6.1 INTRODUCTION

Vibration measurement is an important area of study to experimentally determine the parameters of a vibrating body. While developing analytical solutions, a large number of assumptions and simplification are done. However, a real time study of a system would give a lot of data, which may not always completely agree with the analytical results due to the approximations. It is thus important, to measure small and rapid vibration, especially in a high speed machinery, so as to obtain relevant data for further analysis.

Many a times, the vibration analysis cannot be done in a laboratory, as it would not be possible to move large structures. In such cases, field tests are the only solution.

In current times, vibration measurement has become all the more important with the trends to produce high speed optimised equipment. Some of the major reasons for vibration measurement are listed below :

1. Economical products made from light weight materials having optimum section properties and running at high speeds result in resonant conditions, thereby reducing the reliability of the system. In such cases measurement of natural frequencies or other parameters becomes important to ensure that the observed values do not deviate substantially from the analytical values predicted by the designer.

2. The natural frequency measurement is also important to ensure that other nearby machines are not made to run at speeds which may create resonating conditions.

3. The amplitudes of vibration form the basis of determining the magnitude of the dynamic forces produced in the system, which is an important parameter for the system designer.

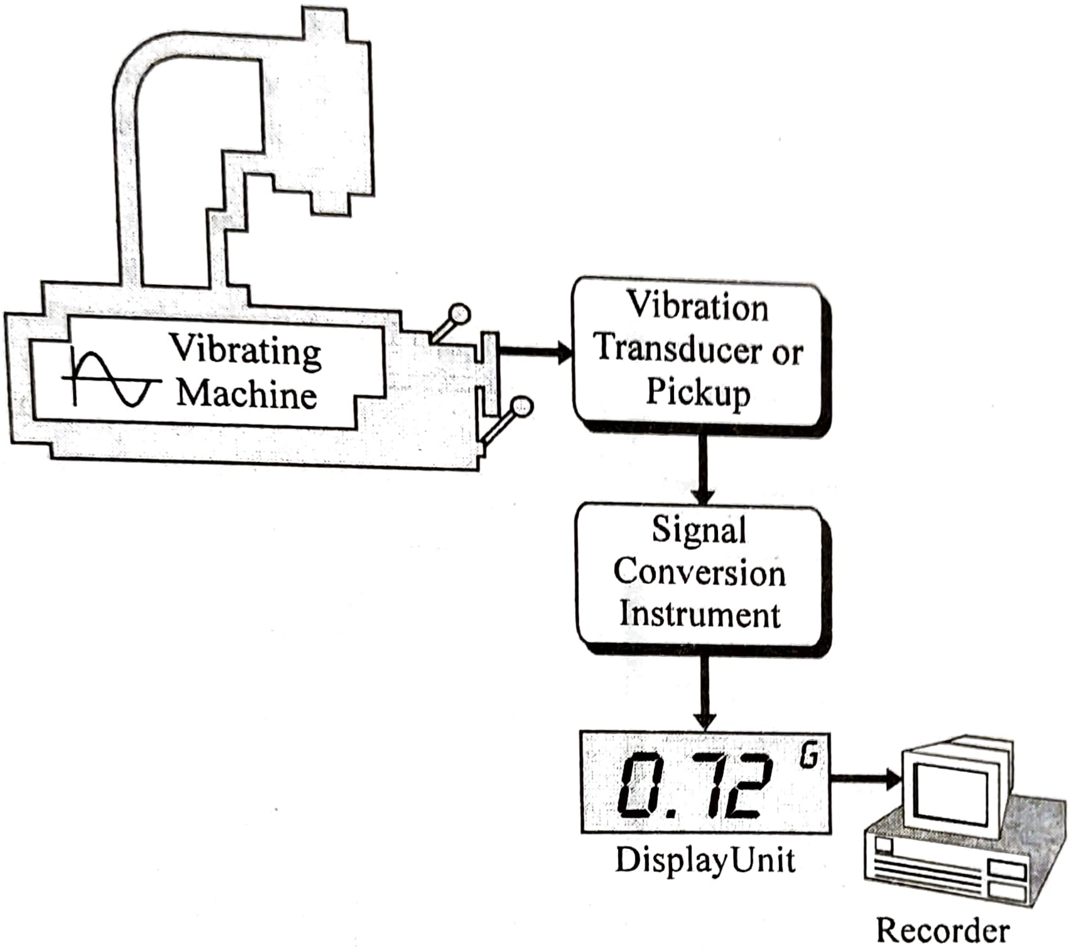
4. Vibration measurement also establishes the validity of the results obtained by the analytical process. It would automatically guarantee that the assumptions chosen by the designer in modelling the system are correct.

5. In many cases, the survivability of a system is decided by the fact that the system can successfully undergo a vibration test at adverse conditions.

6. In a vibration test, a certain input is given and the corresponding output is measured. This data helps in identifying important system parameters such as mass, stiffness and damping.

7. Vibration measurement also serves as a tool to monitor the state and condition of a machine and to help the technician in predicting the possibility of failure of a particular component.

A typical vibration measurement scheme is shown in Fig. 6.1.1. It consists of the vibrating body, to which is connected a vibration pickup or a transducer. This is a device which transforms a mechanical quantity such as displacement, velocity, acceleration or force into a small electrical voltage or current. This output from the transducer is not strong enough for recording a... hence would require a signal conditioner or a signal conversion instrument. The output fro... the signal conversion unit can then be used to display the values or can be recorded by... recording unit such as a computer. Further analysis of the recorded data can then be done... determine the vibration response and other characteristics.

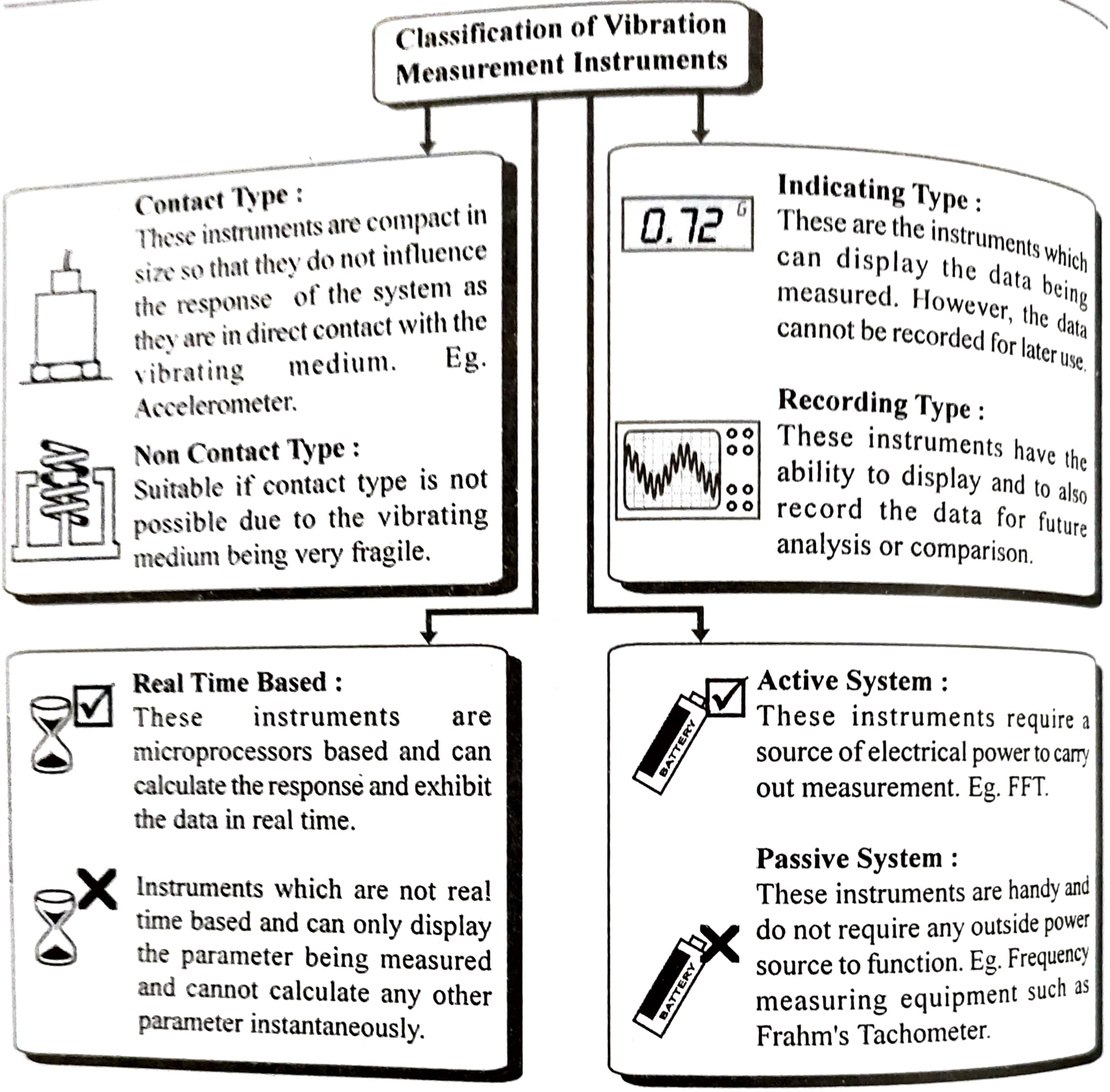


Vibration Measurement Scheme
Fig. 6.1.1

Besides these, vibration measurement includes frequency and damping measurement... An experimental setup to determine damping coefficient was explained earlier in the article o... logarithmic decrement and has not been repeated in this chapter. In a vibration lab, equipmen... such as exciters and analysers are used to study the response of systems.

Depending on the parameter measured, the vibration measuring instrument can be called as a vibrometer, a velocity meter or an accelerometer. If the instrument is meant to record the data and not just display it, then the suffix *meter* is replaced by *graph*. (eg. vibrograph).

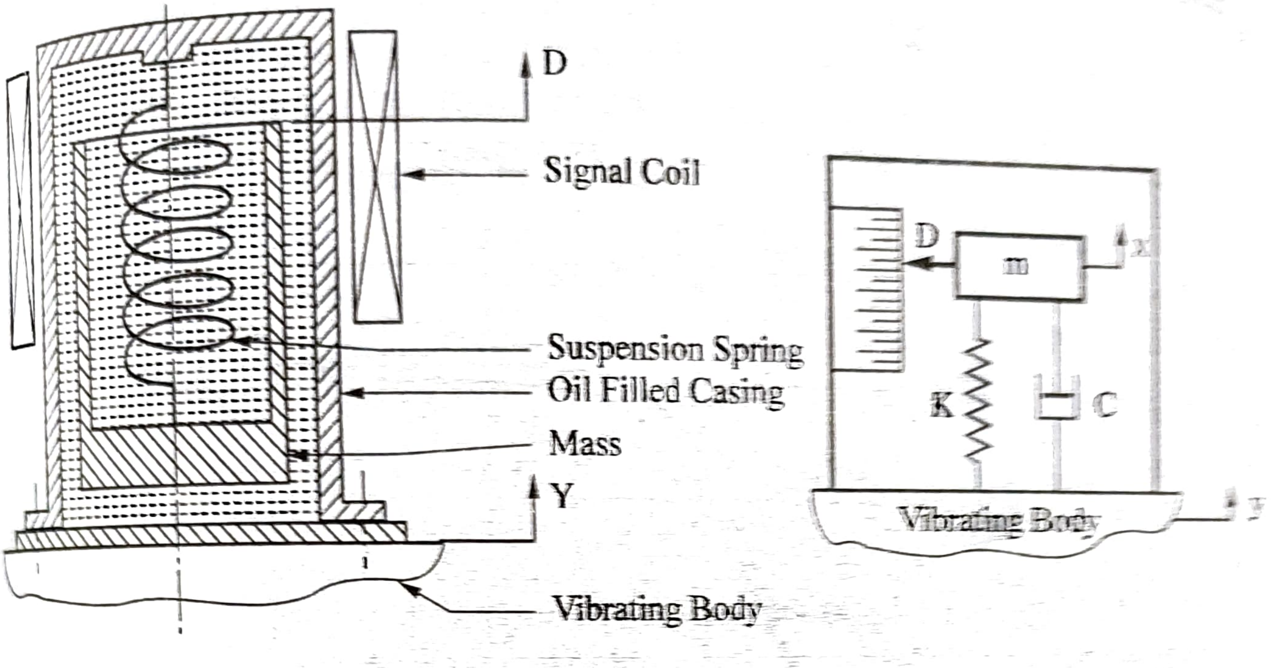
In general vibration measuring equipment can be broadly classified into four types as shown in Fig. 6.1.2. Their choice is made on the basis of the accuracy, sensitivity of the vibration response and the kind of vibrating medium.



Classification of Vibration Measurement Instruments
Fig. 6.1.2

6.2 SEISMIC VIBRATION MEASUREMENTS

The seismic pickup is one of the most frequently used apparatus to measure vibration. The constructional details of this kind of pickup is very similar to a seismograph, which is used to measure earthquake tremors. It consists of a very large inertia member which is very delicately suspended with a very low stiffness spring (refer Fig. 6.2.1) in a casing filled with oil. The oil in the casing provides for damping. As the objective of a seismic vibration pickup is to observe vibrations, its size must be as small as possible, so as not to influence the characteristics of vibrations of the system on which it is mounted. The pickup is then mounted on the body whose vibrations are to be observed. Assuming that the body has harmonic vibrations of the form $y = Y \sin \omega t$, it is clear that would be a case of forced vibrations with excited support. The pickup works on the basis of observing the motion of the mass (inertia member) of the pickup.



(a) Constructional Details of a Seismic Pickup

(b) Vibration Model

Fig. 6.2.1

We know that the natural frequency of such a system is given by :

$$\omega_n = \sqrt{\frac{K}{m}}$$

By keeping a very low stiffness and a relatively high mass, the natural frequency of the pickup will be very low. For the pickup to be effective, it is important that its natural frequency is considerably lower than the excitation frequency. This ensures that the amplitude of vibrations of the suspended mass is very small. This phenomenon can be better explained by considering the analytical equations.

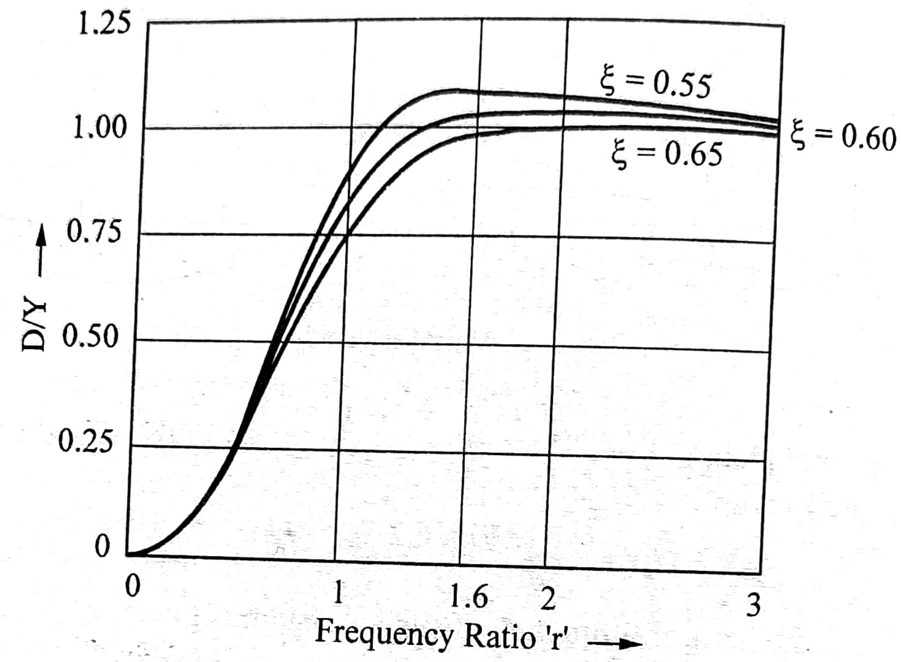
From Equation (4.12.15), we have

$$D = Y r^2 \Omega$$

or

$$\frac{D}{Y} = r^2 \Omega$$

As mentioned earlier, the motion on the mass is measured. It should be noted that this motion is at a very small level and direct measurement is not practical and hence it requires a transducer to convert the physical variable into an electrical signal. This could be electrodynamic, strain guage type, LVDT (inductive type) or piezoelectric. Many a times, a signal coil is wound around the casing. The movement of the mass relative to the coil produces minute inductive changes; which is sensed, amplified, and then displayed visually or recorded. This motion is the relative amplitude 'D'. However, the objective is to measure the specimen vibration amplitude 'Y'. As discussed before, the natural frequency of the pickup is to be kept very low as compared to the excitation frequency. This ensures that the frequency ratio 'r' is fairly high. Consider the graph (Fig. 6.2.2) of 'D/Y' versus 'r'. It is seen that for higher frequency ratios the value of 'D/Y' almost tends to one. Normally, for a damping factor in a range of 0.55 to 0.65, the graph is fairly linear beyond a frequency ratio of 1.6 and is almost equal to 1. This would mean that the amplitude of the mass 'D' observed would be almost equal to the amplitude of the body 'Y' and hence this is the ideal range for the pickup to work effectively.



'D/Y' versus frequency ratio 'r'
Fig. 6.2.2

The principle of a seismograph is the basis for the various vibration measurement devices such as a Vibrometer, Velocity pickup and Accelerometer.

a). Vibrometer :

A Vibrometer is an instrument to measure the displacement of a vibrating machine part. As the natural frequency of the vibrometer is low as compared to that of the vibration to be measured, it is observed that

$$\frac{\text{Recorded Value}}{\text{Actual Value}} = \frac{D}{Y} \approx 1$$

Thus, at high frequencies, the seismic mass remains stationary. Generally, the instrument natural frequency is designed twice as slow as the slowest vibration to be recorded. Since there is no relative motion for large values of 'r' (as 'D/Y' = 1), the relative motion between the mass and casing represents amplitude of motion. This can be sensed, amplified and calibrated to display the amplitude of vibrations. When the ratio 'D/Y' cannot be one, then

$$\frac{\text{Recorded Value}}{\text{Actual Value}} = r^2\,\Omega$$

The error would be maximum when this ratio is maximum. As seen earlier, the above ratio is maximum, when

$$r = \frac{1}{\sqrt{1-2\xi^2}} \qquad \text{(from equation 4.11.9)}$$

and,

$$\left(\frac{D}{Y}\right)_{max} = \frac{1}{2\xi\sqrt{1-\xi^2}} \qquad \text{(from equation 4.11.10)}$$

b). Velocity Pickup :

The same setup as used for a vibrometer can be easily used for velocity measurement. In this case, use is made of a secondary strain sensing transducer, of the type in which a magnet is rigidly fixed to a seismic mass in a coil fixed to the frame. Then the output voltage at the two ends of the coil will be proportional to relative velocity. As 'r' is large, ('D/Y' ≈ 1). Therefore, the relative velocity so obtained is equal to input velocity. The output voltage can then be amplified and calibrated to display the input velocity. The same equations as determined for vibrometer can be used to determine true velocities.

c). Accelerometer :

An accelerometer is an instrument which records the acceleration of the body. In this case the natural frequency of the accelerometer is kept *very large* as compared to that of the vibration to be measured. This can be done by using a very light mass suspended on a fairly stiff spring. Suitable amount of damping is introduced to ensure that the magnification factor 'Ω' = 1. This can be done by knowing the range of the possible values of 'r', and then reversely calculating the value of 'ξ' for which 'Ω' is 1.

For

$$\Omega = \frac{1}{\sqrt{(1-r^2)^2+(2\xi r)^2}} = 1$$

$$\therefore \quad (1-r^2)^2 + (2\xi r)^2 = 1$$

$$1 - 2r^2 + r^4 + 4\xi^2 r^2 = 1$$

$$4\xi^2 r^2 = 2r^2 - r^4$$

$$\xi^2 = \frac{1}{4}(2-r^2)$$

$$\xi = \frac{1}{2}\sqrt{2-r^2} \qquad \ldots (6.2.1)$$

Using this value of 'ξ', for the given value of 'r' will ensure that 'Ω' = 1. However, the instrument is to cater to a range of different values of 'r', and therefore, some errors will be introduced, if we consider 'Ω' = 1 at different frequency ratios.

$$\therefore \quad \frac{D}{Y} = r^2\,\Omega$$

$$D = r^2 \Omega Y = \frac{\omega^2 Y}{\omega_n^2} \Omega$$

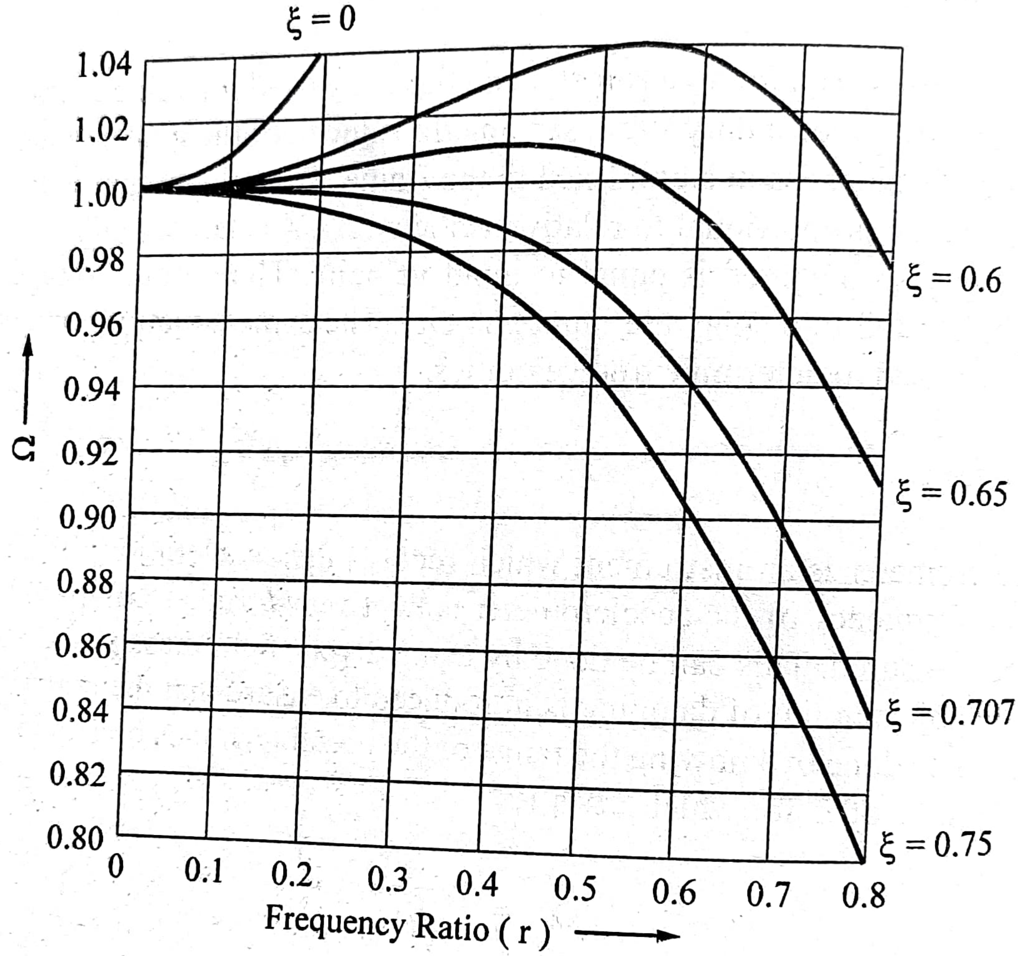
∴

$$D \omega_n^2 = \omega^2 Y \Omega$$

or,

$$\text{Recorded Acceleration} = \text{Actual Acceleration} \times \Omega$$

$$\frac{\text{Recorded Acceleration}}{\text{Actual Acceleration}} = \Omega$$



Acceleration Error with Frequency Ratio for Different Values of Damping Ratio
Fig. 6.2.3

If the value of Ω is close to 1, then the error is not very large. It is seen in Fig. 6.2.3 that at $\xi = 0.707$, the value of Ω is very close to 1 for the operating zone shown. As the value of Ω is approximated as one, the errors in general may not be very large if 'r' and 'ξ' do not vary much from the assumed values. Therefore, the above equation can be simplified to :

∴

$$\frac{D}{Y} = r^2$$

∴

$$D = r^2 Y = \frac{\omega^2 Y}{\omega_n^2}$$

or,

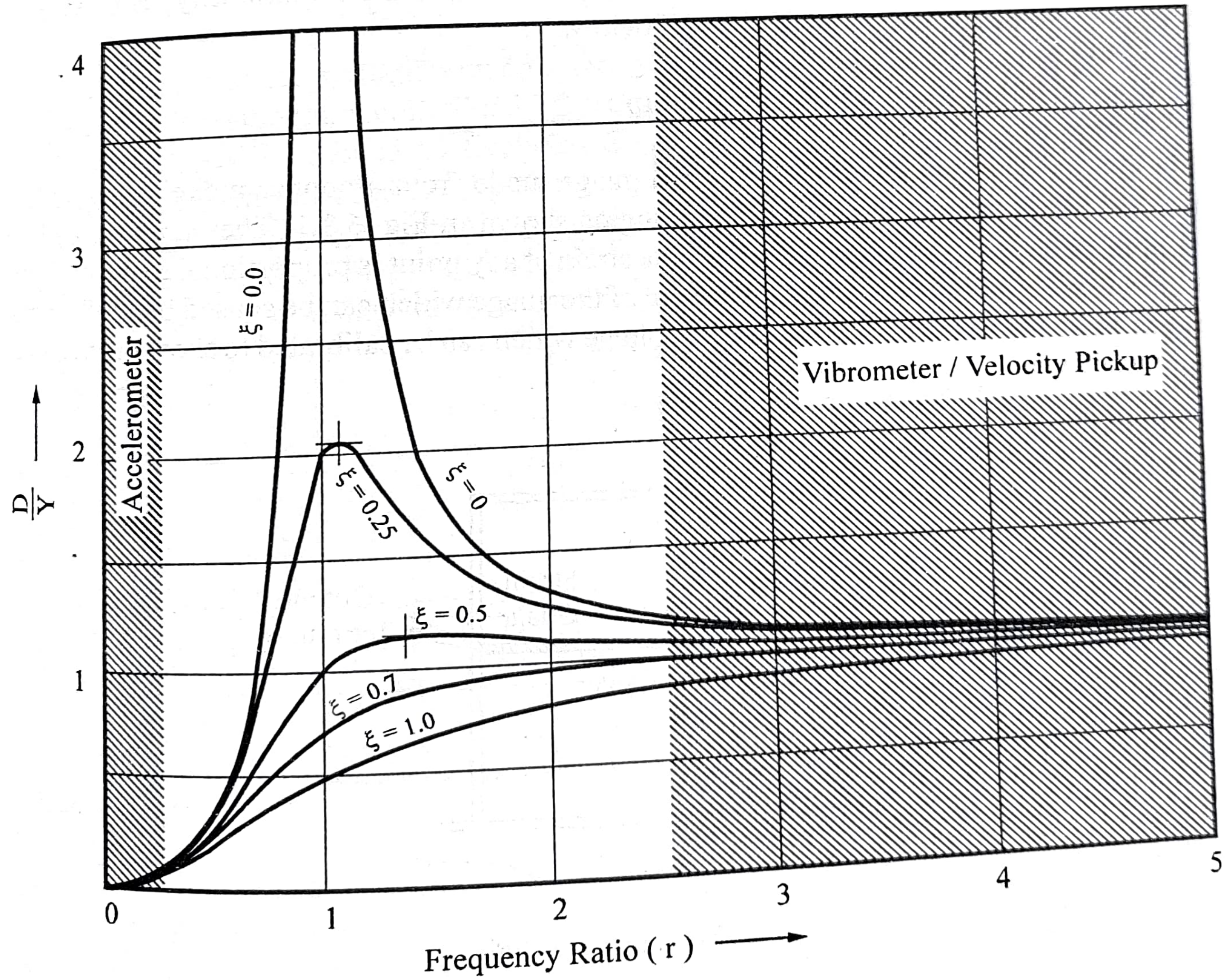
$$D \omega_n^2 = \omega^2 Y$$

Recorded Acceleration $\approx$ Actual Acceleration (when $\Omega \approx 1$)

It should be noted that '$\omega^2 Y$' is the acceleration amplitude of the body. Hence, D is directly proportional to the acceleration as 'ω_n' is a constant. The natural frequency of an acceleration should be atleast twice as high the frequency of the vibration to be measured. (Generally, $f_n = 10{,}000$ Hz).

The relative motion is generally converted into an electric signal through winding coils, to generate a voltage, which can be sensed, amplified and calibrated to give the values of acceleration.

The major difference in a vibrometer / velocity pickup and accelerometer is in the working range. As mentioned earlier, the accelerometer works in low frequency ratio zone, whereas the vibrometer / velocity pickup in the higher frequency ratio zone. Fig. 6.2.4 shows the typical working zone of these.



Working Zone of Instruments
Fig. 6.2.4

6

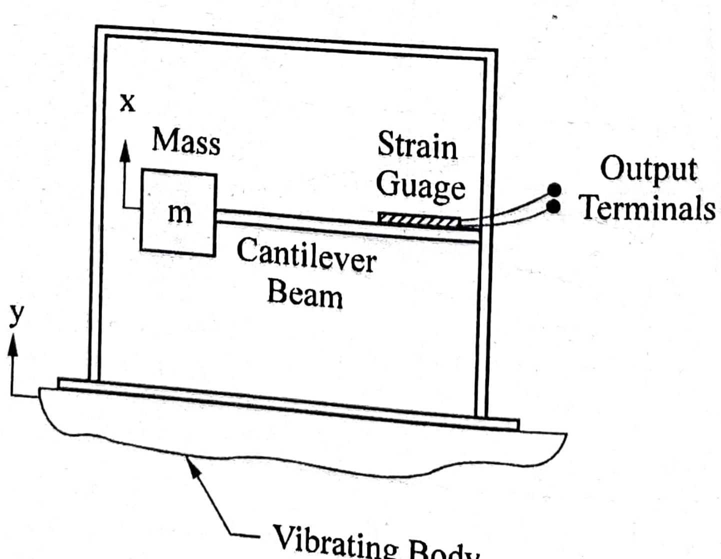
6.3 TYPES OF VIBRATION PICKUPS

It was mentioned earlier that various methods are used to convert the vibration parameters into an equivalent electrical signal. This is normally done by using transducers. A device in which the transducers are used along with other components, which permit processing and transmitting of a signal are called as a *pickup*. These transducers can be contact type or non contact type.

Contact type transducers such as LVDT and electromagnetic / inductive type are based on the movement of a coil or a permanent magnet or the core. The strain guage type transducers are also contact type transducers and are attached to the test specimen. Contact type transducers have the effect of loading the test specimen, thereby influencing the parameters recorded. They are also not suitable in measuring vibrations in rotating members. On the other hand, non contact or non intrusive or proximity transducers rely on the principle of change in capacitance or reluctance or the loss of eddy current field in the measurement circuit due to a change in the gap between the transducer and the test member. Some of the important types of vibration pickups and their principles are discussed below.

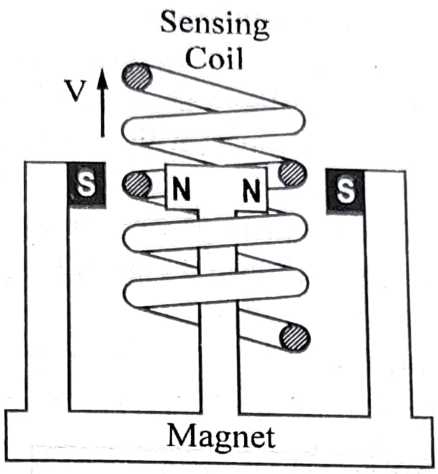
a). Strain Guage as a Vibration Pickup :

This kind of a pickup uses a strain guage made from a copper nickel alloy which is mounted on an elastic element of the spring as shown in Fig. 6.3.1. They are also called as *variable resistance transducer pickups*. The strain at any point is proportional to the deflection of the mass. Strain influences the resistance of the guage which can be sensed by a Wheatstone bridge. This change influences the output voltage which can be calibrated to show the magnitude of displacement.



Strain Guage Vibration Pickup
Fig. 6.3.1

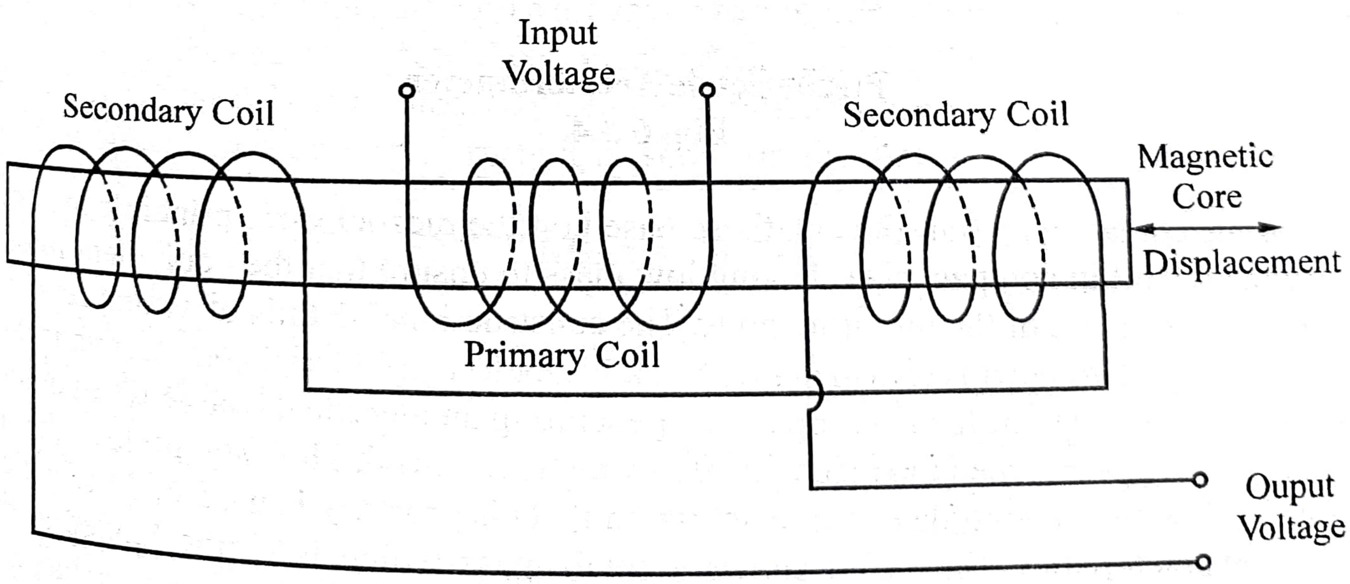
b). **Electrodynamic or Electromagnetic Transducer as a Velocity Pickup**



Sensing Mechanism in an Electromagnetic Transducer
Fig. 6.3.2

In these transducers, a coil is made to move in a magnetic field or conversely a magnet is made to move in a stationary coil. Fig. 6.3.2 shows the sketch of the sensing mechanism of the pickup. When the coil is moved relatively in a magnetic field, a voltage is generated in the coil. The magnetic field maybe produced by either a permanent magnet or it can be electromagnetic. The magnitude of voltage generated by the coil is directly proportional to the relative velocity of the coil. This makes it possible to calibrate the voltage to the velocity and hence electrodynamic or electromagnetic transducers are used as velocity pickups.

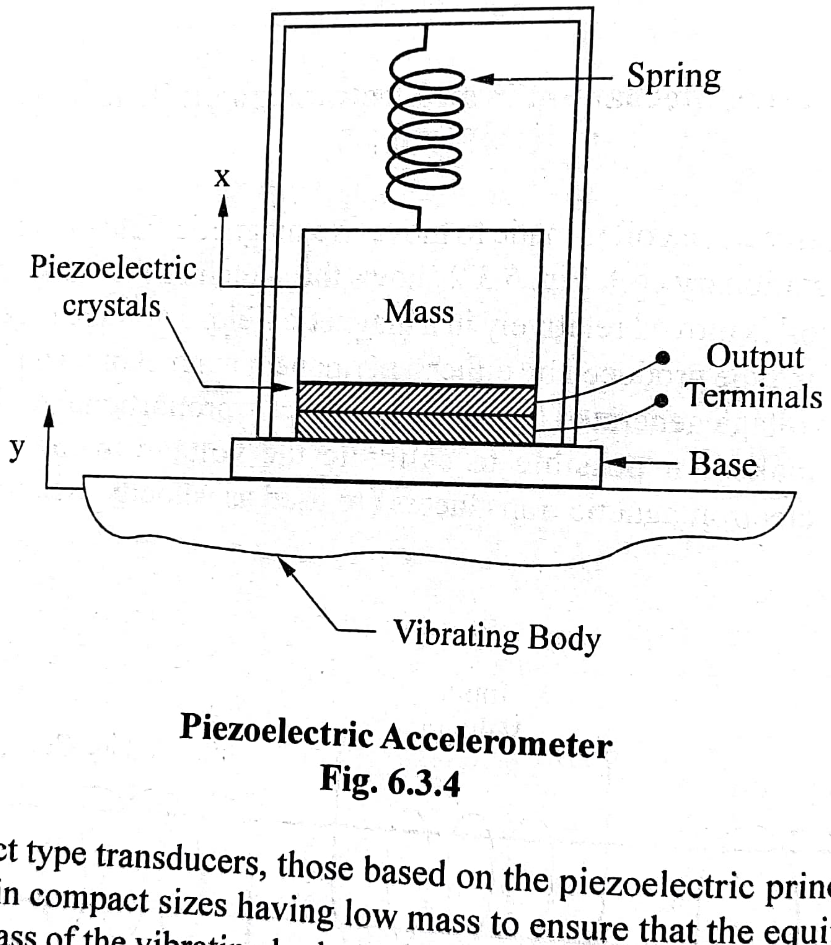
c). **LVDT :**



Schematic Sketch of LVDT
Fig. 6.3.3

A Linearly Variable Differential Transducer (LVDT) has a primary coil in the centre and two secondary coils at the ends. A magnetic core can freely move axially in between these coils as shown in Fig. 6.3.3. When an alternating input voltage is applied to the primary coil, the magnetic core varies the coupling between it and the secondary coil. When the core is in the centre position, the coupling to the secondary coils is equal. The secondary coils are connected in opposite phase and hence the output voltage is zero, when the core is at the centre. As the core moves away from the centre position, the coupling to one secondary coil increases whereas it would reduce for the other. This would increase the voltage in one coil and reduce in the other. The output voltage is thus directly proportional to the displacement of the core. LVDT are insensitive to temperatures and are suitable for high frequency applications.

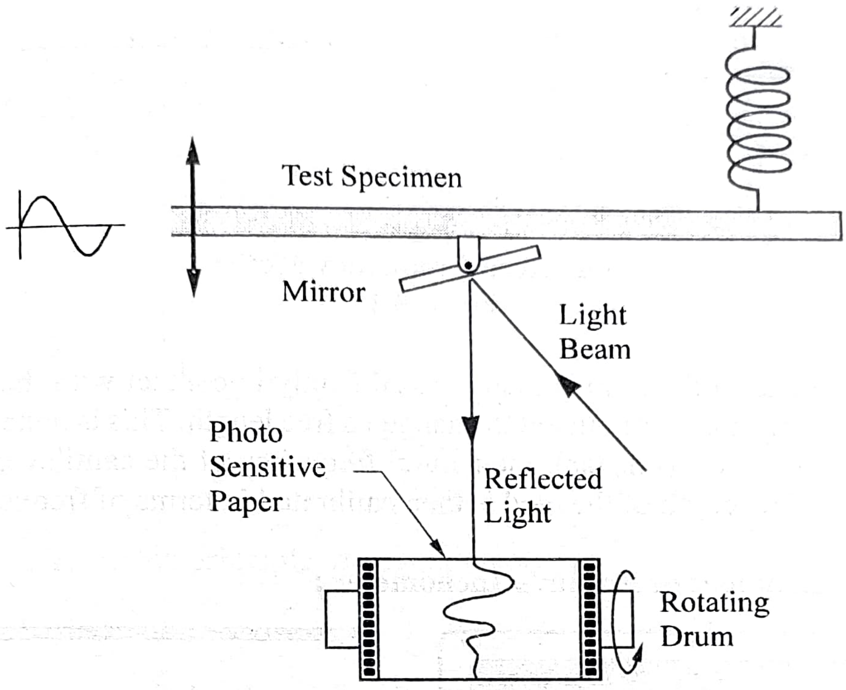
d). Piezoelectric Accelerometer



Piezoelectric Accelerometer
Fig. 6.3.4

Of the contact type transducers, those based on the piezoelectric principle are popular. These can be built in compact sizes having low mass to ensure that the equipment mass does not influence the mass of the vibrating body. The constructional details of a compression type piezoelectric accelerometer is shown in Fig. 6.3.4. Piezoelectric materials such as quartz, lithium sulphate and Rochelle salt have a property of generating an electrical charge when deformed. This charge disappears when the mechanical loading is removed. The magnitude of the charge is influenced by the magnitude of force acting on it. This property is used in determining the vibration characteristics. Fig. 6.3.4 shows a small mass which is spring loaded against a piezoelectric crystal. When the base vibrates, the mass vibrates. The change in acceleration of the mass, changes the magnitude of force exerted on the crystal. This would influence the output voltage from the crystal which on calibration would give the magnitude of acceleration in the system. Piezoelectric accelerometers are compact, rugged and have high sensitivity and work well in high frequency range.

6.4 OPTICAL RECORDING INSTRUMENT



Optical Recording Instrument
Fig. 6.4.1

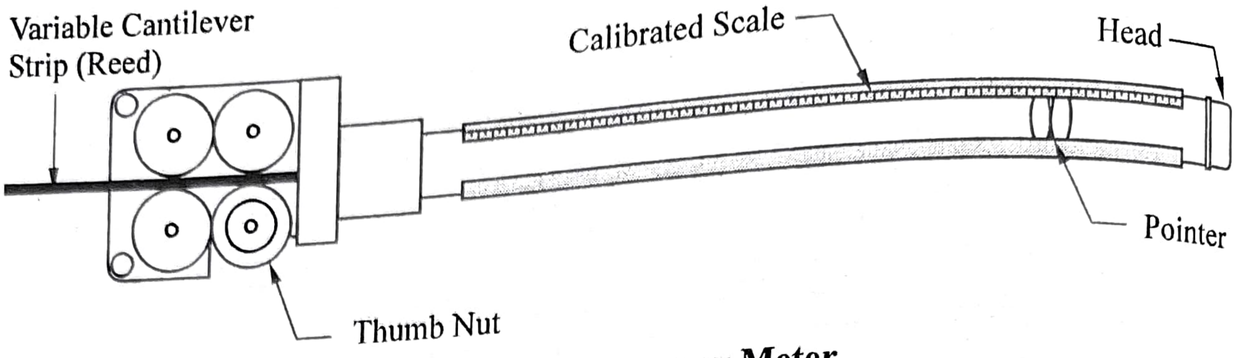
Optical devices which are based on principles of light and are non contact type recording instruments. A mirror is connected to the vibrating body through a linkage. The instrument uses a light signal which is reflected through a mirror on to a rotating drum. A photo sensitive paper or film is fixed on the drum to record the vibratory motion. The major advantage of this kind of an instrument is that it is insensitive to frequency ratio, as they have negligible inertia. A sketch of an optical recording instrument is as shown in Fig. 6.4.1.

6.5 VIBRATION FREQUENCY MEASUREMENT

Besides measuring the amplitude, velocity and the acceleration of vibrations, it is important to find the frequency of vibrations. Most frequency measuring instruments of the mechanical type are based on the *principle of resonance*. These are usually one of the two kinds as discussed below.

a). Single Reed Frequency Meter or Fullarton Tachometer :

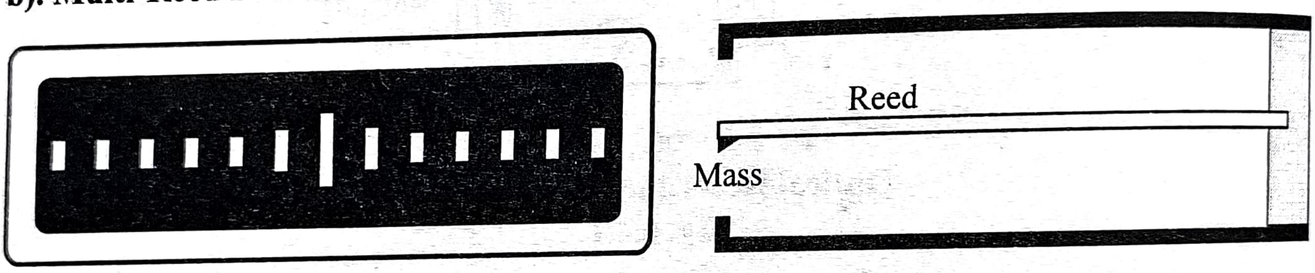
This instrument consists of a variable length cantilever strip or a reed of spring steel as shown in Fig. 6.5.1. One end of this strip is clamped, and its free length can be changed by a screw mechanism. Changing the length directly affects the natural frequency of the strip.



Single Reed Frequency Meter
Fig. 6.5.1

The clamped end of the strip is then pressed firmly in contact with the vibrating body and the screw mechanism is manipulated to change its free length. This is done till the free end shows large deflection. At this instant, the natural frequency of the cantilever is equal to the exciting frequency. The length of the reed is then calibrated in terms of frequency.

b). Multi-Reed Instrument or Frahm's Tachometer :



Multi-Reed Instrument or Frahm's Tachometer
Fig. 6.5.2

This instrument contains a number of reeds, with white tips arranged in a box will dull interior (Refer Fig. 6.5.2). Each reed is in the form of a cantilever carrying small masses at their free ends, thus having a different natural frequency. When this instrument is attached to the vibrating body, the reed whose frequency is closest to the excitation frequency will exhibit maximum amplitude while the other reeds would hardly move. The frequency of this reed would then be the frequency of the vibrating body. The swinging white tip can be easily observed against the dark interior and if the reeds are calibrated, then their frequency can be easily read.

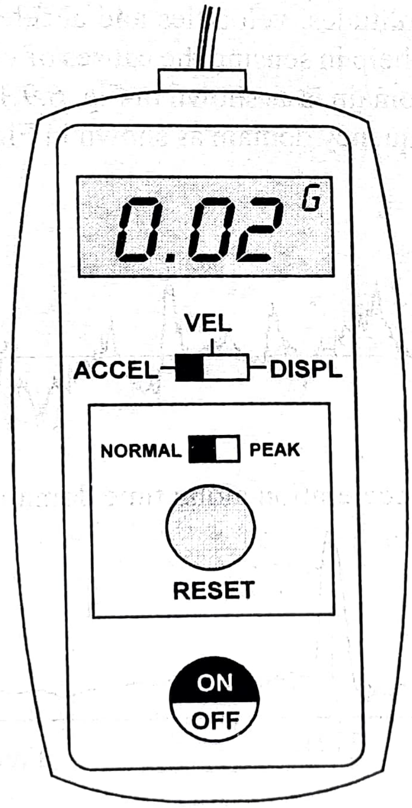
c). Stroboscope :

This is a non contact frequency measurement instrument. It consists of a light source which emits light pulses intermittently. The frequency at which the light pulses are produced can be altered and read from the instrument. The instrument uses the principle of persistence of vision to measure frequency in a rotating body. To do so, a desired point of the vibrating body is viewed with the stroboscope. This point will appear stationary, if and only if the frequency of rotation and the frequency of the pulsating light is the same. The stroboscope can measure frequencies above 15 Hz.

The electrodynamic exciter has two natural frequencies. The low stiffness of the flexible support ensures a low natural frequency, whereas the other frequency due to the moving element maybe designed very high. The operating zone of the exciter would then be in between these two frequencies as shown in Fig. 6.7.4. Typically, these exciters can generate forces as high as 30 kN with a displacement of about 25 mm and work in the frequency range from 5 Hz to 20 kHz. The magnitude of the force is however restricted by the considerable heat produced in the system. Proper cooling needs to be designed to reduce the temperatures in the coil.

The electrodynamic exciter is to be physically connected to the member under test and the excitation occurs through this connection. However, if the test specimen is comparatively small, then the stiffness and the mass of the exciter may considerably influence the characteristic of the test specimen. In such cases, smaller sized non contact shakers are used. These can be used to excite small test specimens which are made from magnetic material. The exciter uses a strong magnet which is placed in the proximity of the test specimen but without any physical contact. When the current flows through the coil, the moving element and the magnet vibrates harmonically. The non contact magnetic bond between the permanent magnet and the test specimen results in the test specimen moving harmonically creating excitation force.

6.8 VIBRATION METER



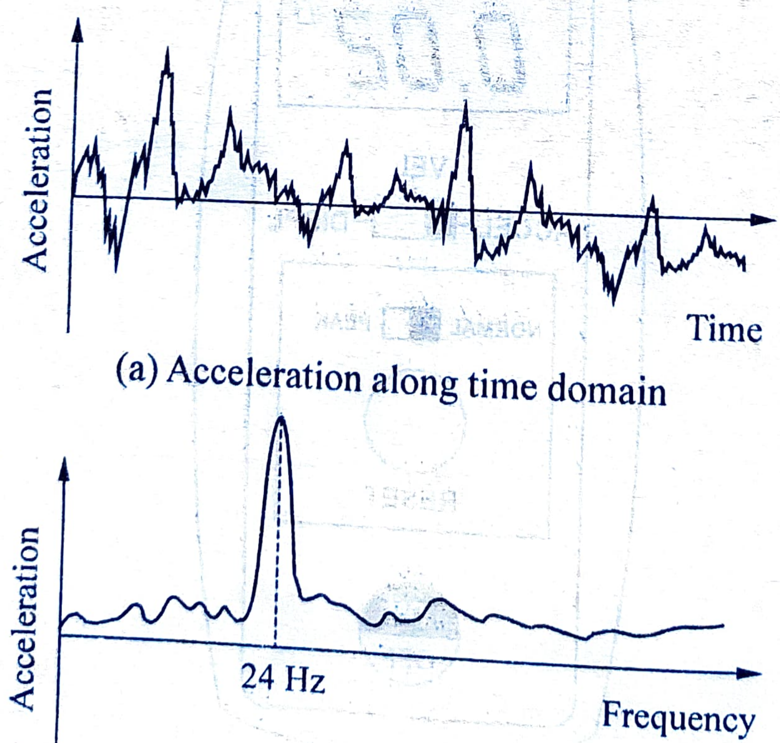
Vibration Meter
Fig. 6.8.1

With the advent of modern electronics, the vibration measuring equipment have undergone a tremendous change. A convenient measurement and display device is a vibration meter as shown in Fig. 6.8.1. This is a hand held light weight unit which can be connected to the piezoelectric accelerometer through a cable. The vibration meter has a digital display and can be set to read the displacement, velocity or acceleration. Besides this, it is accompanied with an electronic stethoscope with headphones, which allow the technician to 'listen' to the vibrations and confirm the values displayed. This human interface helps in prediction the exact nature of a problem based on the experience of the technician.

The vibration meter can be used to in predictive maintenance which is aimed at improving machinery reliability and enhancing productivity. It can measure the overall vibration level over suitable frequency ranges. These readings can then be compared with severity charts as defined by ISO 2372 which would give the condition of the machine. Most vibration meters can also be connected to a computers to collect and store the data being measured.

6.9 FFT SPECTRUM ANALYSER

In a real system, the vibratory signals received from the machine under steady running conditions with respect to time domain are called as *signature*. This response is generally periodic as the disturbing forces may have different frequencies and harmonics. Rarely would the signature be harmonic. This signature obtained from the meters would help in giving the mean, rms or peak values of amplitudes, velocities and acceleration. However, the response along the time domain would not help in sensing the causes of vibration. A typical acceleration response as read along the time domain is as shown in Fig. 6.9.1 (a). This response needs to be analysed and converted to the frequency domain as shown in Fig. 6.9.1 (b) and is referred to as the *spectrum*.



(a) Acceleration along time domain

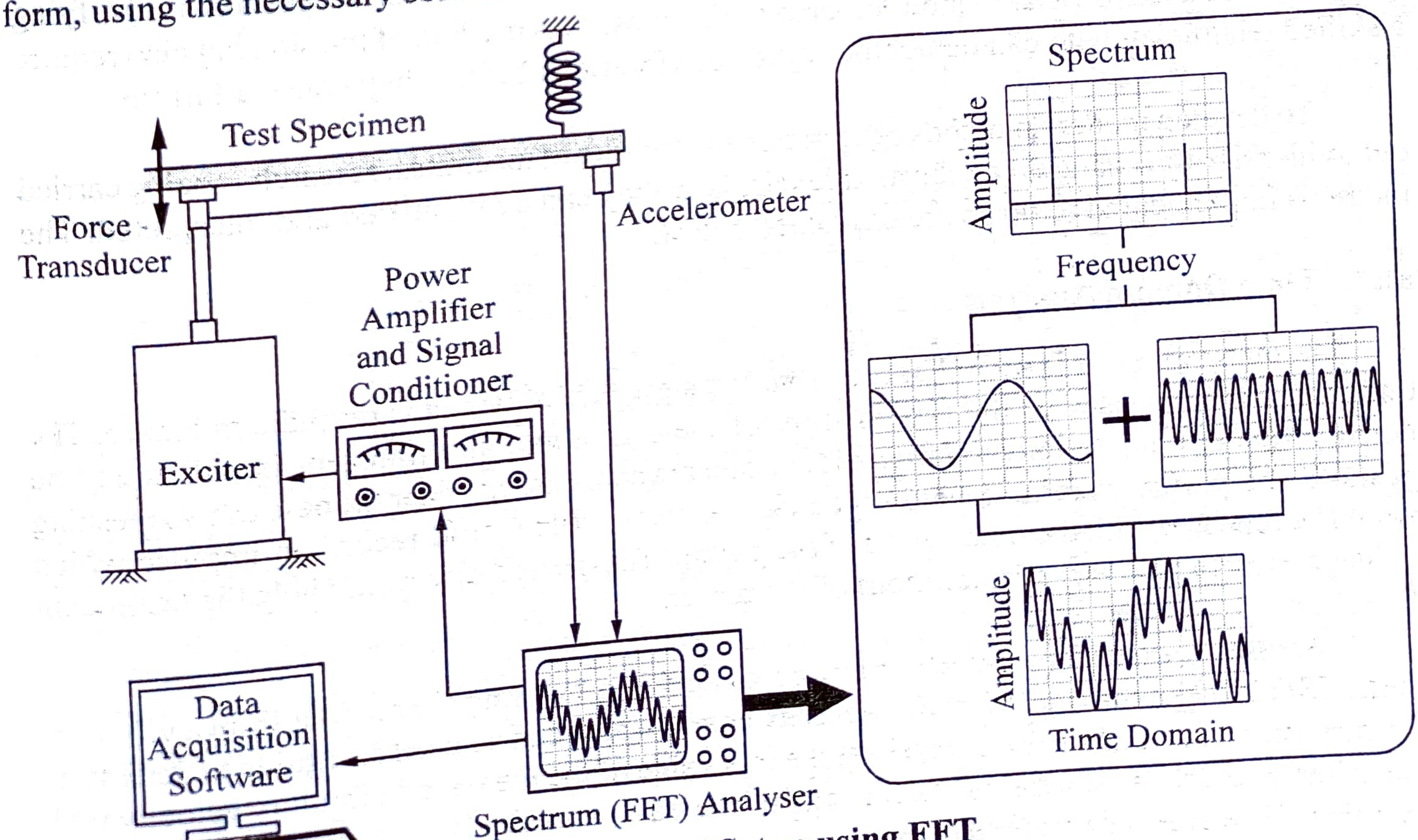
(b) Acceleration along frequency domain

Fig. 6.9.1

For the case considered in Fig. 6.9.1, it can be seen that the acceleration reaches a high value at about a frequency of 24 Hz. The operating speeds of major sources of vibrations like motors can then be checked and a particular motor can be identified which has a rotational speed of about 24 Hz. Thus, the acceleration spectrum allows the technician to identify a particular motor which would be the cause of vibration. Corrective action such as motor replacement or change in operating speed of the motor can then be suggested to avoid resonance. To generate this kind of data for analysis, spectrum analysers are used. The raw data obtained from a vibration meter or a transducer are in time domain. This signal is then analysed by an analyser and the data is then presented in the frequency domain.

To analyse a periodic motion, use is made of the *Fourier series*. As per this series, any periodic motion can be represented by an infinite sum of *sine* and *cosine* terms. Thus the vibrations signature can be converted into a mathematical equation and the transformations of this equation would allow the conversion from time domain to frequency domain and vice versa.

The instruments required for vibration measurement have improved vastly in the last few years. The most accepted among these is the FFT (Fast Fourier Transform) Spectrum Analyser. The FFT spectrum analyser provides a huge store of information and can give the complete idea of the dynamic motion in real time and store the data for later use. FFT uses fast microprocessors to instantaneously transform data using Fourier transforms from time domain to frequency domain and vice versa in real time. The data analysed through FFT can be used to find the natural frequencies, damping ratios, and other mode shapes in numerical or graphical form, using the necessary software and hardware.



Experimental Setup using FFT
Fig. 6.9.2

The method of conversion and the experimental setup is schematically shown in Fig. 6.9.2 . The FFT comprises of fast processors which are developed for creating the necessary data in real time mode. The analog data can than be used to generate a set of discrete data points using a DFT (Discrete Fourier Transform) which can be digitally stored for future analysis. This data is recorded digitally using a data acquisition system which is connected to a computer. Computer based FFT analysers can also be used to observe the trends of vibration signals. Vibration signatures can be recorded and compared graphically with the previous results. This would highlight the state of the machine and corrective procedures can then be employed by detecting the source of vibration.

6.10 VIBRATION MONITORING OF MACHINES

New machines when installed do not have large vibrations to begin with, as they are accordingly designed. However, with use, the machines are subjected to wear, fatigue, foundation settlement, misalignment, clearances between mating parts, initiation of cracks, imbalances and other such factors, which are the sources of larger vibrations in the machine. As the machine life increases, these vibrations keep on increasing, finally leading to failure.

A skilled technician can monitor the state of the machine by *aural* means. Careful listening to the noise of the machine reveals a lot about the state of the machine. In some cases, where accessibility is restricted, the technician may use the help of microphones to detect sounds which can point out the possible problem areas of the machine. Necessary corrective and preventive action can then be taken to eliminate these problems. Stroboscopes and magnifying glasses can be used to visually monitor large deflections. This method of monitoring also require a skilled technician who can detect the source of vibrations before they cause a failure.

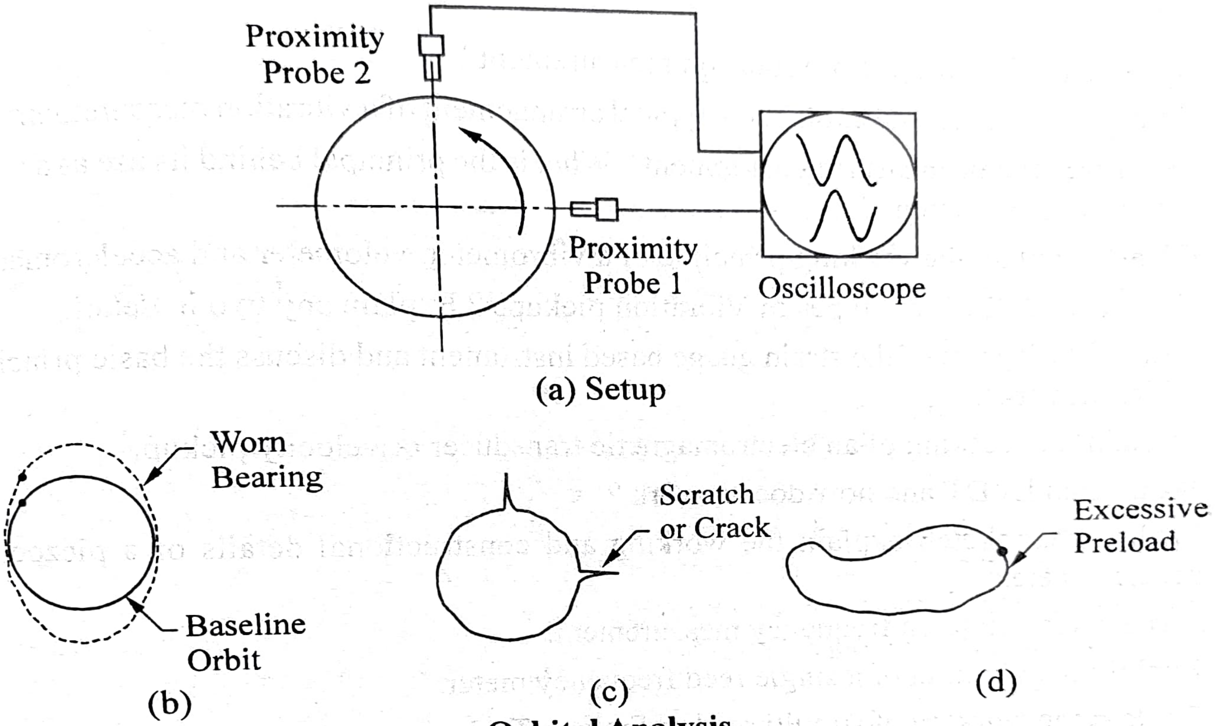
To develop modern methods of vibration monitoring of machines, research is being carried out to identify the changes in vibration levels, how they can be identified and interpreted. The methods implemented to do so are explained below.

a). Time Domain Analysis :

In many cases, it is seen that the vibration signature obtained is periodic in nature. The time domain analysis uses the time history of the signal and any transient impulses can be noted. To understand the interpretation of time domain analysis, consider the case of two meshing gears. If the pinion were to develop a crack, the transducer would record an impulse which would be repeated with the time period of the pinion. This periodicity would help the technician to identify a crack in a particular tooth of the pinion.

Another form of time based vibration monitoring is by using the readout from a vibration meter. ISO 2372 has created vibration severity charts which can be used as a guide to determine the condition of a machine by comparing the rms value of the measured vibratory velocity with the criteria set by the standards. This is one of the easiest methods to monitor the state of the machine. However, this method does not give the necessary warning of a possible failure of an individual component, as the signal obtained is that of a complete system.

Vibration analysis can also be carried out by using certain patterns called as *Lissajous figures*. This form of analysis is used in identifying faults in a rotating system and is also called as *orbital analysis*. The method involves the use of two transducers arranged with a phase difference of 90° as shown in Fig. 6.10.1. The readings are then fed to an oscilloscope and the resulting orbital graph is plotted. Any change in the pattern of these figures or orbits can be used to provide considerable information about the rotor dynamic behaviour. For example, consider Fig. 6.10.1 (b), where it is seen that orbit diameter has increased in the vertical direction. This would mean a larger clearance in the vertical direction.



Orbital Analysis
Fig. 6.10.1

b). Frequency Domain Analysis :

The frequency domain analysis or frequency spectrum is a plot of the amplitude of vibration versus the frequency. This can be generated from the time domain signal using a FFT spectrum analyser. The frequency spectrum gives useful information in detecting vibrations caused by a particular component of the system as seen earlier in article 6.9. It thus works as a health chart of the machine and gives status and condition of its major components. As the spectrum is studied, the various peaks relate to various machine components. The fault frequencies of standard components like bearings, fans, pumps, gearboxes, and pulleys can be compared with standard formulas worked out. This would allow the technician to detect unbalance, misalignment, resonance, oil whirl and loosening of parts.

c). Cepstrum Analysis :

A spectrum analysis helps in identifying the faults of individual components like gear boxes. However, the analysis gets complicated if a particular gear is to be identified in a gearbox having multiple gear pairs. In such cases a Cepstrum procedure is used. A cepstrum is essentially the spectrum of a spectrum. This analysis can detect any periodicity of the spectrum caused by a faulty part of a component such as a blade of a fan, gear tooth of a gear and so on. The word *cepstrum* is obtained by rearranging the letters of the word *spectrum*.

EXERCISES ?

1. What is the importance of vibration measurement ?
2. Draw a neat sketch and explain the typical arrangement of a vibration measurement system.
3. What are seismic measuring equipment ? What is the principal behind its use as a vibration measuring instrument ?
4. Clearly explain the working principle of a vibrometer, velometer and accelerometer.
5. What are the different types of Vibration pickups ? Explain any two in detail.
6. Draw the diagram of the strain guage based instrument and discuss the basic principle on which it works.
7. Explain the working of an electromagnetic transducer or velocity pickup.
8. What is an LVDT and how does it work ?
9. With a neat sketch explain the working and constructional details of a piezoelectric accelerometer.
10. Write a short note on frequency measurement.
11. Explain the working of a single reed frequency meter.
12. Explain the working of a multi reed or Frahm's Tachometer.
13. What is a stroboscope and how is it used ?
14. What are vibration exciters ? Explain the types of mechanical vibration exciters.
15. What is an electrodynamic exciter ?
16. What are vibration meters ?
17. What is the significance of the Fourier series ?
18. What are FFT Analysers ?
19. Explain how frequency spectrum can be used to detect vibration related faults in a system.
20. Draw a neat sketch of the experimental setup of for vibration measurement using an FFT analyser.
21. Write a short note on vibration monitoring of machines.
22. What do you understand by time domain and frequency domain analysis ? How are they useful in predicting vibration failures ?
23. What do you understand by orbital analysis ?
24. Define the term Cepstrum.