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.

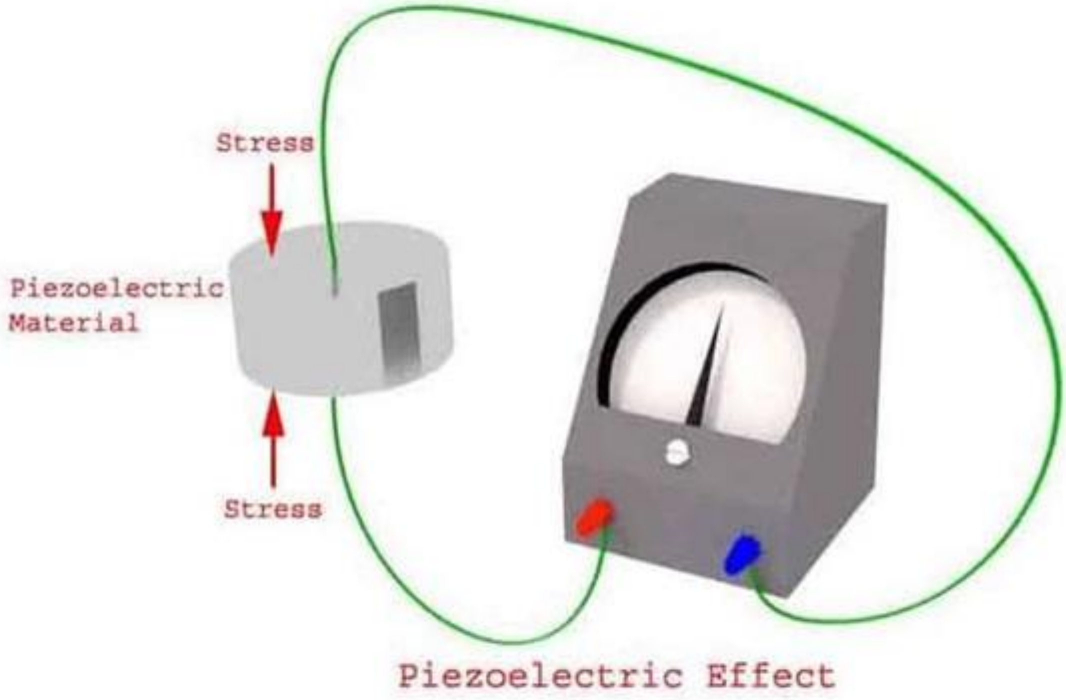

Fig 5.1.1 Piezoelectric Effect

[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.

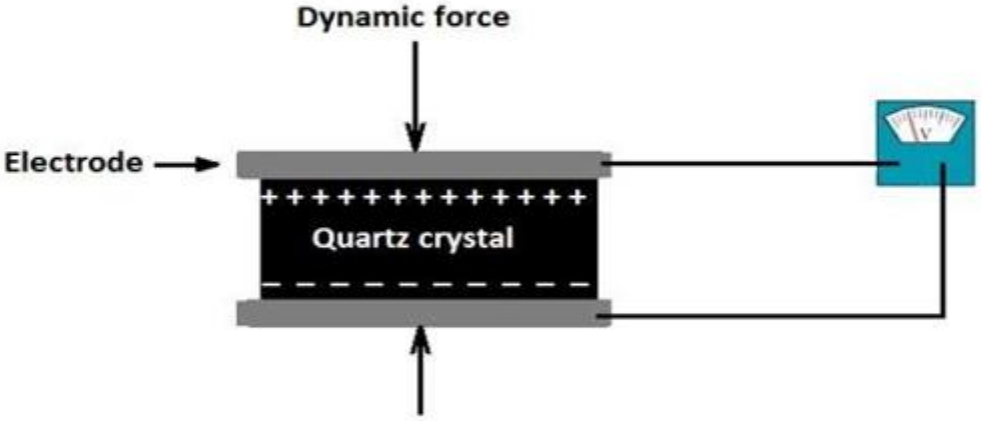

Fig 5.1.2 Working Model

[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.

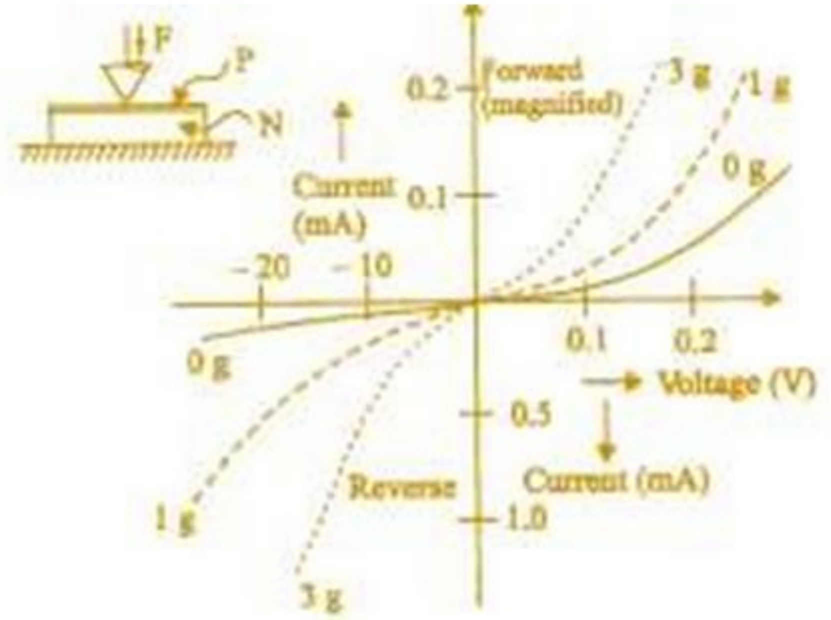

Fig. 5.1.3 Piezoelectric semiconductor diode and It’s characteristics
[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 806]

- 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.

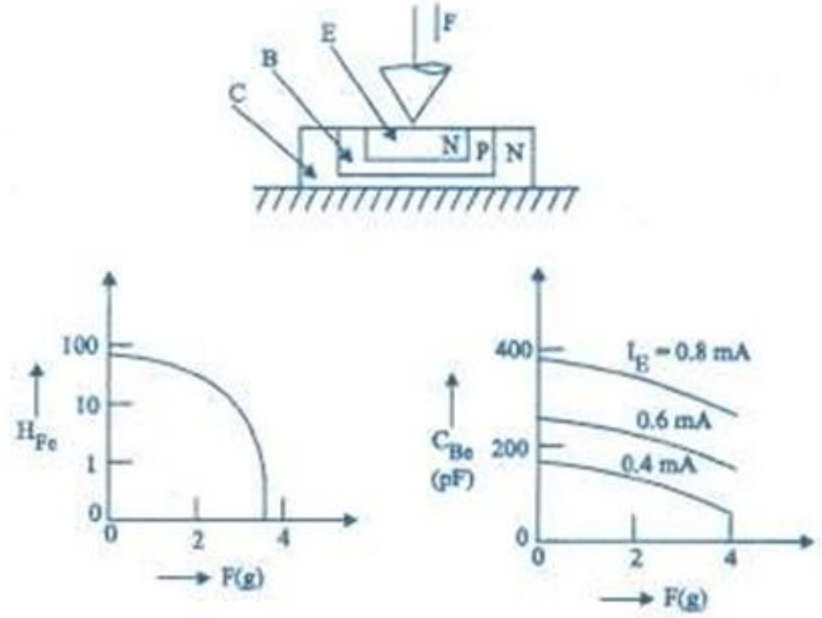

Fig. 5.1.4 Piezoelectric semiconductor transistor and its characteristics. [Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 807]

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.

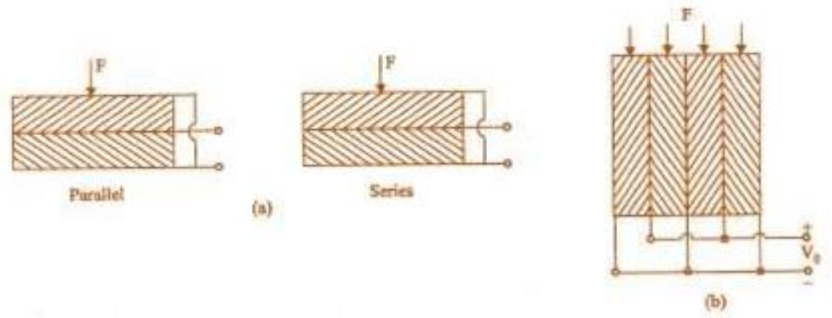

Fig. 5.1.5 (a) Parallel and Series connected bimorphs (b) Multimorph of four piezoelectric elements.

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

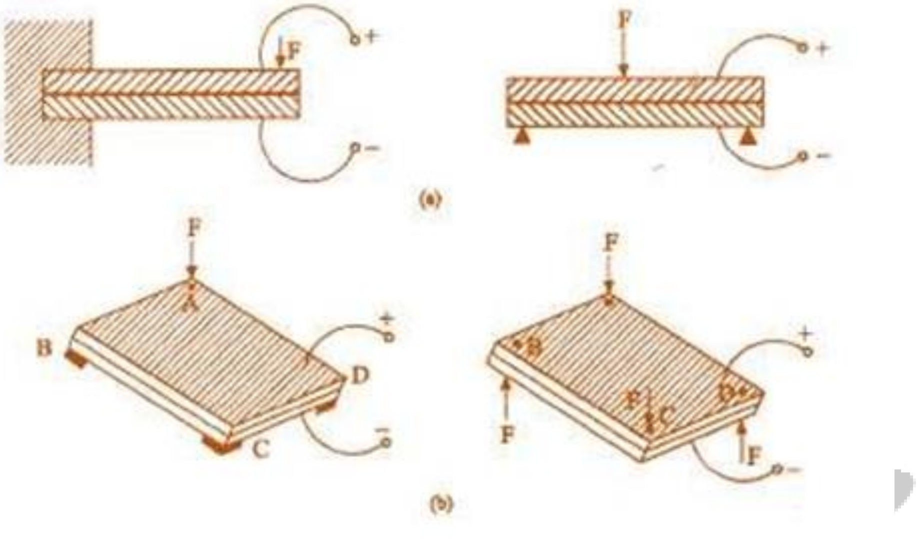

Fig. 5.1.6 (a) Bender type bimorphs (b) Twister type bimorphs

[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

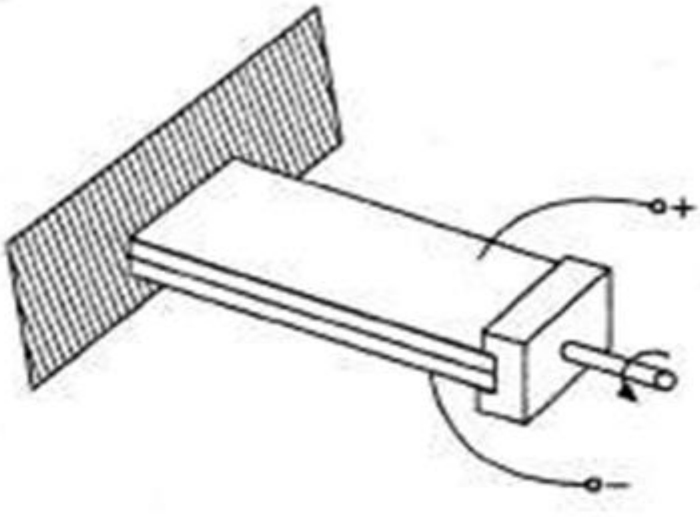

Fig. 5.1.7 A cantilever type twister bimorph

[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).

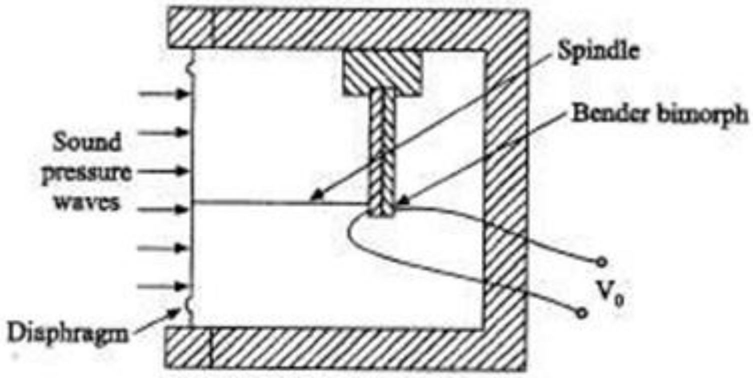

Fig. 5.1.8 Piezoelectric microphone

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

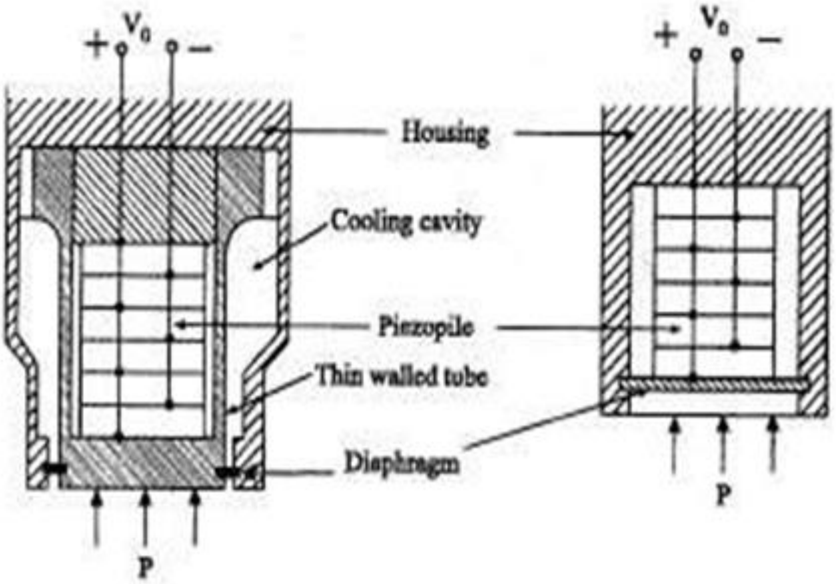

Fig. 5.1.9 Piezoelectric pressure transducers prestressed by (a) a thin-walled tube (b) a thick diaphragm

[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.

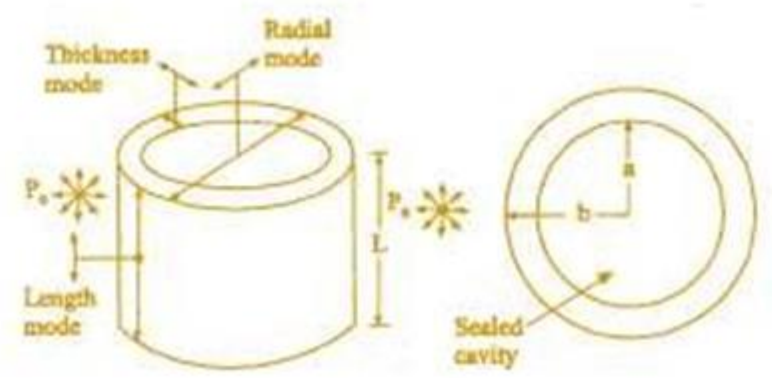

Fig. 5.1.10 Pressure transducer for under water pressure measurement [Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 817]

- 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).

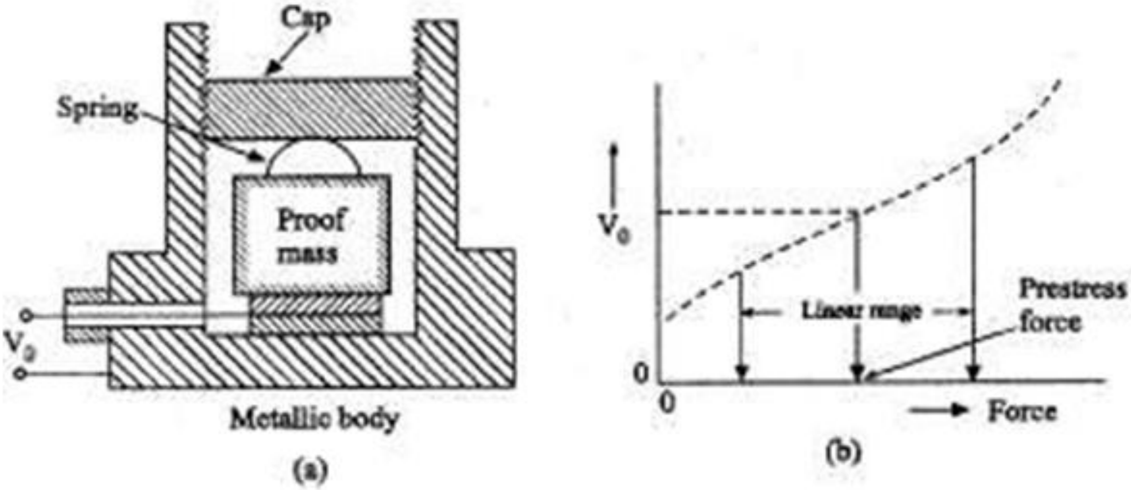

Fig. 5.1.11 (a) Piezoelectric acceleration transducer (b) Its input-output Characteristics

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