FORBES MARSHALL SHINKAWA

VIBRATION MONITORING SYSTEM BASICS

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1. Basics of Vibration .

1. FUNDAMENTALS OF VIBRATION

A. What is Machine Vibration?

Most of us are familiar with vibration; a vibrating object moves to and fro, back and forth. A vibrating object oscillates.

We experience many examples of vibration in our daily lives. A pendulum set in motion vibrates. A plucked guitar string vibrates. Vehicles driven on rough terrain vibrate, and geological activity can cause massive vibrations in the form of earthquakes.

There are various ways we can tell that something is vibrating. We can touch a vibrating object and feel the vibration. We may also see the back-and-forth movement of a vibrating object. Sometimes vibration creates sounds that we can hear or heat that we can sense. To observe how vibration can create sound and heat, rub your feet back and forth on a carpet.

In industrial plants there is the kind of vibration we are concerned about: machine vibration.

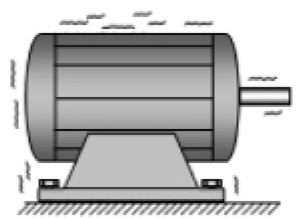
What is machine vibration? Machine vibration is simply the back and forth movement of machines or machine components. Any component that moves back and forth or oscillates is vibrating.

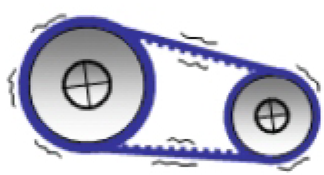
Machine vibration can take various forms. A machine component may vibrate over large or small distances, quickly or slowly, and with or without perceptible sound or heat. Machine vibration can often be intentionally designed and so have a functional purpose. (Not all kinds of machine vibration are undesirable. For example, vibratory feeders, conveyors, hoppers, sieves, surface finishers and compactors are often used in industry.)

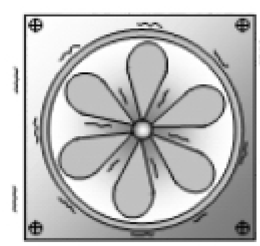
At other times machine vibration can be unintended and lead to machine damage. Most times machine vibration is unintended and undesirable. This article is about the monitoring of undesirable machine vibration.

Shown below are some examples of undesirable machine vibration.


Vibrating Pumps


Vibrating Motors


Vibrating Belts


Vibrating Fans

Perhaps the simplest illustration of a mechanical vibration is a vertical spring with weight, as shown in Figure 1. In this position, the deflection of the spring from its free state is just sufficient to counterbalance the weight W. This deflection is called the static deflection of the spring. The position in which the spring is at rest is #1. The spring is then slowly extended to position #2, and released. The subsequent motion of the weight as a function of time, when there is negligible resistance to the motion, is wavy and repetitive as shown in the graph. It exhibits many of the basic characteristics of mechanical vibrations.

The maximum displacement from the rest or mean position is called the AMPLITUDE of the vibration. The vibratory motion repeats itself at regular intervals (A1, A2, A3). The interval of time within which the motion sequence repeats itself is called a CYCLE or

PERIOD. The number of cycles executed in a unit time (for example, during one second or during one minute), is known as the FREQUENCY. In a high-speed oscillation the frequency is high and conversely. When, as in Figure 1, the spring-weight system is not driven by an outside source, the vibration is a FREE VIBRATION and the frequency is called the NATURAL FREQUENCY of the system.

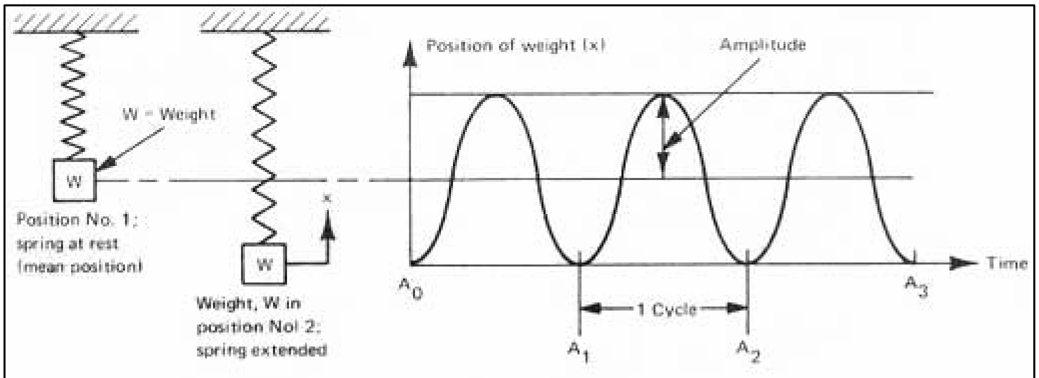


Figure 1

In general, vibratory motion may or may not be repetitive and its shape as a function of time may be simple or complex.

Typical vibrations, which are repetitive and continuous, are those of the base or housing of an electric motor, household fans, vacuum cleaners and sewing machines, for example.

Vibrations of short duration and variable intensity are frequently Initiated by a sudden impact or shock load; for example, rocket equipment upon takeoff, equipment subject to impact and drop tests, a package falling from a height, or a lading in a freight car.
In many machines, the vibration is not part of its regular or intended operation and function, but rather it cannot be avoided. The task of vibration isolation is to control this unwanted vibration so that its adverse effects are kept within acceptable limits.

B. What Causes Machine Vibration?

Almost all machine vibration is due to one or more of these causes:

(a) Repeating forces

(b) Looseness

(c) Resonance

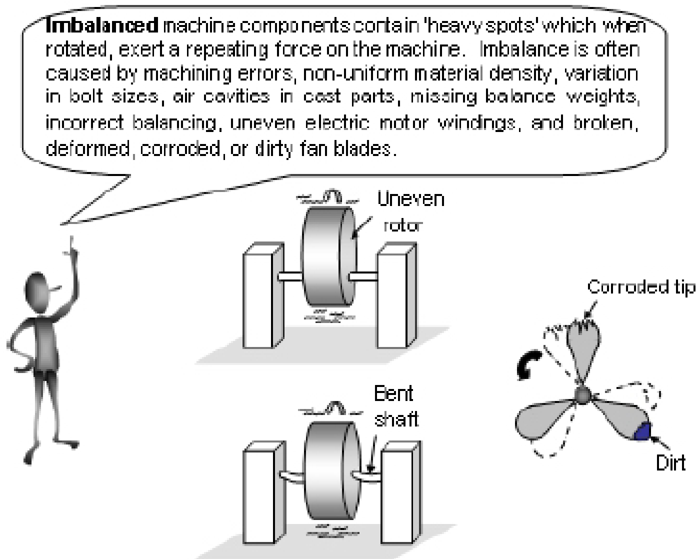
(a) Repeating Forces

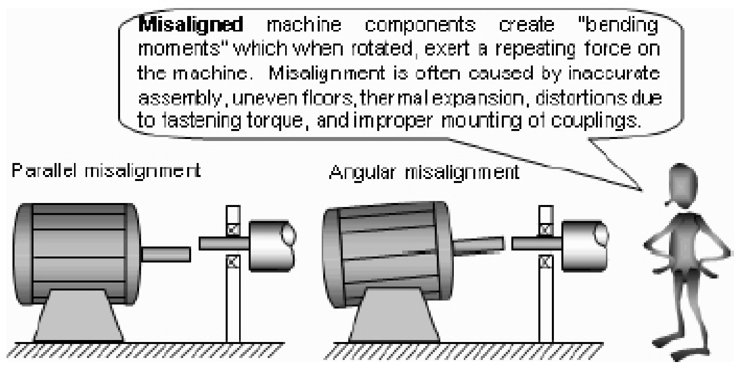
Imagine a boat anchored in a bay. Waves are slapping the sides of the boat, and as long as the waves continue to act on the boat we would expect the boat to rock.

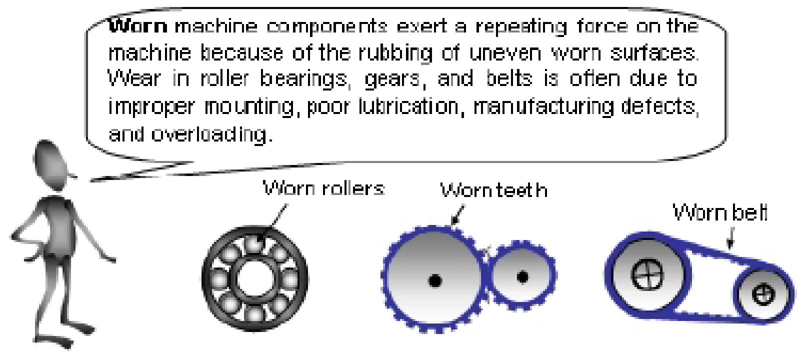
The boat would be rocking because the waves would be exerting a repeating force on the boat - a force of a pattern repeated over and over again.

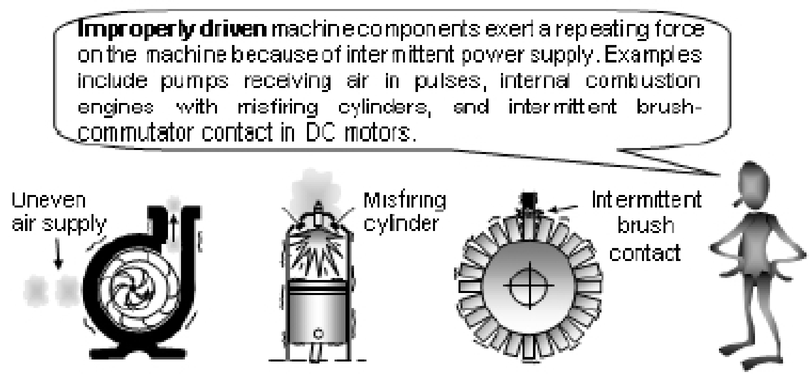
Most machine vibration is due to repeating forces similar to those causing the boat to rock. Repeating forces such as these act on machine components and cause the machine to vibrate. Where do the repeating forces that cause machine vibration come from?

Repeating forces in machines are mostly due to the rotation of imbalanced, misaligned, worn, or improperly driven machine components. Examples of these four types of repeating forces are shown below.


Imbalanced machine components contain 'heavy spots' which when rotated, exert a repeating force on the machine. Imbalance is often caused by machining errors, non-uniform material density, variation in bolt sizes, air cavities in cast parts, missing balance weights, incorrect balancing, uneven electric motor windings, and broken, deformed, corroded, or dirty fan blades.
Uneven rotor
Corroded tip
Bent shaft
Dirt

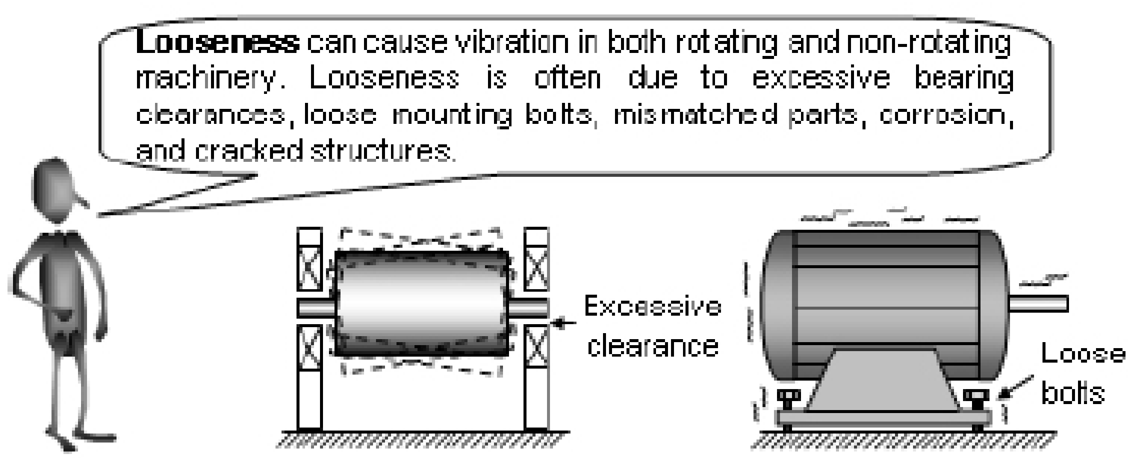

Misaligned machine components create "bending moments" which when rotated, exert a repeating force on the machine. Misalignment is often caused by inaccurate assembly, uneven floors, thermal expansion, distortions due to fastening torque, and improper mounting of couplings.
Parallel misalignment
Angular misalignment





(b) Looseness

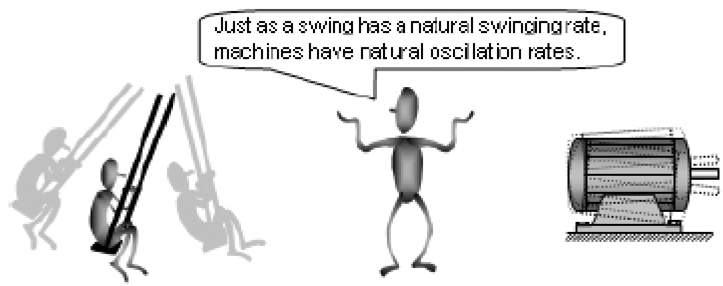
Looseness of machine parts causes a machine to vibrate. If parts become loose, vibration that is normally of tolerable levels may become unrestrained and excessive.



(c) Resonance

Imagine a child swinging freely on a swing, that is, without the child propelling himself or anyone pushing him. If we observe the motion closely we will see the child swinging at a particular rate. For example, we may see that it consistently takes him three seconds to complete one cycle of swinging.

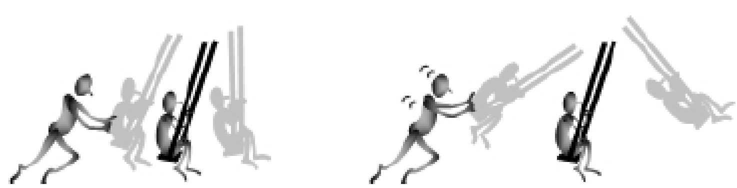
The rate of the child's free-swinging is in fact a physical property of the child-swing system - much as the weight of the child is a physical property of the child. It is the rate at which the child will tend to swing while seated on that particular swing. It is the child's most natural swinging rate on the swing, and the only way he can change it is to interfere with the natural swinging by propelling himself with his feet, changing his posture, rubbing his feet on the ground and so on.



Machines also tend to vibrate at certain oscillation rates. The oscillation rate at which a machine tends to vibrate is called its natural oscillation rate. The natural oscillation rate of a machine is the vibration rate most natural to the machine, that is, the rate at which the machine 'prefers' to vibrate.

A machine left to vibrate freely will tend to vibrate at its natural oscillation rate. Most machines have more than one natural oscillation rate. For example, a machine comprising two substructures of different natural oscillation rates will exhibit at least two natural oscillation rates. In general, the more complex the machine, the more natural oscillation rates it has.

Now consider again the child on the swing. If we aided the swinging motion by repeatedly pushing the child, we would expect the child to swing higher and higher over time.



We would however only cause the child to swing higher and higher if we pushed with the right rhythm. If our pushing rhythm is such that he is sometimes pushed down while he is ascending, we would not expect him to swing properly. To make him swing higher and higher, our pushing rhythm would in fact need to be in harmony with his natural oscillation rate.

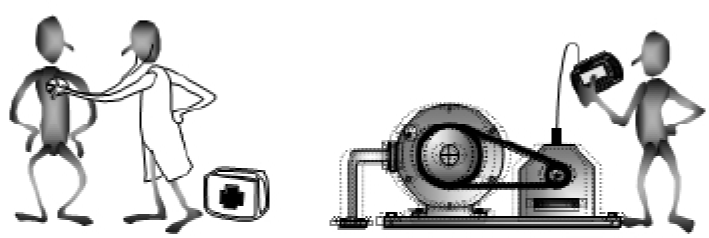
For example, we could push him every time - or every alternate time - he reaches his highest point. Only by pushing the child at a rate which is in harmony with his natural or preferred oscillation rate can we cause him to quickly swing higher and higher.

What happens if a machine is 'pushed' by a repeating force with a rhythm matching the natural oscillation rate of the machine? A similar situation will arise – the machine will vibrate more and more strongly due to the repeating force encouraging the machine to vibrate at a rate it is most natural with. The machine will vibrate vigorously and excessively, not only because it is doing so at a rate it 'prefers' but also because it is receiving external aid to do so. A machine vibrating in such a manner is said to be experiencing resonance.

A repeating force causing resonance may be small and may originate from the motion of a good machine component. Such a mild repeating force would not be a problem until it begins to cause resonance. Resonance, however, should always be avoided as it causes rapid and severe damage. For example, whole bridges have collapsed due to their natural oscillation rates being excited by the mere rhythm of soldiers marching in unison across the bridges.

C. Why Monitor Machine Vibration?

To do a good job of monitoring machine vibration and to fully reap the benefits, we must understand the answers to the above question. Monitoring the vibration characteristics of a machine gives us an understanding of the 'health' condition of the machine. We can use this information to detect problems that might be developing.



Why be concerned about the condition of a machine? Why not just continue to run the machine until it breaks down and then repair it? Operating a machine until it breaks down might be acceptable if the machine were a 'disposable' one. Most machines, however, are not 'disposable' due to their cost.

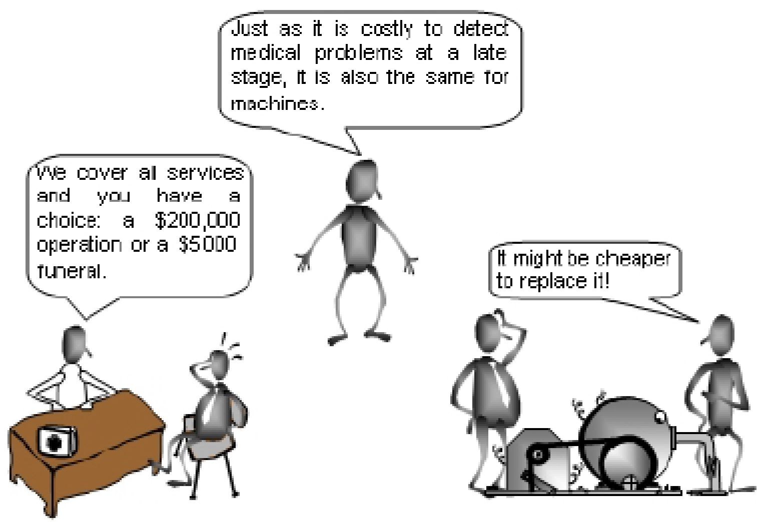
If we regularly monitor the conditions of machines we will find any problems that might be developing, therefore we can correct the problems even as they arise.

In contrast, if we do not monitor machines to detect unwanted vibration the machines are more likely to be operated until they break down.

Because machine vibration monitoring finds potentially damaging vibration, we can prevent problems arising and this saves a lot of time, money, and frustration. How? Below we discuss some common problems that can be avoided by monitoring machine vibration. These problems are worth avoiding as the costs of dealing with them are large and far exceed the cost of reasonably priced machine vibration monitoring programs.

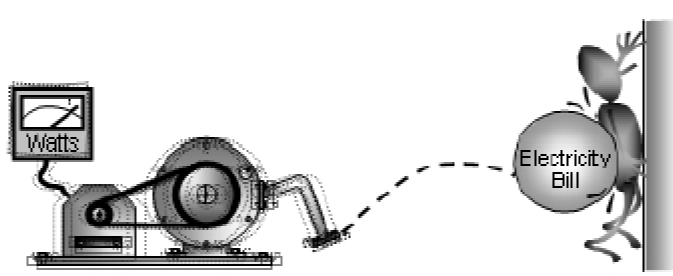
(a) Severe Machine Damage

Machine vibration that is not detected early enough will often lead to severe machine damage requiring costly repairs or even total machine replacement. However, if the condition of a machine is monitored regularly, potential problems can be detected – and corrected - at an early stage when the repair required is simpler, faster, and cheaper. This is similar to our own health. Regular visits to a doctor help us to detect problems early and so avoid the large costs of remedying severe health damage.



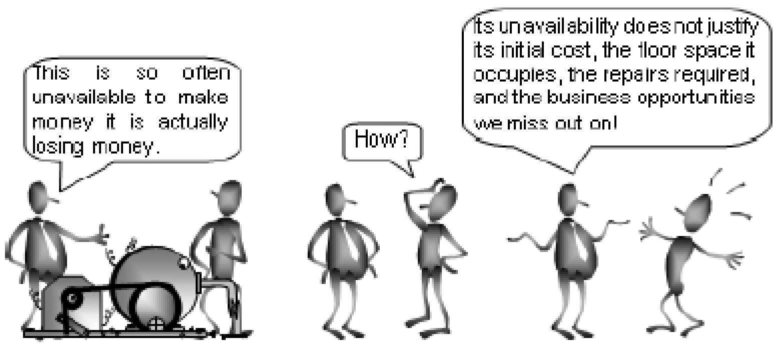
(b) High Power Consumption

A machine that is vibrating consumes more power. As well as the power required for the machine to perform its intended function, additional power is also required to sustain the vibration. We can minimize this problem by regularly monitoring and maintaining the machine.



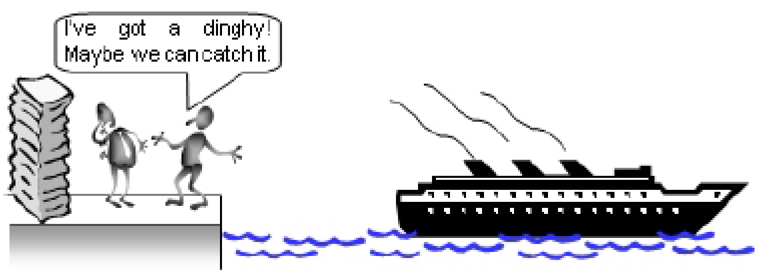
(c) Machine Unavailability

Because an unmonitored machine is more likely to break down, it is more often out of action. However, the cost of procuring and operating a machine is normally justified by its availability to process goods efficiently, or by its availability to convert raw material into cash. A machine should be consistently available to generate the money to justify its investment. Regular monitoring helps ensure that a machine is always available to generate money.



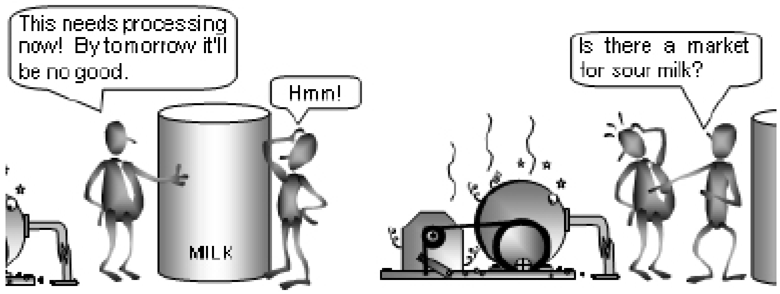
(d) Delayed Shipments

Because an unmonitored machine is more likely to break down, it is also more likely to cause delays in the shipping of goods. Customers have to wait and their payment is delayed. Customers could also cancel their order and stop doing business with us.



(e) Accumulation of Unfinished Goods

Because an unmonitored machine is prone to breaking down it is often unavailable. Goods still in the making tend to get stuck at the input point of the machine. This leads to unnecessary wastage – the waiting goods run the risk of spoiling, occupy floor space, and tie up money.

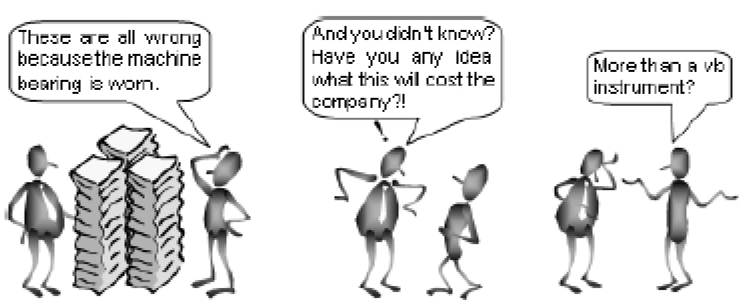


(f) Unnecessary Maintenance

To constantly ensure proper machine condition, some companies stop running machines according to predetermined schedules to adjust and replace parts regardless of whether or not the machines are malfunctioning. As a result, machines are often stopped unnecessarily to replace parts that are still good and to correct problems that do not exist. We can avoid such waste if the machines are regularly monitored and repaired only when necessary.

(g) Quality Problems

Sometimes a machine can be running into trouble even though it appears to be functioning normally. This is a dangerous situation. If not caught early, the problem could lead to poor quality products being made, large yield losses, rework costs, or worse still, warranty returns by irate customers. A machine that is regularly monitored is less likely to lead to such problems.

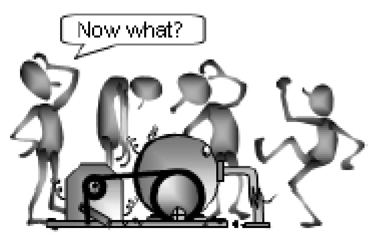


(h) Bad Company Image

We noted above that machines that are not regularly monitored can lead to shipment delays and produce goods of poor quality. Just one incident of shipment delinquency or product defect is often enough to seriously strain or even end relationships with customers. A bad company image associated with shipment delays and poor quality is something to be avoided. For a relatively small cost, machine vibration monitoring can protect customer relations and thus profitability.

(i) Occupational Hazards

Due to the noise and shaking they create, vibrating machines can cause occupational hazards and human discomfort. Human discomfort results in a loss to the company as workers who feel unwell will not be fully productive. Also, unexpected machine breakdowns leave workers with no work, and production planners with frustration.



2. Types of Vibration Monitoring Parameters.

2.1. PRINCIPLE

Vibration amplitude may be measured as a displacement, a velocity, or acceleration. Vibration amplitude measurements may either be relative, or absolute.

An absolute vibration measurement is one that is relative to free space. Absolute vibration measurements are made with seismic vibration transducers. Seismic vibration transducers include swing coil velocity transducers, accelerometers and velometers.

A relative vibration measurement is one that is relative to a fixed point on the machine. Relative vibration measurements are generally limited to displacement measurements, the displacement of the bearing journal relative to the bearings being the predominate example.

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2.2. Displacement

Displacement measurement is the distance or amplitude displaced from a resting position. The SI unit for distance is the meter (m), although common industrial standards include mm and mils. Displacement vibration measurements are generally made using displacement eddy current transducers.

2.3. Velocity

Velocity is the rate of change of displacement with respect to change in time. The SI unit for velocity is meters per second (m/s), although common industrial standards include mm/s and inches/s. Velocity vibration measurements are generally made using either swing coil velocity transducers or acceleration transducers with either an internal or external integration circuit.

2.4. Acceleration

Acceleration is the rate of change of velocity with respect to change in time. The SI unit for acceleration is meters per second^2 (m/s^2), although the common industrial standard is the g. Acceleration vibration measurements are generally made using accelerometers.

3.Vibration Monitoring Sensors & Selections.

3.1 Sensors & Sensor Selection :

In industry where rotating machinery is everywhere, the sounds made by engines and compressors give operating and maintenance personnel first level indications that things are OK. But that first level of just listening or thumping and listening is not enough for the necessary predictive maintenance used for equipment costing into the millions of dollars or supporting the operation of a production facility. The second layer of vibration analysis provides predictive information on the existing condition of the machinery, what problems may be developing, exactly what parts may be on the way to failure, and when that failure is likely to occur. Now, you may schedule repairs and have the necessary parts on hand. This predictive maintenance saves money in faster, scheduled repairs and prevents failures that are much more expensive in terms of repairs or lost production.

Types of Sensors

The types of sensors providing the vibration information are familiar to many NDT personnel. The three principal vibration sensor or monitor types are displacement, velocity, and accelerometer. The displacement transducer is an eddy current device, the velocity transducer is often a spring held magnet moving through a coil of wire, and the accelerometer is a piezoelectric device somewhat similar to ultrasonic transducers. The following information briefly describes how these transducers work, where they work best, and what kind of results they provide.

Displacement sensors are non-contact devices measuring the gap between the plant equipment and the fixed sensor. It is usually mounted 380-2,030 µm (15-80 milli-in.) from the part to be observed. The coil in the eddy current device is usually a pancake coil in the end of cylindrical tube that can be mounted close to the moving part. Excitation is very high frequency, about 240,000 Hz, for detection of small gap changes (as low as 1 µm [40 milli-in.]) at 0.5 MHz.

The sensor measures vibration as horizontal or vertical motion (requiring two different mountings of one sensor or two sensors). *The best measurements are at low frequencies of vibration of the part, below 1,000 Hz*, where signals as large as 4,000 mV/µm (100 mV/milli-in.) can be obtained. Since the signal can be large, very low amplitude displacements or vibrations can be measured. *Displacement sensors work well for applications such as shaft motion and clearance measurements.*

Velocity sensors find use from the *low to middle range of frequencies (10 to 1,500 Hz)* or 600 to 150,000 cycles per minute of machine vibration. The basic velocity pickup is a magnet (as a seismic mass) suspended on a spring moves through a coil of wire. The case of the sensor attaches to the device being measured such that the coil of wire moves through the magnetic field and generates an electrical signal. No external electrical excitation is necessary for these "self-generating" devices. *The signal* generated is high level (milli volts) for the useful range of frequencies and *is relatively free from high frequency noise signals*. The sensors find considerable use in handheld probes, providing useful information for vibration monitoring and balancing of rotating machinery.

Accelerometers work well over a very *wide range of frequencies (1 to 20,000 Hz)*. They work best for high frequencies where acceleration is large. Examples are *the passage of turbine blades*, which may be one hundred times the shaft rotation, or the meshing of gears or ball/roller bearings, which may be many times the shaft rotations per minute. Other advantages include their small size, lightweight, good temperature stability, and moderate price.

Accelerometers develop a voltage from a piezoelectric crystal that has a mass mounted upon it. A quartz crystal is frequently used. When the mass fixed to the crystal vibrates from the motion of the device upon which the sensor is attached, the crystal generates a voltage proportional to the force applied by the mass as it vibrates with the machinery. While no external excitation is required for the sensor to produce its voltage signal, the signal is small (self-generated) and requires a preamplifier. The preamp is often in the sensor case so the connecting cable must carry preamp power to the sensor as well as the signal from it. The accelerometer is the workhorse of vibration sensors because they offer such a wide range of working frequencies plus the other advantages given above.

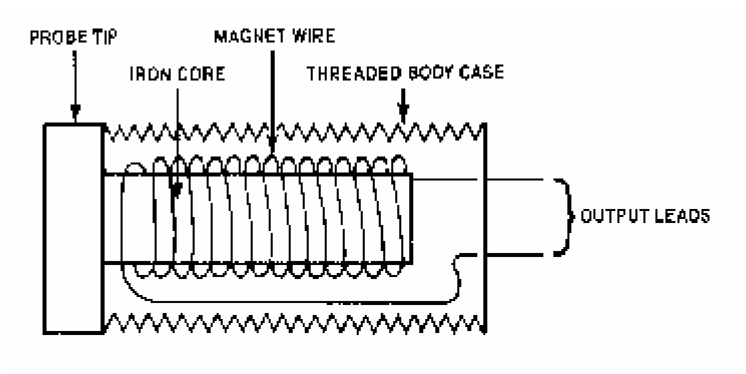
Application

Application of these vibration sensors, with their associated equipment, provides effective reduction in overall operating costs of many industrial plants. The damage to machinery the vibration analysis equipment prevents is much more costly than the equipment and the lost production costs can greatly overshadow the cost of equipment and testing. Predicting problems and serious damage before they occur offers a tremendous advantage over not having or not using vibration analysis. Specific areas of application include any rotating machinery such as motors, pumps, turbines, bearings, fans, and gears along with their balancing, broken or bent parts, and shaft alignment. The vibration systems find application now in large systems such as aircraft, automobile, and locomotives while they are in operation. Dynamic fluid flow systems such as pipelines, boilers, heat exchangers, and even nuclear reactors use vibration analysis to find and interpret internal problems.

3.2 Sensors Details – Operation Principal :

1. Non-contacting probe (eddy current)

Magnet wire wound around a ferrous core creates a magnetic field. The probe is placed in proximity to a shaft, where the shaft to be measured completes the magnetic field. Typically, an external electronic unit called oscillator-demodulator conditions the high frequency signal. As the measured object vibrates, the resulting eddy currents modulate the signal from the oscillator which is then demodulated to produce an output signal proportional to the displacement of the measured shaft vibration.
The non-contact probe stands off a certain distance, or gap, from the shaft, usually 40-50 mils. The output per probe is usually 200 mV/mil. Two probes are typically mounted 90° apart from top vertical centre.



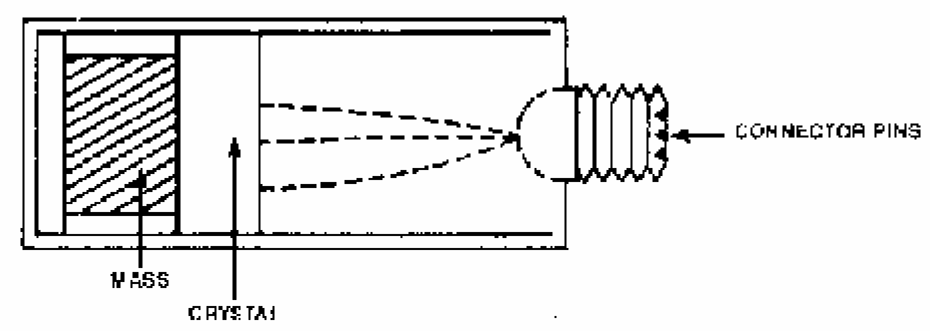
Generally, since the geometric centre of a rotating shaft seldom follows a perfect circular orbit, a pair of sensors is needed to determine the true vibration level. Two probes are required, one for horizontal movement and one for vertical movement. Most sleeve bearings have locking pins attached on either side of the bearing housing to prevent probe installation at the strictly vertical and horizontal direction. Therefore, it is necessary to mount the probes 45° from the top vertical position. When viewed with an oscilloscope, with respect to time, the vibration appears as a sinusoidal waveform. This sine wave is proportional to the displacement in mils, peak to peak.

Displacement eddy current transducers are relative transducers. Absolute displacement measurements can be made by integrating the output from a velocity transducer, or double integrating the output from an acceleration transducer. Relative measurements may also be made using two absolute transducers and subtracting the output of one from the other.

2. Accelerometer

Another type of transducer is the accelerometer. The accelerometer is not self-generating and requires an input voltage excitation.

A crystal cut to resonate at a specific frequency is supported within a case. Mounted above the crystal is a mass. As the case of the pickup vibrates, the force of gravity acting on the mass attempts to deform the crystal. The crystal is a piezoelectric element, so it generates an electrical charge when a mechanical force is applied to it.



Although an accelerometer does not measure velocity directly, an electronic integration can be performed on the output signal of the accelerometer to obtain velocity. Accelerometers generate high-frequency responses suitable for high-speed machinery and are very useful for monitoring vibrations in high temperature areas.

Transducer installation depends on the mechanical configuration of the assembly. Anti-friction bearings usually require contact pickups due to the low casing damping. Journal bearings generally need non-contact pickups. In this fashion, we are looking at relative motion of the shaft.

Generally, two velocity pickups, one mounted on the inboard bearing for radial vibration and one mounted on the outboard bearing in the axial direction, are adequate for determining misalignment and axial thrust. The inboard bearing usually consists of two non-contact probes, one for readings in the horizontal direction, and one for readings in the vertical direction.

Accelerometers are absolute transducers. To make a relative velocity measurement two transducers are used and the output of one is subtracted from the other. Making acceleration measurements by means of differentiating the output from a velocity transducer, or double differentiating the output from a displacement transducer, is rare. To make a relative acceleration measurement two accelerometers are used and the output of one is subtracted from the other. Accelerometers are also available with internal integrators; these are sometimes termed velometers.

Vibration Configuration Selection Guide

TYPE EQUIPMENT	HP	SPEED	BEARINGS *	PICK-UPS	MODE
Pumps	500-	600+	J,AF	Contact	Velocity
Pumps	500+	600+	J	Proximity	Displacement
Boiler Feed Pumps	1500+	3600+	J	Proximity	Displacement
Fans	-	600+	AF	Contact	Velocity
Fans	-	600-	AF	Proximity	Displacement
Fans	-	600+	J	Contact/Proximity	Velocity/Displacement
Compressors	-	3600+	J	Proximity	Displacement
Motors	-	1200+	AF	Contact	Velocity
Motors	-	1200+	J	Contact/Proximity	Velocity/Displacement
Gas Turbines	-	3600+	J	Contact	Velocity
Steam Turbines	-	3600+	J	Proximity	Displacement
Gear boxes	-	-	-	Contact	Acceleration
AF Bearings	-	-	AF	Contact	Acceleration

KEY ‘J’=ournal Bearing, ‘AF’= Anti-Friction Bearing

Vibration sensors on each bearing housing are recommended on large motors and pumps in critical applications. The sensors will measure vibration signals in the radial direction. To detect axial vibration, another contact pickup is fixed to the machine where axial movement can be measured.

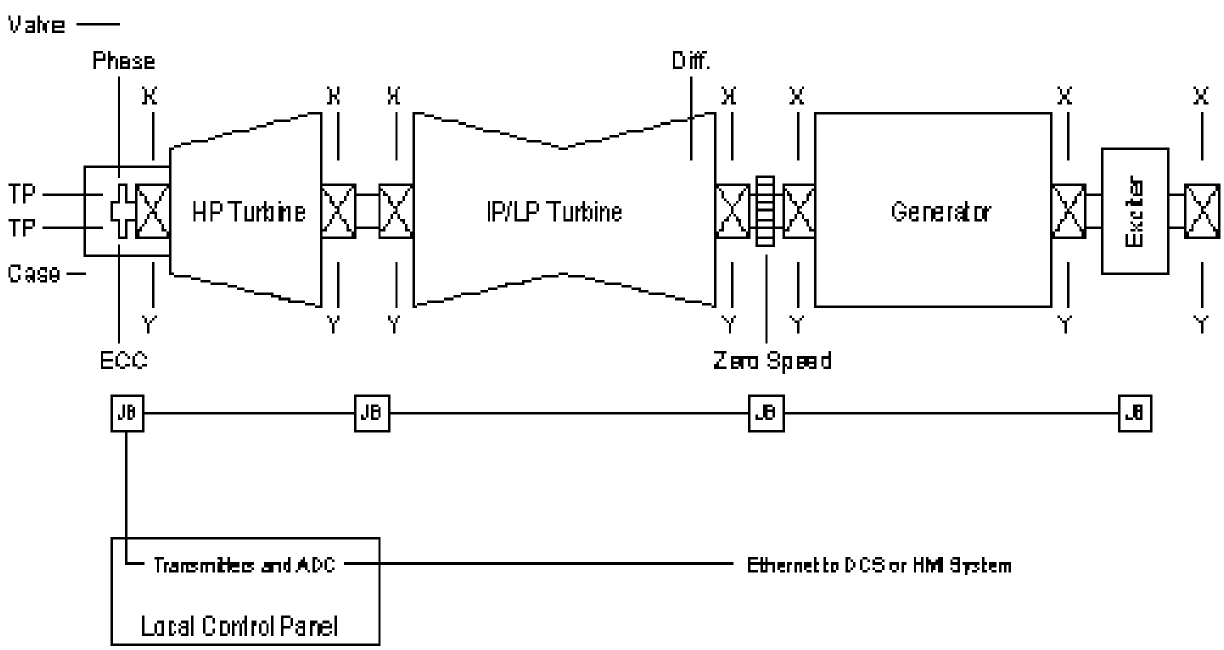
4.Vibration Monitoring Systems in Turbines.

TSI SYSTEM :

When an existing TSI system is being retro-fitted, the immediate indication is that a one-for-one replacement of each original parameter is sufficient. This approach may be adequate if the original system was complete. However, recent experience with retro-fitting TSI systems has brought to light that many of the existing systems can be greatly enhanced with additional parameters. Also, certain parameters should be considered for complete replacement including a different type of sensor.

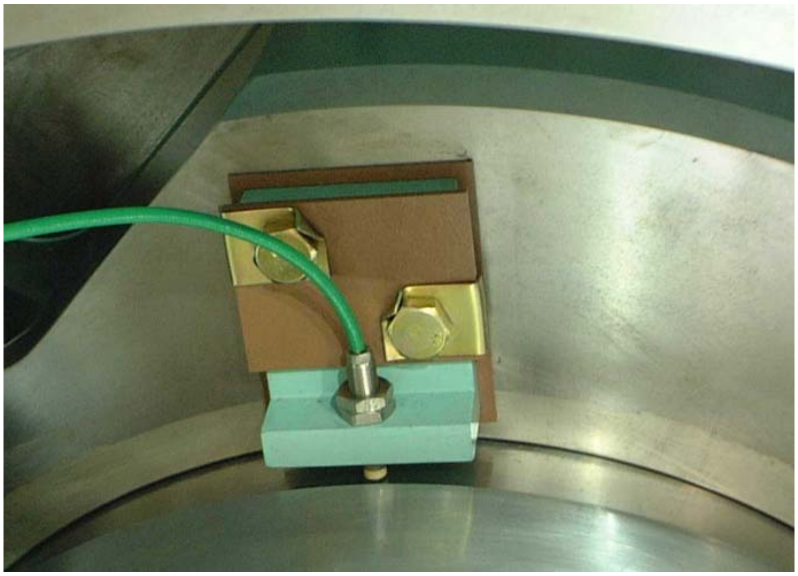
TSI systems not only measure bearing vibration levels, but can include:

4.1 Types of Monitoring Systems



Monitoring Parameters

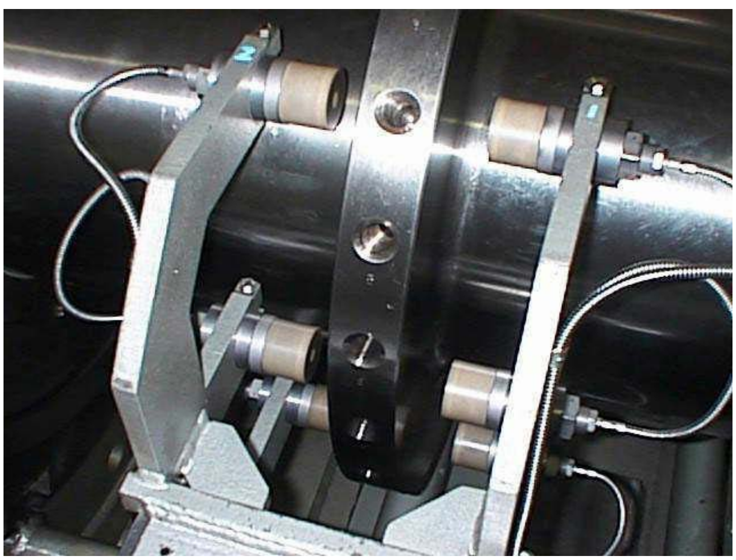
Radial Vibration is usually the heart of the TSI system. It gets the most attention and generally gives the first indication of out of specification conditions. Most OEM TSI systems utilized a shaft rider transducer system to monitor vibration with a shaft absolute output signal. An exact replacement transducer system can be supplied, but most customers and OEMs are specifying Eddy Probe Systems. A complete vibration system would install two probes per bearing, with the sensors located 90° from each other (X and Y).



Thrust Position indication includes one or two Eddy Probe Systems to observe the position of the thrust collar within its bearings. This system is an internal installation and need not replace the existing system because many original installations utilize a differential pressure system that interfaces with the turbine hydraulic control system.

Shell Expansion is the measure of a turbine case or shell moves in relation to a fixed location usually measured with a Linear Variable Differential Transformer (LVDT). Some existing OEM systems still use spindle micrometers or dial indicators that are subject to mechanical damage and human error. Although many systems installed with only one LVDT are adequate, a complete TSI system specification should consider two LVDTs located at each corner of the turbine shell. A second sensor will monitor shell cocking or uneven thermal growth which is a fairly common occurrence during startup when the sliding feet may have inadequate lubrication.

Differential Expansion measurements are an important parameter receiving much attention during turbine startup and warming. This parameter measures how the turbine rotor expands in relation to the turbine shell, or casing. A new differential expansion system using Eddy Probes can be retro-fitted to any existing system. An Eddy Probe is more reliable and robust than OEM supplied induction coil systems.

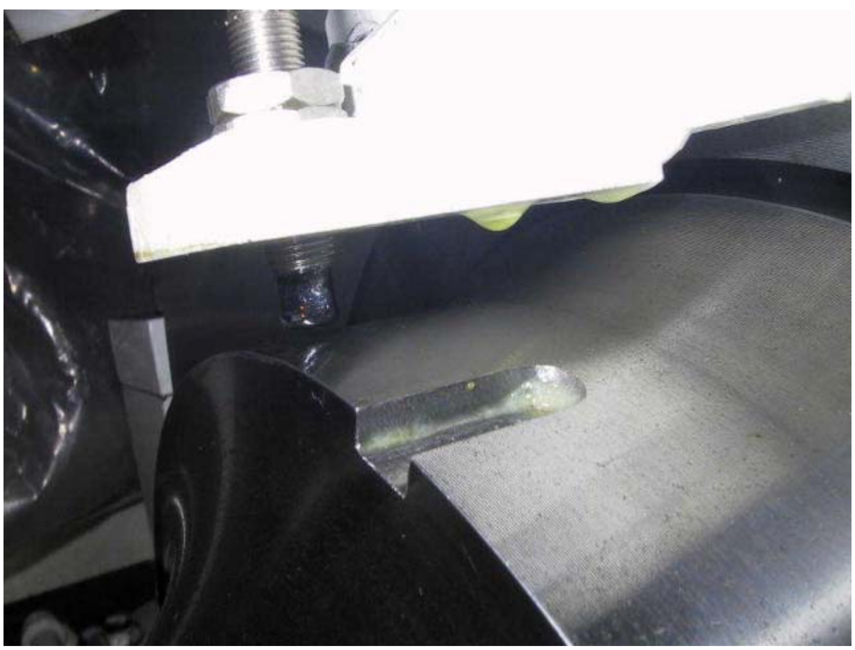


Valve Position - Correct valve positioning is required to efficiently operate a steam turbine. Some turbines may require several throttle valves be monitored, and some turbines will instrument the main stop valve(s) to determine when they crack from their seats. Retro-fit valve position measurements use DC LVDTs or DC Rotary Potentiometers. All OEM TSI systems include valve position measurement(s) as a startup and operation parameter. Some OEM systems utilized AC LVDTs while others use mechanical linkages and scales for indication. A retro-fitted system can be installed in the same position or relocated to a more accessible or protected position.

Eccentricity - A rotor which has been sitting idle during overhaul or has been inadvertently stopped during coast-down for an extended period will develop a bow or bend. This condition must be corrected by turning gear operation and, possibly, with auxiliary heating prior to high speed operation to prevent internal clearance rubbing. Eccentricity systems installed by OEMs monitor the turbine stub shaft or a shaft collar using induction coils. A retro-fit Eddy Probe system will monitor at the same location, and many times use the same bracketry.

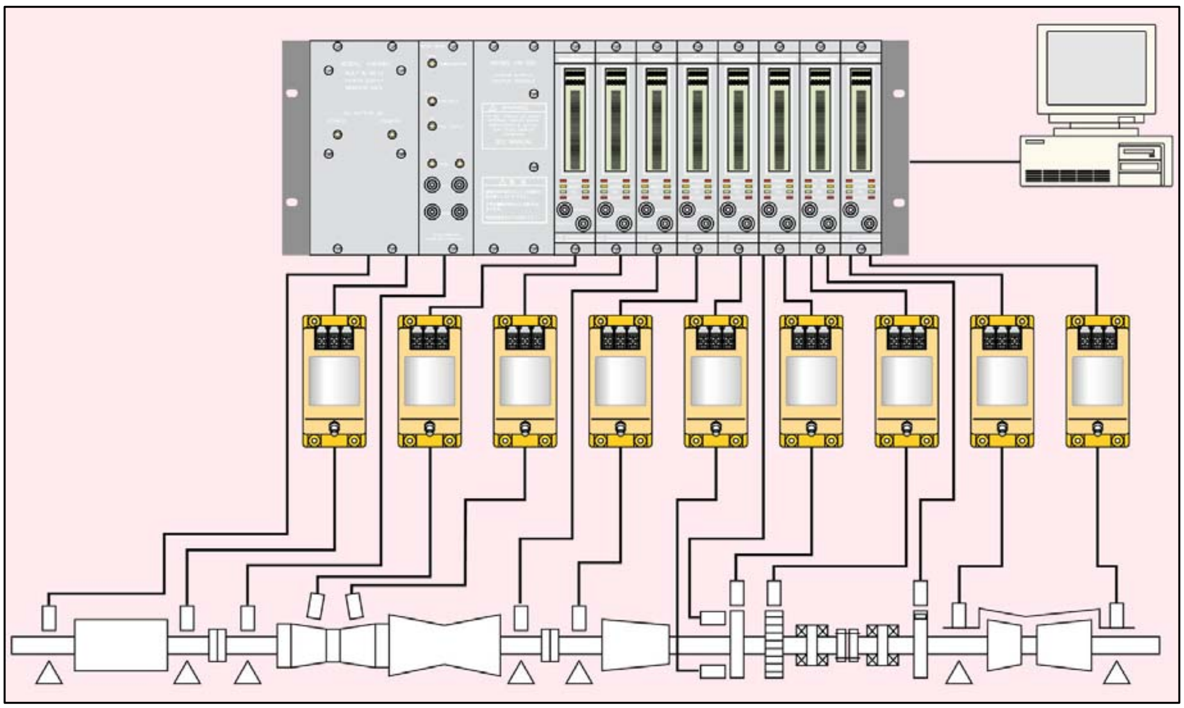
Speed - Turbine speed indication supplied by OEMs comes in many forms: observing a gear wheel located inside the front standard, electrically converting the generator output frequency, or monitoring the turning gear. A retro-fitted system using Eddy Probe's can be specified to observe any multi-toothed gear wheel. Applications monitoring generator output frequency without an integral turning gear may require installation of a custom gear wheel. Speed indication may be specified as an analog display or as a digital display and can be interfaced to a zero speed system for turning gear engagement.

Phase or phase angle, is a measure of the relationship of how one vibration signal relates to another vibration signal and is commonly used to calculate the placement of a balance weight. This parameter is not usually displayed continuously but is monitored periodically to determine changes in the rotor balance condition, deviations in system stiffness such as a cracked shaft. Phase angle measurements are sometimes not supplied by OEMs, but can be installed using an Eddy Probe system. Installation involves locating or installing a once-per-turn event such as a key or notch that the Eddy Probe will view. An Eddy Probe viewing a notch is easier to install and adjust, but the installation of the notch requires special tooling to cut the notch. Keys are easier to apply using glues or epoxies and are subject to coming off due to centrifugal forces.



Temperature of bearings is a measure of the how hot a bearing is operating. It may be due to overloading, mis-alignment, improper lubricant pressure and/or flow. Nearly all turbine generator bearings were originally installed or retro-fitted with bearing temperature sensors. These sensors may be thermocouples or RTDs. This parameter is often overlooked possibly due to the OEM output display located at some other panel not within the vicinity of the retro-fitted TSI system. Any bearings that was not originally equipped with temperature sensors can be retro-fitted to accept thermocouples or RTDs.

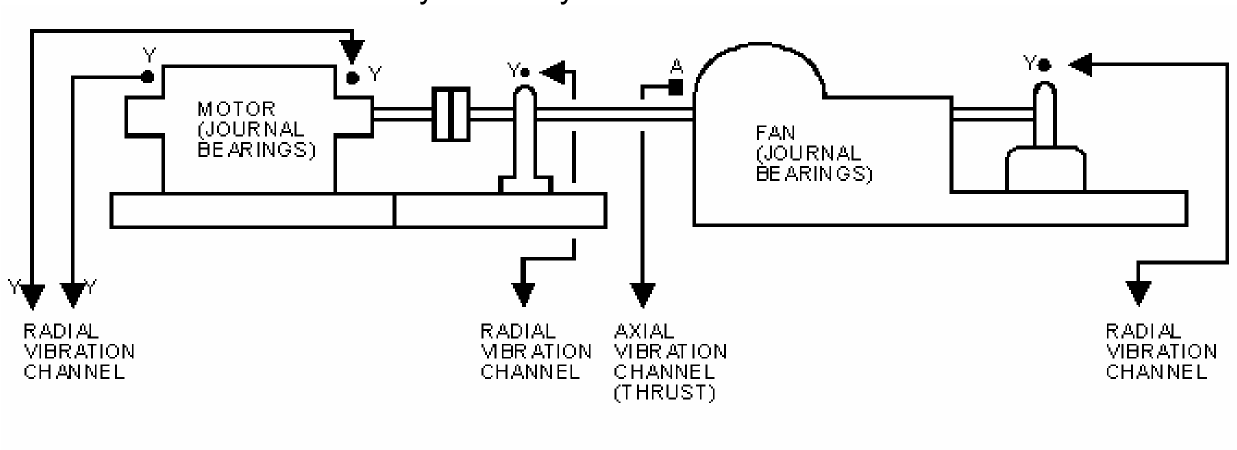
Typical Layout of TSI



5.Vibration Monitoring System for Balance of Plants.

5.1.Common Configurations

Machines having anti-friction bearings can be satisfactorily mounted with contact type pick-ups. Many of these machines can be adequately protected by the use of one pickup mounted on the inboard bearing for radial vibration, and a second contact pickup mounted on the outboard bearing in the axial direction to determine misalignment and excessive axial thrust. Velocity is usually the measurement used.



Machines that have journal bearings, centrifugal compressors, gear boxes, boiler feed pumps and most motors with sleeve bearings, usually require non-contact pick-ups such as eddy current proximity probes. These probes are recommended for mounting on the inboard and outboard bearings and for measuring displacement in the case of steam turbines, centrifugal compressors, and even large fans with journal bearings.

GLOSSARY OF TERMS

Acceleration

The time rate of change of velocity. For harmonic motion, this is often expressed as g or a. Typical units for acceleration are feet per second per second (ft/s2) pk, meters per second per second (m/s2) pk, or more commonly g pk (= acceleration of earths gravity = 386.1 in/s2 = 32.17 ft/s2 = 9.81 m/s2). Acceleration measurements are generally made with an accelerometer and are typically used to evaluate high frequency vibration of a machine casing or bearing housing due to blade passing, gear mesh, cavitation, rolling element bearing defects, etc.Note: Acceleration, as well as velocity, is zero to peak measurement (Notation = pk)

Amplitude

The magnitude of periodic dynamic motion (vibration). Amplitude is typically expressed in terms of signal level, e.g., millivolts or milliamps, or the engineering units of the measured variable, e.g., mils, micrometers (for displacement), inches per second (for velocity), etc. The amplitude of a signal can be measured in terms of peak to peak, zero to peak, root mean square, or average.

Average Shaft Position

The static or average position of the shaft relative to a stationary component on the machine to which the displacement probe is mounted. The most common application is rotor axial thrust position relative to the thrust bearing. Another important application is shaft average radial position. These measurements are made using the dc (position) component of the proximity probe signal. Two proximity probes mounted in an XY configuration are required for this two-dimensional, radial position measurement.Correlation of shaft position measurements: stopped versus at speed, cold versus hot, no load versus normal load, is an important diagnostic tool.

Axial

In the same direction as the shaft centerline or the line around which the shaft rotates.

Balance Resonance Speed

A shaft rotative speed (or speed range) which is equal to a lateral natural frequency of the rotor system. Due to rotor unbalance, when the speed increases or decreases ranges, the observed vibration characteristics are (1) a peak in the 1X amplitude and (2) a more rapid change in the 1X vibration phase lag angle. The resonance speed is at the point which is 90 deg. phase lag from the angle of the heavy spot for that resonance mode. This may be slightly different than the rotative speed peak amplitude point. These changes may not happen at the same frequency because of nonlinearity, damping, and/or asymmetry in the system stiffness.

Bearing

Any low friction structure which supports the rotor and provides dynamic constraint in the radial (lateral) and/or axial directions. The two main categories are fluid film bearings and rolling element bearings. Type: journal bearing (radial), thrust bearing (axial).

Bow, Initial
A condition of plastic deformation of a shaft which results in a bent geometric shaft centerline. Often the centerline is bent in a single plane, due to gravity sag, thermal warpage, etc., however, the bow may be three dimensional (corkscrew). Shaft bow can be detected by measuring the shaft relative displacement with a proximity probe(s) at rotor slow roll speed. Note: Careful. A straight shaft becomes bowed after a balance resonance if it is unbalanced
Displacement
The change in distance or position of an object relative to a reference. Machinery vibration displacement is typically a peak to peak measurement of the observed vibrational motion or position, and is usually expressed in units of mils or micrometers. Proximity probes measure displacement directly. Signal integration is required to convert a velocity signal to displacement, but does not provide the initial displacement (distance from a reference) measurement.

Eddy Current
Electric current which is generated in a conductive material when such material intercepts the electromagnetic field of a proximity probe

Electrical Run-out
A noise component in the output signal of a proximity probe transducer system resulting from non-uniform electrical conductivity and magnetic permeability properties of the observed material. Also caused by local (spot) magnetic fields on the circumference of the shaft surface. A change in the Proximitor® output signal, which does not result from a probe gap change (dynamic motion or change in average shaft position). The error repeats exactly with each shaft revolution.

Forced Vibration
The response vibration of a mechanical system due to a forcing function (exciting force). Typically, forced vibration has the same frequency as that of the exciting force.

Free Vibration
Vibration response of a mechanical system following an impulse-like initial perturbation (change of position, velocity or external force). Depending on the kind of perturbation, the mechanical system responds with free vibrations at one or more of its natural frequencies.

The repetition rate of a periodic vibration per unit of time. Vibration frequency is typically expressed in units of cycles per second (Hertz) or cycles per minute (to more easily relate to shaft rotative speed frequency). In fact, since many common machine malfunctions produce vibration which has a fixed relationship to shaft rotative speed, vibration frequency is often expressed as a function of shaft rotative speed. 1X is a vibration with a frequency equal to shaft rpm, 2X vibration is at twice shaft rpm, 0.5X vibration with a frequency equal to one-half shaft rpm, etc.

Frequency
Frequency of the vibration precession, f, of a rotor measured in Hz, rad/s (circular frequency) or cpm is often related to the rotative speed W measured in rpm or rad/s. For a synchronous precession:

Frequency of vibration precession can also be independent of rotative speed, e.g., locked to a natural frequency of the rotor system.

Integrator
An electronic circuit that converts a velocity signal to a displacement signal or converts an acceleration signal to a velocity signal.

Keyphasor® Transducer
A transducer that produces a voltage pulse for each turn of the shaft, called the Keyphasor® signal. This signal is used primarily to measure shaft rotative speed and serves as a reference for measuring vibration phase lag angle. It is an essential element in measuring rotor slow roll bow or runout information.The Keyphasor® transducer is typically a proximity probe (recommended for permanent installations in which the probe observes a physical gap change event), an optical pickup (used for temporary installations in which the pickup observes a change in reflectivity event) or a magnetic pickup. Keyphasor® is a Bently Nevada registered trademark.

Mechanical Run-out
A noise component in the output signal of a proximity probe transducer system; a probe gap change which does not result from either a shaft centerline position change or shaft dynamic motion. Common sources include out-of-round shafts, scratches, chain marks, dents, rust or other conductive buildup on the shaft, stencil marks, flat spots, and engravings.

Micrometer
A unit of length or displacement equal to 10-6 metres. One micrometre equals 0.0394 mil. (1mil = 25.4 micrometers.). Also called micron (obsolete).

Mil
A unit of length or displacement equal to 0.001 inch. One mil equals 25.4 micrometres.

Natural Frequency
The frequency of free vibration of a mechanical system at which a specific natural mode of the system elements assumes its maximum amplitude.

Optical Pickup
A noncontacting transducer which emits light from an internal infrared light emitting diode (LED), and detects the level of reflected light with a phototransistor. The most common application of this pickup is as a temporary Keyphasor transducer, observing a once-per-turn change in shaft reflectivity (dark or light paint spot or small strip of highly reflective tape on the shaft).

Peak to Peak value
The difference between positive and negative extreme values of an electronic signal or dynamic motion

Phase Lag Angle
The timing relationship, in degrees, between two vibration signals, such as a Keyphasor® pulse and a vibration signal; also, the phase difference between two signals, such as the input force signal and output response signal. The "lag" corresponds to "minus" in mathematical formulations

Probe Gap
The physical distance between the face of a proximity probe tip and the observed surface. The distance can be expressed in terms of displacement (mils, micrometres), or in terms of voltage (millivolts). Standard polarity convention dictates that a decreasing gap results in an increasing (less negative) output signal.

Proximitor
A signal conditioning device which sends a radio frequency signal to an eddy current proximity probe, demodulates the probe output, and provides output signals proportional to probe gap distances. Also called an oscillator-demodulator.

Proximity probe
A noncontacting device which measures the displacement motion and position of an observed surface relative to the probe mounting location. Typically, proximity probes used for rotating machinery measurements operate on the eddy current principle, and measure shaft displacement motion and position relative to the machine bearing(s) or housing.

Radial
A direction on a machine which is perpendicular to the shaft centerline in the XY plane; usually refers to direction of shaft lateral or casing motion or measurement
Radial Vibration
Shaft dynamic motion or casing vibration which is measured in a direction perpendicular to the shaft axis, often called lateral vibration.

Relative Transducer
A proximity probe observing shaft motion referenced to the probe mounting, usually the bearing or bearing housing

Resonance
The condition in which the frequency of an external force coincides with a natural frequency of the system. A resonance typically is identified by an amplitude peak, accompanied by a maximum rate of change of phase lag angle.

Rolling Element Bearing
A bearing in which the low friction property derives from mechanical rolling (usually with fluid lubrication), using ball or roller elements between two constraining rings.

Signal Conditioner
A device placed between a signal source and a readout instrument to change the signal. Examples: attenuators, preamplifiers, filters, and signal converters (for changing one electrical quantity into another, such as voltage to current or analog to digital).

Slow Roll Speed
Low rotative speed of a rotor at which dynamic motion effects from forces such as unbalance are negligible. The speed at which shaft bow and runout can be measured. Typically, slow roll speed should be below 10% of the first balance resonance.

Transducer
A device for translating the magnitude of one quantity into another quantity. The second quantity often has units of measure different from the first and serves as the source of a useful signal. Vibration transducers convert mechanical motion into a proportional electronic signal (typically a voltage signal proportional to displacement).

Unbalance
Unequal radial mass distribution on a rotor system; a shaft condition where the mass centerline (principal axis of inertia) does not coincide with the geometric centerline. Eccentricity of local center of gravity (c.g.) of rotor from undisturbed axis of rotation. Also, product of rotor local mass times eccentricity of c.g. from shaft elastic axis. Often expressed in terms of eccentricity alone, e.g., in microinches of eccentricity. Also, the effective mass that causes rotor lateral synchronous vibration.

Velocity
The time rate of change of displacement. Typical units for velocity are inches/second or millimetres/second, zero to peak. Velocity measurements are used to evaluate machine housing and other structural response characteristics. Electronic integration of a velocity signal yields displacement, but not position

XY
Orthogonal (perpendicular) axes in a Cartesian coordinate system. Usually used to indicate orthogonal (mutually perpendicular) radial vibration transducers. Y represents the vertical axis, and X represents the horizontal axis.

Zero-to-Peak Value
One-half of the peak to peak value.