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Piezoelectric properties of ceramic materials and components - Part 3: Methods of measurement - High power

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Piezoelectric properties of ceramic materials and components Part 3: Methods of measurement - High power

Propriétés piézo-électriques des
matériaux et composants céramiques
Partie 3: Méthodes de mesure -
Grande puissance

Piezoelektrische Eigenschaften von
keramischen Werkstoffen
und Komponenten
Teil 3: Meßverfahren -
Großsignal

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

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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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 50324-3 on 2001-01-12.

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– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2004-12-01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 part 3 is to be read in conjunction with EN 50324-1 and EN 50324-2.

Contents

1 Scope

This European Standard relates to piezoelectric transducer ceramics for power application over a wide frequency range both as electromechanical or mechanoelectrical converters.

This standard covers the large signal characterization of piezoelectric ceramics material only, and not the characterization of a complete assembled transducer.

The selection of a material for a given power application is difficult and the advice given in clause 2 is mainly indicative.

2 Specification of material

2.1 Power applications criteria

Most mechanical, electrical and piezoelectric coefficients defined in EN 50324-2 exhibit a non-linear behaviour when the piezoelectric material is subjected to large electrical and/or mechanical signals.

However, the difference in non-linear behaviour of the various ceramic compositions is not the only criterion to decide which is the most suited for a given power application. In general, the material factors which limit the available acoustic power capacity of a piezoceramic based transducer are mainly

- the dynamic mechanical strength of the ceramic,
- the reduction in efficiency due to dielectric and mechanical ceramic internal losses,
- depolarization due to temperature rise.

2.2 Materials for electromechanical conversion

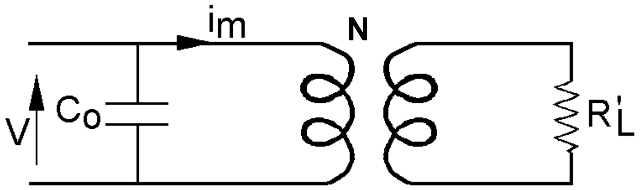
2.2.1 *Figure of Merit M*

The figure of Merit characterizes the ability of the material to convert the electrical energy into mechanical energy. It may be represented by the appropriate electromechanical coupling factor measured under high power conditions. A more suited figure of Merit for power applications is M_{ij}, derived from the electromechanical transformer ratio N of the Mason equivalent electric circuit (see Figure 1). This figure of Merit is measured at low signal level and it is assumed that it is constant at high level.

The power, P, supplied to the load resistance R'_L is:

$$P = M_{ij}\frac{V^2}{R'_L}\frac{A^2}{\ell^2}$$

$$N = \frac{A}{\ell}\sqrt{M_{ij}}$$



A = electrode area

ℓ = length for longitudinal and transverse length modes, thickness t for thickness extensional and thickness shear modes

R'_L = mechanical or acoustical load resistance

C_o = clamped capacitance of the sample

i_m = motional current

V = applied voltage

N = electromechanical transformer ratio

Figure 1 - Equivalent circuit of a purely capacitative piezoelectric element at the series resonance

Table 1 lists the electromechanical coupling coefficients kij and the Mij corresponding to the main resonant modes.

Table 1 - Figures of Merit for the main modes of vibration of piezoelectric elements

Mode	$\mathbf{k_{ij}}$	$\mathbf{M_{ij}}$ **C^2 m^{-4}**
Parallel expander bar	k_{33}	$(d_{33}/s^E_{33})^2$
Transverse expander bar	k_{31}	$(d_{31}/s^E_{11})^2$
Thickness extensional plate	k_t	e^2_{33}
Thickness shear plate	k_{15}	e^2_{15}

NOTE The piezoelectric, dielectric and elastic coefficients depend on the electric field and on the uniaxial stress.
So the k_{ij} and M_{ij} values should be determined under high power conditions in order to take into account the non-linearities of these coefficients. However, to a first approximation the low signal values may be used.

2.2.2 *Methodology for the composition selection*

The power radiated in a medium with specific acoustic impedance Z_a is:

$$P = 4\pi^2 \; R_e(Z_a)\, A^2 f^2 \; u^2$$

where

$R_e(Z_a)$ is the real part of Z_a, u is the RMS mechanical displacement, f the frequency and A the radiating area.

The losses of the transducer depend on the dielectric, mechanical and piezoelectric non-linear coefficients. When the device is at the resonance frequency, for a low quality Q factor the mechanical displacement u is low, for a high electric field. Therefore, the dielectric losses will be a limiting factor in this case. When the device has a high Q, factor the mechanical displacement u will be very high at the resonance frequency and the mechanical losses will be a limiting factor.

In all cases, it is necessary to use the mechanical Q factor of the device, not of the material.

Because the power losses of the device also depend on the frequency, both factors, device Q factor and frequency, modify the composition selection.

2.2.2.1 *Materials for very low frequency transducers or low Q factor (high E)*

At frequencies lower than 10 kHz or Q < 50, the velocity $\dot{u} = 2\pi f u$ is very small and the mechanical losses are not a limiting factor.

The acoustic load reflected at the "material – medium" interface can be very high as well as the applied electric field is high in order to maintain a high mechanical displacement. In such transducers, the dielectric losses are the limiting factor. Type 300 materials are required with a low large signal dielectric loss tangent:

$$\tan \delta_d \le 0{,}01 \text{ at } E = 400 \text{ kV/m}$$

2.2.2.2 *Materials for medium frequency transducers or medium Q factor*

In such transducers, the working conditions of the piezoelectric materials are the most severe. Both the dielectric and mechanical losses are limiting factors. Type 300 materials are required with reduced large signal mechanical and dielectric loss tangents:

$\tan \delta_d \le 0{,}01$ at $E = 400$ kV/m
$\tan \delta_{0m} \le 0{,}0015$ and $\alpha \le 8\ 10^4$ (see definition of α and $\tan \delta_{0m}$ in 3.2.2)

2.2.2.3 *Materials for high frequency transducers or high Q factor (high u)*

At frequencies higher than 50 kHz or Q < 500, a high power per unit area is delivered due to the high velocities. The limiting factor is the mechanical losses. Type 300 materials may be used but type 100 materials can also be used because of their higher electromechanical activity.

2.2.2.4 *Materials for pulsed transducers*

These transducers work with high pulsed voltages at a very low duty cycle. As a consequence, the losses are not important, and the material dielectric breakdown strength is the limiting factor. Type 100 materials with high piezoelectric coefficients, may be used as well as some type 200 materials.

2.3 Materials for mechanoelectrical conversion

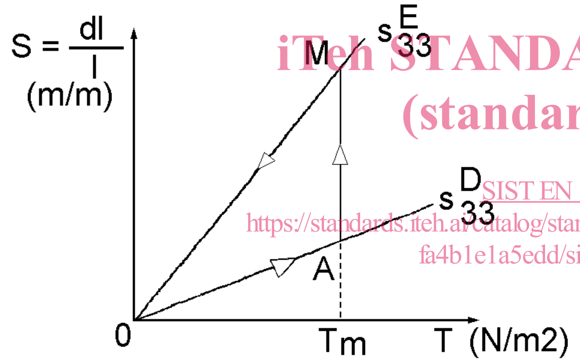
2.3.1 *Figure of Merit*

The figure of Merit characterizes the ability of the material to convert the mechanical energy into electrical energy. Figure 2 shows the mechanoelectrical energy cycle for a piezoceramic used in a gas fire igniter. During the spark, the strain of the material rapidly changes at constant stress (A-M). The electrical power delivered per unit volume may be expressed as follows:

$$W_E = \frac{1}{2} M \; T_m^2$$

where

$M = d.g$ is the figure of Merit for mechanoelectrical conversion.



T_m = stress during the spark

Area OAM = W_d

$$W_d = \frac{1}{2} (s_{33}^E - s_{33}^D) \, T_m^2$$

$$s_{33}^E - s_{33}^D = k_{33}^2 \, s_{33}^E = d_{33} \, g_{33}$$

Figure 2 - Strain-stress diagram for mechanoelectrical energy conversion (longitudinal stress along direction 3)

2.3.2 *Methodology for the composition selection*

For spark transducers, $M = d.g$ must be large up to the maximum stress reached during the conversion. Application of repetitive and high level stresses must not lead to depolarization. Modified materials of group 100 may be used in quasi-static compression type generators and modified materials of group 200 may be used in dynamic compression type generators.

3 Boundary conditions and methods of measurement for the large signal parameters of piezoceramic materials and components

Non-linear behaviour in ferroelectric materials arises from the influence of the mechanical and electrical stresses on domains. The limits on linear behaviour vary for the different ceramic compositions, and are related to the coercive force.

Non-linearities of displacement with respect to applied field ($D = f(E)$, $S = f(T)$) give rise to dissipation, lower the efficiencies and generate heat.