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**DEPARTMENT OF BIOMEDICAL ENGINEERING**

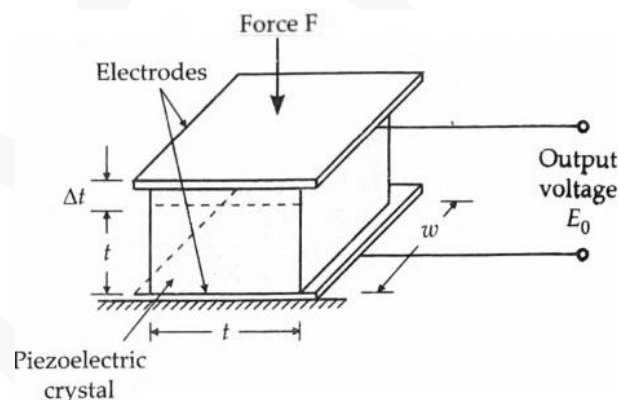
**III Semester- BM3301 SENSORS AND MEASUREMENTS**

**UNIT - 3**

**3.10 Piezoelectric Active Transducer-  
Equivalent circuit and its characteristics.**

**3.10.1 What do you understand by the term piezoelectric? How does a 'piezoelectric'? material act as a transducer? (April/May 2019)**

The term "piezoelectric" refers to a property exhibited by certain materials that can generate an electric charge in response to mechanical stress or deformation. Conversely, these materials can also experience mechanical deformation in response to an applied electric field. This phenomenon is known as the **piezoelectric effect**.



**Fig. 3.10.1** Piezo electric crystal used for the measurement of Force

When a piezoelectric material is mechanically deformed or subjected to stress (such as compression, tension, or bending), it undergoes a change in its internal polarization. This change in polarization results in the movement of electric charges within the material, leading to the generation of an electric voltage across its surfaces.

Conversely, if an electric field is applied to a piezoelectric material, it causes the material to change its shape or deform mechanically. This phenomenon is known as the reverse piezoelectric effect. A piezo-electric crystal is shown in Fig. 3.10.1

Mechanical deformation generates a charge and this charge appears as a voltage across the electrodes. The voltage is  $E = Q / C$ .

The piezo-electric effect is direction sensitive. A tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity.

### 3.10.2 Piezo Electric Materials:

#### Naturally occurring crystals:

- ✓ Quartz crystal
- ✓ Rochelle salt.
- ✓ Tourmaline

#### Man-made Piezo Electric Materials:

- ✓ Barium titanate ( $BaTiO_3$ ).
- ✓ Lead titanate ( $PbTiO_3$ )
- ✓ Lead zirconate titanate (PZT).

### 3.10.3. Construction of Piezo-Electric Transducer:

A piezoelectric transducer is a device that converts mechanical energy into electrical energy or vice versa using the piezoelectric effect. The piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress or to generate a mechanical strain in response to an applied electric field.

The following materials are used in constructing piezoelectric transducer:

- i. Piezoelectric crystal or ceramic disc (common materials include quartz, lead zirconate titanate, or PZT)
- ii. Conductive electrodes (typically made of metal like silver or nickel)
- iii. Insulating material (to support and protect the piezoelectric element)
- iv. Connecting wires
- v. Soldering iron and solder
- vi. Amplifier or signal conditioning circuit (optional, depending on the application)

The construction of Piezo electric transducer includes;

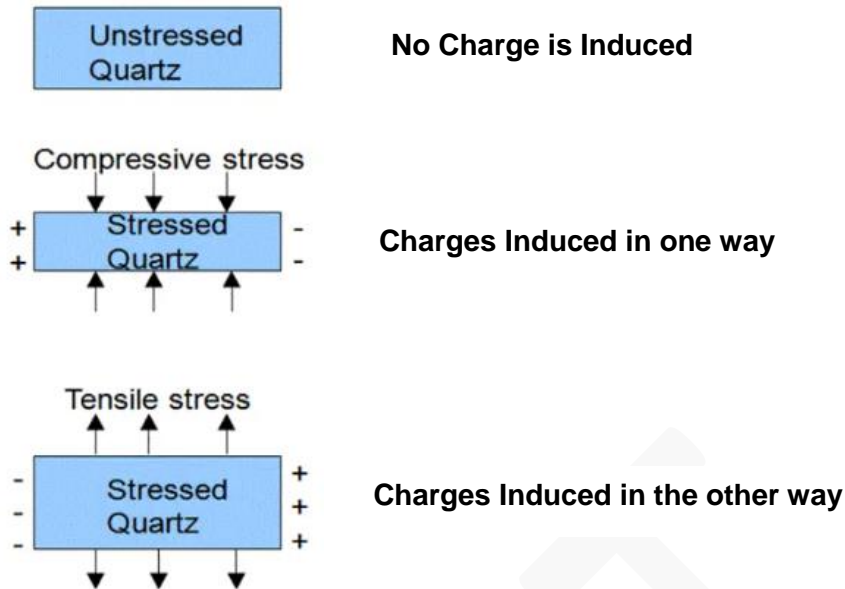
1. Choose a suitable piezoelectric material based on your application requirements.
2. Cut the piezoelectric material into the desired shape. It is often in the form of a disc.
3. Apply conductive electrodes to both sides of the piezoelectric material
4. Place the piezoelectric element on an insulating support. This support material should be non-conductive and provide mechanical stability.
5. Connecting Wires: Solder wires to the electrodes.
6. Testing: Test the piezoelectric transducer by subjecting it to mechanical stress (compression, tension, or shear depending on the design). Alternatively, apply an electrical field to observe the mechanical response.
7. Optional Amplification Circuit: Depending on the application, you may need to connect the piezoelectric transducer to an amplifier or a signal conditioning circuit to boost the generated electrical signal.

#### 3.10.4. Working of Piezo-Electric Transducer:

When pressure or acceleration is applied to the PZT material, an equivalent amount of electrical charge gets generated across the crystal faces. Electrical charge will be proportional to the applied pressure. Piezoelectric sensor cannot be used to measure static pressure. At the constant pressure, the output signal will be zero.

Working of a Piezoelectric Sensor can be summarized as,

1. In a piezoelectric crystal the charges are exactly balanced in unsymmetrical arrangement also.
2. The effect of the charges cancel out with each other and hence no net charge will be found on the crystal faces.
3. When the crystal is squeezed, the charge in the crystal becomes unbalanced.
4. Hence, from now on the effect of charge does not cancel with each other which make net positive and negative charge to appear on the opposite faces of the crystal.
5. Therefore, by squeezing the crystal, voltage is produced across the opposite face and this is known as **piezoelectricity**.



### 3.10.5. Equivalent Circuit of Piezo-Electric Transducer:

The basic equivalent circuit of a piezo-electric transducer is shown in **Fig. 3.10.2**.

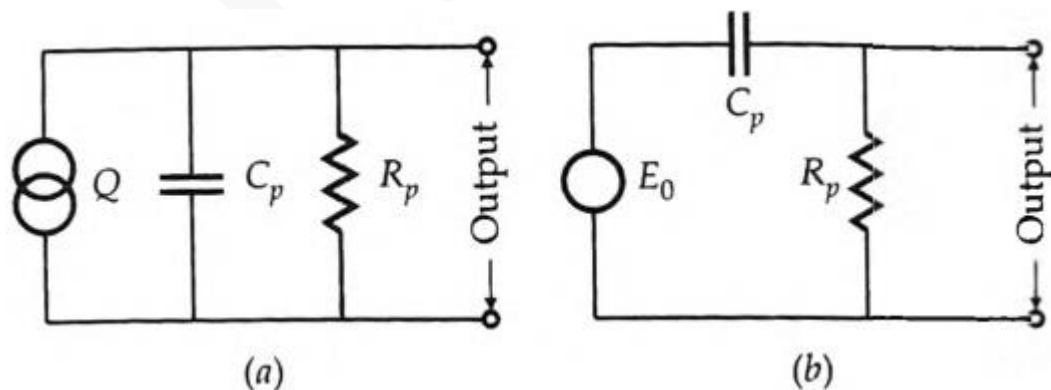
The source is a charge generator. The value of the charge is  $Q = dF$

The charge generated is across the capacitance,  $C_P$  of the crystal and its leakage resistance  $R_P$ .

The charge generator can be replaced by an equivalent voltage source having a

$$\text{voltage of } E_0 = \frac{Q}{C_P} = \frac{dF}{C_P}$$

in series with a capacitance,  $C_p$ , and resistance,  $R_p$ , as shown in **Fig. 3.10.3. (b)**



**Fig. 3.10.3. (b) Equivalent circuits of piezo-electric transducers.**

### 3.10.6. Characteristics of Piezo-Electric Transducer:

Piezoelectric transducers exhibit several characteristics that make them useful for various applications. Here are some key characteristics:

1. **Piezoelectric Effect:** The fundamental characteristic of piezoelectric transducers is the piezoelectric effect itself. This effect allows the conversion between mechanical stress and electrical charge (direct piezoelectric effect) or between an applied electric field and mechanical strain (inverse piezoelectric effect).
2. **Sensitivity:** Piezoelectric transducers are highly sensitive to changes in mechanical stress or pressure. Even small amounts of force or vibration can generate measurable electrical signals. This sensitivity makes them suitable for applications such as sensors and actuators.
3. **Frequency Response:** Piezoelectric transducers have a wide frequency response, ranging from very low frequencies to ultrasonic frequencies. This characteristic is advantageous in applications such as ultrasonic sensors, where the transducer needs to operate at high frequencies.
4. **High Output Voltage:** When subjected to mechanical stress, piezoelectric materials can produce relatively high output voltages compared to some other types of transducers. This feature is useful in applications where a strong electrical signal is required.
5. **Compact Size and Low Weight:** Piezoelectric transducers are often compact and lightweight, making them suitable for applications where space and weight are critical factors. This characteristic is beneficial in industries like aerospace, where weight reduction is crucial.
6. **Quick Response Time:** Piezoelectric transducers have a rapid response time. They can react to changes in the applied force or pressure almost instantaneously, which is valuable in applications that require real-time responsiveness.
7. **Durability:** Piezoelectric materials are known for their durability and robustness. They can withstand a large number of load cycles without significant degradation in performance, making them suitable for applications that involve repetitive stress or vibration.

8. **Wide Operating Temperature Range:** Piezoelectric transducers can operate over a broad temperature range. This characteristic makes them suitable for applications in diverse environments, including those with extreme temperatures.
9. **Wide Range of Applications:** Due to their versatility, piezoelectric transducers find applications in various fields, including sensors (pressure sensors, accelerometers), actuators (precision positioning systems), ultrasonic devices (ultrasonic cleaners, medical imaging), and energy harvesting.
10. **Relatively Low Cost:** In comparison to some other types of sensors and transducers, piezoelectric devices can be relatively cost-effective. This cost-efficiency contributes to their widespread use in many consumer and industrial applications.

It's important to note that the specific characteristics of a piezoelectric transducer can depend on factors such as the type of piezoelectric material used, the design of the transducer, and the intended application.

### 3.10.7. Applications of Piezo-Electric Transducer:

1. As piezoelectric materials cannot measure static values, used mainly for **dynamic** measurements
2. They are used in **seismographs** to measure vibrations in rockets.
3. In strain gauges to measure **force, stress**, vibrations etc...
4. Used by **automotive industries** to measure detonations in engines.
5. These are used in **ultrasonic imaging** in medical applications.
6. Barium titanate, one of the piezoelectric materials employed in **ultrasonic generators**. Used in industrial cleaning equipment, and in **sonar** (sonar is an underwater detection system).
7. Piezoelectric materials are used in **accelerometers**.
8. Piezoelectric elements can be used in **vibration pick-up**.

### 3.10.8. Advantages and Limitations of Piezoelectric Transducers

The advantages and limitations of piezoelectric transducers include the following.

### **Advantages**

1. These are active transducer i.e. they don't require external power for working and are therefore self-generating.
2. The high-frequency response of these transducers makes a good choice for various applications.

### **Limitations**

1. Temperature and environmental conditions can affect the behavior of the transducer.
2. They can only measure changing pressure hence they are useless while measuring static parameters.

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