ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY
AUTONOMOUS INSTITUTION
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VII Semester

AU3008 Sensors and Actuators

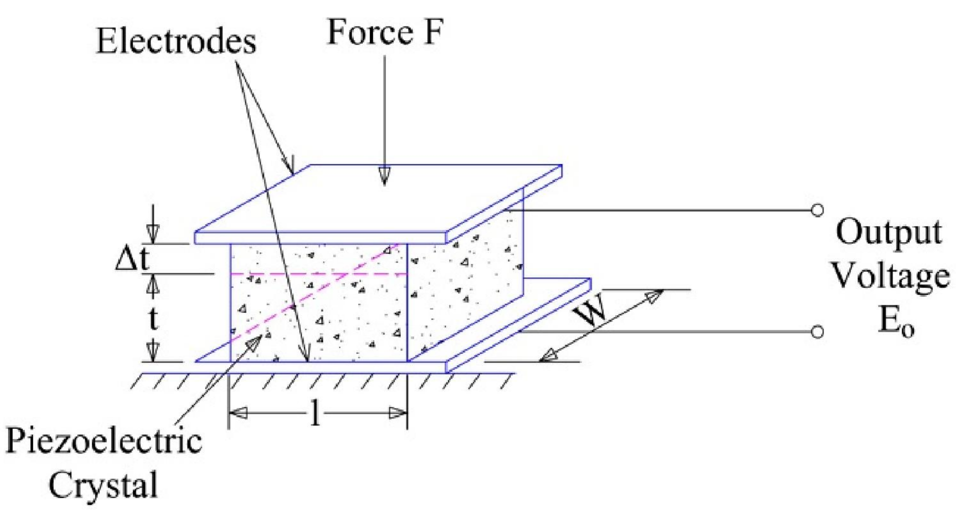
UNIT – 3 - Variable and Other Special Sensors

3.2 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.

3.2.1 Piezoelectric Effect:

The piezoelectric effect is the ability of certain materials to generate an electric charge when mechanical stress is applied to them. The process is reversible which means if potential difference across some specified surface is changed, the dimension of the piezoelectric material will also change. This effect is known is ***Piezoelectric Effect***.



3.2.2 Piezoelectric material:

- Basically, there are two types of piezoelectric materials: **Natural** and **Synthetic**.
- A natural piezoelectric material is one which occurs in nature and can be used as such.
- **Quartz** and **Ceramic** are examples of natural piezoelectric material.
- Synthetic piezoelectric materials are those materials in which piezoelectric properties are not found in their original state but these properties are produced using special techniques such as polarizing treatment.
- **Lead zirconate titanate, barium titanate, Lead titanate, Lithium Sulphate, Polyvinylidene fluoride.**

3.3.3 Piezoelectric Quartz Crystal:

- A quartz crystal is a piezoelectric material that can generate a voltage proportional to the stress applied upon it.
- For the application, a natural quartz crystal has to be cut in the shape of a thin plate of rectangular or oval shape of uniform thickness.
- Each crystal has three sets of axes – Optical axes, three electrical axes OX1, OX2, and OX3 with 120 degree with each other, and three mechanical axes OY1, OY2 and OY3 also at 120 degree with each other.
- The mechanical axes will be at right angles to the electrical axes. Some of the parameters that decide the nature of the crystal for the application are
    i. Angle at which the wafer is cut from natural quartz crystal
    ii. Plate thickness
    iii. Dimension of the plate
    iv. Means of mounting

- The X-Y axis of a piezoelectric crystal and its cutting technique is shown in the figure below.

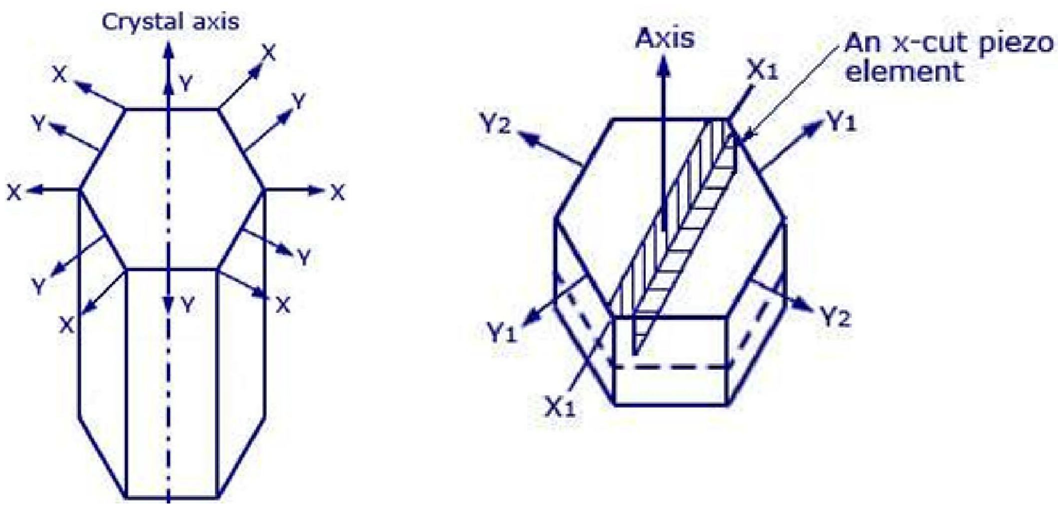


Figure 3.2.1 X-Y Axes of a Piezoelectric Crystal

If an electric stress is applied in the directions of an electric axis (X-axis), a mechanical strain is produced in the direction of the Y-axis, which is perpendicular to the relevant X-axis. Similarly, if a mechanical strain is given along the Y-axis, electrical charges will be produced on the faces of the crystal, perpendicular to the X-axis which is at right angles to the Y-axis.

3.3.4 Equivalent Circuit of a Piezoelectric Crystal

Consider Fig. 3.2.3 The charge generated by the crystal can be expressed as

$$q = K_q X_i$$

where K_q is in coulomb/cm and

X_i is the deformation in cm.

The resistances and capacitances in the equivalent circuit of Fig. 3.2.3 b can be combined as shown in Fig. 3.2.3 c. The charge generated can be converted into a current generator as $i = \frac{d_q}{d_t}$

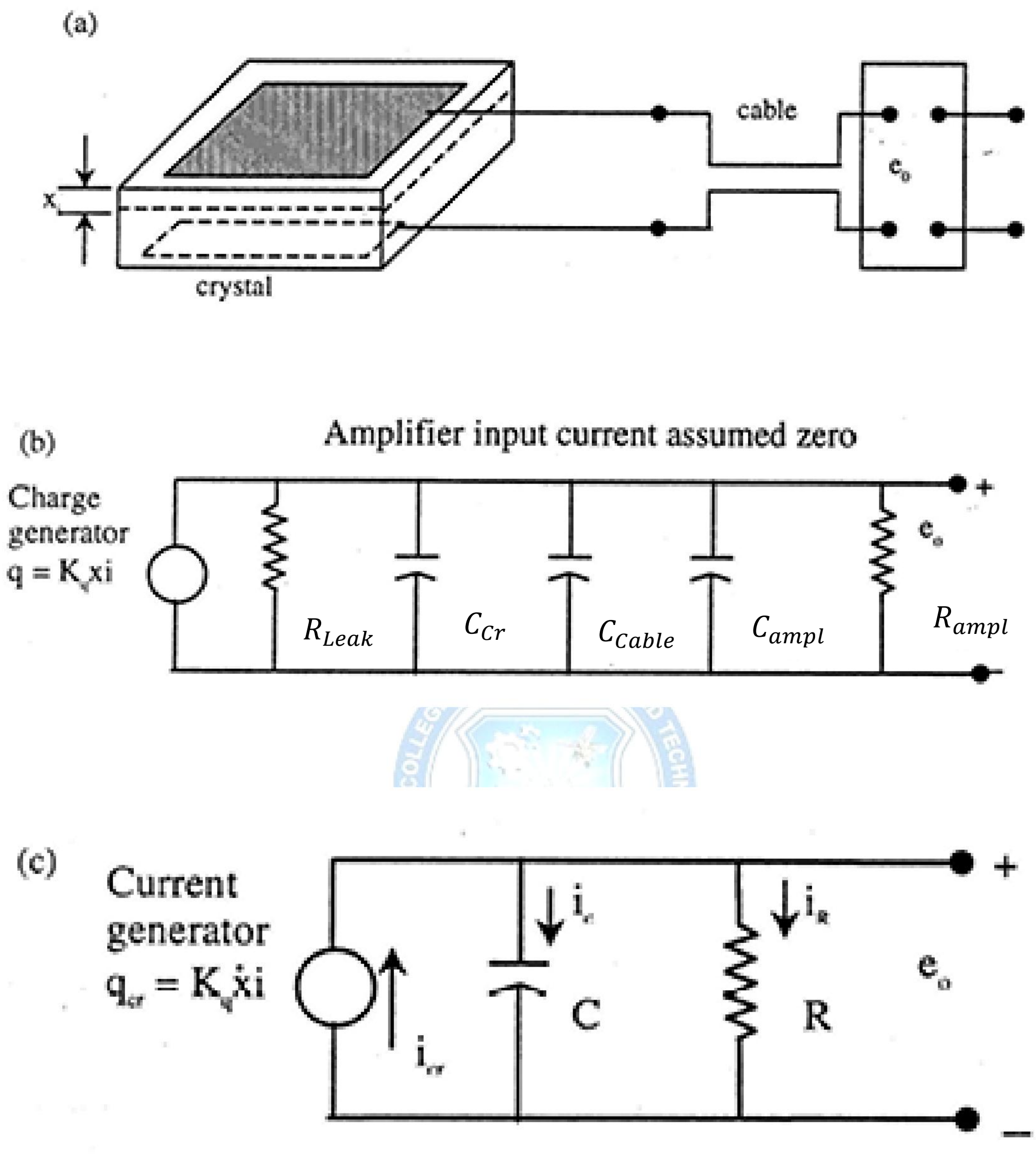


Fig. 3.2.3 Equivalent circuit of piezoelectric crystal

For the circuit in Fig. 3.2.3 c, the following equations can be written

$$i_{cr} = \frac{dq}{dt} = K_q \frac{dX_i}{dt} = K_q \dot{X}_i$$

$$R \cong \frac{R_{ampl} \cdot R_{leak}}{R_{ampl} + R_{leak}} \approx R_{ampl}$$

$$C \cong C_{cr} + C_{cable} + C_{ampl}$$

Then

$$i_{cr} = i_c + i_R$$

$$k_q \frac{dx_i}{dt} = C \frac{de_0}{dt} + \frac{e_0}{R}$$

Taking the laplace transform on both sides, assuming zero initial conditions,

$$k_q s\, x_1(s) = C\, s\, E_0(s) + \frac{E_0}{R}(s)$$

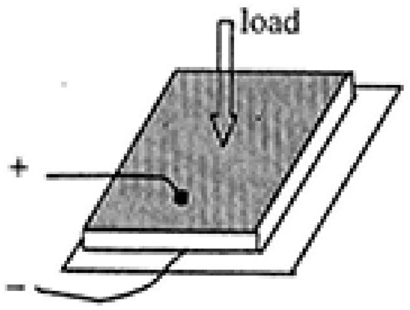
$$\frac{E_0(s)}{X_1(s)} = \frac{K\tau s}{\tau s + 1}$$

where $K = k_q/C$ = sensitivity in volts / cm
$\tau = RC$ = Time constant in sec.

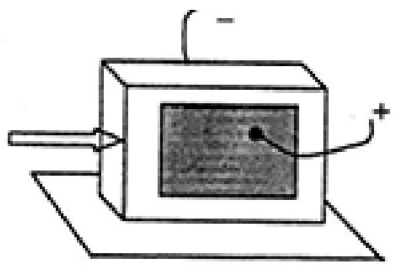
This has a steady state response to a constant x, is zero just like the capacitance pick up. So static displacement cannot be measured. For a flat amplitude response within say 5 percent, the frequency must exceed ω_i

3.3.5 Modes of Deformation:

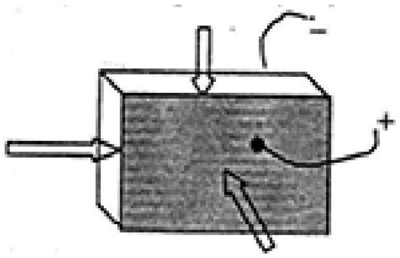
There are a number of possible modes of deformation a piezoelectric transducer may suffer under load. They are portrayed in fig. 3.2.4.



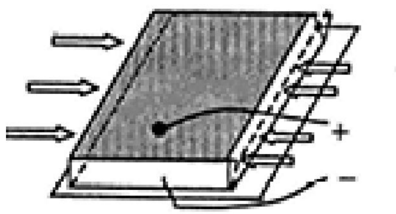
(a) Thickness expander (T.E)



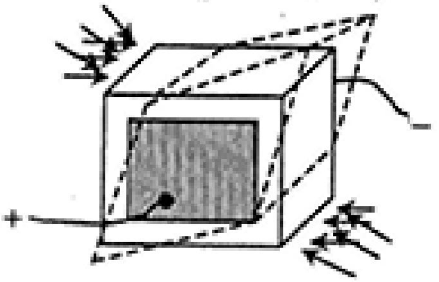
(b) Length expander (L.E)



(c) Volume expander (V.E)



(d) Thickness shear (T.S)



(e) Face shear (F.S)

3.3.6. General form of Piezoelectric Transducers:

- Construction details of a piezoelectric accelerometer is as shown in **Fig. 3.2.5**.

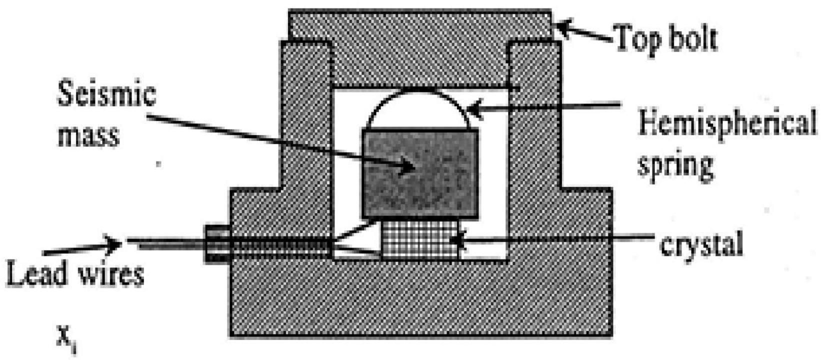


Fig.3.2.5 Piezoelectric accelerometer

- The crystal is preloaded to about 600 kg/cm2 stress by screwing down on the hemispherical spring.

- The prestressing puts the piezoelectric material at a more linear part of its stress charge curve.
- Vertical acceleration is converted into a varying force by the seismic mass.
- It allows measurement of acceleration in both directions without the crystal going into tension.
- When the preload is applied, a voltage of certain polarity is developed but this soon leaks off to zero.
- Any further load due to acceleration gives a plus or minus charge depending on the direction of the motion.

3.3.7 Applications of Piezoelectric transducers:

1. ***In microphones***, the sound pressure is converted into an electric signal and this signal is ultimately amplified to produce a louder sound.
2. Automobile seat belts lock in response to a rapid deceleration is also done using a piezoelectric material.
3. It is also used in ***medical diagnostics***.
4. It is used in ***electric lighter*** used in kitchens. The pressure made on piezoelectric sensor creates an electric signal which ultimately causes the flash to fire up.
5. They are used for studying ***high-speed shock waves*** and blast waves.
6. It is also used in **restaurants or airports** where when a person steps near the door and the door opens automatically. In this, the concept used is when a person is near the door pressure is exerted ***person weight on the sensors*** due to which the electric effect is produced and the **door opens automatically**.
7. Piezoelectric accelerometers are used in automobile ***safety airbag systems***.
8. ***Fuel injectors*** that use piezoelectric technology are said to be more accurate than their conventional counterparts.

3.3.8. Advantages and Disadvantages of Piezoelectric Transducer:

<u>The advantages of piezoelectric transducers are</u>:

1. No need for an external force
2. Easy to handle and use as it has small dimensions

3. High-frequency response it means the parameters change very rapidly
4. **Rugged and durable:** Can withstand harsh environments and mechanical stresses
5. **Fast response time:** Provide rapid and accurate measurements.

The disadvantages of piezoelectric transducers are:

1. It is ***not*** suitable for measurement in ***static condition***
2. It is affected by ***temperatures***
3. The ***output is low*** so some external circuit is attached to it.
4. It is very ***difficult*** to give the ***desired shape*** to this material and also desired strength
5. **Hysteresis:** May exhibit a hysteresis effect, where the output signal depends on the history of the input signal.
6. **Cost:** Can be relatively expensive, especially for high-precision or specialized transducers.

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