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MECHANICAL ENGINEERING MEASUREMENTS

UNIT 5 : VIBRATION AND STRAIN MEASUREMENT

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INTRODUCTION

- ✓ Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point.
- ✓ The word comes from Latin vibrationem ("shaking, brandishing").
- ✓ The oscillations may be periodic, such as the motion of a pendulum or random, such as the movement of a tire on a gravel road.
- ✓ Vibration can be desirable: for example, the motion of a tuning fork, the reed in a woodwind instrument or harmonica, a mobile phone, or the cone of a loudspeaker.

INTRODUCTION

- ✓ In many cases, however, vibration is undesirable, wasting energy and creating unwanted sound.
- ✓ For example, the vibrational motions of engines, electric motors, or any mechanical device in operation are typically unwanted.
- ✓ Such vibrations could be caused by imbalances in the rotating parts, uneven friction, or the meshing of gear teeth.
- ✓ Careful designs usually minimize unwanted vibrations.

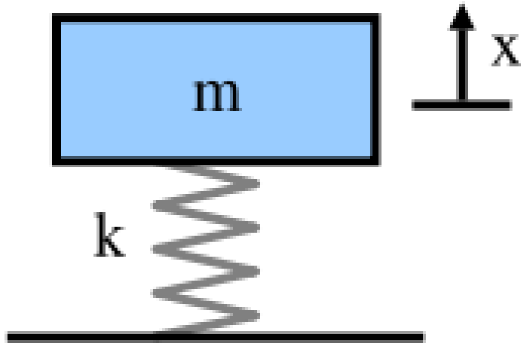
INTRODUCTION

- **Natural frequency**, also known as Eigen frequency, is the frequency at which a system tends to oscillate in the absence of any driving or damping force.
- The motion pattern of a system oscillating at its natural frequency is called the **normal mode** (if all parts of the system move sinusoidal with that same frequency).

- **Types of vibration**
  - Free vibration
  - Forced vibration
  - Damped vibration

INTRODUCTION

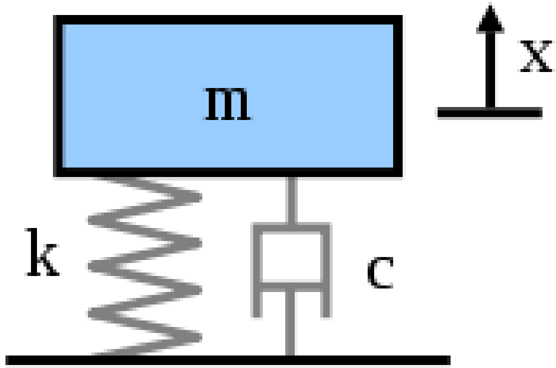
- ✓ For the simple mass–spring system, fn is defined as:



$$w_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

- ✓ Free vibration with damping

$$m\ddot{x} + c\dot{x} + kx = 0$$



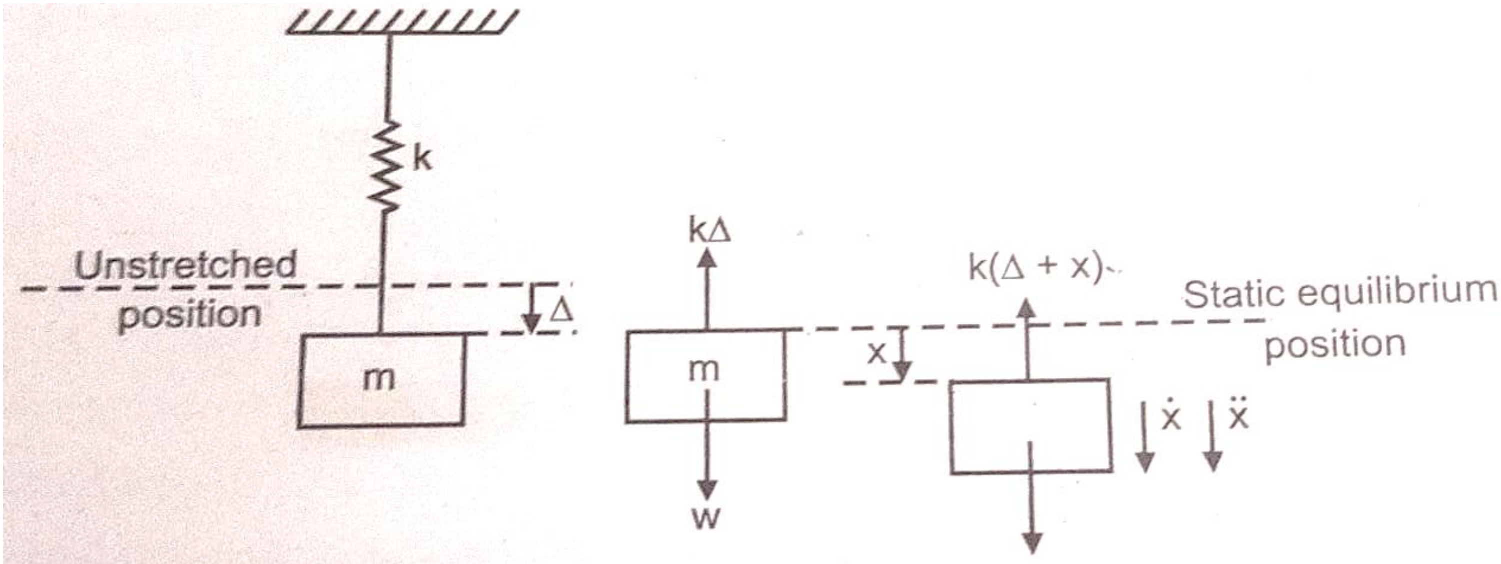
$$\Rightarrow \ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}x = 0$$

$$\Rightarrow \ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2 x = 0$$

$$\omega_d = \sqrt{1-\zeta^2}\omega_n$$

INTRODUCTION

✓ **Equation of Motion : Natural Frequency**



Vibration Measurement

- **Reasons for the measurement of vibrations**

- ✓ Some machines are running at high speeds which may cause resonant condition and they may get fail.
- ✓ In some situations the excessive vibrations may transfer to the nearby machines or structures.
- ✓ To check the health of the machines.
- ✓ To understand the dynamic behavior it is necessary to measure the vibrations.
- ✓ It helps to identify important parameters of system such as mass, stiffness, damping.

Vibration Measurement

- **Classification of vibration measuring instruments**

1. Classification base on contact

    1. Contact type
    2. Non-contact type

2. Classification base on display method

    1. Indicating type
    2. Recording type

3. Classification base on time base measurement

    1. Real time based
    2. Non-real time based

4. Classification base on power source

    1. Active system
    2. Passive system

Vibration Measurement

1. Classification base on contact

I. Contact type

These types of vibration measuring instruments are in direct contact with the vibration machines. These instruments are compact in size.

e.g. Accelerometer

II. Non-contact type

These types of vibration measuring instruments are used when it is very difficult to use the contact type vibration measuring instruments. These types of instruments also small in size.

Vibration Measurement

2. Classification base on display method

I. Indicating type

In these instruments, the measured data are displayed on the display unit of the instruments.

II. Recording type

These instruments are used to display and also to record the data for future analysis.

e.g. FFT analyzer

Vibration Measurement

3. Classification base on time base measurement

I. Real time based

The real time based data can be measured using these instruments. These instruments are working based on microprocessor.

II. Non-real time based

These instruments are not real time based. The measure data can only display on the display unit of the instruments.

Vibration Measurement

4. Classification base on power source

I. Active system

In these instruments, source of power is required to operate the instruments for vibration measurement.

e.g. FFT analyzer

II. Passive system

These instruments do not require any outside source of power to operate the instruments. They are compact, handy and battery operated.

e.g. Frahm’s tachometer

Vibration Measuring Instruments

- The instruments or equipments which are used for measure the displacement, velocity, frequency, phase distortion and acceleration of a vibrating g body are called vibration measuring instruments.
- The displacement, velocity and acceleration is identify by the relative motion of the suspended mass of the instruments with respect to its case which is placed on the vibrating body.
- Vibration measuring devices having mass , spring , dashpot etc. are called seismic instruments .

- The quantity which is measure by the instruments are displayed on the screen in the form of electric signal which can be readily amplified and recorded.
- The output of electric signal of the instrument is proportional to the quantity which is measured. The input is reproduced as output very precisely.

Vibration Measurement

❑ Vibration Transducers

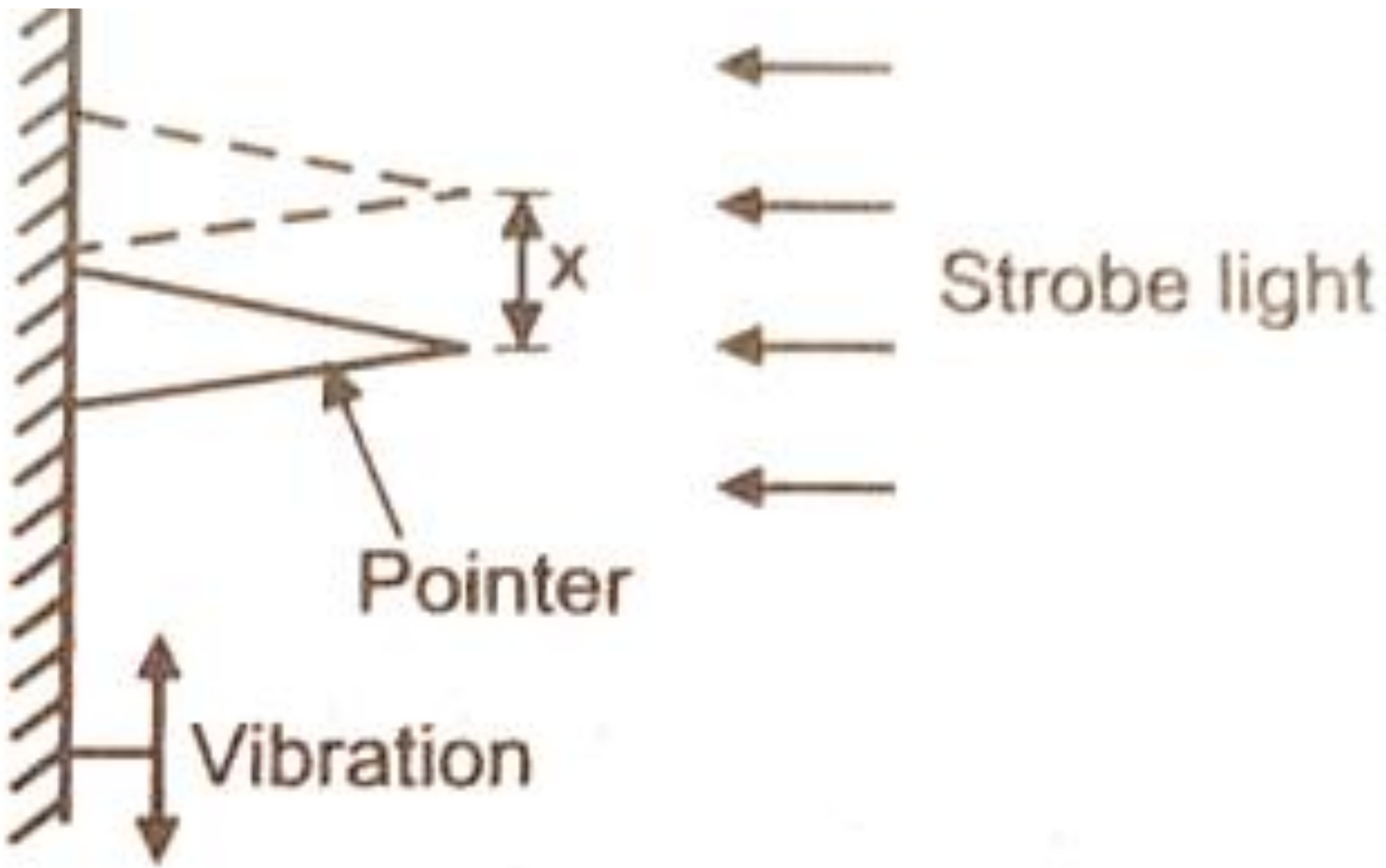
I. The Stroboscope Method

- ✓ The fixed pointer or stud, shown in Figure, is attached to the vibrating surface and is used to give an indication of the displacement only.
- ✓ By using the light of a stroboscope to “freeze” or “slowly move” the stud, quite high-frequency small-amplitude vibrations may be measured.
- ✓ The typical upper range of frequency is quoted at 500 Hz for direct measurement.

Vibration Measurement

- **Vibration Transducers**

I. The Stroboscope Method



Vibration Measurement

❑ Vibration Transducers

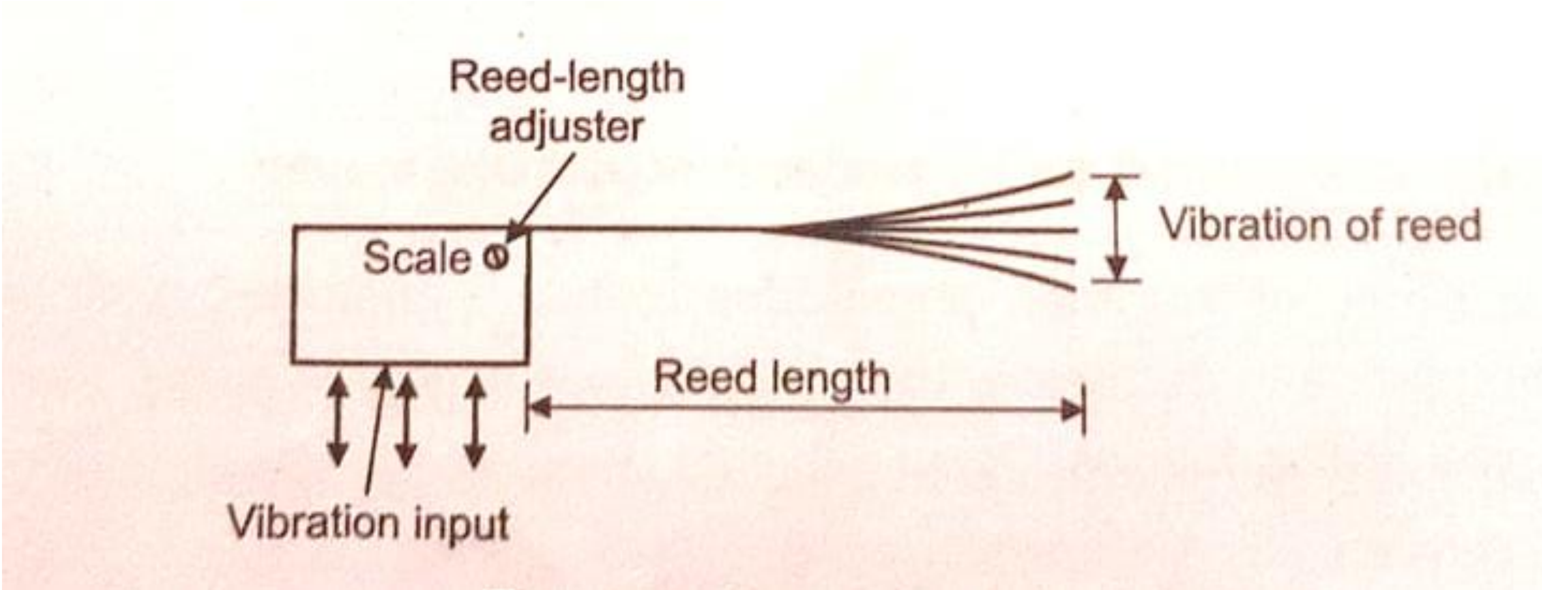
II. The Reed Vibrometer

- ✓ The variable-length reed vibrometer shown in Figure, is used to measure the main frequency component of the vibration.
- ✓ In practice the length l is adjusted until the maximum reed vibration occurs, when its resonant frequency is the same as the frequency of the vibrating mechanism or structure.
- ✓ The length l is calibrated directly in Hz.
- ✓ A small mass may be added to the cantilever if the vibrometer is to be used for very-low frequency investigation, but the scale readings would then need to be corrected for the additional mass.

Vibration Measurement

❑ Vibration Transducers

II. The Reed Vibrometer



- ✓ The range of measurement is quoted as 5 Hz to 10kHz.

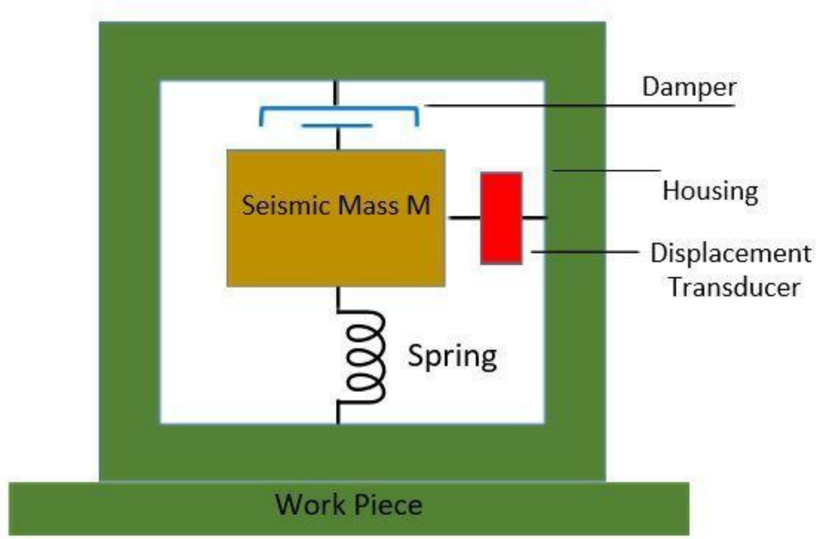
Vibration Measurement

❑ Vibration Transducers

III. The Seismic-Mass Transducer

Definition: The seismic transducer is used for measuring the vibration of the ground.

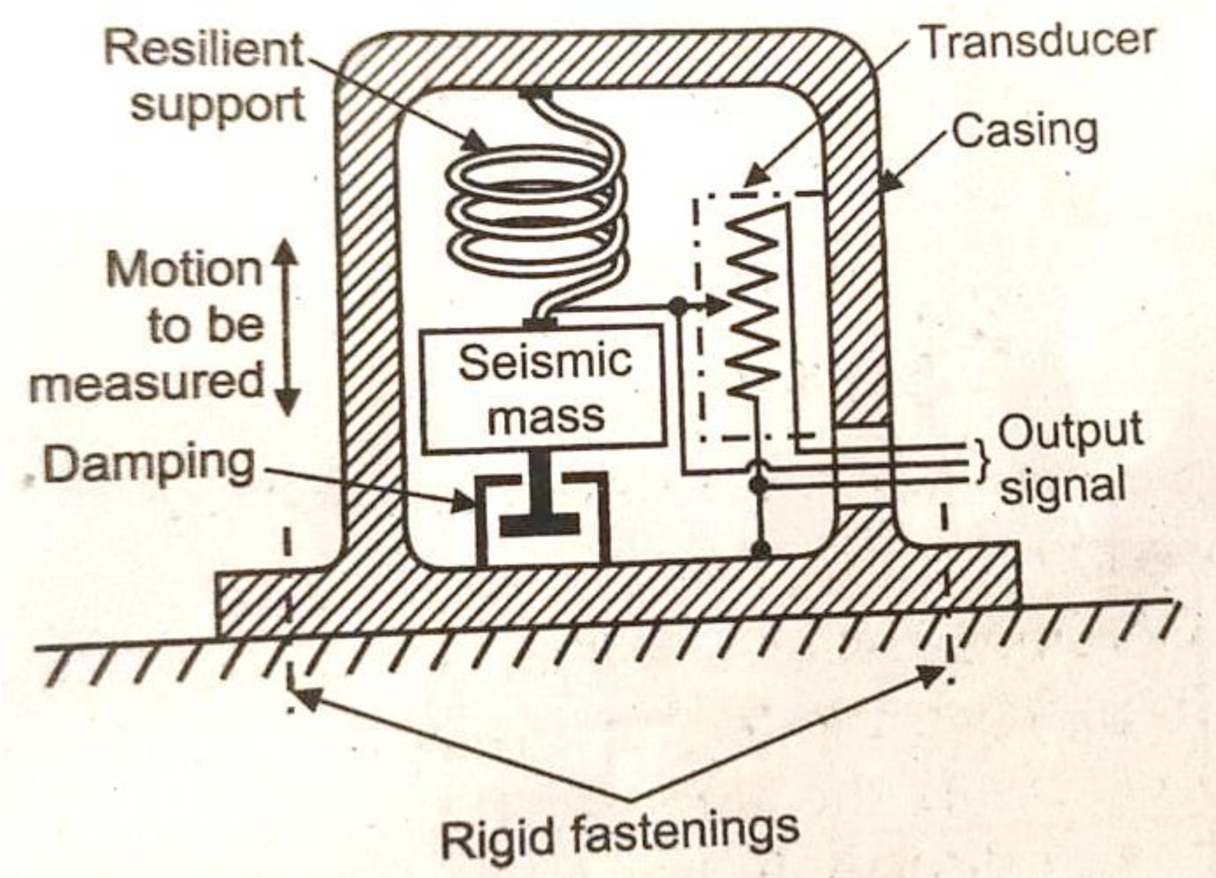
The spring mass damper element and the displacement transducer are the two main component of the seismic transducer.



Vibration Measurement

❑ Vibration Transducers

III. The Seismic-Mass Transducer



Vibration Measurement

❑ Vibration Transducers

III. The Seismic-Mass Transducer

Mode of Transducer

The seismic transducer works in two different modes.

I. Displacement Mode

II. Acceleration Mode

The selection of the mode depends on the combinations of the mass, spring and damper combinations. The large mass and soft spring are used for the displacement mode measurement while the combination of the small mass and stiff spring is used for the acceleration mode.

Vibration Measurement

❑ Vibration Transducers

III. The Seismic-Mass Transducer

Types of Seismic Transducer

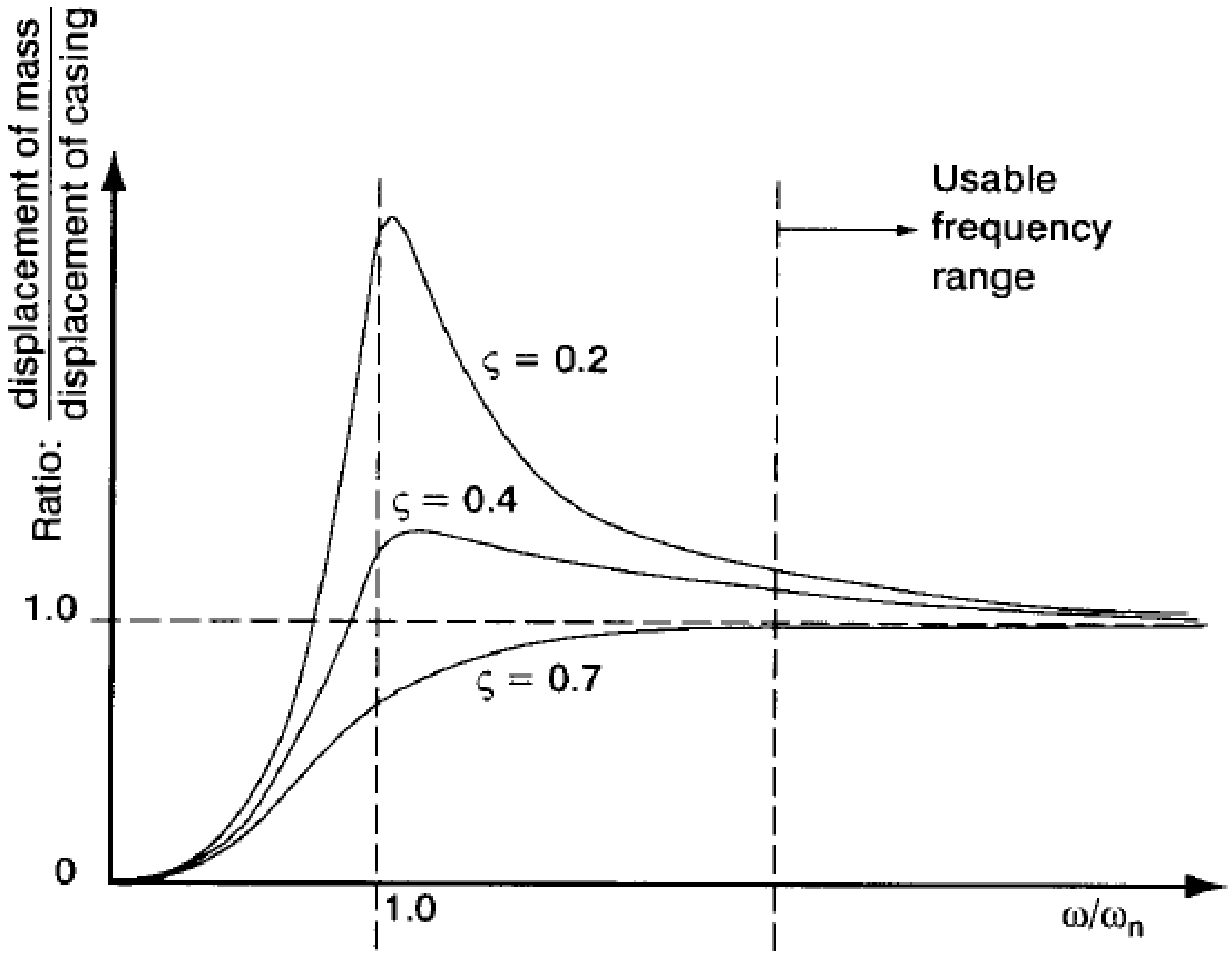
1. Vibrometer – The vibrometer or low-frequency meter is used for measuring the displacement of the body. It also measures the high frequency of the vibrating body. Their frequency range depends on the natural frequency and the damping system.

2. Accelerometer – The accelerometer measures the acceleration of the measuring body. The acceleration shows the total force acting on the object.

Displacement Pickups

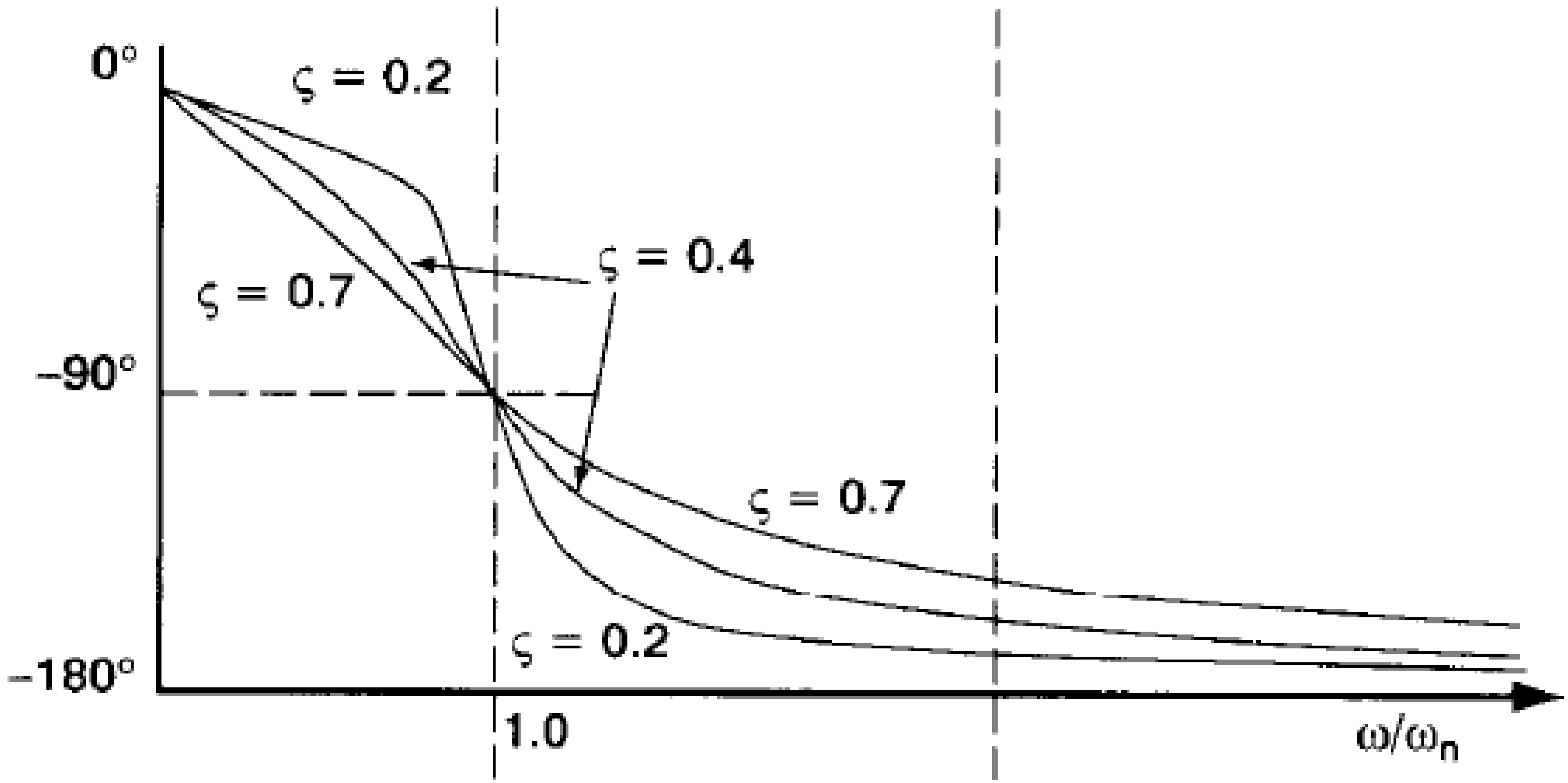
- ✓ This type of pickup is used to measure the displacement of a vibrating body when there is no fixed reference point available, for example in determining the movement of the chassis of a vehicle.
- ✓ We therefore want the seismic mass to behave (as far as possible) as though it was fixed in space.
- ✓ This can be arranged by using a relatively large seismic mass and a relatively 'floppy' resilient support.
- ✓ This gives a low value of ωn to the spring-mass system. Figure shows the frequency response of such a pickup with various values of damping ratio ζ.

Displacement Pickups



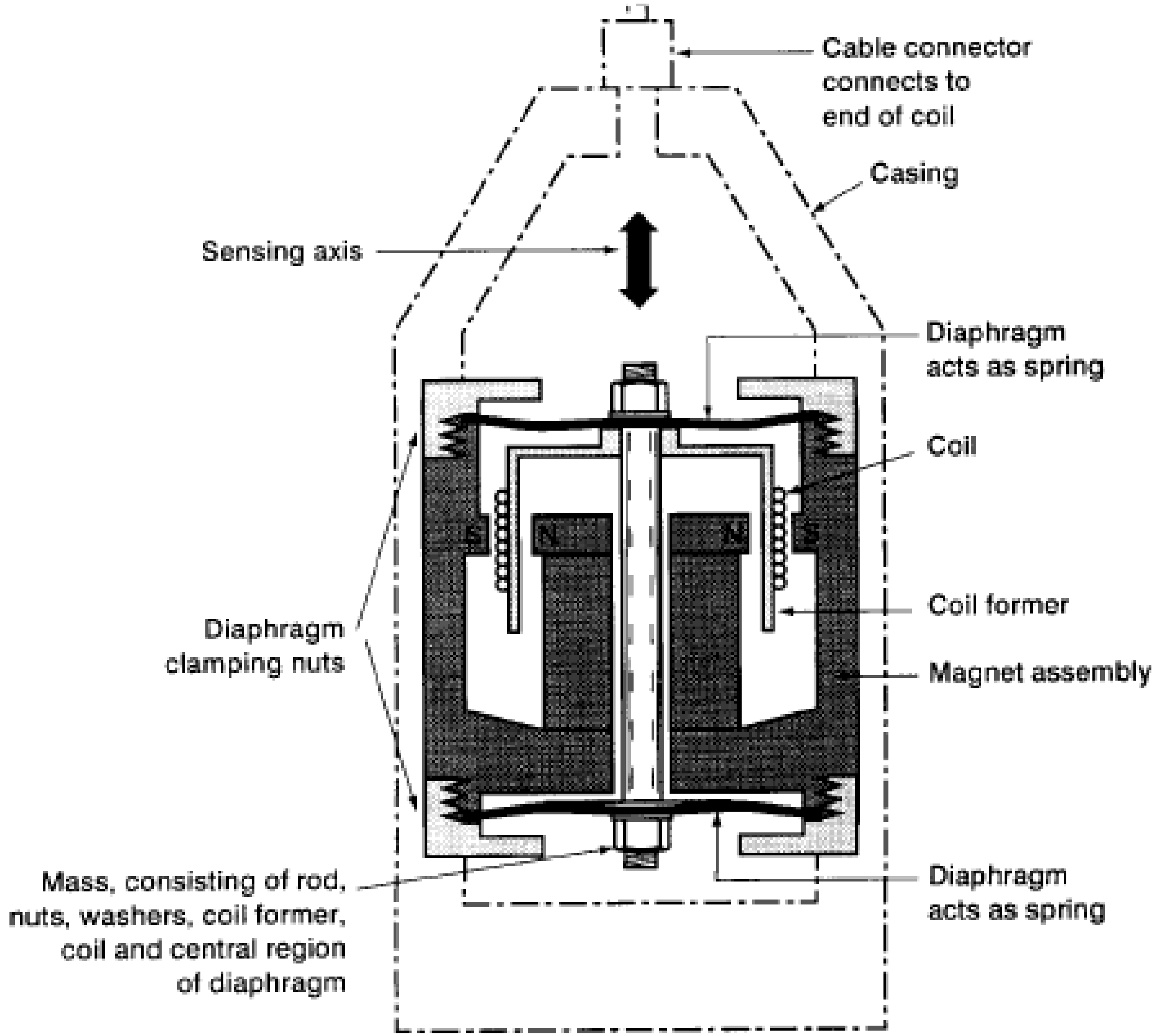
Frequency response of a seismic displacement pickup amplitude

Displacement Pickups



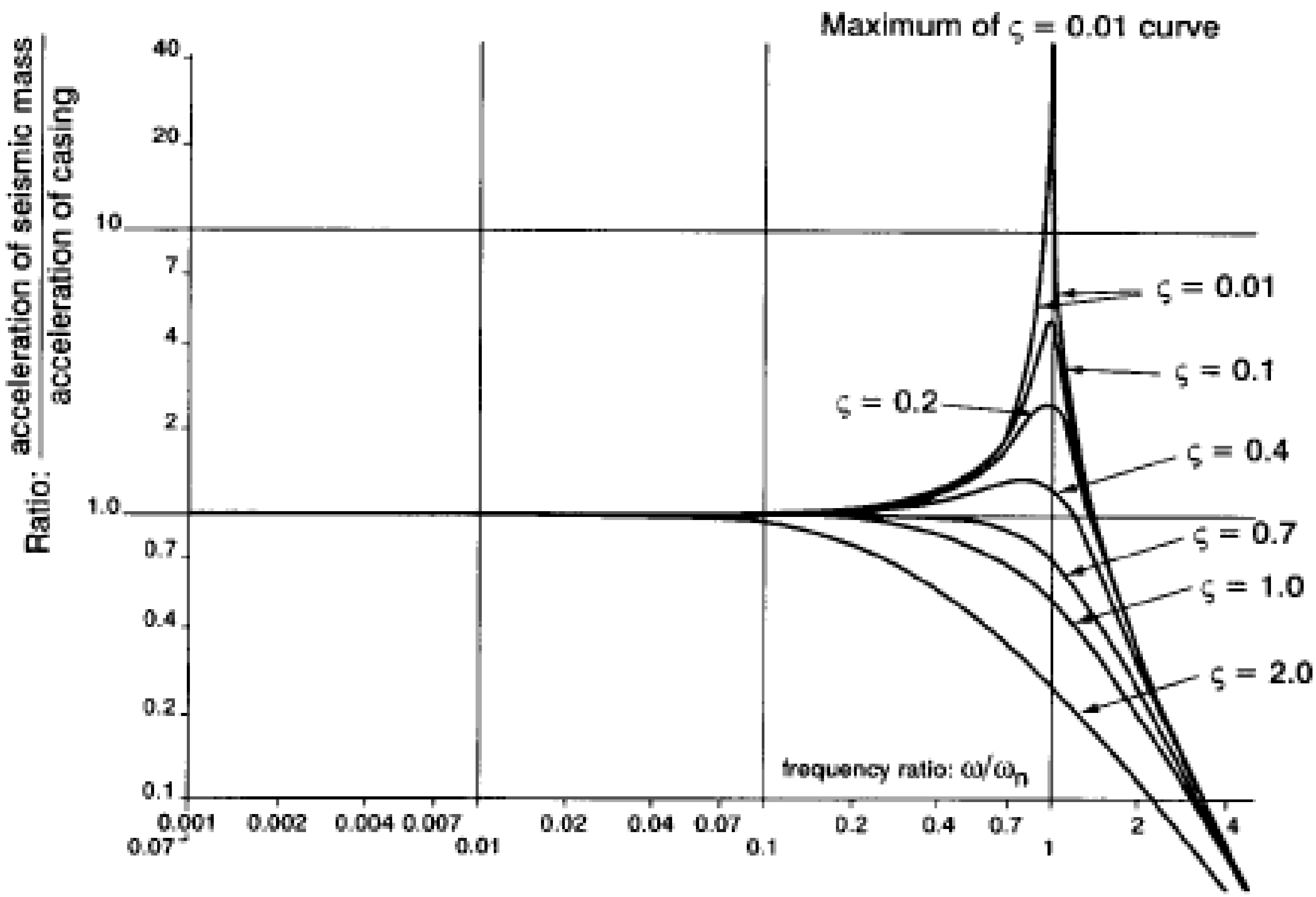
Frequency response of a seismic displacement pickup phase

Velocity Pickups



Seismic Velocity Pickup

Acceleration Pickups (accelerometers)



Frequency Response of a Seismic Accelerometer

Vibration Measurement

- **Vibration Measuring Instruments**

- **Displacement measuring instrument (Vibrometer)**

- **Velocity measuring instrument (Velometer)**

- **Acceleration measuring instrument (Accelerometer)**

Types of Vibration Measuring Devices

- Vibrometer
- Accelerometer

Figure : 1

Vibrometer

- A Vibrometer or seismometer is used for measuring displacement of a vibrating body. Basically it is design under the condition of low natural frequency due to this reason it is also called as low frequency transducer. This is used to measure high frequency ω of a vibrating body.
- Its natural frequency has ranged between 1 Hz to 5 Hz and useful natural frequency range of 10 Hz to 2000 Hz.
- The sensitivity of this instruments is in the range between the 20 to 350 mV/cm/s. The maximum displacement is ranged between the 0.5 peaks to one peaks.

Application & Disadvantages of Vibrometer

Application

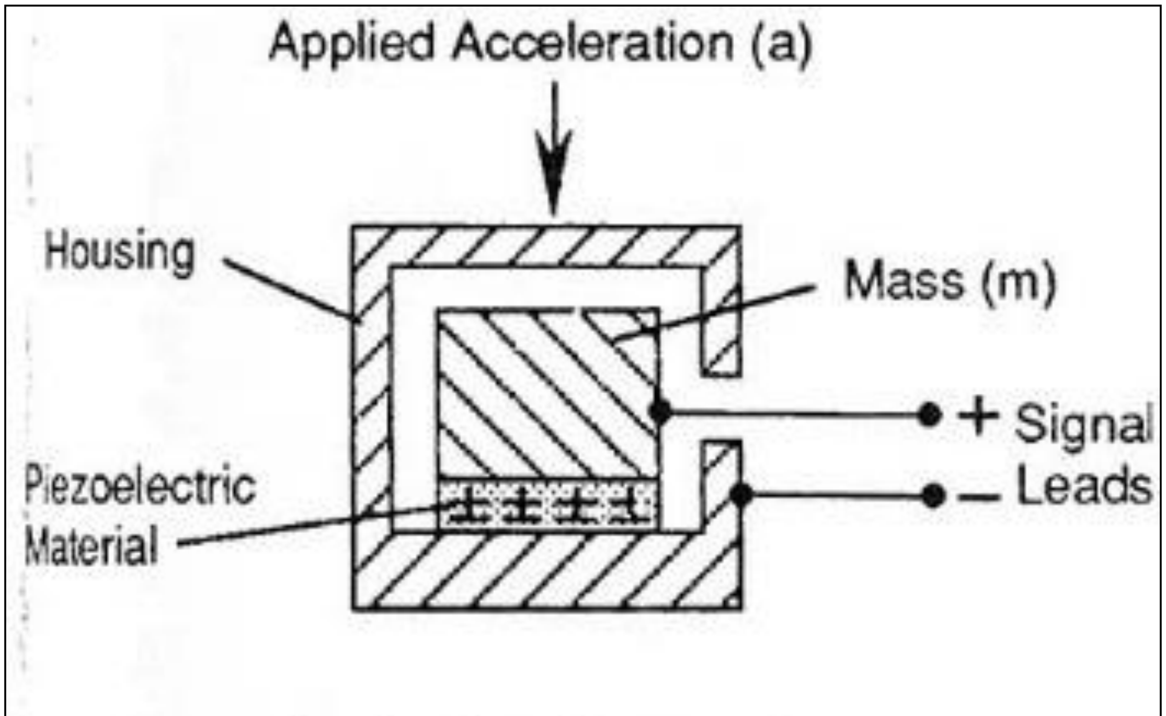
- The instrument is used to record building vibrations. also used for measuring vibration of the huge structure like railway bridge.

Disadvantage

- It is large in size because of its relative motion of the seismic mass must be of the same arrangement of the magnitude as that of the vibration to be measured.

Accelerometer

- Accelerometer is a instrument used for measuring the acceleration of the vibrating body. The accelerometer is design with the high natural frequency and it is said to be high frequency transducer.



Basic Accelerometer

Types of Accelerometer

- ***Electromagnetic type of accelerometer*** use damper to extend the useful natural frequency range. it is also using for the prevents phase distortion.
- ***Piezoelectric crystal accelerometer*** having zero damping is operating without distortion. It is used for measuring high frequency.
- ***Seismic mass accelerometer*** is used for low frequency vibration. The supporting springs are four electric strain gauges wires which is connected with the bridge circuit.

Comparison of Vibration-Measuring Systems

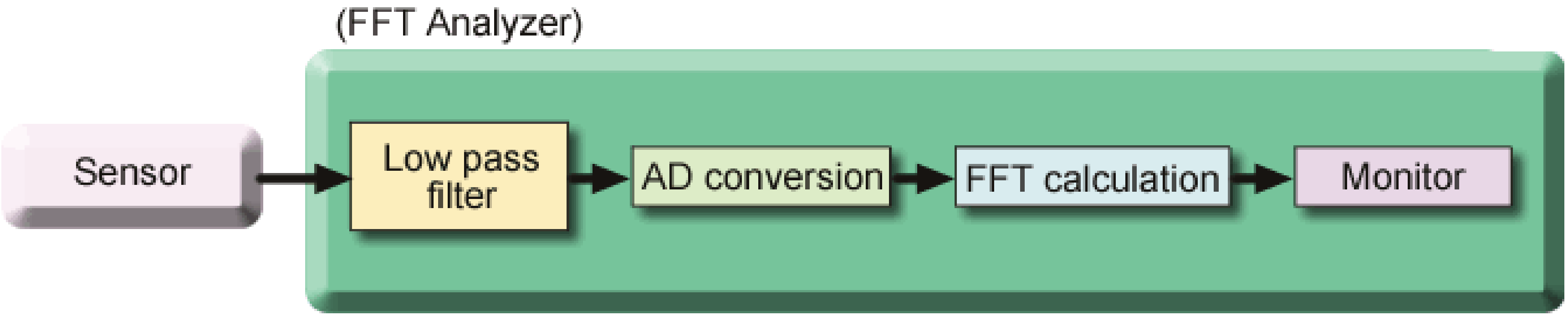
Transducer	Parameter	Signal conditioner	Frequency range	Remarks
Capacitive Inductive	Displacement	Amplitude modulation with bridge circuits	0-0.1 f_c f_c = carrier frequency	Usually relative displacement only
Electro-magnetic	Velocity	May need an amplifier	15 to 1000Hz	Poor low frequency response
Piezo-electric	Acceleration	Charge amplifier	0-0.3 f_n (f_n, the natural frequency, is typically 22 kHz)	Wide range of measurement. Typical ±10000g

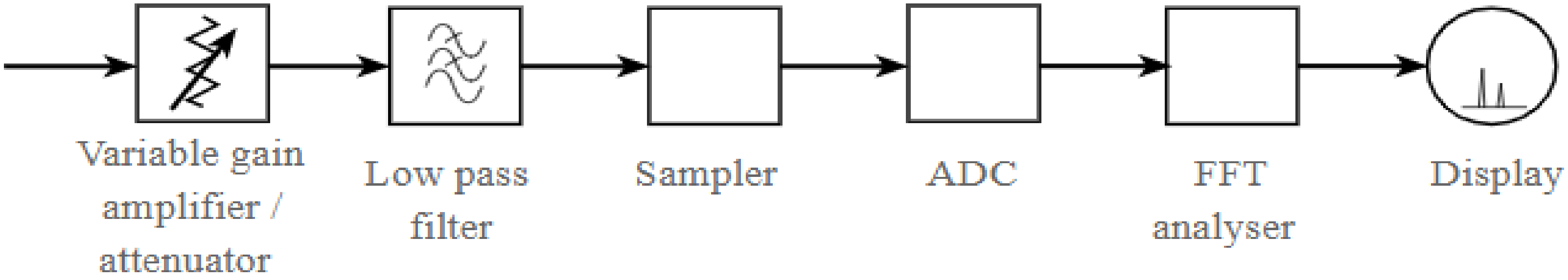
FFT Analyzer

- ✓ FFT, an abbreviation for Fast Fourier Transform, is an algorithm to transform time series signal to frequency axis signal.
- ✓ A continuous signal voltage from sensors such as vibration detector or microphone is sampled in regular intervals, and performed analog-digital conversion to FFT calculation.
- ✓ To avoid aliasing phenomenon that provides us with the frequency components which do not exist in actuality, low pass filter is used before sampling.
- ✓ FFT processed signal is calculated to power spectrum, frequency response or others and made best use of presuming abnormal part of the instrument or natural vibration measurement of

FFT Analyzer

- ✓ FFT processed signal is calculated to power spectrum, frequency response or others and made best use of presuming abnormal part of the instrument or natural vibration measurement of structures which is difficult in waveform analysis.





Frequency Measuring Instruments

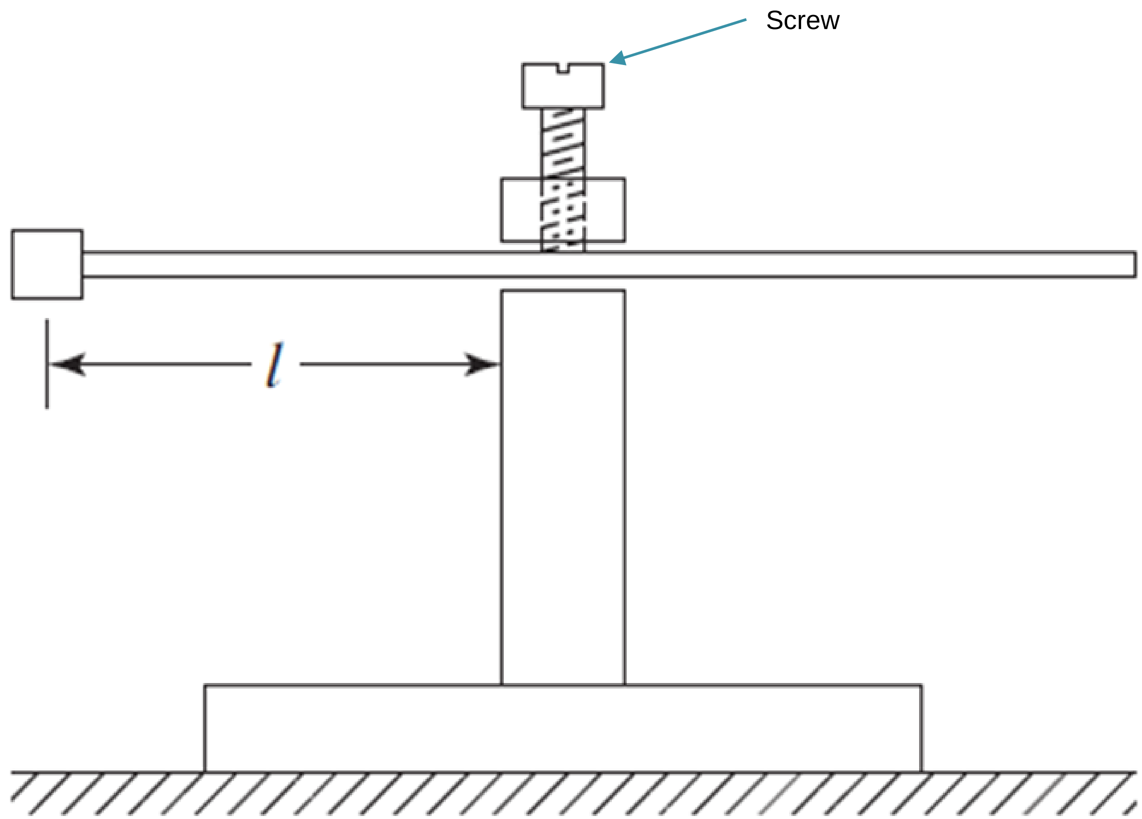
Most frequency-measuring instruments are of the mechanical type and are based on the principle of resonance.

There are two types of frequency measuring instruments

1. Fullarton tachometer
2. Frahm tachometer.

Single Reed Instrument or Fullarton Tachometer

- This instrument consists of a variable length cantilever strip with a mass attached at one of its ends.
- The other end of the strip is clamped, and its free length can be changed by means of a screw mechanism.



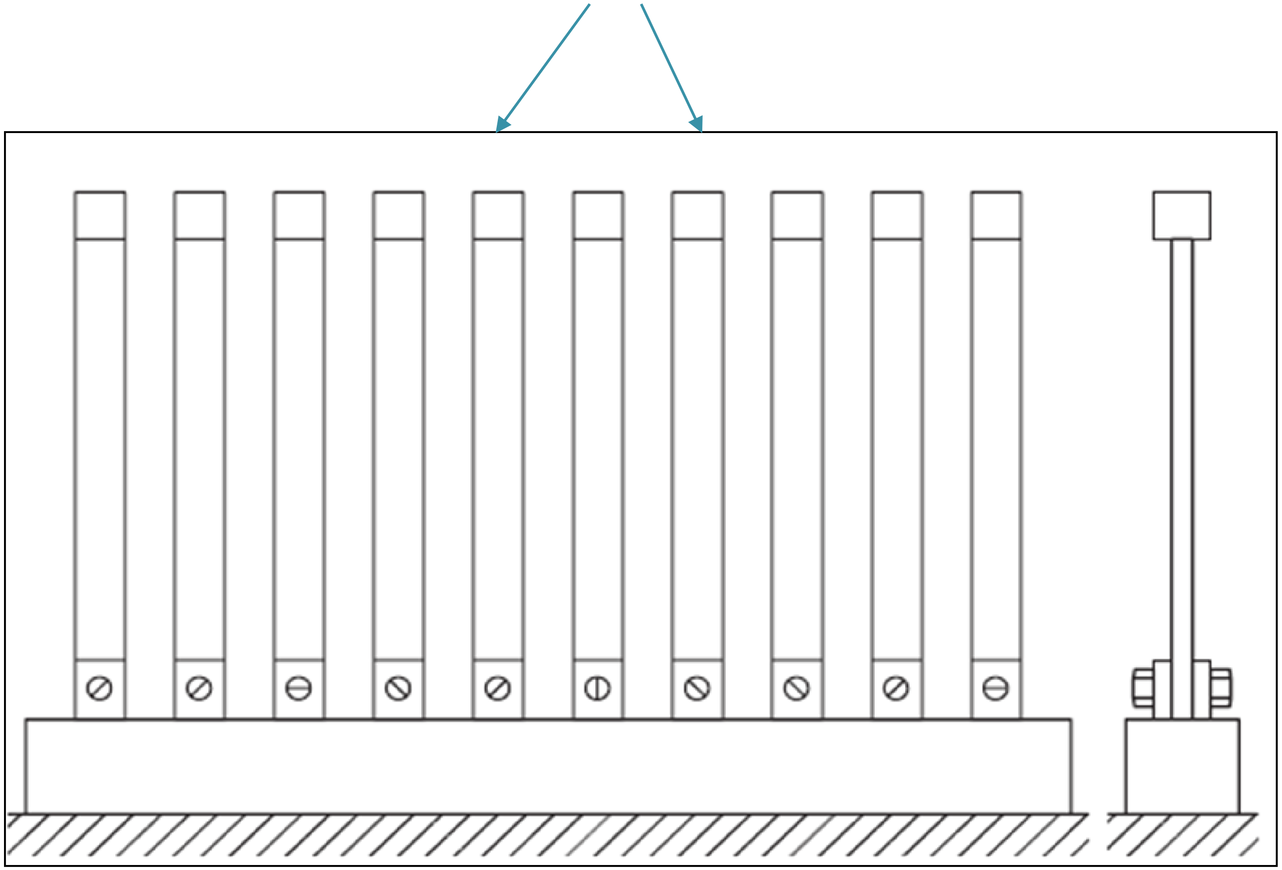
- Since each length of the strip corresponds to a different natural frequency, the reed is marked along its length in terms of its natural frequency.
- In practice, the clamped end of the strip is pressed against the vibrating body, and the screw mechanism is manipulated to alter its free length until the free end shows the largest amplitude of vibration.
- At that instant, the excitation frequency is equal to the natural frequency of the cantilever; it can be read directly from the strip.

Multi Reed Instrument or Frahm Tachometer

- Frahm's reed tachometer is used to measure the frequency of vibrations.
- The instrument consists of a number of reeds in the form of cantilever carrying small masses at their free ends.
- The reed with natural frequency rear to that of excitation frequency to be measured will vibrate at resonance to produce large amplitude of the vibration.

Multi Reed Instrument or Frahm Tachometer

Cantilever reeds



- Each reed has a different natural frequency and is marked accordingly. Using a number of reeds makes it possible to cover a wide frequency range.
- When the instrument is mounted on a vibrating body, the reed whose natural frequency is nearest the unknown frequency of the body vibrates with the largest amplitude.
- The frequency of the vibrating body can be found from the known frequency of the vibrating reed.

Disadvantage

- The main disadvantage of these instruments is the small range of frequencies which can be measured.