UNIT – 1

SCIENCE OF MEASUREMENT AND TRANSDUCERS

Piezoelectric transducer

Force Measurement: Piezoelectric Transducers

- A piezoelectric material is one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force
- This potential is generated by the displacement of charges. The effect in reversible, i.e. conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it
- This effect is known as piezoelectric effect
- Common piezoelectric materials include Rochelle salts, quartz, barium titanate (Ceramics A & B), ammonium dihydrogen phosphate, lithium sulphate, etc.
- The ceramics A & B do not have piezoelectric properties in their original state but these properties are produced by special polarizing treatment

Piezoelectric Transducers (-contd.)

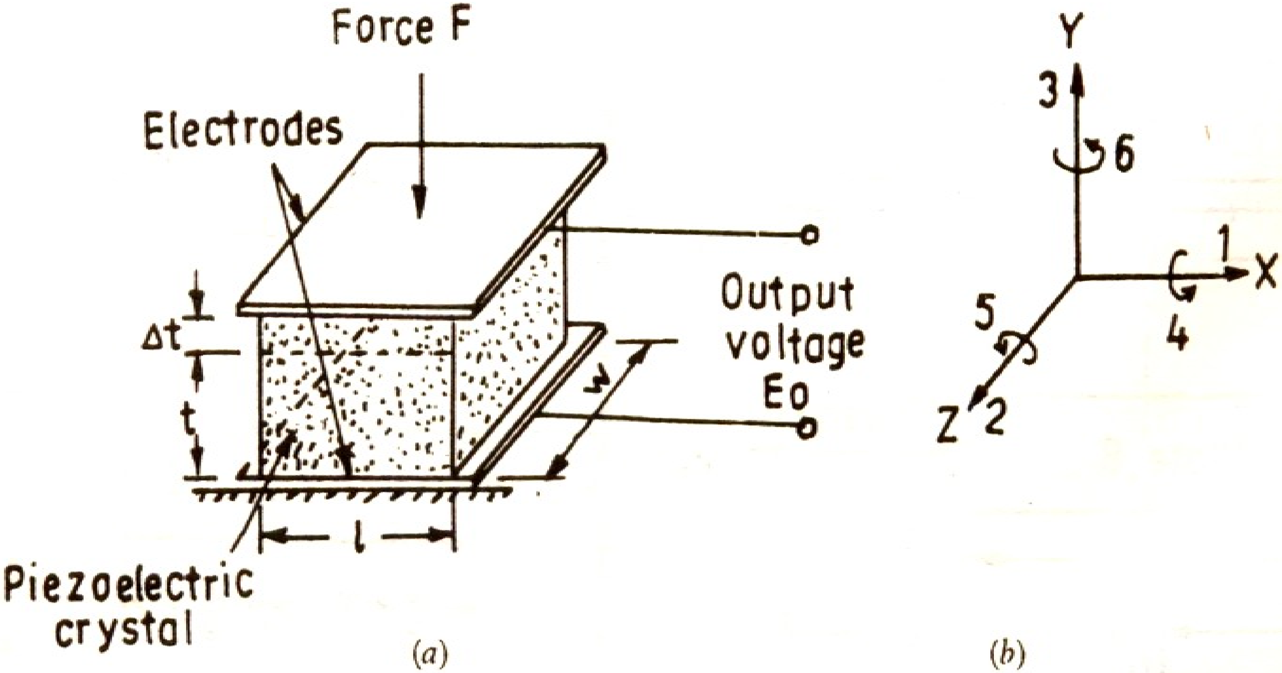
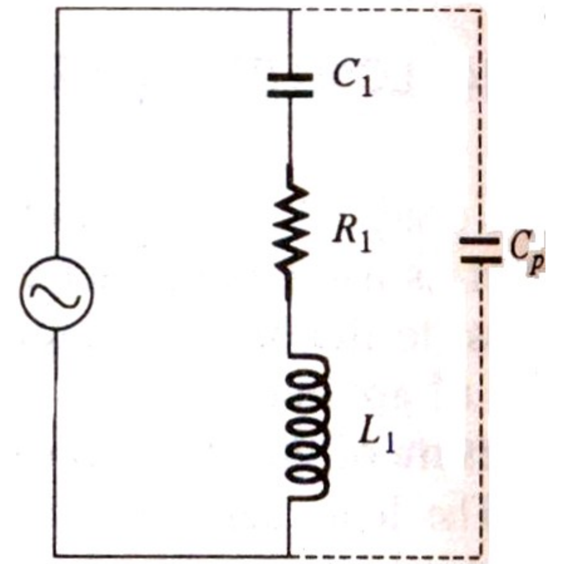


Fig. 25.121. (a) Piezo-electric crystal used for measurement of force.
(b) Axis numbering system for the crystal.



Equivalent Circuit
of Crystal

Piezoelectric Transducers (-contd.)

- The piezoelectric effect can be made to respond to (or cause) mechanical deformations of the material in different modes: thickness expansion, transverse expansion, thickness shear, & face shear
- The mode of operation depends on the shape of the body relative to the crystal axis and location of the electrodes
- A piezoelectric element used for converting mechanical motion to electrical signals may be thought as charge generator & a capacitor
- Mechanical deformation generates a charge and which appears as a voltage across the electrodes, i.e.

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$$\text{Voltage } E_0 = \frac{Q}{C_p} = \frac{Q}{\varepsilon_r \varepsilon_0 A/t} \qquad \ldots(1)$$

$$\left(C_p : \text{Capacitance between electrodes} = \frac{\varepsilon A}{t} = \frac{\varepsilon_r \varepsilon_0 A}{t} \right)$$

Piezoelectric Transducers (-contd.)

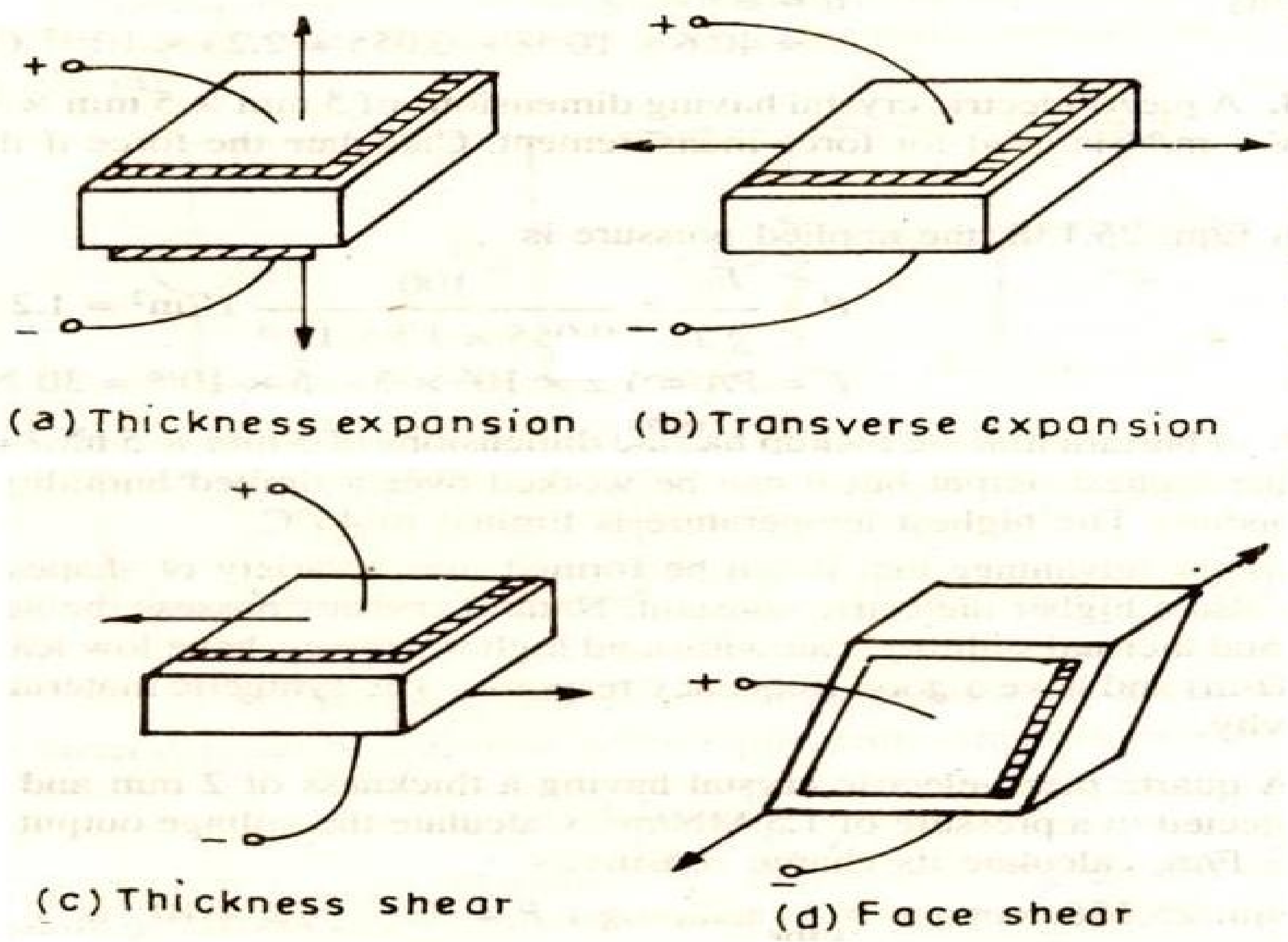

Fig. 25.122. Modes of operation of piezo-electric crystals.

Piezoelectric Transducers (-contd.)

- The piezoelectric effect is direction sensitive, a tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity
- The magnitude and polarity of the induced surface charges are proportional to the magnitude and direction of the applied force (F)
- The induced charge is given by

$$Q = d \times F \qquad \ldots (2)$$

where, d is charge sensitivity of the crystal (constant for a given crystal)

- If the force (F) causes a change (Δt) in thickness (t) of the crystal, then

$$F = \frac{AE}{t} \cdot \Delta t \qquad \ldots (3)$$

where, A: area of the crystal, $\mathbf{E: Young's\ modulus} = \frac{\mathbf{Stress}}{\mathbf{Strain}} = \frac{\mathbf{F/A}}{\mathbf{\Delta t/t}}$

- From eqns. (2) & (3), we have $Q = dAE\left(\frac{\Delta t}{t}\right) \qquad \ldots (4)$

Piezoelectric Transducers (-contd.)

- From eqns. (1) & (2), we get

$$E_0 = \frac{dF}{\varepsilon_r \varepsilon_0 A/t} = \left(\frac{d}{\varepsilon_r \varepsilon_0}\right).t.\frac{F}{A}$$

$$\Rightarrow \quad E_0 = g \times t \times P \quad ...(5)$$

$$where, g = \frac{d}{\varepsilon_r \varepsilon_0} : voltage\ sensitivity\ of\ crystal\ (Vm/N), P : Stress$$

- We can write eqn. (5) as: $g = \frac{E_0/t}{P} = \frac{Electric\ Field}{Stress}$

Table 25.8. Properties of Barium Titanate and Quartz

Material	*Voltage Sensitivity g Vm/N*	*Permittivity, ∈ F/m*	*Charge Sensitivity, d pC/N*
Barium titanate	12×10^{-3}	12.5×10^{-9}	150
Quartz	50×10^{-3}	40.6×10^{-12}	2

Piezoelectric Transducers (-contd.)

- The piezoelectric transducer is cut from a large crystal in the direction of any of the electrical or mechanical axis perpendicular to the optical or crystal axis
- The values of 'd' and 'g' are not necessarily the same but are dependent upon the axis of cut

<u>Properties of Piezoelectric Crystals</u>:

- The desirable properties of piezoelectric materials are stability, high output, insensitivity to temperature and humidity and the ability to be formed into most desirable shape
- Quartz is the most stable piezoelectric material, however, its output is quite small
- On the other hand, Rochelle salt provides the highest output but it can be worked over a limited humidity range and has to be protected against moisture. Its highest temperature is limited to 45^0C

Piezoelectric Transducers (-contd.)

- Barium titrate has the advantage that it can be formed into a variety of shapes and sizes since it is polycrystalline. It also has a higher dielectric constant
- Natural crystals possess the advantages that they have higher mechanical and thermal stability, can withstand higher stresses, have low leakage (resistivity is of the order of 10^{16} Ω/m) and have a good frequency response
- The synthetic materials, in general, have a higher voltage sensitivity

Uses of Piezoelectric Material and Transducers:

(1) Because of its stability, quartz is commonly used for stabilizing **electronic oscillators**. The crystal is ground to proper shape and is connected in an appropriate electronic cut whose frequency is controlled by it.

Piezoelectric Transducers (-contd.)

(2) The use of piezoelectric transducer elements is confined primarily to dynamic measurements. The voltage developed by application of strain is not held under static condition. Hence the elements are primarily used in the measurement of such quantities as surface **roughness, in accelerometers** and **vibration pickups**

(3) **Ultrasonic generator elements** also use barium titrate, a piezoelectric material and theses ultrasonic generator elements are used in industrial cleansing apparatus and also in underwater detection system (known as sonar)