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# Piezoelectric properties of ceramic materials and components Part 1: Terms and definitions

Propriétés piézoélectriques des matériaux et composants en céramique
Partie 1: Termes et définitions

Piezoelektrische Eigenschaften von keramischen Werkstoffen und Komponenten
Teil 1: Begriffe



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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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## Foreword

This European Standard was prepared by the CENELEC BTTF 63-2, Advanced technical ceramics.

The text of the draft was submitted to the formal vote and was approved by CENELEC as EN 50324-1 on 2001-12-01.

The following dates were fixed:

| | | |
|---|---|---|
| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2002-12-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn | (dow) | 2004-12-01 |

This draft European Standard consists of three parts:

Part 1 Terms and definitions

Part 2 Methods of measurement - Low power

Part 3 Methods of measurement - High power

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## Introduction

The principles underlying the piezoelectricity of ceramics are discussed in IEC 60483 "Guide to dynamic measurements of piezoelectric ceramics with high electromechanical coupling". Piezoelectric ceramics are polycrystalline ferroelectrics mainly based on lead zirconate titanate ($Pb(ZrTi)O_3$), barium titanate ($BaTiO_3$) and lead titanate ($PbTiO_3$). Their piezoelectricity is the result of the preferential orientation of polar regions at remanent polarisation. In ceramics, the remanent polarisation is created by application of a dc electric field to the polycrystalline material. The value of this remanent polarisation results in the high level of piezoelectric activity in piezoceramics.

Both the direct and inverse piezoelectric effects are utilized. In a variety of applications, piezoelectric transducers operate at resonance. Static and quasi-static applications complete a wide range of functions.

## 1 Scope

This European Standard relates to piezoelectric transducer ceramics for application both as transmitters and receivers in electroacoustics and ultrasonics over a wide frequency range. They are used for generation and transmission of acoustic signals, for achievement of ultrasonic effects, for transmission of signals in communication electronics, for sensors and actuators and for generation of high voltages in ignition devices.

Piezoelectric ceramics can be manufactured in a wide variety of shapes and sizes. Commonly used shapes include discs, rectangular plates, bars, tubes, cylinders and hemispheres as well as bending elements (circular and rectangular), sandwiches and monolithic multilayers.

Relevant sections of IEC 60302 “Standard definitions and methods of measurement for piezoelectric vibrators operating over the frequency range up to 30 MHz” and IEC 60642 “Piezoelectric ceramic resonators and resonator units for frequency control and selection” have been taken into consideration when drafting this standard.

## 2 Normative references

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies (including amendments).



IEC 60302 Standard definitions and methods of measurement for piezoelectric vibrators operating over the frequency range up to 30 MHz

IEC 60483 Guide to dynamic measurements of piezoelectric ceramics with high electromechanical coupling

IEC 60642 Piezoelectric ceramic resonators and resonator units for frequency control and selection - Chapter I: Standard values and conditions - Chapter II: Measuring and test conditions

## 3 Definitions

The fundamental parameters of the equivalent electric circuit of a piezoelectric resonator are defined in IEC 60302 and, additionally, IEC 60642 defines terms commonly used to characterize piezoelectrics. The additional terms defined in this standard describe the properties and performance parameters of piezoelectric ceramics.

### 3.1 Ferroelectricity of ceramics

**3.1.1**
**ferroelectric ceramic**
non-linear spontaneously polarised ceramics, generally with a high level of permittivity, exhibit hysteresis in the variation of the dielectric polarization as a function of electric field strength and temperature dependence of the permittivity (see “Curie temperature”). Ferroelectric ceramics become piezoelectric by the induced alignment of dipoles, a process generally referred to as poling

To create the macroscopic piezoelectric effect, the polar axes of dipole regions (domains) in crystallites of ferroelectric ceramics must be aligned. This requires the application of a high dc field at determined conditions of temperature and time. The poled ceramic has a remanent polarization $P_r$ which is necessary for piezoelectric activity.

**3.1.2**
**anisotropy**
Figure 1 defines the crystallographic axes, as described for the elasto-piezoelectric-dielectric-matrix in IEC 60483, Table 1. The dielectric, elastic, and piezoelectric properties of poled ferroelectric ceramics depend on the direction of excitation and piezoelectric action with respect to the direction of remanent polarization

**3.1.3**
**Curie temperature $\vartheta_C$**
this temperature corresponds to the maximum permittivity of ferroelectric ceramics. Ceramics are not piezoelectric above the Curie temperature

**3.1.4**
**permittivity $\varepsilon_{ij}^T$; $\varepsilon_{ij}^S$**
after poling dielectric anisotropy is present (see Figure 1) and the permittivity may be: “free” permittivity $\varepsilon_{ij}^T$ measured well below resonant frequencies; or “clamped” permittivity $\varepsilon_{ij}^S$ measured far above resonant frequencies

**3.1.5**
**(relative) dielectric permittivity, ε**
ratio of (absolute) permittivity $\varepsilon_{ij}$ to the permittivity of free space

$$\varepsilon_0 = 8{,}854 \times 10^{-12} \text{ F/m},$$

$$\varepsilon_{3r}^T = \varepsilon_{33}^T/\varepsilon_0 \ ; \ \varepsilon_{1r}^T = \varepsilon_{11}^T/\varepsilon_0$$



**3.1.6**
**dielectric dissipation factor tan δ**
ratio of resistive power (dielectric power loss) to reactive wattless power at sine-wave voltage of determined frequency; for piezoceramics measured well below the lowest resonant frequency usually at 1 kHz, together with free capacitance



**3.1.7**
**free capacitance $C^T$**
capacitance of a piezoelectric device, measured well below the lowest resonant frequency (see “free” permittivity) usually at 1 kHz

**3.1.8**
**clamped capacitance $C^S$**
capacitance of a piezoelectric device, measured far above the resonant frequency (see “clamped” permittivity)

**3.1.9**
**poling**
procedure for creating a macroscopic piezoelectric effect by aligning the polar axes of dipole regions (domains) in crystallites of ferroelectric ceramic under high electric dc field. The poled ceramic has a remanent polarisation needed for piezoelectricity

**3.1.10**
**remanent polarisation $P_r$**
macroscopic dipole moment of ferroelectric ceramic after poling

## 3.2 Piezoelectricity of ceramics

### 3.2.1 *Piezoelectricity*

Piezoelectricity can be understood as the coupling of elastic and dielectric properties of a solid exhibiting linear dependence of either

- a mechanical load generating a charge, dependent upon the magnitude and direction of the load (direct piezoelectric effect), or
- an electric field generating a deformation, dependent upon the strength and direction of the electric field (inverse piezoelectric effect).

**3.2.1.1**
**electromechanical coupling factor k**
defined by the square root of the ratio of the mutual elasto-dielectric energy density squared to the product of the stored elastic and dielectric energy densities; defined for different boundary conditions, and a combination of elastic, dielectric, and piezoelectric constants. See also (material) coupling factors for different vibration modes and effective coupling factors respectively

**3.2.1.2**
**piezoelectric charge constant $d_{ij}$**
also: piezoelectric deformation constant
couples the electric displacement with the mechanical stress and the strain with the electric field strength respectively. For piezoceramics there are three constants $d_{33}$ , $d_{31}$, $d_{15}$ independent of each other



**3.2.1.3**
**piezoelectric voltage constant $g_{ij}$**
also: strain constant
couples the electric field strength with the mechanical stress and the strain with the electric displacement. For piezoceramics there are three constants $g_{33}$, $g_{31}$, $g_{15}$ independent of each other



**3.2.1.4**
**piezoelectric component**
one or more piezoelectric parts made from poled ferroelectric ceramic (piezoceramic), used for mechano-electrical or electro-mechanical conversion of energy or for signal processing

**3.2.1.5**
**piezoelectric transducer**
piezoelectric part made from poled ferroelectric ceramic (piezoceramic), used for mechano-electrical or electro-mechanical conversion of energy. In the case of electro-mechanical conversion of energy (see inverse piezoelectric effect) the piezoelectric solid will be excited to forced vibrations or to self-excited (resonant) vibrations (see vibration modes)

### 3.2.2 *Resonant vibration modes*

**3.2.2.1**
**fundamental vibration mode** (see Figure 2)
vibration at the lowest resonance frequency of a given vibration mode

**3.2.2.2**
**overtone**
vibration (resonance) excited above the fundamental vibration of a given vibration mode