UNIT-3
Vibration

periodic back-and-forth motion of the particles of an elastic body or medium, commonly resulting when almost any physical system is displaced from its equilibrium condition and allowed to respond to the forces that tend to restore equilibrium.
Vibrations fall into two categories: free and forced
. **Free vibrations** occur when the system is disturbed momentarily and then allowed to move without restraint. A classic example is provided by a weight suspended from a spring. In equilibrium, the system has minimum energy and the weight is at rest. If the weight is pulled down and released, the system will respond by vibrating vertically. The vibrations of a spring are of a particularly simple kind known as simple harmonic motion (SHM). This occurs whenever the disturbance to the system is countered by a restoring force that is exactly proportional to the degree of disturbance. In this case, the restoring force is the tension or compression in the spring, which (according to Hooke’s law) is proportional to the displacement of the spring. In simple harmonic motion, the periodic oscillations are of the mathematical form called sinusoidal.

Most systems that suffer small disturbances counter them by exerting some form of restoring force. It is frequently a good approximation to suppose that the force is proportional to the disturbance, so that SHM is, in the limiting case of small disturbances, a generic feature of vibrating systems. One characteristic of SHM is that the period of the vibration is independent of its amplitude. Such systems therefore are used in regulating clocks. The oscillation of a pendulum, for instance, approximates SHM if the amplitude is small.
A universal feature of free vibration is damping. All systems are subject to frictional forces, and these steadily sap the energy of the vibrations, causing the amplitude to diminish, usually exponentially. The motion is therefore never precisely sinusoidal. Thus, a swinging pendulum, left undriven, will eventually return to rest at the equilibrium (minimum-energy) position.
Forced vibrations occur if a system is continuously driven by an external agency. A simple example is a child’s swing that is pushed on each downswing. Of special interest are systems undergoing SHM and driven by sinusoidal forcing. This leads to the important phenomenon of **resonance**. Resonance occurs when the driving frequency approaches the natural frequency of free vibrations. The result is a rapid take-up of energy by the vibrating system, with an attendant growth of the vibration amplitude. Ultimately, the growth in amplitude is limited by the presence of damping, but the response can, in practice, be very great. It is said that soldiers marching across a bridge can set up resonant vibrations sufficient to destroy the structure. Similar folklore exists about opera singers shattering wine glasses.

Electric vibrations play an important role in electronics. A circuit containing both inductance and capacitance can support the electrical equivalent of SHM involving sinusoidal current flow. Resonance occurs if the circuit is driven by alternating current that is matched in frequency to that of the free oscillations of the circuit. This is the principle behind tuning. For example, a radio receiver contains a circuit, the natural frequency of which can be varied. When the frequency matches that of the radio transmitter, resonance occurs and a large alternating current of that frequency develops in the circuit. In this way, resonating circuits can be used to filter out one frequency from a mixture.

In musical instruments, the motion of strings, membranes, and air columns consists of a superposition of SHM's; in engineering structures, vibrations are a common, though usually undesirable, feature. In many cases, complicated periodic motions can be understood as the superposition of SHM at many different frequencies.

Types of vibrations

Free vibration occurs when a mechanical system is set in motion with an initial input and allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and letting it go, or hitting a tuning fork and letting it ring. The mechanical system vibrates at one or more of its natural frequencies and damps down to motionlessness.

Forced vibration is when a time-varying disturbance (load, displacement or velocity) is applied to a mechanical system. The disturbance can be a periodic and steady-state input, a transient input, or a random input. The periodic input can be a harmonic or a non-harmonic disturbance. Examples of these types of vibration include a washing machine shaking due to an imbalance, transportation vibration caused by an engine or uneven road, or the vibration of a building during an earthquake. For linear systems, the frequency of the steady-state vibration response resulting from the application of a periodic, harmonic input is equal to the frequency of the applied force or motion, with the response magnitude being dependent on the actual mechanical system.

Damped vibration: When the energy of a vibrating system is gradually dissipated by friction and other resistances, the vibrations are said to be damped. The vibrations gradually reduce or change in frequency or intensity or cease and the system rests in its equilibrium position. An example of this type of vibration is the vehicular suspension dampened by the shock absorber.

Vibration testing

Spring-Mass Systems

1. All systems possessing mass and elasticity are capable of free vibration, or vibration that takes place in the absence of external excitation. Of primary interest for such a system is its natural frequency of vibration.
2. The basic vibration model of a simple oscillatory system consists of a mass, a massless spring, and a damper.

3. If damping in moderate amounts has little influence on the natural frequency, it may be neglected. The system can then be considered to be conservative.

An undamped spring-mass system is the simplest free vibration system. It has

one DOF.

Equation of Motion

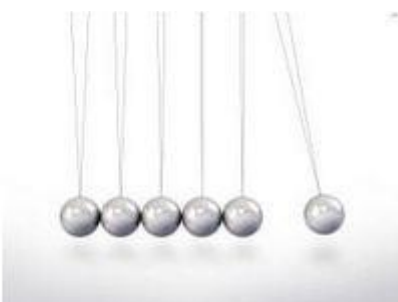
(Natural frequency) $v = \frac{w}{2\pi}$

Where w is the frequency given by w=√(k/m)

Here, k is the spring constant and m is the mass of the object attached to spring

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 vibrate: we can touch a 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.



But, what is vibration? In simplest terms, vibration in motorized equipment's is merely the back and forth movement or oscillation of machines and components, such as drive motors, driven devices (pumps, compressors and so on) and the bearings, shafts, gears, belts and other elements that make up mechanical systems. The unexpected breakdown of rotating machinery is the single largest cause of emergency downtime in industries.

A broad range of complex vibration problems can occur on industrial machines. These include roller-bearing wear-out, problems with roll drive systems, and structural issues (including resonance). Successful analysis and resolution of machine vibration problems requires a thorough understanding of the equipment, and the ability to apply various diagnostic and damping techniques.

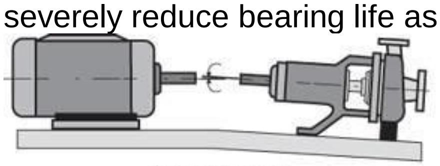
Causes of machine vibration
Vibration can result from a number of conditions, acting alone or in combination. Keep in mind that vibration problems might be caused by auxiliary equipment, not just the primary equipment.

Misalignment/shaft run-out — Vibration can result when machine shafts are out of line. Angular misalignment occurs when the axes of (for example) a motor and pump are not parallel. When the axes are parallel but not exactly aligned, the condition is known as parallel misalignment. Misalignment can be caused during assembly or develop over time, due to thermal expansion, components shifting or improper reassembly after maintenance. The resulting vibration can be radial or axial (in line with the axis of the machine) or both.

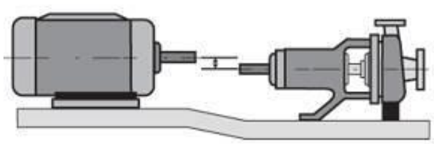
Wear—As components such as ball or roller bearings, drive belts or gears become worn, they might cause vibration. When a roller bearing race becomes pitted, for instance, the bearing rollers will cause a vibration each time they travel over the damaged area. A gear tooth that is heavily chipped or worn, or a drive belt that is breaking down, can also produce vibration.

Looseness—Vibration that might otherwise go unnoticed can become obvious and destructive if the component that is vibrating has loose bearings or is loosely attached to its mounts. Such looseness might or might not be caused by the underlying vibration. Whatever its cause, looseness can allow any vibration present to cause damage, such as further bearing wear, wear and fatigue in equipment mounts and other components.

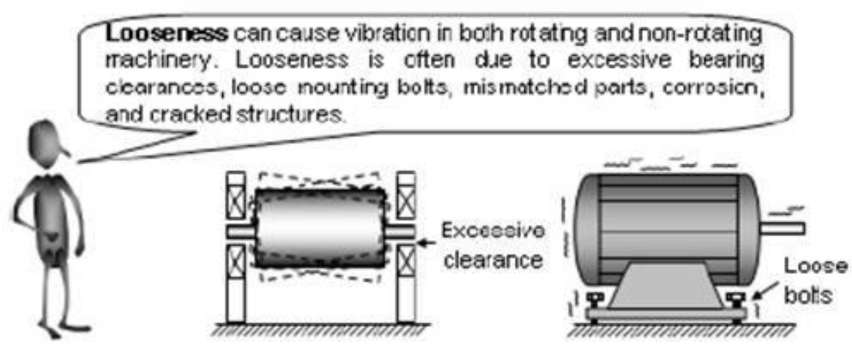
Imbalance — A 'heavy spot' in a rotating component will cause vibration when the unbalanced weight rotates around the machine's axis, creating a centrifugal force. Imbalance could be caused by manufacturing defects (machining errors, casting flaws) or maintenance issues (deformed or dirty fan blades, missing balance weights). As machine speed increases the effects of imbalance become greater. Imbalance can severely reduce bearing life as well as cause undue machine vibration.



Angular Misalignment



Parallel Offset Misalignment



Effects of vibration

The effects of vibration can be severe. Unchecked machine vibration can :

4. Accelerate rates of wear (i.e. reduce bearing life) and damage equipment.
5. Vibrating machinery can create noise, cause safety problems and lead to degradation in plant working conditions.
6. Vibration can cause machinery to consume excessive power and may damage product quality.
7. Vibration can damage equipment so severely as to knock it out of service and halt plant production.

Some important questions:

Q.1. Define vibration. What are its different types? Explain.

Answer.

Vibration

when a particle goes on one side from mean position and returns back and then it goes to other side and again returns back, then it is known as one vibration. In other words, to and fro motion of a particle about a fixed point is known as vibration.

Types of Vibrations

There are three important types of vibrations from subject point of view:

1. Free or natural vibrations,
2. Damped vibrations,
3. Force vibrations.

1. **Free or natural vibrations :** If the vibrations of a particle after giving it an initial displacement remain continued, then the vibrations are called free or natural vibrations.

No external force acts on the particle. In other words, the vibrations of the particle with fundamental frequency under the influence of the restoring force are called free vibrations.

2. **Damped vibrations :** The vibrations of a body whose amplitude goes on reducing over every cycle of vibrations are known as damped vibrations. This is due to the fact that a certain amount of energy possessed by the vibrating body is always dissipated in overcoming frictional resistance to the motion.In these vibrations, the amplitude of the vibrations decreases exponentially due to damping forces like frictional force, viscous force, hysteresis etc.
3. **Forced Vibrations :** When the body vibrates under the influence of external periodic force, the n the vibrations are known as forced vibrations.The body does not vibrate with its natural frequency, but it vibrates with the frequency of the driver. The amplitude of the vibrations decreases due to damping forces, but on account of energy gained from the external source, it remains constant. In these vibrations, the amplitude and energy remains constant with respect to the time.

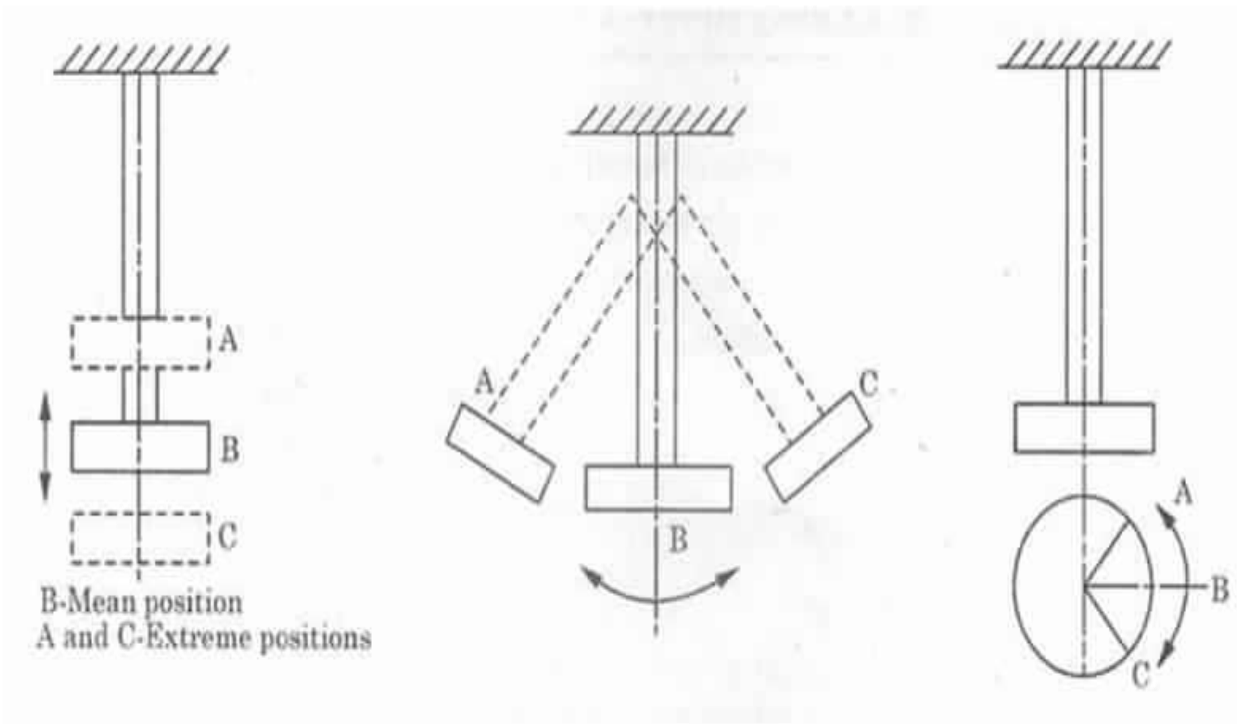
Q. 2. Explain different types of free vibrations.

Answer.

There are three types of free vibrations:

1. **Longitudinal vibrations,**
2. **Transverse vibrations,**
3. **Torsional vibrations.**

Let us consider a weightless bar of length l whose one end is fixed and other end carries a disc as shown in fig. The system may have one of the above mentioned three types of free vibrations.



(a) Longitudinal Vibrations **(b) Transverse Vibrations** **(c) Torsional Vibrations**

Fig. Types of Free Vibrations

1. **Longitudinal vibrations :** When the particles of a bar or disc move parallel to the axis of the shaft, then the vibrations are known as longitudinal vibrations as shown in fig. (a). The bar is elongated and shortened alternately and thus the tensile and compressive stresses are inducted in the bar. The motion of spring mass system is longitudinal vibrations.
2. **Transverse Vibrations :** When the particles of the bar or disc move approximately perpendicular to the axis of the bar, then the vibrations are known as transverse vibrations as shown in fig.(b). In this case, bar is straight and bent alternately. Bending stresses are induced in the bar.
3. **Torsional Vibrations :** When the particles of the bar or disc get alternately twisted and untwisted on account of vibratory motion of suspended body, it is said to be undergoing torsional vibrations as shown in fig. (c). In this case, torsional shear stresses are induced in the bar.

Q3. Define time period related to vibratory motion.

Answer.

The time interval after which the motion is repeated itself is called time period. It is usually expressed in seconds.

Q.4. Define time cycle related to vibratory motion.

Answer.

The motion completed during one time period is called cycle.

Q.5. frequency related to vibratory motion.

Answer. The number of cycles executed in one second is called frequency. It is usually expressed in hertz (Hz).

$1 \text{ Hz} = 1 \text{ cycle/s}$

Q.6. Define Resonance

Answer.

Resonance is the tendency pf a system to oscillate amplitude at a certain frequency. Thus frequency is known as the system's natural frequency of vibrations, resonant frequency, or Eigen frequency

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Q.6. What are the causes, harmful effects and remedial measures of vibrations?

Answer.

Causes of Vibrations in machines

For minimizing the undesired vibrations of machines, it is utmost important to find the causes of vibrations in them. The major cause of vibration in machines is unbalancing. So it can also be said that vibrations are the symptoms of unbalance. The basic cause is the non symmetrical mass distribution in various machine components. The various causes of vibrations are listed as below:

8. Lack of Compact Soil : If the soil under the foundation of machine is not compact or has settled down being wet or loose, then it may lead to misalignment of the machine which will result in development of vibrations.
9. Unbalance Parts : The machine consists of a number of rotating and reciprocating parts having motion in different planes. If these are not dynamically balanced, the unbalanced parts may produce unbalanced forces, which may give rise to unbalanced couples resulting in development of vibrations in machines.
10. Loose Fittings : If the machine components are not properly fitted i.e. nuts, bolts and screws including foundation bolts are not properly tightened or they get loosened during operations, then these may lead to development of vibrations in the machines.
11. Disturbance due to Vibration Waves : If the heavy machines such as pneumatic hammer, presses,etc. are installed in the near by space, then they produce sound waves due to

their working which in turn impinge on the adjoining machines resulting in vibrations in them. A train passing through a plant where a precision machining is being done, may result in vibrations in the machines which may lead to manufacturing defects.

12. Effect of Temperature : The temperature may cause changes in structure which increases in vibrations, by bringing critical speed closer to operating speed. Thus a machine which is smooth in cold may be rough when it is hot due to vibrations.
13. Hydraulic Vibrations : These may occur from cavitation in pumps. These may be excited by fluid flows and other condition also.
14. Manufacturing Defects : The manufacturing defects such as non-symmetry in cast parts, non homogeneity of materials, poor distribution of mass in a completely machined component, variation in mass distribution etc. the causes which will lead to vibrations.
15. Lack of Isolation : If the vibrations produced in a machine are not isolated by means of rubber pads or other isolating materials. Between machine and foundation, the vibrations may be transmitted to the adjoining machines also.
16. Incorrect Alignment : In a machine, there are many parts fastened together for transmission of power. If the driving and the driven parts are not properly aligned or there is no proper alignment between foundation and the machine, the vibrations may set up in the machine.

Harmful Effects : As discussed earlier in the article that if the vibrations are allowed to exist in the machine parts, the machine produces unwanted noise, high stresses, wear and premature failure of parts. This will not only reduce the efficiency of machines, but also shorten their life. The vibrations are also a great source of human discomfort in the form of physical and mental strain. This adversely effects the working efficiency of the workers.

Remedies

Vibrations can be controlled by

4. Removing or controlling or balancing the disturbing forces.
5. Changing the natural frequency so that it is far away from the operating frequency of machines so as to avoid resonance.