5.2 MAGNETOSTRICTIVE TRANSDUCERS:

- Magnetostrictive transducers are similar to piezoelectric transducers and are based on the, application of the magnetostriction phenomenon.
- They are converters of mechanical energy into magnetic energy and are also known as magneto-elastic transducers.
- The phenomenon is reversible and the devices developed convert energy from one form to another.
- The natural of the transducers can be as high as 10 KHz and are very much used as transmitters (senders) and receivers in vibration and acoustic studies.
- The transducers possess very high mechanical input impedance and are suitable for measurement of force and hence acceleration and pressure.
- They can measure large forces, both static and dynamic.
- They are rugged in constructional features and when used as active transducers, the output impedance is low.
- Nickel and nickel-alloys are frequency mostly used.
- It is the basic non-linearity in the B-H characteristic which is responsible for its limited scope of application, especially when high accuracy is desired.

Magnetostriction Phenomenon

- Certain ferromagnetic materials are considerably affected in their magnetic properties when they are mechanically stressed. This phenomenon is known as "magnetostriction" (Villari effect) and is particularly significant in nickel and nickel- iron alloys.
- The shape and size of the B – H characteristic and the B - H loop is sufficiently altered when the material is subjected to tensile compression or shear stress.
- The B – H characteristics of nickel and nickel-iron (Ni, 68%) alloy are presented in Fig. (5.2.1) showing the effect of increasing tensile stress on the

materials.

- Similarly, the magnetization characteristic is affected and it is observed that the permeability increases with increase in tensile stress in the case of nickel-iron alloys and decreases in the case of pure nickel.

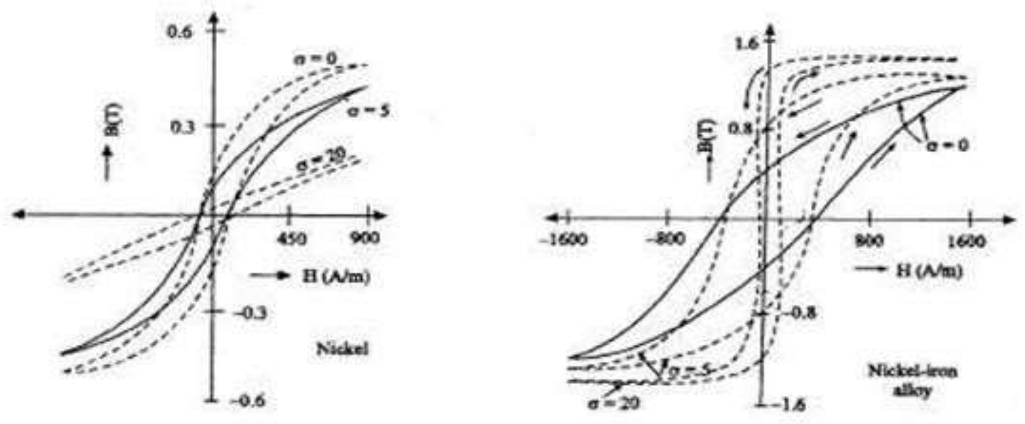

Fig. 5.2.1 B-H characteristics under different stress values (a) For nickel (b) For Nickel-lron alloy

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 822]

The change in the shape of the B - H loop alters the remnance Br of the material. When Br and permeability decrease with increase-in stress, it is known as "negative magnetostriction".

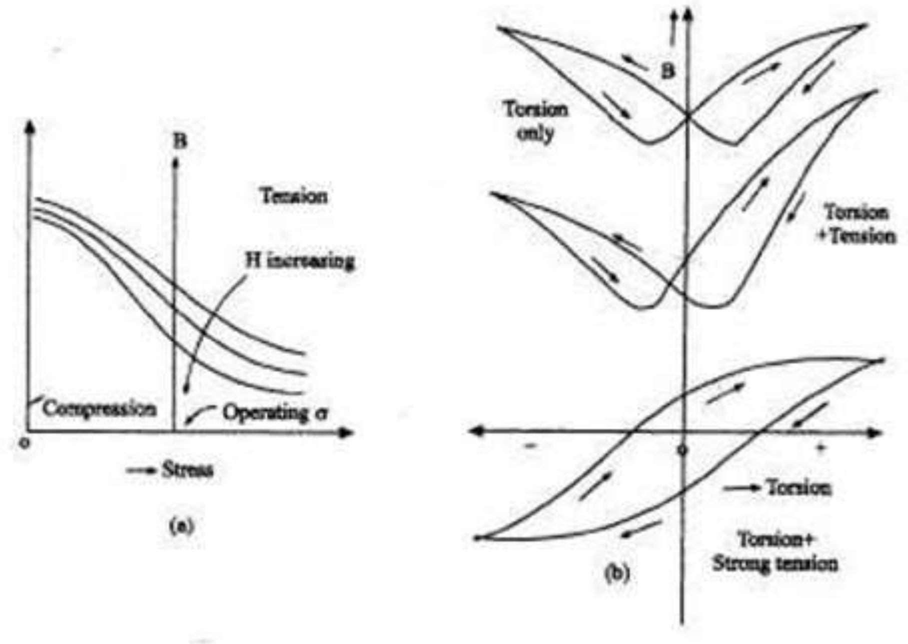

Fig. 5.2.2 Characteristics of a nickel sample (a) For H variation (b)For superposed cyclic torsion.

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 822]

The percentage of nickel in the nickel-iron alloy has considerable influence on the characteristics.

The materials are sensitive to the polarity of stress and hence the transducers enable measurement of alternating forces.

Some ferrite materials such as 'Ferroxcube B' exhibit magnetostriction of considerable degree but due of their brittleness, they are not used. Fig, 5.2.2 (a) shows the variation of B with stress at different values of H and Fig. 5.2.2 (b) shows the effect of superposition of cyclic torsion on tensile stress for the case of a nickel sample.

Magnetostrictive Force Transducer

- The self-inductance of an iron-cored coil change if the core characteristic is changed due to application of force.

- It is the mechanical strain that affects the orientation of the magnetic domains, and hence the change in the value of effective permeability.
- The magnetic path should be continuous with no air gap present.
- The core may be laminated.
- The laminations are stacked to form the core and a coil is provided to enable measurement of its self-inductance.
- The coil current is so adjusted as to make the self-inductance maximum and make it most sensitive to stress.
- One of the simple configurations commonly employed is shown in Fig.(5.2.3).
- The arrangement in fig. (5.14) allows the measurement of large static forces and 10-20 percent change in self-inductance is observed with nickel and nickel-iron alloy transducers.
- Application of stress results in a change of B hv depending on the material.
- The sensitivity of the transducer is defined as the ratio and is given by,

$$S = \frac{\Delta B}{\sigma}\Big|_{B = B_o}$$

B_o = Operating point of flux density

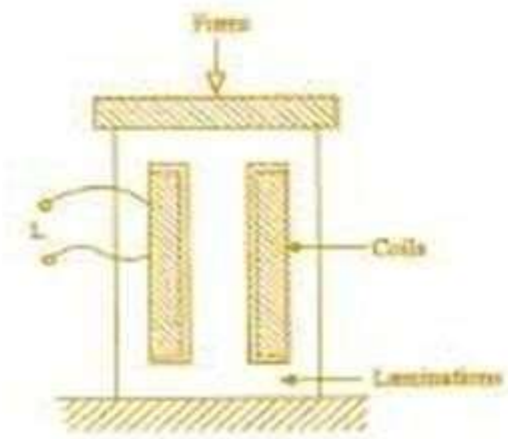

Fig. 5.2.3 Magnetostrictive force transducer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 825]

Magnetostrictive Acceleration Transducer

- To extend the application of the transducer for measurement of acceleration, addition of proof mass is required.
- The mass of the core itself serves as proof mass to some extent and additional mass is provided by a brass cylinder of at least an equal mass as shown in fig. 5.2.4.
- To prevent the transducer from responding to transverse accelerations, the brass cylinder is guided by a flexible diaphragm.
- The induced emf of the coil is integrated in such a way as to extend the bandwidth of the system towards the lower frequencies.
- As compared to piezoelectric accelerometers, these transducers are of larger size and mass and are lower in accuracy.
- While measuring acceleration, the variation in the earth's magnetic field affects the sensitivity.
- Laminations and coil should be rightly held in position so as not to be affected under high accelerations.

Magnetostrictive Torsion Transducer

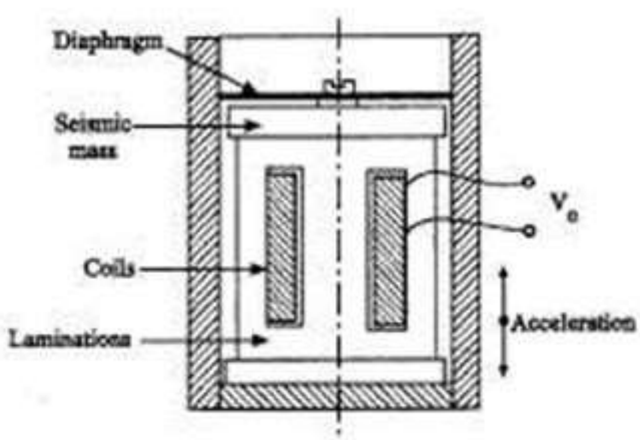

Fig. 5.2.4 Magnetostrictive acceleration transducer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 827]

Magnetostrictive torsion transducer consists of a nickel wire of 0.5 - 1mm diameter kept stretched between the poles of a permanent magnet and having a small stylus rigidly attached to it at the midpoint.

- The wire is pre stressed bytwisting it, before being installed into the position.
- Two pick-up coils of fine wire arc .wound round the wire on either side of the mid- point, as shown in fig. 5.2.5.
- Any displacement of stylus to one side or the other increases the torsion on one side and decreases it by an equal amount on the other side.
- This results in an increase of magnetic flux in one-half and a decrease in the other half.

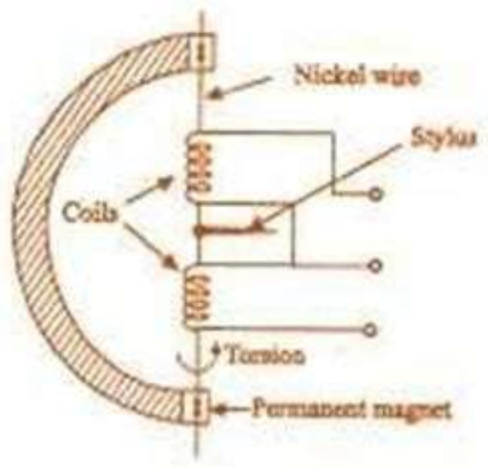

Fig. 5.2.5 Magnetostrictive torsion transducer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 829]

- The corresponding induced emfs are in phase opposition and are processed by suitable networks as in the case of linear variable differential transformer.

- It is used as phonograph pick-up and is designed to have flat frequency response over 150 Hz- 15 KHz frequency range.
- Due to the nonlinearity and hysteresis in the, performance, it is normally limited for use when time-varying torsions of small amplitude are to be measured.

5.1 PIEZOELECTRIC TRANSDUCER:

A piezoelectric transducer (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.

A transducer can be anything that converts one form of energy to another. The piezoelectric material is one kind of transducers. When we squeeze this piezoelectric material or apply any force or pressure, the transducer converts this energy into voltage. This voltage is a function of the force or pressure applied to it.

The electric voltage produced by a piezoelectric transducer can be easily measured by the voltage measuring instruments. Since this voltage will be a function of the force or pressure applied to it, we can infer what the force/pressure was by the voltage reading. In this way, physical quantities like mechanical stress or force can be measured directly by using a piezoelectric transducer is shown in Fig 5.1.1.

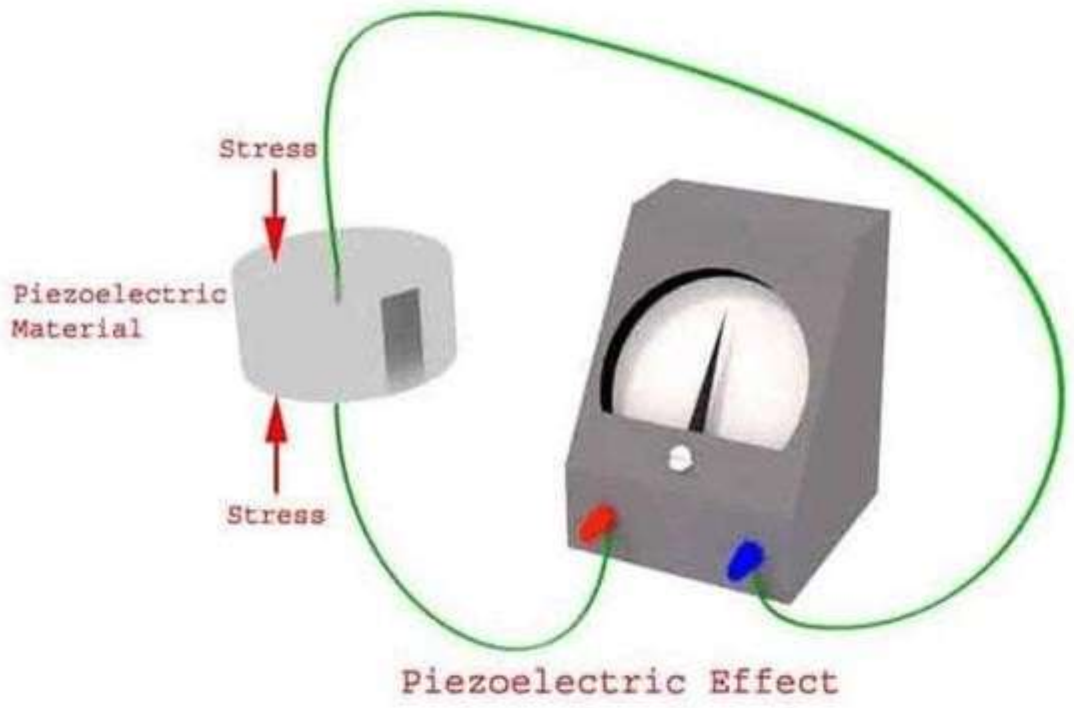

Fig 5.1.1 Piezoelectric Effect

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 802]

Piezoelectric Transducer Working Principle

A quartz crystal exhibits a very important property known as the Piezoelectric Effect. When some mechanical pressure is applied across faces of a quartz crystal, a voltage proportional to the applied mechanical pressure appears across the crystal. Conversely, when a voltage is applied across the crystal surfaces, the crystal is distorted by an amount proportional to the applied voltage. This phenomenon is known as the piezoelectric effect and the material that exhibits this property is known as a piezoelectric material is shown in 5.1.2.

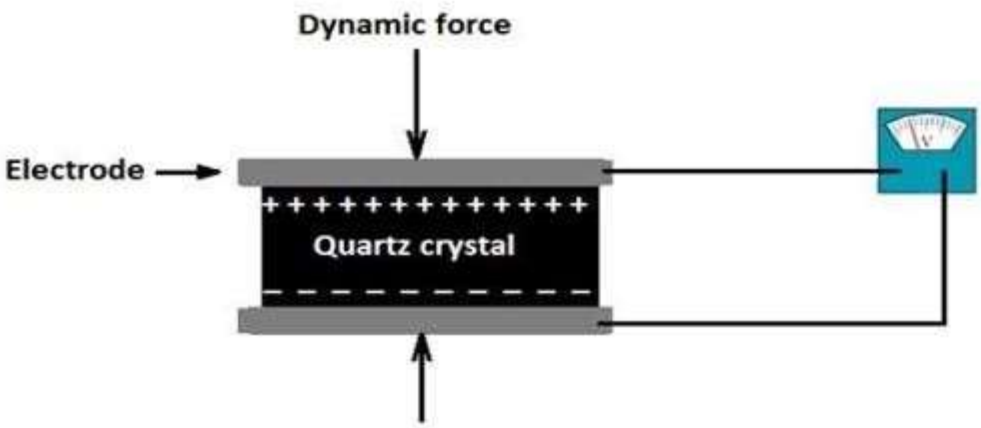

Fig 5.1.2 Working Model

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 803]

Materials for Piezoelectric Transducers

- The materials exhibiting the piezoelectric phenomenon are divided into two groups:
  - (i) Natural
  - (ii) Synthetic
- The natural group consists of quartz, Rochelle salt and tourmaline.
- The synthetic group consists of ammonium dihydrogen phosphate (ADP), lithium sulphate (LS) and Dipotassium Tartarate (DKT).
- Depending on the crystal structure, discs or wafers are-cut and used for measurement of force in one or the other of the modes described.
- Quartz is the most stable material and artificially grown quartz is normally preferred as it is purer than the natural quartz.
- Tourmaline is the only material exhibiting a large sensitivity.
- Rochelle salt is the material that is being produced on industrial scale for producing gramophone pick-ups.and crystal microphones.

- It has the highest relative permittivity among the natural group.
- ADP crystals possess the lowest resistivity which is also temperature dependent. With temperature compensation they are used in acceleration and pressure transducers.
- Lithium sulphate is highly sensitive.

Ferroelectric Materials

- They are certain polycrystalline ceramic compounds which exhibit the property of retaining electric polarization when exposed to intense electric fields.
- These materials are known as ferroelectric materials (equivalent to ferromagnetic materials), and after polarization, their behaviour is similar to the piezoelectric materials.
- Three such common substances which are popularly used for piezoelectric transducers are Barium titanate (BaTi03), lead zirconate-titanate, and lead metaniobate.

Piezoelectric semiconductors

- A localized stress on the upper surface of the p - n junction of a semiconductor diode caused a very large reversible current change in the current across the junction.

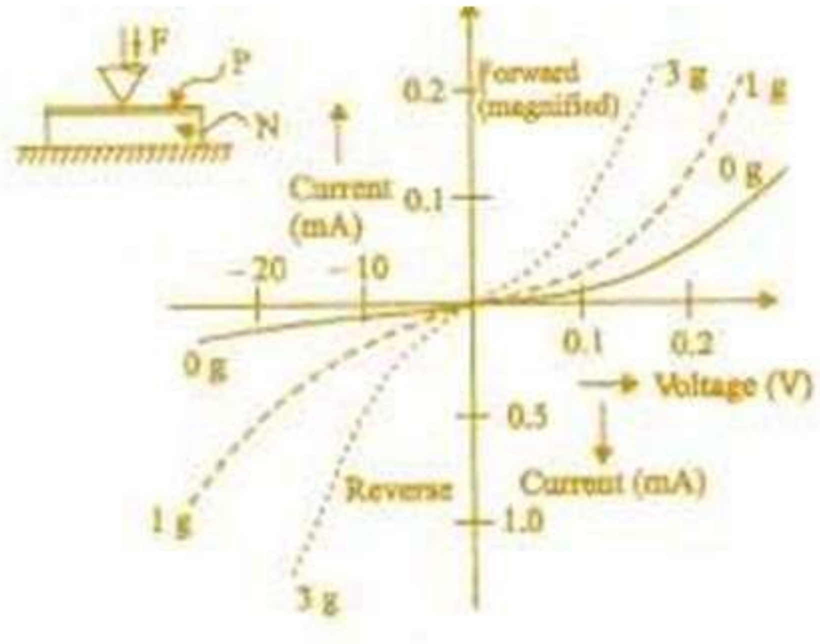

Fig. 5.1.3 Piezoelectric semiconductor diode and It's characteristics [Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 806]

- This phenomenon is due to the. anisotropic stress effect in $p-n$ junctions, and devices utilizing this effect are known as piezoelectric diodes and transistors.
- The variation of current across the junction of a Germanium diode for forward and reverse voltages is shown in Fig. (5.1.3).
- It is observed that considerable change in the magnitude of the current results from application of a few grams of localized force.
- Moreover, the change is reversible.
- The behavior of a silicon N-P-N planar transistor is shown in Fig(5.1.4).
- The force is applied to the surface by means of a pointed stylus.
- The current gain of the transistor decreases with increase of force, and the capacitance between base and collector changes in a similar fashion.

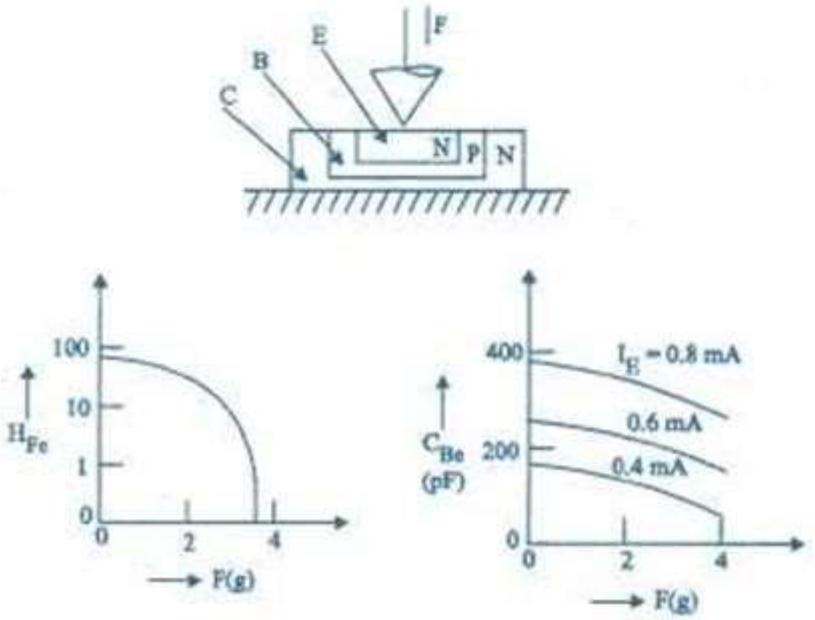

Fig. 5.1.4 Piezoelectric semiconductor transistor and its characteristics.

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 807]

Coefficients

The d-coefficient **gives the charge output per unit force input (or** charge density per unit pressure) under short-circuit condition.

Dividing the d-coefficient by the absolute dielectric constant yields the g-coefficient **representing the generated e.m.f gradient per unit** pressure input. It is the most convenient coefficient for computing the output voltage of piezoelectric transducer.

While the d-and g-coefficients are related to the applied forces, the h-coefficient **is related to a given deformation of the crystal.** It is obtained by multiplying the g-coefficient by Young's modulus valid for the appropriate crystal orientation of the material, and thus measures the e.m.f. gradient per unit mechanical deformation.

The coupling coefficient-k **can be computed from the square root of** the product of h and d. It represents the square root of the ratio of the mechanical energy stored in the crystal, to the electric energy supplied, and is thus a measure of the efficiency of the crystal as an energy converter.

Piezoelectric Force Transducer

- The element can be directly stressed by application of force at one point of the surface. Multiple forces can also be applied at more than one point of the surface and summed by using one single crystal.
- To increase the charge sensitivity, more than one element can be used to form a transducer system and such combinations are known as bimorphs or multimorphs (or piezopile), depending on whether they are of two elements or more.
- The series and connected bimorphs are shown ill Fig. (5.1.5).
- A multimorph of four elements, which develops four times the charge of a single element is shown in Fig. (5.1.6).
- The four elements are parallel mechanically in series but electrically in parallel and hence the net capacitance of the transducer increases correspondingly.
- When bimorphs are made up of ceramic elements, the direction of polarization of the two elements should be noted, and then connected so as to develop charges, and voltages under stress as shown in Fig. (5.1.6(a)). These are called as Bender-type bimorphs.
- A twister bimorph is shown in Fig. (5.1.6(b), with the force applied at A, while the remaining three corners B, C and D are held rigidly.
- If the four corners can be subjected to concentrated forces as shown in the four point twister of Fig. (5.1.6 (b), the expanding diagonals will be perpendicular to each other, and on opposite sides of the bimorph.

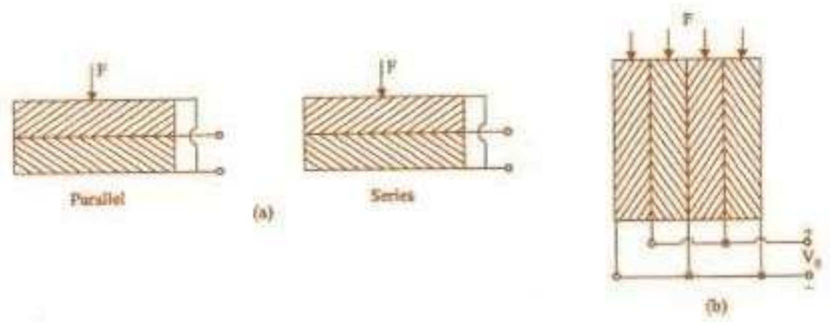

Fig. 5.1.5 (a) Parallel and Series connected bimorphs (b) Multimorph of four piezoelectric elements.

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 810]

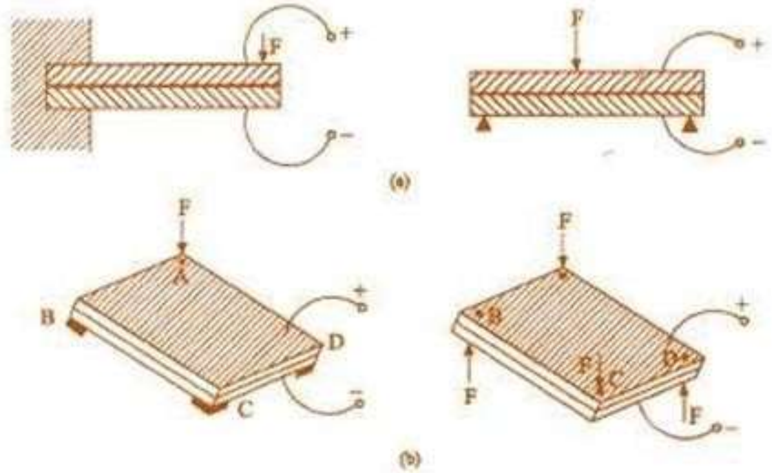

Fig. 5.1.6 (a) Bender type bimorphs (b) Twister type bimorphs

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 810]

Piezoelectric Strain Transducer

- Any piezoelectric element cemented to the surface of the structure is under stress, the strain in the structure is transmitted to the element.

- A voltage proportional to strain is directly available from the transducer.
- The output is obtained by using the h-coefficient given by

$$V_O = h\,et$$

Where,

e is strain

t is thickness of the element m

- The sensitivity of the transducer is very high.
- Piezo-resistive strain transducers though known to be suited for transient strain measurements are not as sensitive as the piezoelectric type.
- If accuracy and stability are of primary interest, metallic alloy resistive strain gauges are chosen especially when static strain is monitored over a long period of time.

Piezoelectric Torque Transducer

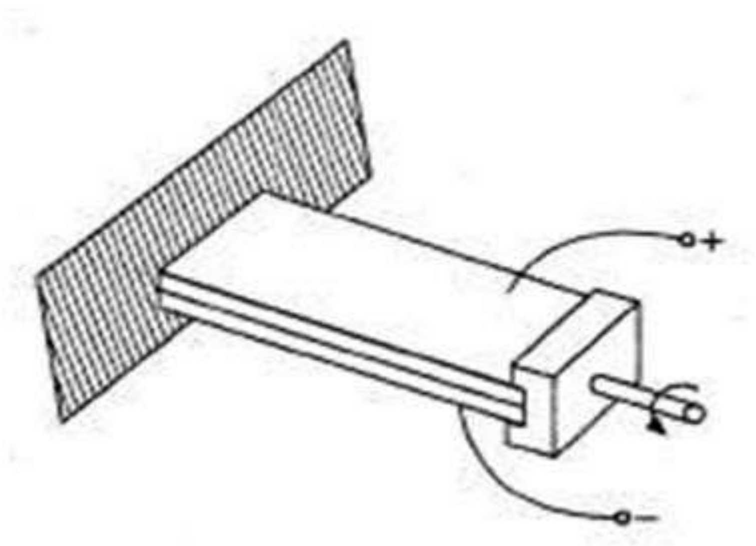

Fig. 5.1.7 A cantilever type twister bimorph

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 812]

- A cantilever type bender bimorph can be used as a twister bimorph for the measurement of torque as shown in Fig.(5.1.7).
- The twisting moment may be due to a small force transmitted through a lever or may be obtained directly by connecting it to a driving shafts/spindle as obtained in instrument mechanisms.
- The sensitivity is high and is therefore very much useful for measurement of small driving torques under dynamic conditions.

Piezoelectric Pressure Transducers

- Piezoelectric transducers are more suitable for pressure measurements under dynamic conditions only and are often used as microphones, hydrophones and engine pressure indicators.
- In the piezoelectric microphone, the diaphragm and the bimorph are connected together by means of a fine needle (spindle) as shown in Fig. (5.1.8).
- The natural frequency of the diaphragm, the bimorph and the associated system should be made higher than the highest frequency to be responded to (10 KHz normally).
- When used in sound level meters, it is essential for microphone to have flat frequency response upto 10 KHz.
- Large pressure variations occurring at frequencies upto 20 KHz in internal combustion engines are measured using multimorphs (piezopile) of quartz elements.
- The surfaces of the elements, connecting electrode surfaces in between and the diaphragm or load plate at the extremes, should be optically flat, and

no air should be trapped in between as it would reduce the natural frequency of the system.

- The transducer is pre-stressed so as to enable pressure fluctuations about a mean value to be measured.
- The pre-stressing is produced by a thin-walled tube under tension, as shown in Fig. 5.1.9 (a).

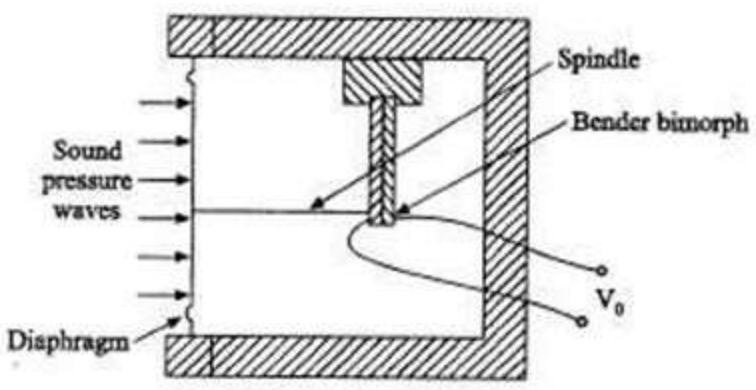

Fig. 5.1.8 Piezoelectric microphone

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 815]

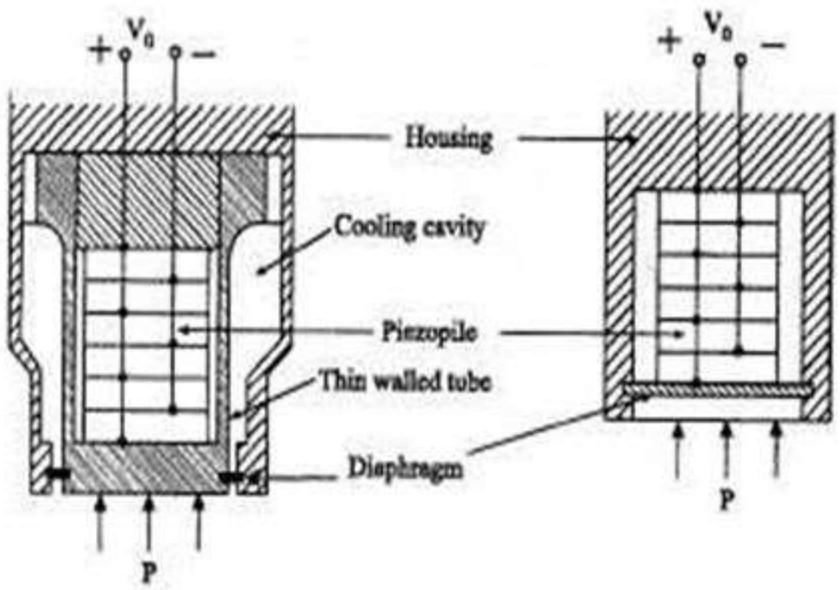

Fig. 5.1.9 Piezoelectric pressure transducers prestressed by (a) a thin-walled tube (b) a thick diaphragm

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 815]

- A very thin diaphragm of flexible material is used for sealing.
- The preload may also be developed by a stiff diaphragm as shown in Fig. 5.1.9 (b).
- The net force F1 to which the piezo pile responds is given by

$$\frac{F_1}{F} = \frac{K_1}{K_1 + K_2}$$

Where,

F = Total force acting in the transducer

K_1 = Spring rate of piezopile

K_2 = Spring rate of preloading tube or diaphragm

For the measurement of air-blast pressures and underwater pressure transients.

A small hollow cylinder shown in Fig. 5.1.10 is used is most cases.

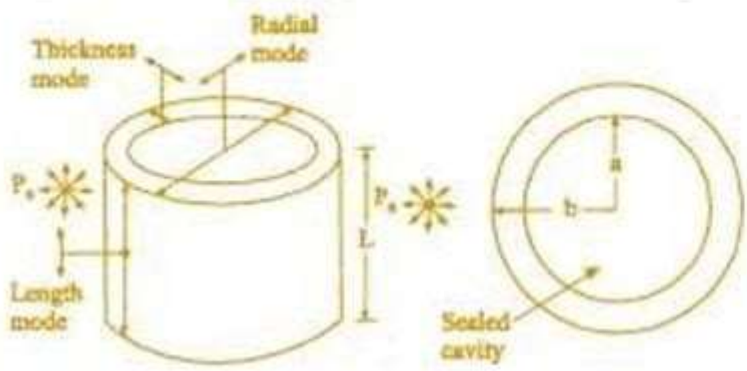

Fig. 5.1.10 Pressure transducer for under water pressure measurement [Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 817]

- The outer and inner surfaces are metallized and used as electrodes.
- The walls are polarized in a radial direction.
- The tube cavity may be sealed against the external pressure and the blast pressure is applied to the outer surfaces.
- The cylinder responds to the pressure Pe in all the three modes as shown in Fig. 5.1.10.

Piezoelectric Acceleration Transducer

- The acceleration transducer design is like that of a force transducer except that a proof mass is added to the acceleration transducer for developing force under acceleration inputs.
- The single crystal or the piezo-pile is pre-stressed by screwing down the cap on the hemispherical spring shown in Fig. 5.1.11 (a).
- The input output characteristics of piezoelectric acceleration transducer is shown in Fig. 5.1.11 (b).

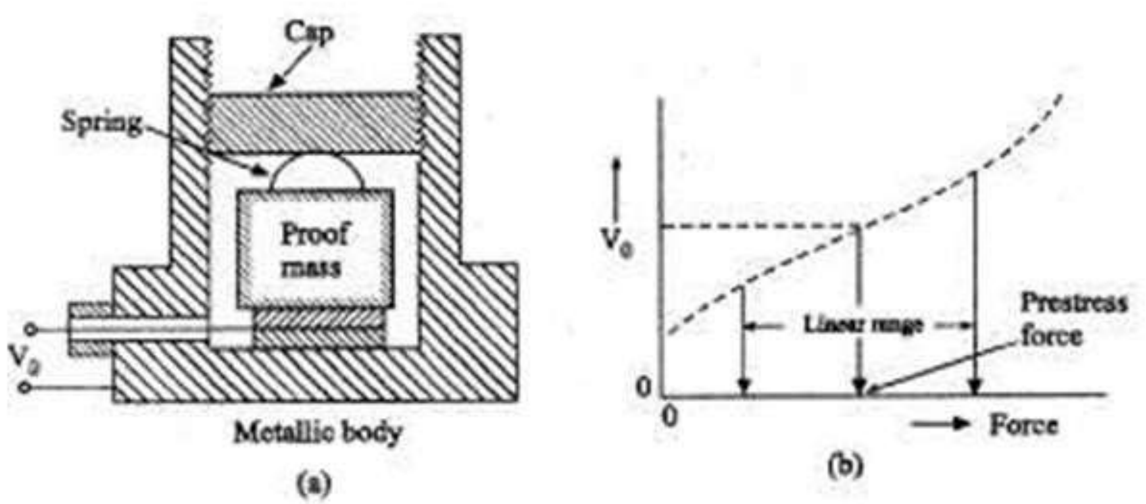

Fig. 5.1.11 (a) Piezoelectric acceleration transducer (b) Its input-output Characteristics

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 820]