INTRODUCTION TO VIBRATION-BASED CONDITION MONITORING

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November 2022

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VIBRATION

1

Vibration is a motion/oscillation of a body about a reference point.

> **A vibration signal captured from a machine is composed of the sum of the vibration of each of its components. A machine can have different vibration levels under different operating conditions (load, speed, environment) and it can be affected by equipment connected upstream or downstream of the machine.**

WHERE DOES VIBRATION COME FROM?

In practice, it is difficult to avoid vibration. It usually occurs because of the dynamic effects of manufacturing tolerances, clearances, rolling and rubbing contact between machine parts, and out-of-balance forces in rotating and reciprocating members.

Vibration waveform has three main characteristics: amplitude, frequency and phase. These are explained below.

AMPLITUDE

Amplitude represents the intensity of motion from a neutral position over a time interval or at a specific time. Amplitude can be expressed/measured as displacement, velocity and acceleration of motion. It is measured in mm, mm/s, mm/s2, g (9.81 m/s2), dB, etc. As seen in *Figure 1*, amplitude is represented by arrows.

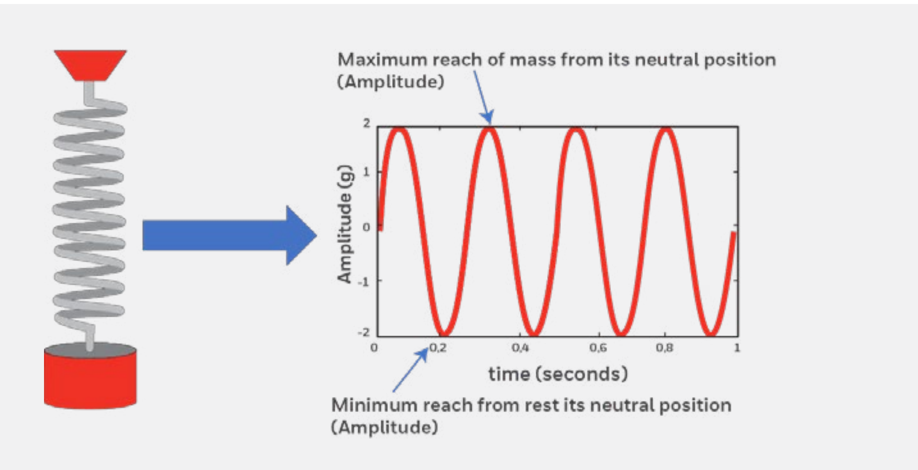


Figure 1: Example of amplitude

FREQUENCY

Frequency denotes how often the motion repeats within a time interval. It is measured in Hertz (Hz) or Cycles per min (CPM) or Cyles per sec (CPS). Referring to *Figure 2*, for a sinusoidal waveform with 1 sec time interval 4 cycles are presented with a second. Thus, frequency of the waveform is 4 Hz.

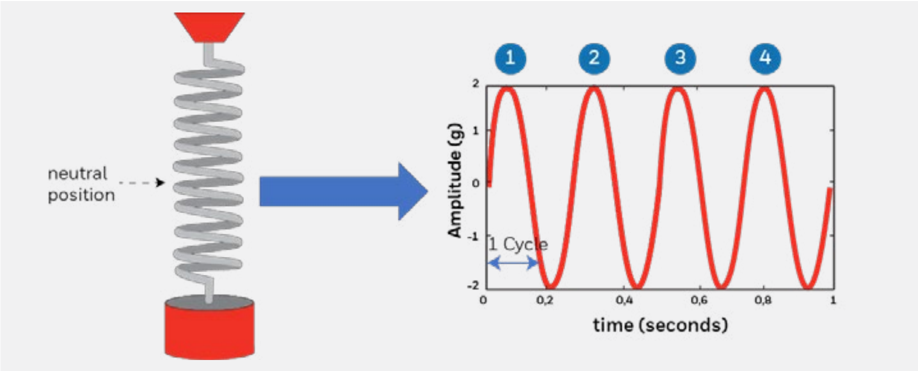


Figure 2: Example of frequency

PHASE

Phase is a measure of the time difference between two waveforms. Phase of vibration signal represents the vibration referring to a reference point or space. It is measured in degrees (0°-360°). Phase can be relative (comparison between two vibration sources) and absolute (comparison between a vibration source and a reference point such as speed). Relative phase is between -180° to 180°. Absolute phase is between 0° to 360°.

In *Figure 3*, two vibration sources have the same amplitude and frequency but different phase. There is a phase shift of 90° (difference in degree for reaching same peak value).

In *Figure 4* shows an example of an absolute phase. A vibration signal is filtered to a certain frequency and compared with a speed signal (tacho). There is a phase shift of 270°.

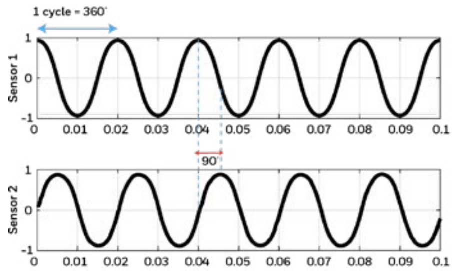


Figure 3: Example of relative phase

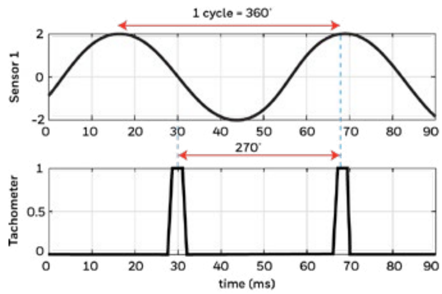


Figure 4: Example of absolute phase

CAUSES OF VIBRATION IN MACHINES

Forces generated within the machine cause vibration. Forces can be due to operation in healthy or abnormal condition (internal and external causes). These forces may:

- Change in direction with time, such as the force generated by a rotating unbalance.
- Change in amplitude or intensity with time, such as the unbalanced magnetic forces generated in an induction motor due to an unequal air gap between the motor armature and the stator (field).
- Result from friction between rotating and stationary machine components in much the same way that friction from a rosined bow causes a violin string to vibrate.
- Cause impacts, such as gear tooth contacts or the impacts generated by the rolling elements of a bearing passing over flaws in the bearing raceways.
- Include randomly-generated forces such as flow turbulence in fluid-handling devices such as fans, blowers and pumps, or combustion turbulence in gas turbines or boilers.

- Vibration can be linked to periodic events in machine operations (rotating shafts, meshing gear teeth, rotating electric field, etc.). Some vibrations are due to events that are not completely phase locked to shaft rotations such as combustion cycles. Vibration can be linked to fluid flow – for example, in pumps, gas turbines, transformers and valves.

Vibration can be absolute vibration (machine housing) or relative vibration (shaft and housing). Another type is torsional vibration i.e., angular fluctuations of the shafts and components such as gears and rotor discs.

The relationship between vibration signals and machine condition was first recognized by Rathbone (1939) through his paper on vibration tolerance in Power Plant Engineering magazine.

WHY USE VIBRATION DATA FOR MACHINE HEALTH?

Machines exhibit a characteristic, non-anomalous (acceptable) vibration "signature". Acceptable vibration varies based upon not only on the type of equipment but also operating conditions and even environmental variables such as temperature or humidity. When an anomaly in machine operation occurs, the vibration signature changes. The change in vibration signature can capture majority of failure modes in a machine (particularly rotating machines) and can thus be used to diagnose problems. ISO 10816/20816 describe the standards to be adopted for failure mode diagnostics using vibration information.

Some of the most common machinery problems that cause vibration include:

- Misalignment of couplings, bearings and gears
- Unbalance of rotating components
- Looseness
- Deterioration of rolling-element bearings
- Gear wear
- Rubbing
- Aerodynamic/hydraulic problems in fans, blowers and pumps
- Electrical problems (unbalance magnetic forces) in motors
- Resonance
- Eccentricity of rotating components such as "V" belt pulleys or gears

TYPES OF VIBRATION MONITORING

2

Vibration analysis reacts immediately to abnormality in machines and can therefore be used for permanent as well as intermittent monitoring.

Table 1 shows a comparison between the two monitoring methods.

Critical machines often have permanently mounted vibration sensors and are continuously monitored so that they can be shut down rapidly in the case of sudden changes which might be a precursor to catastrophic failure.

For the vast majority of machines in a plant, it is not economical to equip them with permanent sensors for continuous monitoring. The time interval of intermittent monitoring must be shorter than the minimum required lead times for maintenance and production planning purposes. In offline monitoring, a large number of machines can then be monitored intermittently with a single sensor and data logger.

METRIC	PERMANENT MONITORING	INTERMITTENT MONITORING
Generic application	Critical machines	Non-critical machines
Cost of monitoring	High	Low
Fault detection	Early	Delayed, within minimum required lead times for maintenance and production planning purposes and can chance that fault can be missed

Table 1: Comparison of permanent and intermittent monitoring

VIBRATION SENSORS

3

Vibration (lateral) can be expressed in three forms: displacement, velocity and acceleration. Proximity probes measure relative displacement; seismic velocity transducers measure velocity; and accelerometers measure acceleration.

Displacement measurement

- Suitable for low frequency vibration (< 10 Hz) or when the analyst needs to know precisely the movement of a rotor and not just the part of the vibration transmitted to the bearing support.
- These measurements are taken directly with proximity probes and are an indicator of the stress or strain the machine is suffering.
- Its unit can be mm.

Velocity measurement

- An indicator of the level of vibration severity and is proportional to the level of fatigue that a mechanical system is sustaining.
- These measurements can be taken with a seismic velocity sensor, although accelerometers are more often used for better frequency response and lower cost. The accelerometer signal is processed to be converted to velocity units.

Acceleration measurement

- Acceleration is the parameter that gives the best indication of the internal forces associated with a particular source of vibration (Force = mass × acceleration)

One can convert signal from one measurement to another. For example, using differentiation (mathematical), displacement to velocity to acceleration can be estimated. However, due to differentiation, signal is noisy. Hence, this approach is rarely used. Conversely, acceleration to velocity or velocity-to-displacement conversion is done through integration. Integration is carried out accurately with a cheap electronic circuit or via software. That is one of the main reasons why the accelerometer is the standard transducer for vibration measurements, since its output signal can be easily integrated once or twice to obtain velocity or displacement.

3.1 PROXIMITY PROBES

Proximity probes give a measure of the relative distance between the probe tip and another surface. A proximity pickup system consists of the sensor and a signal conditioner. The principle is change in electrical inductance of a circuit brought about by changes in the gap as shown in *Figure 5*: Operating principle diagram of proximity probes. Such probes were pioneered by a company called Bently Nevada. *Figure 6* shows the typical location of proximity probes installed in a bearing cap. It is used to measure shaft radial or axial displacement.

The surface whose distance from the tip is being measured must be electrically conducting. The medium in the gap must have a high dielectric value but can be air or gas or oil.

The frequency range is typically 10 kHz. However, the frequency mostly observed (< 1000 Hz) relate to 'rotating speed. Faults arising from components such as bearing, gearbox etc and other process related may not be detected. Thus,restricts the diagnostic capabilities.

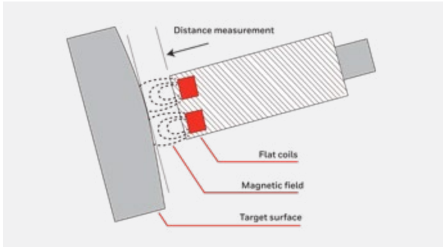


Figure 5: Operating principles of proximity probes [Ref: 9.a]

ADVANTAGES	DISADVANTAGES
Application: It is particularly useful in rigid machinery where very little vibration is transmitted from the shaft to the machine casing. This situation occurs if the mass of the housing is of the same order of magnitude or higher in comparison with the mass of the shaft.	**Costly:** These transducers must be permanently installed. This is always costly, and even impossible in certain cases.
Insight: It measures both the continuous and varying component of a vibration signal providing insight related to shaft.	**Frequency range:** Limited between 0 Hz to 1,000 Hz.
	Sensitivity: Even small cracks in the shaft can make the transducer interpret them as a high vibration activity.

Table 2: Advantages and disadvantages of proximity probes

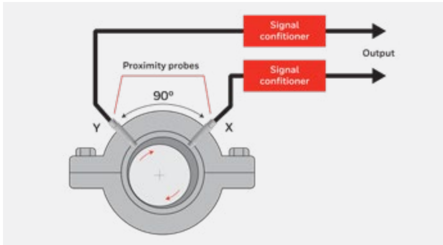


Figure 6: Location of proximity probes [Ref: 9.a]

3.2 VELOCITY SEISMIC TRANSDUCERS

The velocity seismic transducer is used in machines where the shaft transmits vibration to the housing with little damping, i.e., the vibration amplitudes in the housing are high. Figure 7 shows the internal view and a representative picture of the sensor. The velocity sensor consists of a permanent magnet located in the center of a copper wire coil. When the housing vibrates, a relative movement is created between the magnet and the winding based on Faraday law, and voltage proportional to the speed of movement is created.

It was first developed by Arthur Crawford in late 1940s. They are directly mounted on the object in horizontal or vertical direction. They are highly sensitive at low frequencies, are simple to mount and don't need an external power supply. Relative to accelerometers, they are heavier and bulkier.

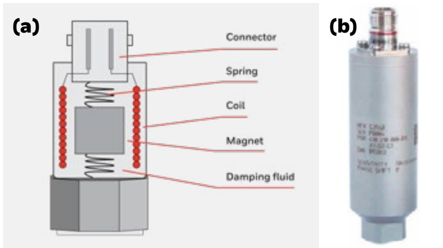


Figure 7: Velocity sensor (a) Internal construction (b) Actual representation [Ref: 9.b]

ADVANTAGES	DISADVANTAGES
Application: Ideal for remote permanently installed	**Size:** Higher in size requiring large magnetic base
Insight: Provides direct information on vibration severity	**Frequency range:** Typically from 10-1000 Hz

Table 3: Advantages and disadvantages of seismic velocity sensor

3.3 ACCELEROMETERS

Accelerometers are well-suited for taking high-frequency vibration data where large forces with relatively small displacements have to be detected. It can measure signals between 10 Hz – 10 KHz with good accuracy. Higher frequencies measured by accelerometers can cover the frequencies generated by faults in rotating machinery. However, the frequency response depends on the mounting methods of the accelerometer. More detail on mounting can be found in Section 6.

Accelerometers are largely designed based on piezoelectric effect. In a typical design (Figure 8a), the piezoelectric element or crystal is sandwiched between a mass and the base. An electric voltage that is proportional to acceleration is generated due to the external vibration applied on a piezoelectric crystal.

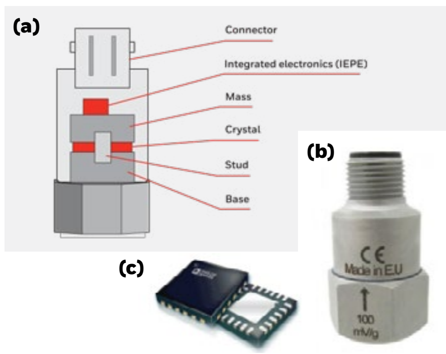


Figure 8: Accelerometer (a) Internal construction (b) Actual representation (c) MEMS type [Ref 9.c]

ADVANTAGES	DISADVANTAGES
Application: Ideal for temporary and remote permanently installed	Output affect by the temperature of the surface
Insight: Can locate the fault	
Frequency range: Typically from 10-10000 Hz	

Table 4: Advantages and disadvantages of accelerometer

So far, we have seen the contact-type vibration measurement which is being adopted across industries. There are also non-contact vibration measurements being developed which are described below.

3.4 LASER VIBROMETER

Laser vibrometer is based on the principle of the laser Doppler. In this technique, a coherent laser beam is reflected from a vibrating surface and is frequency shifted according to the absolute velocity of the surface by the Doppler effect. The frequency shift is measured by an interferometer and converted to velocity. They can be used for modal analysis. Being expensive, it is rarely used in equipment health monitoring.

ADVANTAGES	DISADVANTAGES
Do no load the measurement object and can easily change the measurement point by deflecting the light beam	Expensive
	Bulky and difficult to move around

Table 5: Advantages and disadvantages of laser vibrometers

3.5 MM RADIO WAVES

mmWave is a promising technology for measuring tiny displacements, owing to its short wavelength. This is the latest method of non-contact vibration which costs less than laser vibrometers. It could be used in cases where it is impossible to establish a contact sensor on an object performing mechanical oscillations due to the complexity of fastening or disrupt object rotation balance.

It has advantages over other methods of non-contact -- for example, if the object is located at an excessive distance from the transducer or if there is an optical obstacle such as dust, steam or smoke. These are conditions where ultrasonic sensors (if distance more than 2 m) or laser sensors (if presence of optical interference) cannot operate at all.

ADVANTAGES	DISADVANTAGES
No interference with the machine	Costlier than contact type
Ability to measure in heavy dust and water vapor environment	

Table 6: Advantages and disadvantages of mm radio waves

Torsional vibration measurement is not covered here. Shaft encoders and torsional laser vibrometers are used to measure torsional vibrations. They sometimes carry significant diagnostic information as to machine condition such as with reciprocating machines and gears.

TYPES OF FAULTS IN ROTATING MACHINES

4

In this section, we look at different faults in rotating machines. These generally relate to a rotating shaft, bearing, gearbox, rotor, stator, etc.

4.1 SHAFT UNBALANCE

Definition: Rotation of shaft is more to one side. It is an unequal distribution of mass t

Cause: Unbalance is the unequal distribution of mass within a rotating system (dust on fan, erosion of blade, porous material). The geometric centerline of rotation does not coincide with its mass centerline.

Effect: Excitation forces rotating at the shaft speed is generated mainly in radial direction. Dynamic balancing (adding weights) to shaft is done to mitigate effect.

Detection: Fault is detected at a frequency of 1* RPM in the form of a 180°phase shift across the coupling. (Note: RPM = rotation per minute of shaft).

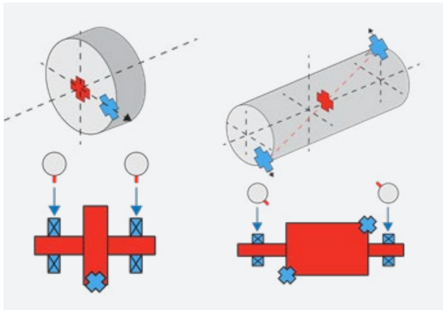


Figure 9: Shaft unbalance [Ref: 9.d]

4.2 SHAFT MISALIGNMENT

Definition: Coupling between two rotors with their supports are not aligned. They can be parallel misaligned or angular misaligned.

Cause: Assembly issue, unlevelled foundation, the coupling loosens through use over time.

Effect: The rotating shaft can bend after a bearing failure. Flexible coupling is used to mitigate the effects.

Detection:

Angular misalignment

- Strong axial vibration at 1x RPM possibly with 2x and 3x harmonics (i.e. vibration at 2x and 3x RPM).
- The 2x RPM harmonic in the axial direction can reach a value equal to or even higher than 1x.
- Vibration in the radial direction, probably of smaller amplitude than in the axial direction, in 1x, 2x and 3x.
- The axial phase measurements on both sides of the coupling are 180° out of phase.

Parallel or offset misalignment

- Strong radial vibration in 1x RPM with 2x and 3x harmonics.

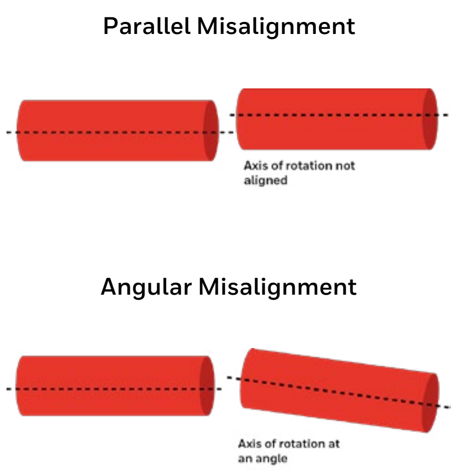


Figure 10: Shaft misalignment

- The 2x RPM harmonic in the radial direction can reach a value equal to or even greater than 1x.
- The radial phase measurements on both sides of the coupling are 180° out of phase.

4.3 BENT SHAFT

Definition: A rotor is considered bent (permanently bowed) when it loses its symmetry with respect to its rotating axis.

Cause: Thermal expansion and higher axial load.

Effect: This fault will show signs of misalignment and unbalance and can change with temperature.

Detection: It can cause a 1× RPM, 2× RPM component in the axial and radial direction. However, unlike unbalance, a significant axial vibration will be measured. Phase shift across the coupling at 180° in axial direction.

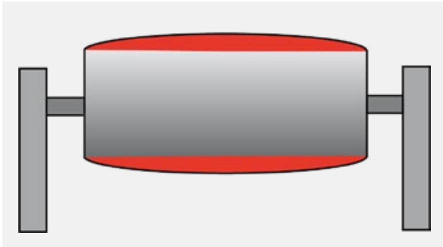


Figure 11: Bent shaft

4.4 LOOSENESS

Definition: Not enough tightening between different mechanical elements. It can be categorized into two types: looseness of rotating elements (rolling element bearings, sleeve bearings, couplings, rotors, etc.); and structural looseness (benches, casters, anchor bolts, etc.).

Cause: Assembly issues, clearance increase due to wear.

Effect: Can lead to unbalance, misalignment, bent shaft.

Detection:

Rotating element looseness

- Presence of frequency with harmonics (1x, 2x, 3x, etc.), subharmonics (0.5x) and half harmonics (1.5x, 2.5x, 3.5x, etc.).
- More in radial directions than axial.

Structural looseness

- Presence of frequency with harmonics (1x, 2x, 3x) in radial direction. Amplitude of 2x,3x and higher than 1x.

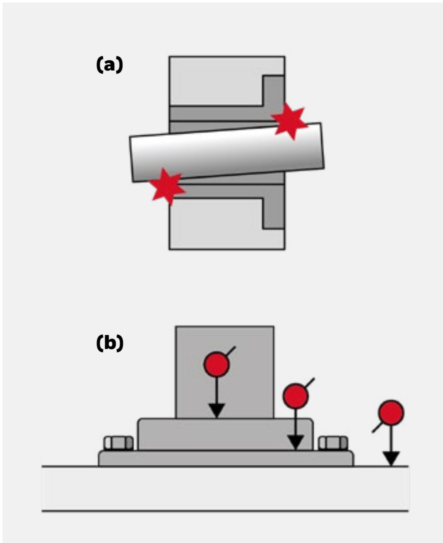


Figure 12: Looseness (a) Rotating element (b) Structural [Ref: 9.e]

4.5 OIL WHIRL AND OIL WHIP

Definition: It occurs in fluid film bearing when lightly loaded. It is like a shaft surfing over fluid film.

Cause: At lower loads, there is a mismatch in velocity of oil adjacent to the shaft and the bearing surface. Also, due to alignment of foundation, thermal effect.

Effect: It can be destructive. It can be eliminated by design or non-cylindrical bearing or tilting pad bearing.

Detection: Vibration at subharmonics (0.5x, 0.3x)

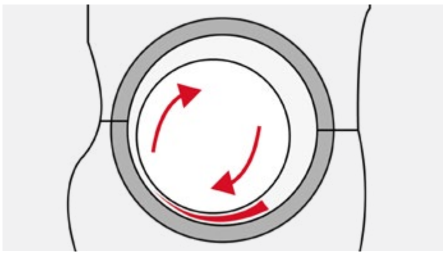


Figure 13: Oil whirl and whip

4.6 BEARING FAULT

Definition: Defects on the bearing components (inner race, outer race, cage, balls). Defects include cracks, wear, pitting etc.

Cause: Degraded lubricant, external environment, fatigue, variable frequency drive currents.

Effect: Misalignment leading to higher vibration and complete coupling failure leading to secondary damage.

Detection: Presence of frequency at characteristic fault frequencies related to bearing components with sidebands. Sidebands are frequencies which would be present around the characteristic fault frequencies.

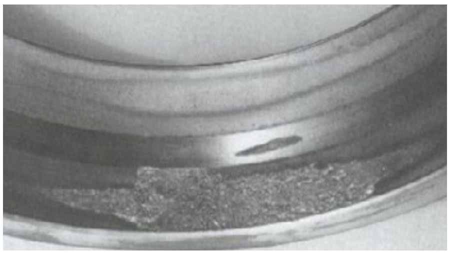


Figure 14: Outer race wear

4.7 GEAR FAULT

Definition: Defects on the gear teeth. Defects include cracks, pitting, missing teeth.

Cause: Degraded lubricant, external environment, fatigue, damaged bearing.

Effect: Misalignment leading to higher vibration, torque imbalance.

Detection: Increase in 2xGMF at initial state followed by harmonics.

Note: GMF = gear meshing frequency, i.e., frequency at which gear teeth roll. (GMF= number of teeth x rotating shaft speed).

Figure 15: Gear defects [Ref: 9.f]

4.8 BLADED MACHINES FAULTS

Definition: Defect in blades or vanes found in fans, pumps, compressors and turbines. Defects include cracks, pitting, missing parts.

Cause: Cavitation, fatigue.

Effect: Catastrophic (sometimes) and can lead to secondary damage on other connected components.

Detection: Increase in amplitude at blade pass frequency (number of blades x rotating shaft speed).

Figure 16: Centrifugal pump blade erosion [Ref: 9.g]

4.9 STATOR FAULTS

Definition: Shorting of turns in winding; crack in stator core.

Cause: Insulation degradation (higher temperature, moisture, fatigue).

Effect: Complete shorting of motor phase; earth fault.

Detection: Stator fault in induction motors will show at pole passing frequency.

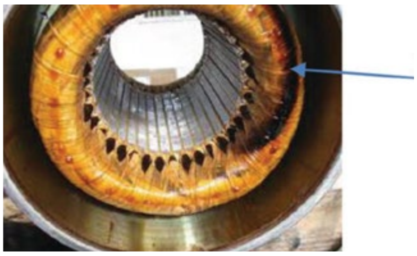


Figure 17: Stator winding shorted [Ref: 9.h]

4.10 BROKEN ROTOR BARS

Definition: Cracks or missing bar in rotor of motor.

Cause: Manufacturing defect, fatigue, high temperature usage.

Effect: Broken bars cause torque and speed oscillations in the rotor, provoking premature wear of bearings and other driven components.

Detection: 1x harmonic running speed with rotor fault frequency sideband (rotor fault frequency/slip frequency * number of poles).

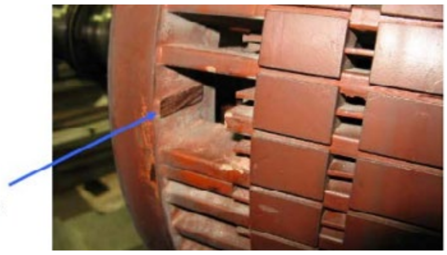


Figure 18: Missing rotor bar [Ref: 9.i]

4.11 ECCENTRICITY

Definition: Offset between the axis of rotation and the axis of symmetry. Eccentricity can take place in different types of mechanical elements, such as pulleys, gears and in any relative positioning between two concentric pieces -- for example, the rotor and stator of an electric motor.

Cause: Uneven surface wear or manufacturing issue or assembly issue.

Effect: Torque unbalance.

Detection: Frequency of elements involved (e.g., speed of motor and pulley).

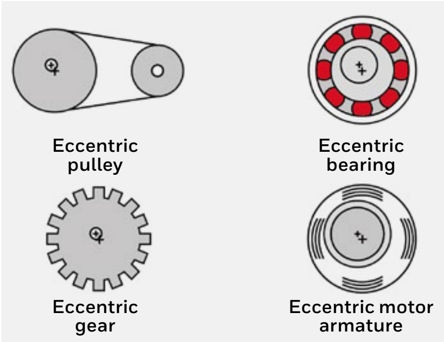


Figure 19: Eccentricity [Ref: 9.j]

4.12 CRACKED SHAFT

Definition: Surface of shaft has transverse crack which can open and close during the operation.

Cause: Manufacturing defect, wear due to environment (inside and outside).

Effect: Can be catastrophic.

Detection: Open crack at a 1× RPM, 2× RPM. Breathing crack at 1× RPM, 2× RPM and 3xRPM (higher).

Figure 20: Cracked shaft due to corrosion [Ref: 9.k]

STANDARDS USED IN VIBRATION-BASED CONDITION MONITORING

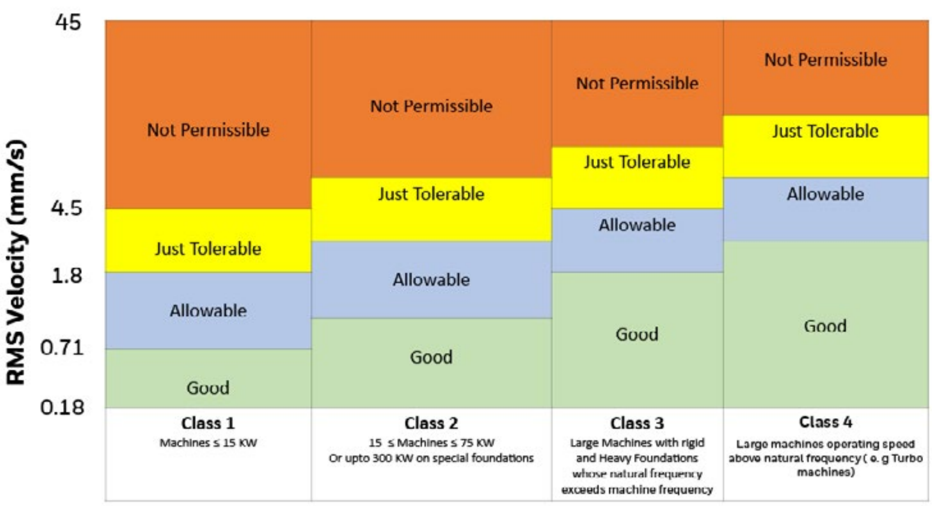
5

FOR PROXIMITY PROBES: API 670

MACHINE	ACCELERATION		VELOCITY	
	Frequency (Hz)	Amplitude (g pk)	Frequency (Hz)	Amplitude (ips rms)
Gearbox	1-10k	0-50	10-1k	0-1
Pumps, Fans, Motors with Shaft Speed less than 750 rpm	5-1k	0-10	5-1k	0-1
Pumps, Fans, Motors with Shaft Speed greater than 750 rpm	10-5k	0-10	10-1k	0-1

Table 7: Proximity probes

FOR VELOCITY SENSOR: VDI 2056 AND ISO 2372



For accelerometer: ISO 10816/ISO 20816 (under development)

ISO 10816-1 is a document that sets out guidelines for the measurement and evaluation of mechanical vibration of machines, as measured on non-rotating parts.

Class I machines may be separate driver and driven, or coupled with units comprising operating machinery up to approximately 15kW (approx 20hp).
Class I machinery - electrical motors 15kW (20hp) to 75kW (100hp), without special foundation, or Rigdly mounted engines or machines up to 300kW (400hp) mounted on special foundations.
Class III machines are large prime movers and other large machinery with large rotating assemblies mounted on rigid and heavy foundation which are reasonably stiff in the direction of vibration.
Class IV includes large prime movers and other large machinery wuth large rotation assemblies mounted on foundations which are relatively soft in the direction of the measured vibration (i.e., turbine generators and gas turbines grater than 100MW (approx 13500hp) output.

VELOCITY SEVERITY		VELOCITY RANGE LIMITS AND MACHINE CLASSES			
				Large Machines	
mm/s RMS	in/s Peak	Small Machines Class I	Medium Machines Class II	Rigid Supports Class III	Less Rigid Supports Class IV
0.28	0.02				
0.45	0.03				
0.71	0.04				
1.12	0.06				
1.80	0.10				
2.80	0.16				
4.50	0.25				
7.10	0.40				
11.20	0.62				
18.00	1.00				
28.00	1.56				
45.00	2.51				

Good

Satisfactory

Unsatisfactory (alert)

Unacceptable (danger)

The ISO 10816-3 standard provides criteria for evaluating the vibration of machinery according to measurements taken on non-rotating parts, such as bearings, bearing pedestals or housings.

ISO 10816-3 applies to machine sets which have a power above 15 kW and operating speeds between 120 and 15,000 RPM [Ref 9.l].

ISO 10816-3		GROUP 1		GROUP 2	
		Large machines 300 kW < power < 50 MW		**Medium machines** 15 kW < power < 300 kW	
in/sec peak	mm/sec rms	**Motor** height > 315 mm		**Motor** 160 mm < height < 315 mm	
0.61	11.0		**Damage occurs**		
0.39	7.1				
0.25	4.5		**Restricted operation**		
0.19	3.5				
0.16	2.8		**Unrestricted operation**		
0.13	2.3				
0.08	1.4				
0.04	0.7		**Newly commissioned machinery**		
0.00	0.0				
Foundation		Rigid	Flexible	Rigid	Flexible

MOUNTING LOCATION AND ITS EFFECTS

6

Mounting is a very important aspect of the vibration measured from a sensor. When the sensor is attached to the machine, the vibration from inside the machine causes the sensor to vibrate, which is picked up by the electronics inside.

If the sensor is not mounted correctly, the sensor will vibrate in a way unrelated to the machine, and the vibration data will be useless. Thus, the job of the person responsible for data collection is critical.

The method of securing the sensor in the machine directly determines the high frequency cutoff (Table 6), since the sensor machine contact acts as a mechanical low pass filter. High frequencies are very low in amplitude (and energy) and are the first type of content to be affected by the mounting method, as there may be loss of energy during transmission to the vibration sensor.

There are several mounting methods used today (Figure 21). Each has pros and cons, so one needs to make sure that the mounting technique used is in line with the requirement.

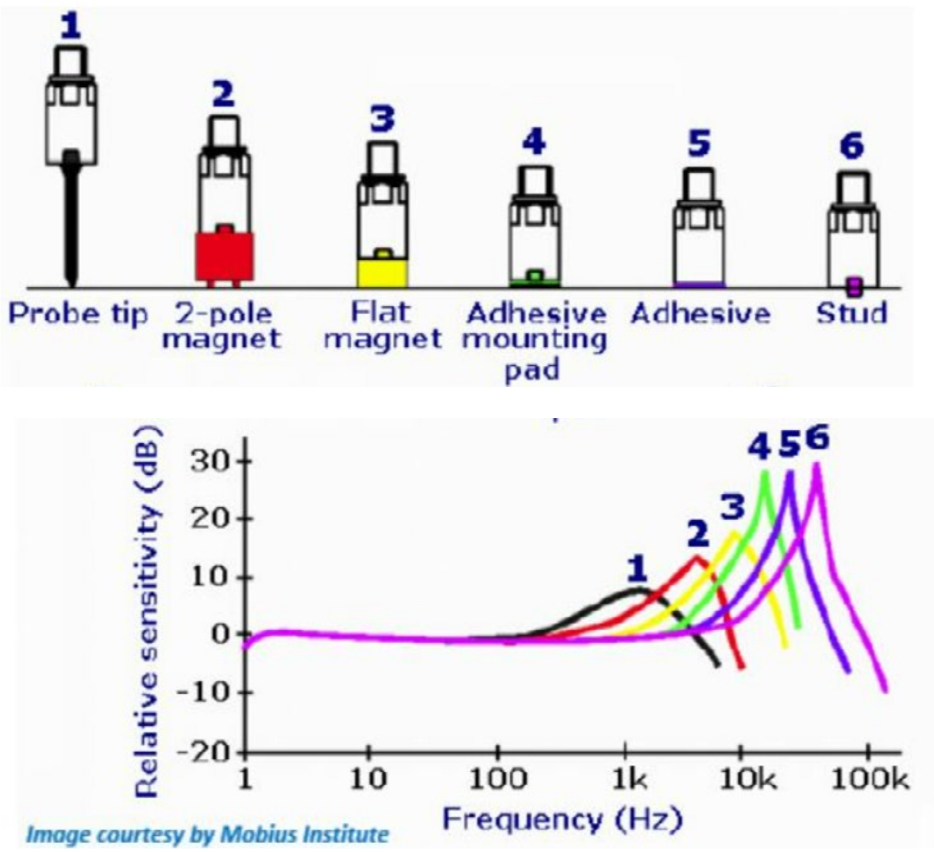


Figure 21: Methods to mount a vibration sensor and its frequency spectrum

MOUNTING METHODS	HIGHEST FREQUENCY
Handheld	2000 Hz
Magnet mounting	5000 Hz
Adhesive mounting	6000 Hz
Screw mounting	7000 Hz

Table 8: Mounting method typical frequency limits

The best mounting method is, of course, by screwing the sensor to the surface of the machine at the measurement location. However, due to the cost, this method is only used in permanent monitoring systems. In order to capture signals at very high frequency (from 6 to 15 kHz), the use of silicon-based greases and adhesives is recommended.

At the end of the day, it is often a compromise between how early you want to detect problems - depending on the machine's use and failure modes - and the solution's "user-friendliness".

DO'S

- The piezoelectric vibration sensor must be as close as possible to the machine's surface. Direct stud mounting or epoxy and cementing pads are most commonly used when screw is not possible.
- The sensor should be mounted in a location as close to the bearings as possible.
- To avoid unintended conduction, ensure all contaminants are removed from isolation material. Isolator mounting bases protect against high voltage, static electricity build-up, ESD shocks and grounding issues such as poor ground bonding, ground loops or different ground potentials.
- 2-pole magnets provide the best connection on curved surfaces.
- Flat magnets are ideal for flat surfaces.
- For accurate trending, mark measurement locations to ensure readings are taken in the same place every time.
- For measurements above 1,000Hz (60,000 cpm), the spot-faced surface should be flat within 1 mil and have a surface texture no greater than 32 microinches.

DON'TS

- Avoid mounting the sensor on thin sections, guards, cantilevers or vibration-free areas (antinodes), or areas with extreme temperature variations.
- Avoid getting debris between the sensor and the surface as this can dramatically reduce the upper frequency response limit.

PROCESSING OF VIBRATION DATA

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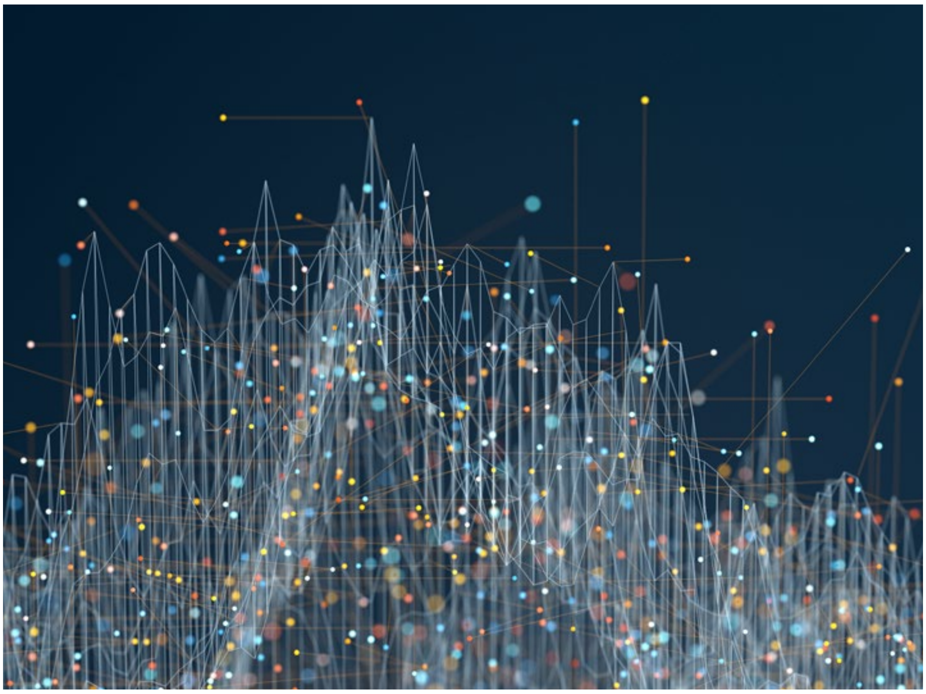
There are multiple ways of processing vibration data. Here are some simple methods:



Time domain: Statistical parameters: root mean square, peak to peak, kurtosis, crest factor.

Frequency domain: Frequency spectrum with trending of amplitude of fault frequencies associated with each fault.

DEFINITIONS

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Absolute vibration: Absolute vibration refers to the vibration of the rotor relative to the ground such as bearing housing vibration. It is measured using a velocity seismic sensor or accelerometers.

Relative vibration: Relative vibration refers to the vibration of the rotor relative to bearing seat. It is measured using proximity probes.

Torsional vibration: Torsional vibration is the twisting of a shaft around its axis due to varying torque. It can be represented as a fluctuation in the rotational velocity of a rotating components. Torsional vibration can be measured using a torsiograph, encoder, or laser vibrometer.

Characteristic fault frequencies and sidebands: Characteristic fault frequencies is used in reference to bearing fault. Faults in each location of bearing such outer race, inner race, cage, and balls can generate vibration at a certain frequency.

$$\text{Inner race fault frequency, } f_i = \frac{Zf_r}{2}\left(1 + \frac{d}{D}\cos\alpha\right)$$

$$\text{Outer race fault frequency, } f_o = \frac{Zf_r}{2}\left(1 - \frac{d}{D}\cos\alpha\right)$$

$$\text{Rolling element fault frequency, } f_b = \frac{Df_r}{2d}\left(1 - \frac{d^2}{D^2}\cos\alpha\right)$$

$$\text{Cage fault frequency, } f_c = \frac{f_r}{2}\left(1 - \frac{d}{D}\cos\alpha\right)$$

Z = number of rolling elements, d = rolling element diameter, D = bearing pitch diameter, α = contact angle, and fr = shaft speed.

Sidebands are frequencies which would be present around the characteristic fault frequencies. An example is shown below.

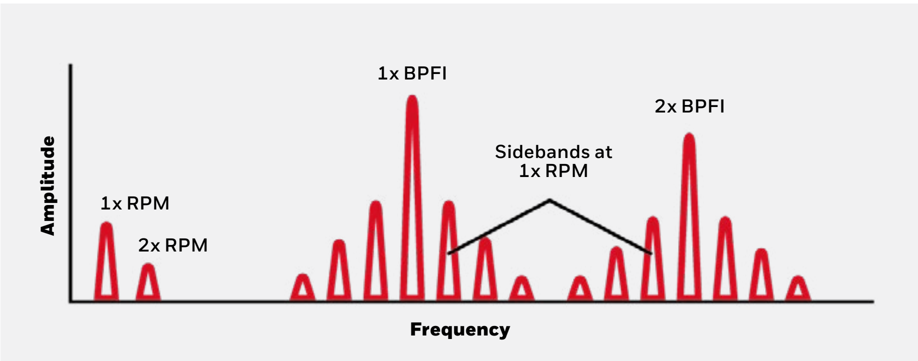

Figure 22: Sideband frequency

SLIP FREQUENCY: Slip frequency of a motor is the difference between synchronous speed (speed at rated frequency) and actual motor speed. (For 4 pole, 50 Hz motor, synchronous speed is 1500 rpm).

POLE PASSING FREQUENCY: Pole passing frequency is the product of slip frequency and the number of poles of a motor.

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For more information

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WPR | 441DS | November 2022
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