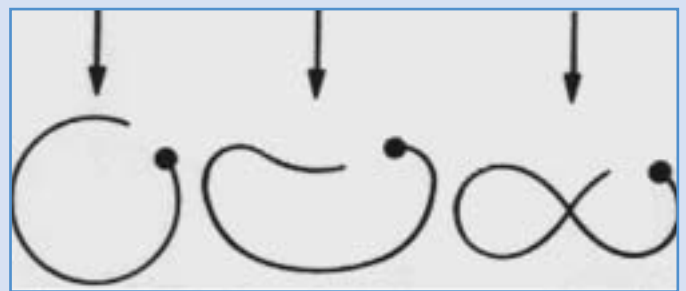


Shaft unbalance orbit showing position of high spot

By aligning the phase marker transducer and the phase marker key way or projection, one can read off the high spot of the shaft. Below the first critical, this high spot indicates the position of unbalance and trial weight needs to be added at 180°. Above the first critical this high spot indicates the position at which the trial weight should be added.

Shaft Pre-load (Misalignment - Aerodynamic Forces - Elliptical Bearings)

A pre-load is defined as a directional load or force applied to the rotating shaft. The immediate result of pre-load is to force the shaft into one sector of a bearing and results in non-linear restraint. This is where the spring constant is much higher in the opposite direction to the pre-load than in the perpendicular direction to the pre-load. This produces the classical twice per rev frequency associated with misalignment. This can be seen below:-



Orbit from machine with misalignment

Oil Whirl

The oil film within a sleeve bearing normally flows around with the journal surface to lubricate and cool the bearing. Film flow occurs because of oil shear viscosity. The speed of this oil film flow is slightly less than half the speed of the journal surface. During normal stable rotor conditions, the oil film separates at 180° from the minimum oil thickness.

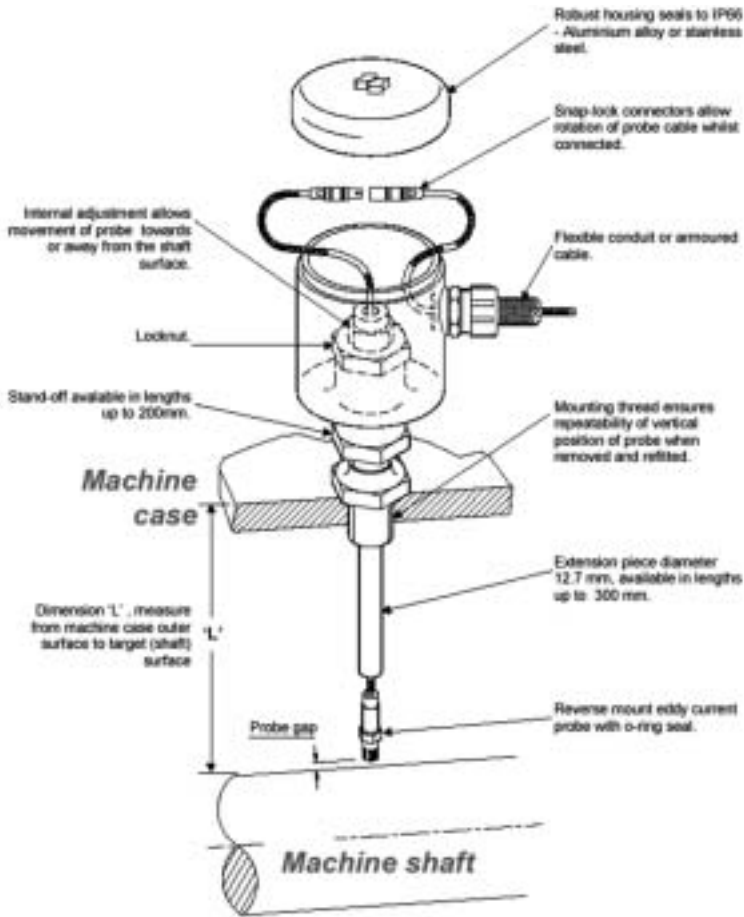
However, when Oil Whirl occurs there is an oil film around the 360° of the bearing. The orbit in the case of Oil Whirl is characterised below. The phase markers are approximately 180° apart and because it is slightly less than 180° the orbit is seen to slowly rotate in the direction opposite to that of rotation. This counter rotation is due to the sub-synchronous frequency of the Whirl at 43% to 46% of rotational speed.



Orbit showing oil whirl

BRACKETRY

It is vital when mounting transducers that the bracket itself and the fixing of the bracket is rigid. An insufficiently stiff bracket will resonate in the frequency range which is being measured and false readings of vibration will result. A robust method of mounting eddy current proximity probes is illustrated below.



The above configuration of probe holder is used almost exclusively with reverse mount probes with an 8mm tip diameter and measurement range of up to 4mm. Since the probe is threaded up in to the extension piece no further adjustment at this point can be achieved, therefore the definition of length 'L' is critical in offering the probe to the shaft. The top section of this extension piece is threaded to permit fine adjustment and therefore appropriate gapping of the probe to the target.

The mounting thread for the holder can be either standard imperial or NPT (tapered), which forms a tight seal when tightened. If a standard thread is utilised and a seal is required on the shaft housing an additional 'O' ring should be fitted on a suitably prepared mounting face.

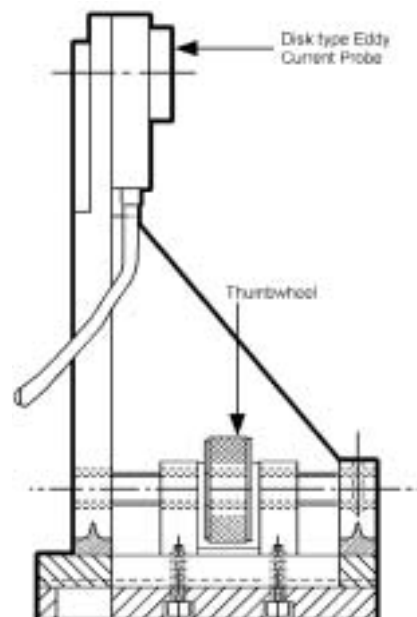
This type of holder permits robust signal cabling methods to be applied to the installation. The probe extension cable is routed from the driver unit and connects with the probe in the main housing body. This allows flexible conduit or armoured cable options to be utilised whilst retaining an IP66 rating and protecting the probe RF cables.



An API670 probe holder

Note: A crude but effective test of the resonant frequency of a transducer and bracket is to attach the output of the transducer to a spectrum analyser and monitor the output when struck with a steel hammer.

The mechanical configuration of disk probes permit large measurement ranges to be achieved against a shaft collar where mounting space is at a premium. However, without appropriate adjustment, the gapping process is virtually impossible. The disk probe bracket below operates on a sliding plate principle in combination with a thumb wheel to allow accurate setting up of the probe.



Right angled disk probe bracket

CUBICLE PANELS



Cubicles are an important part of the turbine supervisory system, forming a central location for the mounting of the instrumentation for collective display as well as terminating the transducer signal cables in the appropriate manner, earthing screens and centralising the communications hub to the DCS.

When drawing up a specification for a cubicle, consideration should be given to the following points:

- Free standing or wall mounted?
- Dimensions of cubicle?
- Top or bottom cable entry?
- Isolated or grounded gland plate?
- Lifting bolts required?
- Anti-vibration pads to be fitted?
- Plinth required?
- IP sealing required?
- Number of spare terminals?
- Ferrule system to be adopted?
- Internal cable sizes?
- Segregation of terminals required?
- Cubicle earthing requirements?
- Canopy for protection against running water to be fitted?
- Removable or fixed gland plate or gland box?
- Paint colour internally and externally?
- Glass or steel front door? (specify type of glass.)
- Removable or fixed internal front panels?
- Number of signal conditioning units to be fitted?
- Number of incoming and outgoing cables? (specify number of cores)
- Spring loaded, standard or terminals with test points?
- Isolation/distribution switch or fused mains power supply?
- Type of crimped terminals to be fitted?
- How many electrical supplies to cubicle and of what type?
- Automatic mains changeover required?
- Door operated or hand light switch?
- Type and number of mains sockets inside cubicle - if required?
- Anti-condensation heater or cooling fans required?
- Automatic fire extinguisher required?

Labelling requirements for:

- Front of cubicle
- Fuses
- Rear of signal
- Terminal rails
- Conditioning racks
- Internal electrical fittings
- Mimic diagram

SEISMIC MONITORING & PROTECTION EQUIPMENT

As well as our turbine supervisory equipment, we supply seismic sensors for power plants. For many, particularly nuclear stations, monitoring earth movement is as important for safety reasons as monitoring the turbines themselves.

Sensonics are the leading supplier of Seismic Monitoring and Protection systems to the UK Nuclear Industry. We offer a range of equipment, which can be scaled to meet the most complex requirements. Integrity and robustness is key to our system concept, offering protected power supply configurations and custom indication panels as well as alarm voting racks suitable for safety critical applications. The systems provide a secure and extremely dependable seismic alarm to the site operational staff, allowing rapid shutdown of plant processes in a controlled manner.

The key system components are as follows:-

Voting Rack - Offering multi-channel 'two out of three' alarm voting. Utilising either robust electromechanical devices or triplicated programmable logic with self-fault diagnosis.

Recorder – Robust PC with embedded operating system, contains on board non-volatile memory for program operation and event data storage.

Annunciator – For local alarm indication and reset facilities. Key operated interlocks and alarm defeat



facilities provide additional system robustness.

Calibrator – Activates individual transducer self test facility for complete system integrity check.

UPS – Typically configured in a dual redundant PSU configuration and available with various hold up times dependant on system load.

Qualifications - Seismic qualification to IEEE Std 344-1987, EMC approval to Def Stan 59-41.

REFERENCE SITES

With over a thousand TSE systems installed within the power sector alone, Sensonics can provide references from most of the major station operators worldwide. Please contact Sensonics for references regarding the monitoring and protection of the following plant:-

Turbine & Generator

Absolute and Relative Vibration

Thrust, Casing & Differential Expansion

Eccentricity, Speed & Overspeed

Infrastructure Monitoring

Voted Protection Systems

Boiler Feed Pump

Absolute Vibration

Voted Protection

Speed, Overspeed & Reverse Rotation

Milling Plant

Absolute Vibration

Impact Monitoring

Fans, Motors & Pumps

Absolute and Relative Vibration

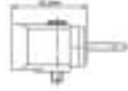





Thrust & Speed






Temperature

Impact



QUICK PRODUCT SELECTION GUIDE

Sensor selection matrix																				
Sensor Range	Measurement and Features	Accel 10 – 500mV/g	Velocity 4mV/mm/s	Vel up to 20mV/mm/s	Velocity 4 – 20mA	Charge 100pC/g	Temperature 120°C	Temperature 140°C	Temperature 200°C	Temperature 240°C	Top Exit	Side Exit	ATEX Approved	Triaxial Version	Connector Version	Armoured Cable	Conduit Version	Broadband <0.5Hz	2-Wire Constant Current	
		PZS		•					•	•			•	•	•	•	•	•	•	•
PZV			•				•				•		•		•	•	•			•
PZDC					•		•				•	•	•		•	•	•			
PZHT		•					•	•	•	•	•					•	•			•
VEL-G			•	•			•	•	•		•	•			•	•	•			
PZP						•	•	•	•		•	•			•			•		•

Monitor selection matrix																		
type	Measurement and Features	Absolute Vibration	Relative Vibration	Eccentricity	Thrust / Movement	Speed	Temperature	Differential Exp	Rod drop	LVDT	Multiple Voting	Bearing Element	RS232 / RS485	TCP / IP Ethernet	Alarm Relays	4 – 20mA	Din Rail Mt	Rack Mount
		Sentry		•	•	•	•	•	•	•	•	•	•		•	•	•	•
Aegis		•	•	•	•	•	•			•	•	•	•	•	•	•		•
Plant Scan		•					•		2/4/8 Channel Configurations of Vibration and Temperature					•	•			
DN2600		•	•		•	•	•			•					•	•	•	•
Spyder Net		•	•		8 Channel Vibration or process inputs with internal trending						•		•	•	•	•	•	

**SENSORS &
SYSTEMS**

KEEPING
INDUSTRY
TURNING



SENSONICS PRODUCT RANGE

For all your turbine supervisory needs

- Industrial Accelerometers and Velocity Transducers
- Eddy Current Proximity Probe Systems
- LVDT Displacement Transducers & Conditioning Units
- SENTRY Programmable API 670 Machine Protection System
- AEGIS Machine Condition Monitoring System
- SpyderNet Remote Multichannel Machine Monitoring Series in DIN Rail Mountable Format with in-built Webserver.
- PLANTSCAN Multi Channel Wall Mounted Vibration Monitor
- VIBCHECK Hand Held Vibration Monitor
- Seismic Transducers and Protection Systems
- Customised Cubicle Design
- Turnkey System Design and Implementation
- Maintenance and Support Services
- Calibration and Refurbishment

Due to Sensonics policy of constant improvement, designs may be subject to alteration without notice.

To order or request a sample or further information

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If you are at all unsure about any application of the Sensonics products & systems please do not hesitate to call our technical sales department, who will be delighted to offer advice without obligation.