Module 6 : Vibration of Mechanical Systems; Types of Vibration; Lumped Parameter Models; Linearization of System

Elements; Degrees of Freedom; Types of Restoration and Dissipation Mechanisms; Types of Excitation

Lecture 9 : Overview of Mechanical Vibrations.

Objectives

In this module, you will learn the following

- Examples of Vibrations
- Types of Vibration
  - Free and Forced Vibrations
  - Linear and Non-linear Vibrations
  - Deterministic and Random Vibrations

Most machinery are subject to time varying forces which cause time dependent motions of the system. For example any mechanism such as used in a shaper machine, lathe, grinder etc involves moving masses that accelerate and decelerate in addition to time dependent cutting forces. A building or a nuclear reactor structure subjected to an earthquake undergoes time dependent deformations and stresses. A crankshaft of a multi-cylinder IC engines used in most cars is continuously subjected to time dependent torques. On the other hand, an aircraft at the time of landing is subject to tremendous impact forces that act for an extremely short duration of time. An automobile is subjected to crushing forces over a few milli-seconds whenever an accident takes place.

Acceleration and deceleration of masses causes inertia forces as we have discussed at length when we looked at the problem of balancing. If we are dealing with only rigid bodies, it is essentially a problem of balancing alone i.e., we aim to minimize unbalanced forces. However most systems are not rigid – for example, for all practical purposes, a building appears quite sturdy and rigid but when an earthquake hits, the whole building shakes as a deformable body and may actually break down. On the other hand automobiles have specially-built-in springy elements in the form of suspension/shock absorbers and when negotiating rough roads, the automobile undergoes vibratory oscillations. While the suspension spring is an example of a concentrated dose of springiness in a system lumped at one place in one device, springiness (elastic or plastic) is actually present throughout the body of the vehicle. This becomes apparent when a car hits an obstacle and the body of the vehicle gets dented (plastically deformed).

Whenever a deformable body is subjected to time dependent forces, it undergoes oscillatory motion as follows. Since it is deformable, it undergoes deformation under the load. In the process, the mass of the body has been accelerated and work has been done against the springiness of the body, leading to restoring forces. Thus, under the action of the external disturbances, inertia and restoring internal forces the body continues to move to and fro. Such a motion is called vibration . In the next few modules we will focus on such vibratory motion of typical mechanical systems.

By and large vibration is considered undesirable. A machine component subjected to vibration of sufficiently high magnitude could eventually fail in fatigue. A passenger in a car may feel extremely uncomfortable, when riding over rough roads. An instrument mounted for example, on the surface of an aircraft, may give erroneous results due to vibrations. Thus our aim, in many instances, is to minimize the vibrations. However there are situations such as vibratory bowl feeder in a material handling system in a factory actually works on utilizing vibrations.

We will begin our discussion with an aim to understand the nature and type of vibrations so that you gain a broader perspective of the subject matter. However within the scope of this course we will not be able to discuss the entire range of vibration problems. We will focus our attention, in subsequent modules, on simple harmonic vibrations of linear systems.

We will first need to distinguish between two types of vibration – viz., free vibration and forced vibration .

When a system is subjected to an initial disturbance and then left free to vibrate on its own, the resulting vibrations are referred to as free vibrations .

When a system is subjected continuously to time varying disturbances, the vibrations resulting under the presence of the external disturbance are referred to as forced vibrations .

When a vehicle moves on a rough road, it is continuously subjected to road undulations causing the system to vibrate (pitch, bounce, roll etc). Thus the automobile is said to undergo forced vibrations. Similarly whenever the engine is turned on, there is a resultant residual unbalance force that is transmitted to the chassis of the vehicle through the engine mounts, causing again forced vibrations of the vehicle on its chassis. A building when subjected to time varying ground motion (earthquake) or wind loads, undergoes forced vibrations. Thus most of the practical examples of vibrations are indeed forced vibrations.

Free vibrations arise once the external excitation dies down. Free vibrations are thus the transient vibrations after the external disturbance is removed but before the system comes to a halt. In the laboratory, many a time, free vibrations are intentionally introduced in the system (for example, by using an impact hammer) to study the inherent dynamics of the system. Free or natural vibration behaviour of the system enables us to gain significant insight into the system behaviour. We will learn about the system natural frequencies and corresponding mode shapes. From the transient response, we will actually be able to measure the system damping. Knowledge of these actually helps us to predict how the system will respond to an external disturbance. Thus it is equally important to study free or natural vibrations.

We can also distinguish between vibrating systems based on the nature of their response to external excitation. Some systems are called Linear systems and hence their vibrations are referred to as Linear vibrations. Some other systems, on the other hand, are known as non-linear systems and their vibrations are therefore referred to as non-linear vibrations.

Linear systems exhibit a linear relationship between the magnitude of excitation force and the response. Thus if the excitation force amplitude (at a given frequency) doubles, we expect the system response also to double. Care must be taken at this stage NOT to confuse this with variation in system response for varying excitation frequency . Even when the amplitude of the force remains constant, as the frequency varies the system response will vary and at certain frequencies, the response may become very large (called resonant frequencies). Even near a resonant frequency, for a linear system, when the force amplitude becomes double or triple, the response will become double or triple respectively.

Non-linearities in most systems can be approximated by equivalent linear systems. For example, nonlinearity in a simple pendulum is approximated by a linear system by considering only small oscillations (i.e., $\sin\theta \approx \tan\theta \approx \theta, \text{ for small } \theta$). Linear systems are described mathematically by linear differential equations, which can be more easily solved than non-linear differential equations. Thus, in engineering, we try and simplify. However when the non-linear behaviour of a spring in an automobile suspension needs to be modeled accurately, we need to include its full non-linear force-deflection relationship rather than approximating by a straight linear relationship. Machine tool chatter, flutter of airfoils, wheel shimmy, vibrations with Coulombic friction are instances of non-linear vibrations

We now come to a third way of classifying vibrations namely, deterministic and random vibrations.

When the rotor of a fan or compressor/turbine has an unbalance, as the system rotates there will be a net dynamic force on the system but the amplitude and time variation of this excitation is essentially precisely known. For example, we know that the unbalance excitation will be at the running speed of the system. Thus, in general, when the external disturbance varies with time in a known manner and its amplitude/time variation can be estimated accurately at each instant, it is said to be a case of deterministic vibrations .

On the other hand, road excitation to a car due to road roughness can not be precisely known and leads to what are known as random vibrations . Even though random, these are not arbitrary – in the sense that we can use certain average properties of the excitation. Supposing we look at a few meters of the road at one place and determine the average roughness parameters of the profile. A few kilometers further down the road, we expect the average roughness parameters, again measured over a few meters of the road, would be essentially the same. We can use such “statistical regularity” and study the resulting random vibrations. Random vibrations occur in most natural phenomena such as vibrations due to earthquakes, gusty winds etc. Thus, while the theory of random vibrations is mathematically involved, its applications are many.

Recap

In this module you have learnt the following

- Examples and importance of vibrations
- Different types of vibrations with examples such as free/forced; linear/non-linear; deterministic/random.