3 PIEZOELECTRIC TRANSDUCERS

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 produced by the displacement of charges. The effect is 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. Elements exhibiting piezoelectric qualities are called as electro-resistive elements.

Common piezoelectric materials include Rochelle salts, ammonium dihydrogen phosphate, lithium sulphate, dipotassium tartarate, potassium dihydrogen phosphate, quartz and ceramics A and B. Except for quartz and ceramics A and B, the rest are man-made crystals grown from aqueous solutions under carefully controlled conditions. The ceramic materials are polycrystalline in nature. They are, basically, made of barium titanate. They do not have piezoelectric properties in their original state but these properties are produced by special polarizing treatment.

The materials that exhibit a significant and useful piezoelectric effect are divided into two categories.

(i) Natural group and (ii) Synthetic group.

Quartz and Rochelle salt belong to natural group while materials like lithium sulphate, ethylene diamine tartarate belong to the synthetic group.

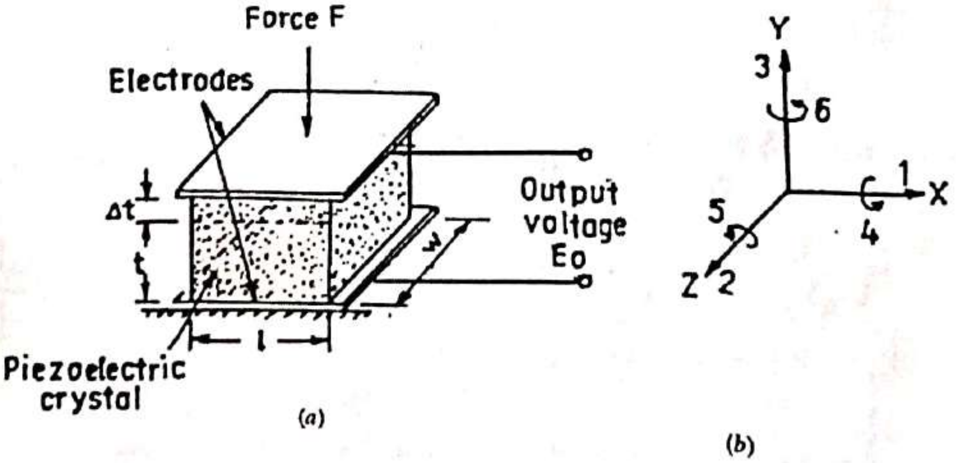

Fig. (a) Piezo-electric crystal used for measurement of force. (b) Axis numbering system for the crystal

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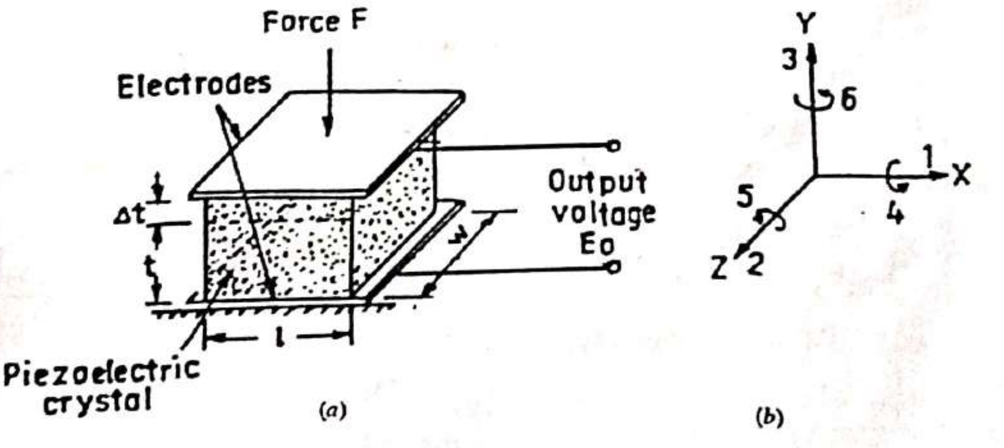


Fig. (a) Piezo-electric crystal used for measurement of force. (b) Axis numbering system for the crystal

The piezoelectric effect can be made to respond to (or cause) mechanical deformations of the ma... different modes. The modes can be: thickness expansion, transverse expansion, thickness shear a... The mode of motion affected depends on the shape of the body relative to the crystal axis and ... electrodes. A piezoelectric element used for converting mechanical motion to electrical signals ma... as charge generator and a capacitor. Mechanical deformation generates a charge and the charge ... voltage across the electrodes. The voltage is

$$E = Q/C.$$

The piezoelectric effect is direction sensitive. A tensile force produces a voltage of one polar... compressive force produces a voltage of opposite polarity.

A piezoelectric crystal is shown in Fig.

The magnitude and polarity of the induced surface charges are proportional to the magnitude and ... applied force F. The polarity of induced charges depends upon the direction of applied force.

Charge $Q = d \times F$ coulomb

Where d = charge sensitivity of the crystal ; C/N : (it is constant for a given crystal)

And F = applied force, N,

The force F causes a change in thickness of the crystal.

$$F = \frac{AE}{t} \Delta t \text{ Newton}$$

where A = area of crystal ; m^2, t = thickness of crystal ; m and E = Young's modulus, N/m^2.

Young's modulus $$E = \frac{\text{stress}}{\text{strain}} = (F/A)\frac{1}{\Delta t / t} = \frac{Ft}{A\Delta t} N/m^2$$

Area $A = wl$ where w = width of crystal; m, and l = length of crystal; m.

∴ From Eqns. we have, charge:

$$Q = dAE(\Delta t/t)$$

The charge at the electrodes gives rise to an output voltage E_0.

Voltage $E_0 = Q/C_p$

Where C_p = capacitance between electrodes; F.

Capacitance between electrodes $C_p = \epsilon_r \epsilon_0 A/t$

$$E_0 = \frac{Q}{C_p} = \frac{dF}{\epsilon_r \epsilon_0 A/t} = \frac{dt}{\epsilon_r \epsilon_0} \frac{F}{A}$$

But $F/A = P$ = pressure or stress in N/M^2.

∴ $$E_0 = \frac{d}{\epsilon_r \epsilon_0} tP$$

$$= g\,t\,P$$

$$g = d/\epsilon_r \epsilon_0$$

where

'g' is the voltage sensitivity of the crystal. This is constant for a given crystal cut. Its units are Vm/N.

Now $$g = \frac{E_0}{tP} = \frac{E_0/t}{P}$$

But E_0/t = electric field strength, V/m, Let $\varepsilon = E_0/t$ = electric field

∴ $$g = \frac{\text{electric field}}{\text{stress}} = \frac{\varepsilon}{P}$$

Now E_0/t is the electric field intensity in the crystal and P is the pressure or the applied stress to the crystal. There crystal voltage sensitivity, g, can be defined as the ratio of electric field intensity to pressure (or stress). Now $E_0.t = \varepsilon$ is the electric field intensity in the crystal and P is the pressure or the stress applied to crystal. Therefore, crystal voltage sensitivity, g, can be defined as the ratio of the electric field intensity pressure (or stress). The units of g are Vm/N.

charge sensitivity $$d = \epsilon_r \epsilon_0 g \quad C/N$$

The two main families of constants i.e. the'd' constants and 'g' constants are considered. For barium titanate the commonly used constant are d_{33} and g_{33}

$$g_{33} = \frac{\text{field produced in direction 3}}{\text{stress applied in direction 3}} = \frac{E_0/t}{F/A}$$

Voltage output $$E_0 = g_{33} \times \frac{F}{A} \times t = g_{33} t P$$

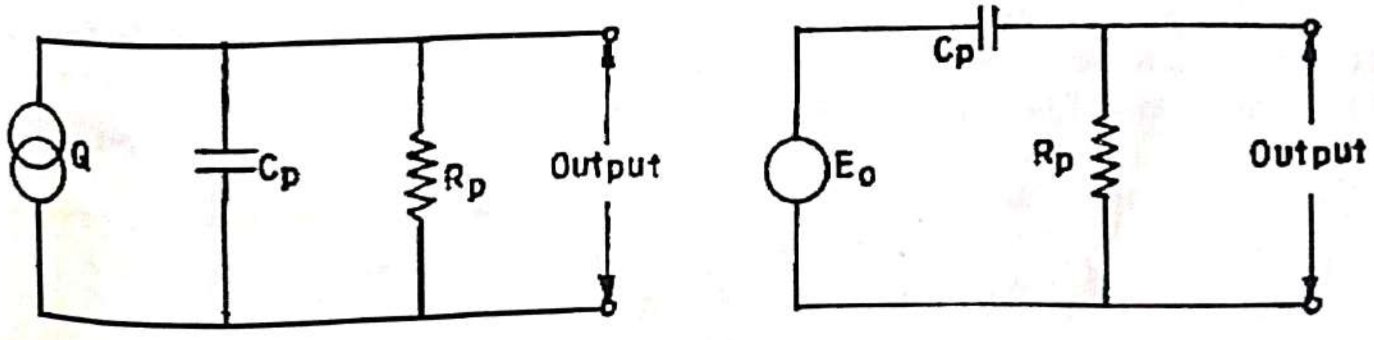
Thus if g is known for a particular material, the voltage output per unit stress can be calculated by knowing the value of t.

Equivalent circuit of Piezoelectric transducers

The basic equivalent circuit of a piezoelectric transducer is shown in Fig. (a)

The source is a charge generator. The value of the charge is Q = dF.

The charge generated is across the capacitance, C_p, of the crystal and its leakage resistance R_p.



(a) (b)