Introduction to Piezoelectric Transducers

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1. Introduction to Piezoelectricity

1.1 Piezoelectric Phenomenon

Piezoelectricity is a property of certain dielectric materials to physically deform in the presence of an electric field, or conversely, to produce an electrical charge when mechanically deformed. There are a wide variety of materials which exhibit this phenomenon to some degree, including natural quartz crystals, semi-crystalline polyvinylidene polymer, polycrystalline piezoceramic, bone and even wood.

Piezoelectricity is due to the spontaneous separation of charge with certain crystal structures under the right conditions. This phenomenon, referred to as ***spontaneous polarization***, is caused by a displacement of the electron clouds relative to their individual atomic centers, i.e., a displacement of the positive ions relative to the negative ions within their crystal cells. Such a situation produces an electric dipole.

Polycrystalline ceramic, one of the most active piezoelectric materials known, is composed of randomly oriented minute crystallites. Each crystallite is further divided into tiny “domains,” or regions having similar dipole arrangements. The overall effect of randomly oriented polar domains is an initial lack of piezoelectric behavior. However, the material may be induced to exhibit ***macroscopic polarization*** in any given direction by subjecting it to a strong electric field, as shown in *Figure 1*. Such inducible materials are termed ***ferroelectric***. Polarization is accomplished by applying a field of ~2350 volts/mm (60 V/mil) across electrodes deposited on outer surfaces. Once polarized, the ferroelectric material will remain polarized until it is depoled by an opposite field or elevated temperature.

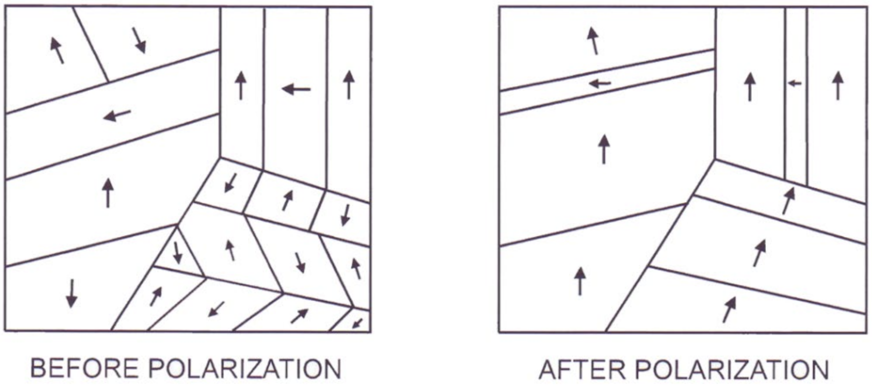

Figure 1. *Inducing macroscopic polarization in a polycrystalline piezoceramic by applying a strong electric field across randomly oriented microscopic polar domains*

During electrical polarization, the material elongates permanently in the direction of the poling field (polar axis) and contracts in the transverse direction. When voltage is subsequently applied to the poled material in the same direction as the poling voltage, the piece experiences further elongation along the polar axis and transverse contraction as stipulated by Poisson's ratio. When the voltage is removed, the piece reverts to its original pole dimensions. When voltage is applied opposite to the poled direction (***depoling direction***), the piece contracts along the polar axis and expands in the transverse direction. Again, it reverts to its original poled dimensions after removing the voltage. These distortions are illustrated in *Figure 2* for a rectangularly shaped piece. If too large a voltage is applied in the depoling direction, the original polarization will be degraded (partially or fully ***depolarized***). Or, the electric dipoles may be partially or completely flipped around 180°, causing the piece to be repoled in the opposite direction. The maximum depoling field a piece can withstand without experiencing depolarization is its ***coercive field***, E_c.

When stress is applied along the poling axis, an electric field arises within the body which tends to oppose the force acting upon it. Compressive stress generates an electric field with the same orientation as the original poling field, trying to induce the piece to elongate in opposition to the compressive forces. The piece reverts to its original poled dimensions after removing the stress. Tensile stress generates an electric field with an orientation opposite to that of the original poling field. These electric fields are illustrated in *Figure 2* for a rectangularly shaped piece.

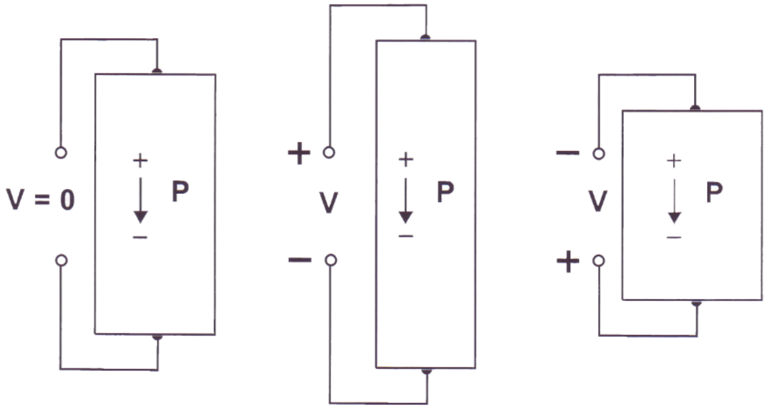

Figure 2. *Physical deformation of a rectangular piezoelectric body under the influence of an applied electric field*

1.2 Piezoelectric and Material Properties of Piezoceramic

1.2.1 TERMINOLOGY AND RELATIONS

This section describes the terminology commonly used in the discussion of piezoceramics and notes the fundamental relationships useful in motor applications. It also defines commonly used notations and sign conventions.

Relationships between applied electric fields and the resultant responses depend upon the piezoelectric properties of the ceramic, the geometry of the piece, and the direction of electrical excitation. The properties of piezoceramic vary as a function of both strain and temperature. It should be recognized that the data commonly presented represents values measured at very low levels at ~20°C.

Directions are identified using the three axes, labeled 1, 2 and 3, shown in *Figure 3*. The "polar" or 3-axis is chosen parallel to the direction of polarization.

In order to conveniently express all the relevant terms, 2nd order tensors such as stress and strain are expressed as 6x1 matrices with only the unique terms listed, as demonstrated by the stress terms in Eq. (1). This allows 3rd and 4th order tensors to be expressed as 6x3 and 6x6 matrices.

$$T_1 = \sigma_{11}, T_2 = \sigma_{22}, T_3 = \sigma_{33}, T_4 = \sigma_{23}, T_5 = \sigma_{13}, T_6 = \sigma_{12} \qquad (1)$$

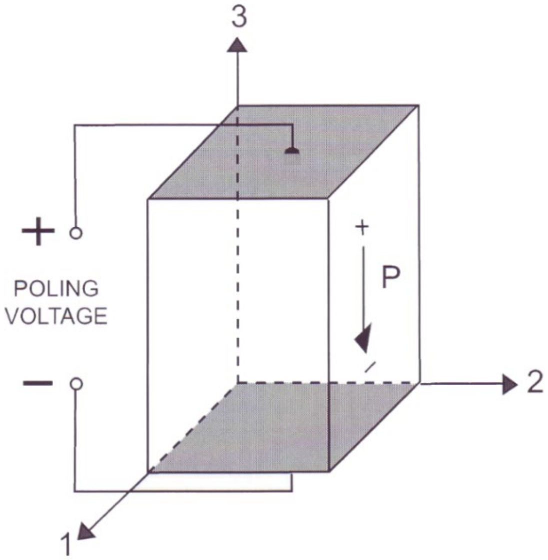

Figure 3. *Definition of axes for a rectangular piezoelectric body showing the polar or 3-axis, and the transverse or 1 and 2-axis*