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English version

Piezoelectric properties of ceramic materials and components Part 2: Methods of measurement - Low power

Propriétés piézoélectriques des matériaux et composants en céramique
Partie 2: Méthodes de mesure -
Faible puissance

Piezoelektrische Eigenschaften von keramischen Werkstoffen und Komponenten
Teil 2: Meßverfahren -
Kleinsignal

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– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2004-12-01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

Contents

1 Scope

The methods of measurement described in this European Standard are for use with piezoelectric components produced from the ceramic materials described in EN 50324-1 "Terms and definitions". Methods of measurement for specific dielectric, piezoelectric and elastic coefficients are generally applicable to piezoelectric ceramics.

The polycrystalline nature of ceramics, statistical fluctuations in composition and the influence of the manufacturing process, result in specified material coefficients being typical mean values. These values are provided for design information only.

Piezoelectric transducers can have widely differing shapes and may be employed in a range of vibrational modes. Material parameters however, are measured on simple test-pieces (discs, rods etc. see EN 50324-1, Figure 2) using specific geometric and electrical boundary conditions. Consequently, the results of the tests provide basic material parameters only and must only be used as a guide to the actual properties of manufactured commercial components.

2 Symbols and units

All material constants and equations appearing in this standard are given according to the International System of Units (SI-units).

Table 1 lists the symbols and, where appropriate, shows the units associated with the physical quantities designated by the symbols.

Table 1 - List of symbols and their units

Symbol	Meaning	SI-unit
A	Area	m^2
c	Ageing rate	See note
c_{ij}	Elastic stiffness constant	N/m^2
C	Capacitance	F
C^T	Free capacitance	F
d	Diameter	m
d_{ij}	Piezoelectric charge (strain) constant	C/N or m/V
e_{ij}	Piezoelectric stress constant	C/m^2 or N/Vm
E_i	Component of the electric field strength	V/m
E_m	Measuring field strength	V/m
f	Frequency	Hz
f_a	Antiresonance frequency (zero reactance)	Hz
f_m	Frequency of minimum impedance	Hz
f_n	Frequency of maximum impedance	Hz
f_p	Parallel resonance frequency (maximum resistance)	Hz
f_r	Resonance frequency	Hz
f_s	Motional (series) resonance frequency (maximum conductance)	Hz
f_1	Frequency at first overtone	Hz
f_3	Frequency at third overtone	Hz
g_{ij}	Piezoelectric voltage (stress) constant	m^2/C or Vm/N

Table 1 - List of symbols and their units (continued)

Symbol	Meaning	SI-unit
$J_0(z)$	Bessel function of first kind and zero order	
$J_1(z)$	Bessel function of first kind and first order	
$J_m(z)$	Modified Bessel function of first order	
k_{eff}	Effective electromechanical coupling factor	
k_{31}	Transverse coupling factor	
k_{33}	Longitudinal coupling factor	
k_{15}	Shear coupling factor	
k_p	Planar coupling factor	
k_t	Thickness coupling factor	
l	Length	m
M	Figure of merit	
n	Overtone order	
N_t	Frequency constant for thickness mode	Hz·m
N_p	Frequency constant for radial mode	Hz·m
Q_m	Mechanical quality factor	
R_i	Isolation resistance	Ω
S_i	Strain component	
s_{ij}	Elastic compliance constant	m^2/N
t	Thickness	m
TC	Temperature coefficient	K^{-1}
T_i	Stress component	N/m^2
$\tan \delta_d$	Dielectric dissipation factor	
$\tan \delta_m$	Mechanical dissipation factor	
v	Sound velocity	m/s
w	Width	m
Z	Impedance	Ω
δ_r	Relative frequency spacing	
ε_{ij}	Absolute permittivity	
ε_o	Permittivity of free space	F/m
ϑ	Temperature	°C
ϑ_C	Curie temperature	°C
φ	Phase angle	°
ρ	Density	Mg/m^3
ρ_e	Resistivity	Ωm
σ^E	Planar Poisson's ratio	
ω	Angular frequency	rads/sec
NOTE Ageing rate is commonly expressed as % per decade.		

3 Dimensions and finish of standard test specimen

The surface of standard test specimens for characterisation of piezoceramics for transducers should have an average roughness $R_a < 1$ µm before electroding and deviations from flatness and parallelism of the surfaces should not exceed 50 µm per length.

The geometric dimensions of standard test specimens should correspond to the ratios indicated in Figure 2 of EN 50324-1.

At smaller ratios of the geometric dimensions of the piezoceramic parts, deviations of the respective vibration modes appear, only allowing imprecise characterisation of the piezoceramic.

Thickness shear vibrators with rectangular electrode faces have to be polarized in the direction of the long edge.

4 Electrodes

The electrodes for measurement (and for operation) are deposited by

– firing on of precious metal pastes (e.g. Ag, AgPd, Au),

– electroless plating (e.g. Ni, NiAu),

– vacuum coating: evaporation, sputtering (e.g. Ni, CuNi, Au).

5 Environmental requirements

The electrical measurements shall be carried out at temperatures between 20 °C and 25 °C. Before each electrical measurement (after electroding), the test specimen must be stored at these temperatures for at least 24 hours. The test specimen shall be clean and dry.

During measurement, the relative humidity of air in the test laboratory shall be below 65 %.

6 Small signal data - Timing of measurement

The material parameters specified for piezoelectric ceramics (dielectric and electromechanical properties) require essentially linear relationships between the components of mechanical stress and strain on the one hand and of electric field strength and displacement or polarization on the other hand. The material parameters are therefore only valid for a limited range of input level (under measurement and operating conditions).

The limits of linear behaviour can vary significantly between piezoelectric ceramics of different composition.

The dielectric and electromechanical parameters of piezoelectric ceramics are subject to a natural ageing on the basis of the physical phenomenology. Therefore the parameters have to be measured at a defined time not earlier than 24 h after poling. The parameters have to be corrected for measurements in longer intervals after poling, bearing in mind the ageing rates determined according to clause 11.

The parameters of piezoelectric ceramic parts designed as transducers for practical application should be measured within the second decade of ageing, normally 30 days after poling.

7 Number of test specimens

The characteristic material parameters shall be determined on a minimum of 10 test specimens.

8 Methods of measurement

8.1 Determination of relative permittivity and dielectric dissipation factor

The relative permittivity of piezoceramic materials is determined by measurement of the capacitance by means of capacitance measuring meters at $f = (1\ 000 \pm 200)$ Hz and $E_m < 1$ V/mm.

The dissipation factor tan δ results from the same measuring procedure.

The Curie temperature ϑ_C results from the maximum of temperature dependent capacitance. This maximum is generally far above the operating temperature range (see 9.2.2 and 11).

8.2 Determination of the electromechanical properties

8.2.1 *Dynamic method of measurement*

The determination of the electromechanical coupling factors, frequency constants, and the mechanical quality factor is made in principle by dynamic methods of measurement, that is the excitation of piezoelectric vibrators to vibration modes at mechanical resonance.

The value of excitation voltages shall be corresponding to a maximum field strength of 0,01 V/mm in general. The dynamic methods of measurement are based on the impedance diagram (Figure 1) and the admittance diagram respectively of the equivalent circuits of a piezoelectric resonator.

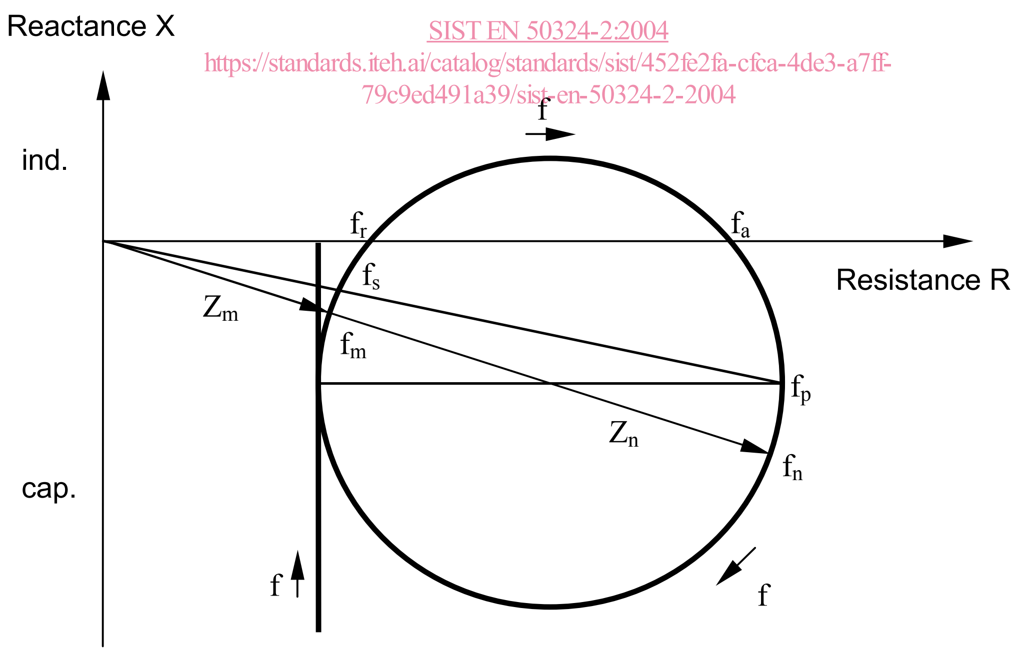

Figure 1 - Vector impedance diagram of a piezoceramic transducer

Three pairs of characteristic frequencies which are significant for the specification of the piezoelectric activity are shown in Figure 1.

The frequencies f_m, f_s, f_r and f_n, f_p, f_a respectively coincide (to a first approximation) for a low-loss piezoelectric resonator, that is one with a figure of merit

$$M = Q_m \frac{k_{eff}^2}{1 - k_{eff}^2} > 20 \qquad (1)$$

This is true of all piezoceramics with $k_{eff} > 0{,}4$ and $Q_m > 80$ or $k_{eff} > 0{,}2$ and $Q_m > 500$ (all material groups except type 800) and can be used in the same way for the determination of the electromechanical coupling factors. Determination of the frequency pair f_s, f_p, is only possible with complex measurements.

The typical characteristics of the measured impedance vs. frequency of a piezoceramic transducer are shown in Figure 2.

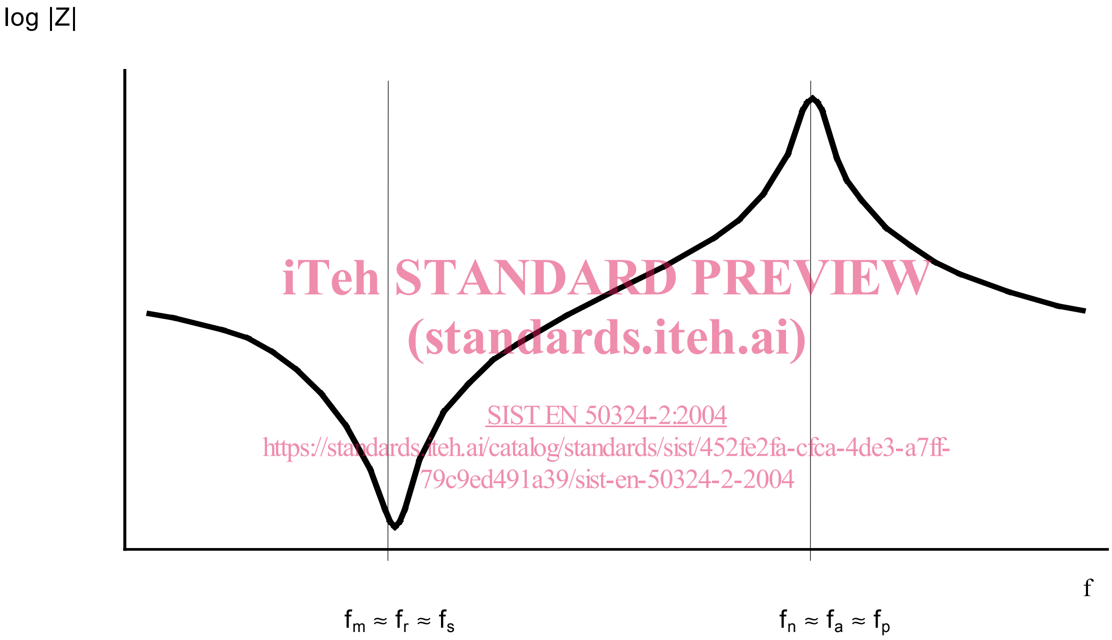

Figure 2 - Measured impedance of a piezoceramic transducer

The use of impedance phase analyzers for the "impedance method" results in the frequency pair f_m, f_n, the frequencies at impedance minimum and maximum and for the "phase method" in the frequency pair f_r, f_a, the frequencies at zero phase angle, $\varphi = 0$. For practical uses, these parameters can be approximated with the frequency pair f_s and f_p in all piezoceramics except type 800.

The use of simple ac voltage divider circuits is permissible, when the test specimen is in the series arm (for f_m see Figure 3a) or in the shunt arm (for f_n see Figure 3b), fulfilling the condition $R_t < |Z|_{min}$ and $R_l > |Z|_{max}$ respectively.

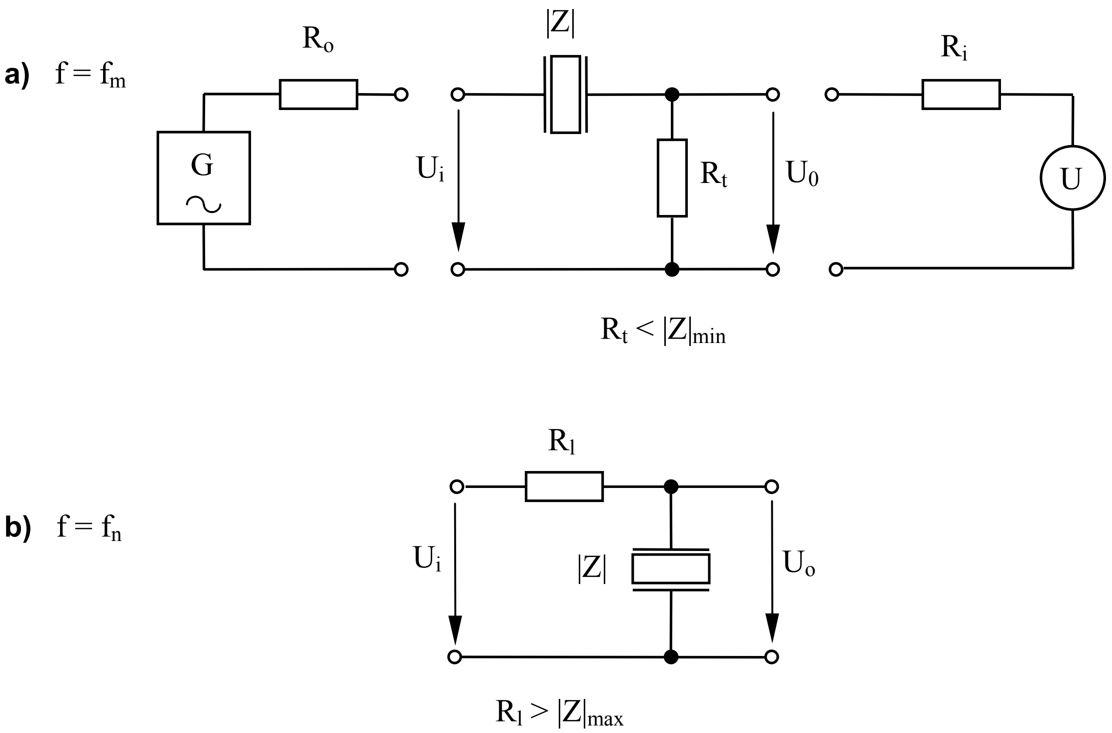

Figure 3 - Determination of the frequencies f_m and f_n by the impedance method

8.2.2 *Determination of electromechanical coupling factors*

The electromechanical coupling factors can be calculated directly from the mathematical relationships of the characteristic frequencies of the respective vibration mode (see 9.2.4.2).

Alternatively, to a first approximation, the electromechanical coupling factors may be determined from the relative frequency spacing

$$\delta_r = \frac{f_p - f_s}{f_p} \qquad (2)$$

The use of the relative frequency spacing δ_r corresponds with the determination of the effective electromechanical coupling factor k_{eff} by the relationship

$$k_{eff}^{\ 2} = \frac{f_p^2 - f_s^2}{f_p^2} \qquad (3)$$

This relationship is valid for all vibration modes and supplies the value for the dynamic electromechanical coupling factor.

The difference in the material coupling factors, which have to be calculated according to the exact relations, results from the elastic boundary conditions of the various vibration modes.

Material coupling factors (see equations (37) to (44)) are determined graphically from the effective coupling factor using Figures 4 to 6.