Module 12 : Instruments for Dynamic Measurements

Lecture 36 : Vibration Measurements

Objectives

In this lecture you will learn the following

- Review of response of systems with Base Excitation
- Working principle of seismograph and accelerometers
- Selection and use of accelerometers
- Time vs Frequency Domain
- Fiber-optic and Laser based non-contact vibration instruments

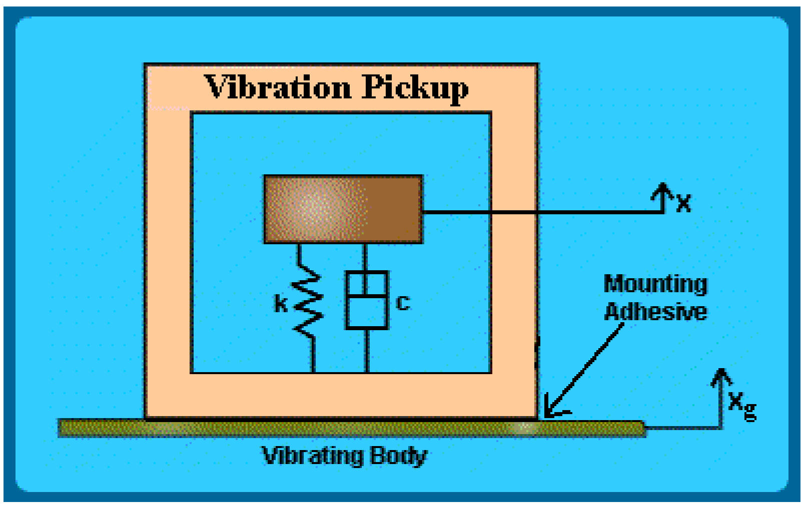

Fig 12.1.1Contact Type Vibration Instrument

A 'contact' type vibration measuring instrument is typically mounted on the system whose vibration is to be measured (as shown in Fig. 12.1.1) and thus the vibrating structure transmits the excitation to the base of the instrument. In order to understand the operating principle of vibration instruments therefore we will first review the analysis of systems subjected to base excitation.

It must be clear that any contact-type instrument acting as a point mass, implicitly affects the vibration of the system onto which it is mounted. Thus non-contact type instruments are also of significant interest to the vibration analyst. These are typically optics based instruments such as a fiber optic probe or a laser Doppler vibrometer etc. We will discuss these later on.

Review of systems with base excitation

The physical system under consideration and the corresponding free body diagram are given in Fig. 12.1.2.

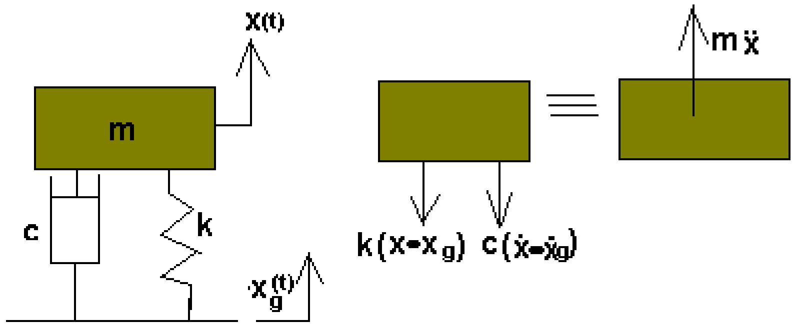

Fig 12.1.2 Free Body diagram of Physical system

Any measuring instrument on a shaking ground can measure only the relative motion of the mass with respect to the ground. If we introduce z = x – xg as the relative motion coordinate, the governing equation in terms of z can be given as:

$$m\ddot{z} + c\dot{z} + kz = -m\ddot{x}_g \qquad 12.1.1$$

We have derived an expression for the steady state response of the mass when xg = Xg sin(Ω t) as:

$$Z_0 = \frac{\left(\frac{\Omega}{\omega_n}\right)^2 X_g}{\sqrt{\left[1-\left(\frac{\Omega}{\omega_n}\right)^2\right]^2 + \left(2\xi\frac{\Omega}{\omega_n}\right)^2}} \qquad 12.1.2$$

Variation of z (i.e. motion of the mass relative to the base) with respect to the forcing frequency is plotted in Fig. 12.1.3. It is observed that at lower frequencies the relative motion of the mass tends to zero while at high frequencies the magnification factor tends to unity.

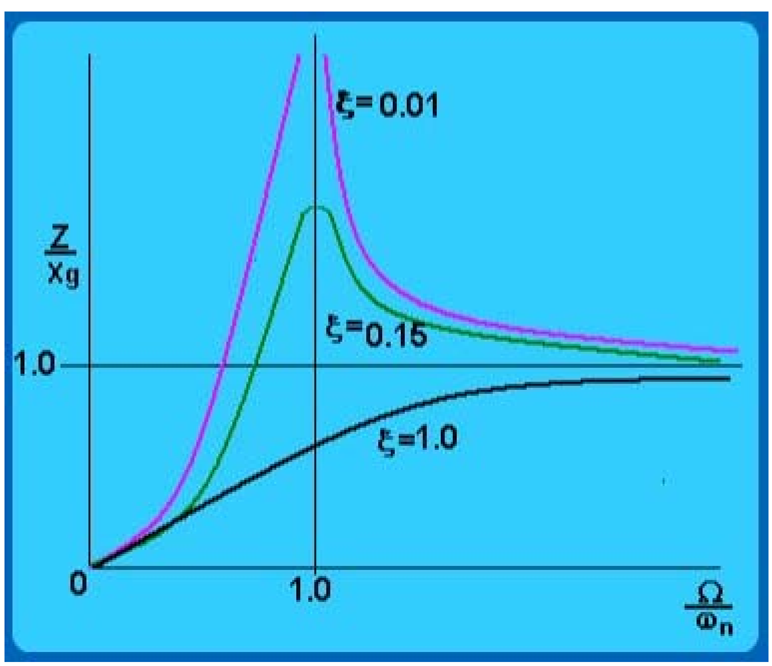

Fig 12.1.3

Acceleration Measurement (Accelerometer)

When the spring-mass of the instrument are so designed that its natural frequency is very large compared to the frequency of vibration of the base i.e. $\omega_n >>> \Omega$, then Ω / ω_n tends to 0 and we can write:

tends to approach unity

$$\sqrt{\left[1-\left(\frac{\Omega}{\omega_n}\right)^2\right]^2+\left(2\xi\frac{\Omega}{\omega_n}\right)^2}$$

hence we get

$$Z_0=\left(\frac{\Omega}{\omega_n}\right)^2 X_g \qquad 12.1.3$$

$\Omega^2 X_g$ represents the acceleration of the vibrating body. It is observed that the read-out by the instrument are this case (Zo) will be proportional to the acceleration of the base and thus this instrument will be useful for acceleration measurement.

Displacement Measurement (Seismograph)

When the spring-mass of the instrument is so designed that its natural frequency is very small compared to the frequency of vibration of the base, i.e. $\omega_n <<< \Omega$, $\frac{\Omega}{\omega_n}$ approaches high values.

$$Z_0=\frac{\left(\frac{\Omega}{\omega_n}\right)^2 X_g}{\sqrt{\left[1-\left(\frac{\Omega}{\omega_n}\right)^2\right]^2+\left(2\xi\frac{\Omega}{\omega_n}\right)^2}}$$

then Zo approaches values close to Xg hence indicating the displacement of the base and this is known as a siesmograph.

It is observed that the read-out by the instrument in this case will be proportional to the displacement of the base and thus this instrument will be useful for displacement measurement.

Piezoelectric accelerometers converting vibratory motion into an electric signal,followed by electronic signal conditioning, have dramatically revolutionized vibration measurements over the past couple of decades.
Some of the advantages of a piezoelectric accelerometer are:

- Very wide frequency range
- Linearity
- Characteristics remain stable over a long period of time
- Self-generating i.e. no external power supply needed
- No moving parts so no wear/tear

Typical accelerometers are shown in Fig. 12.1.4 below.

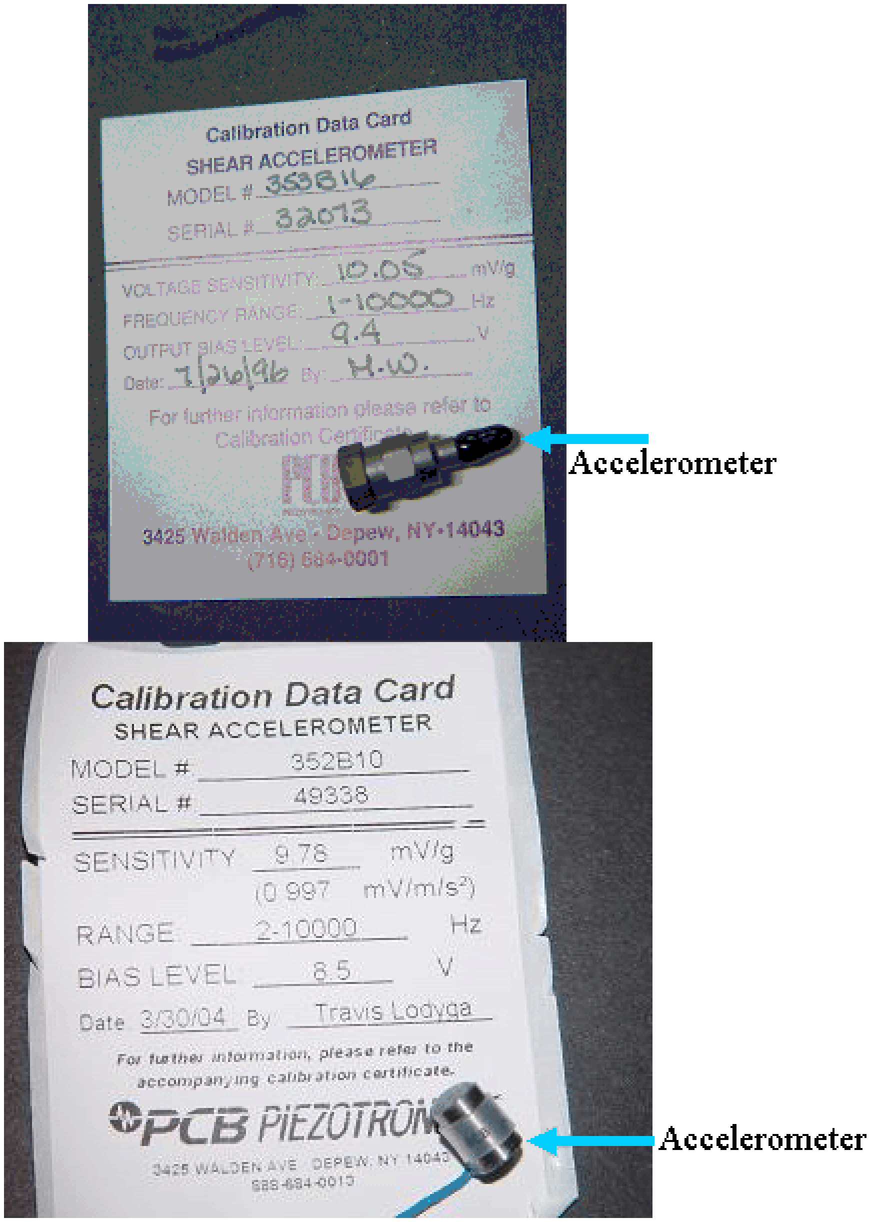

Figure 12.1.4

Selection and use of accelerometers

Several issues are important for proper application of accelerometers in a measurement. We will summarise some of these here:

- Typical measurement frequencies are up to about 10kHz. An accelerometer has two frequency cut-off points viz., the low frequency cut-off and the high frequency cut-off. The high frequency cut-off is due to the resonant frequency of the spring-mass system of the accelerometer.
- As a rule of thumb, **the highest frequency to be measured must be less than one third this upper cut-off frequency** . General purpose accelerometers may have resonant frequency in the range of 20kHz or so while the upper cut-off frequency for miniature accelerometers may be more likely in the range of 200kHz.
- At the lower end, near-DC frequency measurement is generally not very good with the conventional compression type accelerometer but the shear type accelerometer permits accurate measurements even at about 1 Hz.
- Typical general purpose accelerometers tolerate temp eratures up to about 250^0C but special care needs to be taken for high temperature applications.
- Errors (noise related) could creep into the measurements due to the cable itself viz., the cable's mechanical motion (best to tape or glue down the cable as close to the accelerometer as possible);

electromagnetic noise when the cable runs in the vicinity of a running machine.

- Accelerometers may be sensitive to transverse vibrations also i.e., other than its main axis of measurement but this is typically of the order of 1%.
- When dropped from a height, an accelerometer can be subjected to severe shock and cause permanent damage.
- It is generally necessary to make periodic calibration of the accelerometer.

Displacement or Velocity or Acceleration?

As integration is electronically performed, vibratory velocity or displacement can be readily obtained from the measured acceleration.

For a sinusoid, velocity amplitude is frequency times the displacement amplitude and acceleration amplitude is frequency times the velocity amplitude. Thus in general, acceleration measurement will be weighted more towards higher frequencies and displacement is weighted more towards lower frequencies.

In general vibratory **velocity** has been found to be the **best indicator of severity of vibration** . Many standards indicate the permissible vibration levels in terms of velocity limits. However, it must be pointed out that ride comfort of a passenger traveling in an automobile is best quantified in terms of frequency weighted RMS acceleration; similarly displacement can be used as an indicator of unbalance in a rotating machine.

Typical vibration charts are shown Fig.12.1.5

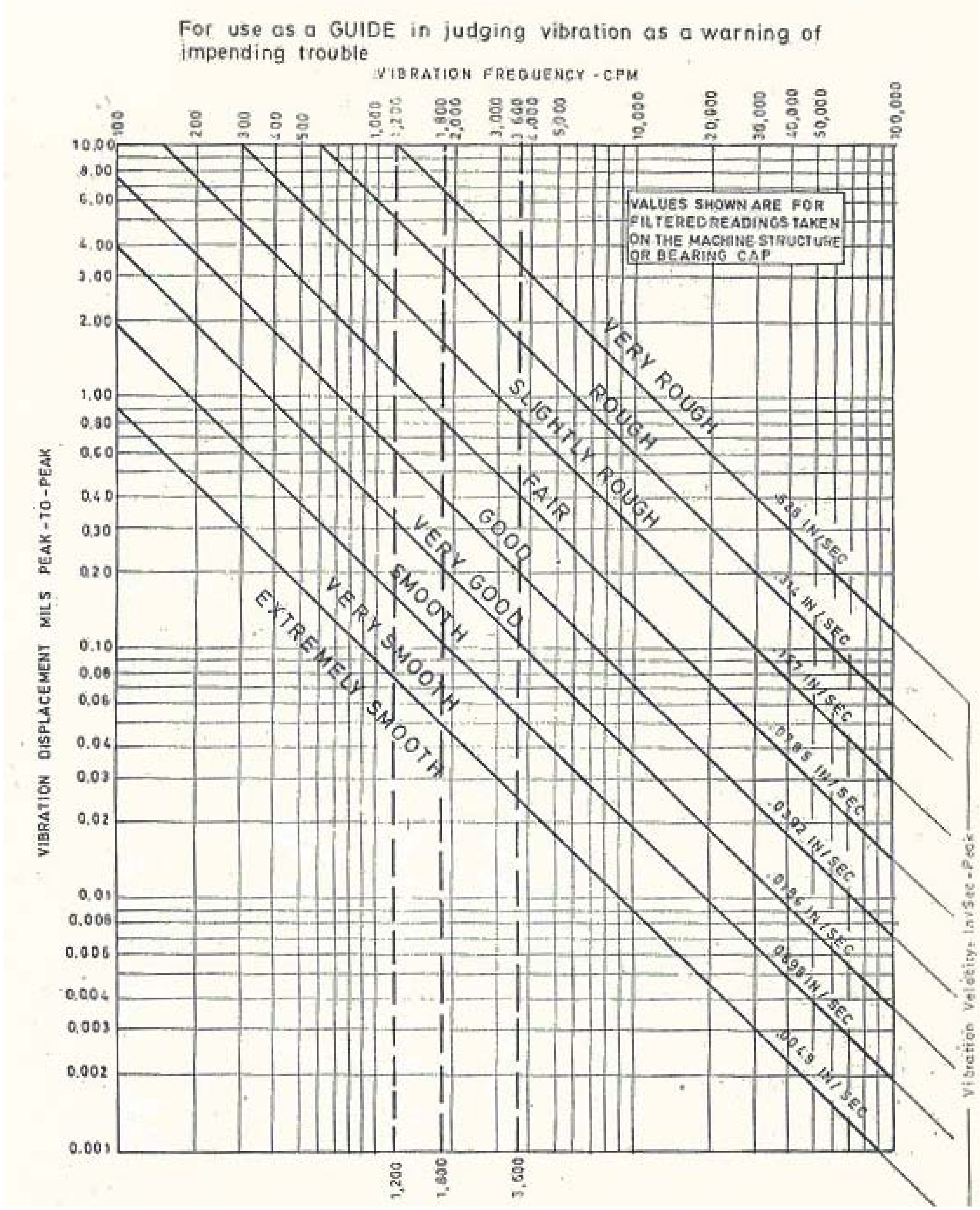

Figure 12.1.5

Constant velocity lines (units inch/sec) are shown in the figure with X-axis as frequency and Y-axis as displacement amplitude. As the velocity of vibration decreases, the machine operates more and more smoothly.

Time vs Frequency Domain

Vibration measurement records usually contain several frequency components – so just looking at the amplitude-time record is not enough.

Fig 12.1.6 Impulse response of a beam

We therefore need to perform an FFT (Fast Fourier Transform) and study the frequency components contained in the signal

Fig 12.1.7 FFT of signal above

Once we understand the frequency content of the measured vibration, we can correlate that to the operating speeds of the machine (or its harmonics) thus leading to an understanding of the source and possible remedial measures.

Measurement of Force, Impedance etc

A force transducer is used to measure the dynamic forces on a structure and this too has a piezoelectric element which gives an electrical output proportional to the force transmitted through it. Therefore the same amplifier and other instrumentation as used for accelerometer, can be used for the force transducer also.

When the force measured from the force transducer and the vibrational velocity obtained using say integration of the accelerometer signal are put together, we get the mechanical impedance of the system.

Use of non-contact measuring instruments

We mentioned two popular non-contact type measuring instruments viz., fiber-optic probe and laser Doppler vibrometer. These are shown below:

Fig 12.1.8 Fibre Optic Probe

Fig 12.1.9 Laser Doppler Vibrometer Schematic

The fiber-optic probe essentially contains several bundles of optical fibers transmitting light which will fall on the vibrating structure and the intensity of reflected light as collected by the receiving fibers is a measure of the displacement.

The laser Doppler vibrometer, as the name implies, relies on the Doppler shift caused by the vibrating body (The **Doppler effect** can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching and an apparent downward shift in frequency for observers from whom the source is receding. It is important to note that the effect does not result because of an actual change in the frequency of the source.)

Associated Equipments

A typical vibration test will involve use of several other equipment as shown in Figure 12.1.10:

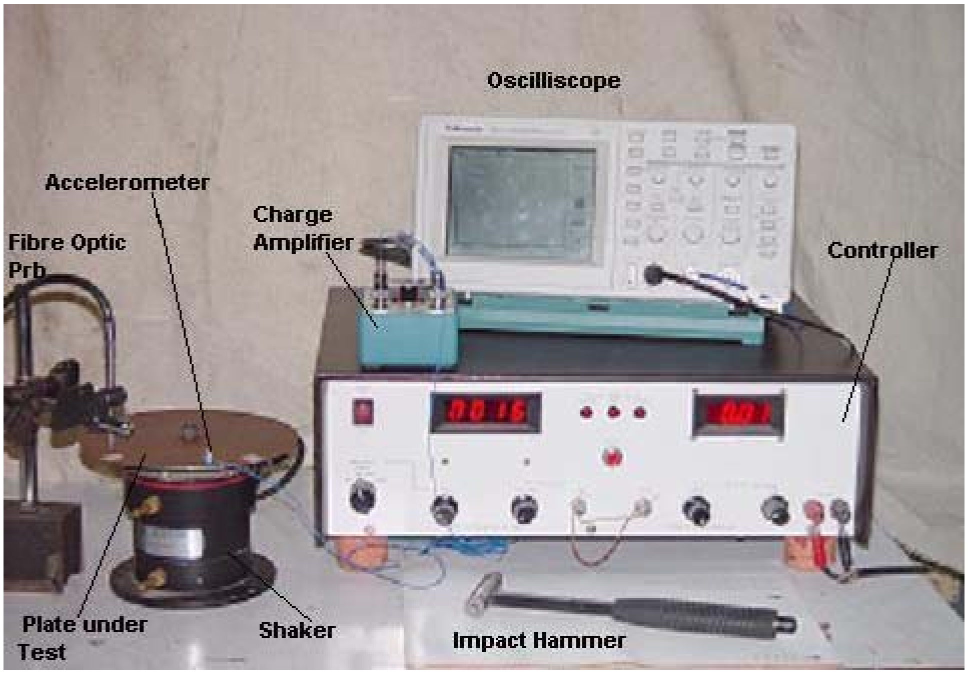

Figure 12.1.10

The experimental setup above shows both free as well as forced vibration instruments. The shaker shown here , induces the forced vibrationinto the plate. The vibrations are picked up by the piezo accelerometer , sent to charge amplifier and could be viewed on oscilliscope. The non-conatct type of instrument fibre optic probe is used to measure displacement of plate at various points.

For free vibrations , impact hammer is used.

Recap

In this lecture you have learnt the following

- The concept of measuring instruments based on fundamentals of dynamics of systems base excitation.
- Types of measuring instruments in vibration analysis.
- Range of operation of instruments and limitations of their application.

Congratulations, you have finished Lecture 1. To view the next lecture select it from the left hand side menu of the page