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Fine ceramics (advanced ceramics, advanced technical ceramics) — Characteristic of piezoelectric properties under high-load conditions —

Part 2: Electrical transient response method under high vibration levels

Céramiques techniques (céramiques avancées, céramiques techniques avancées) — Caractéristique des propriétés piézoélectriques en conditions de charge élevée —

Partie 2: Méthode de la réponse transitoire électrique sous des niveaux vibratoires élevés

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Foreword

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This document was prepared by Technical Committee ISO/TC 206, *Fine ceramics*.

A list of all parts in the ISO 21819 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Fine ceramics (advanced ceramics, advanced technical ceramics) — Characteristic of piezoelectric properties under high-load conditions —

Part 2: Electrical transient response method under high vibration levels

1 Scope

This document specifies a method of measuring piezoelectric properties of piezoelectric fine ceramics and other piezoelectric devices. It applies to electrical transient response methods for evaluating the piezoelectric properties of piezoelectric fine ceramics resonators under high vibration levels.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20507, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20507 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
electrical transient response method
method in which a voltage close to the resonance frequency is applied to a piezoelectric fine ceramic resonator, and a large amplitude state is realized by driving only for a brief time until vibration is excited, before characteristics of piezoelectric properties under an arbitrary vibration level are evaluated by using the attenuation waveform of vibration velocity and the current under short circuit of the electrical terminal

Note 1 to entry: Superior ability to exclude the effects of external electrical fields and temperature allows measurement and evaluation of characteristics in a vibrational stress load environment excluding these factors.

3.2
burst
driving for only a brief duration to excite vibration

4 Symbols

A Force factor (N/V)

d_{31} Equivalent piezoelectric constant (C/N)

f_{ri} Resonance frequency of current (Hz)

f_{rv} Resonance frequency of vibration velocity (Hz)

f_{rv1} Instantaneous frequency of vibration velocity (Hz)

i Current (A)

l_1 Instantaneous amplitude of current (A)

l_0 Amplitude of current (A)

M Mass of test piece determined in 7.2 (kg)

$Q_{\mathrm{m}}{}^*$ Equivalent mechanical quality factor

$s_{11}{}^{\mathrm{E}*}$ Equivalent elastic compliance(m^2/N)

t Time (s)

$T_{\mathrm{m}}{}^*$ Amplitude of equivalent maximum stress on central region of test piece (Pa)

v Vibration velocity (m/s)

V_0 Amplitude of vibration velocity (m/s)

V_1 Instantaneous amplitude of vibration velocity (m/s)

X Width of test piece (m)

Y Length of test piece (m)

β_{i} Decay constant of current (S^{-1})

β_{v} Decay constant of vibration velocity (S^{-1})

β_{v1} Instantaneous decay constant of vibration velocity (S^{-1})

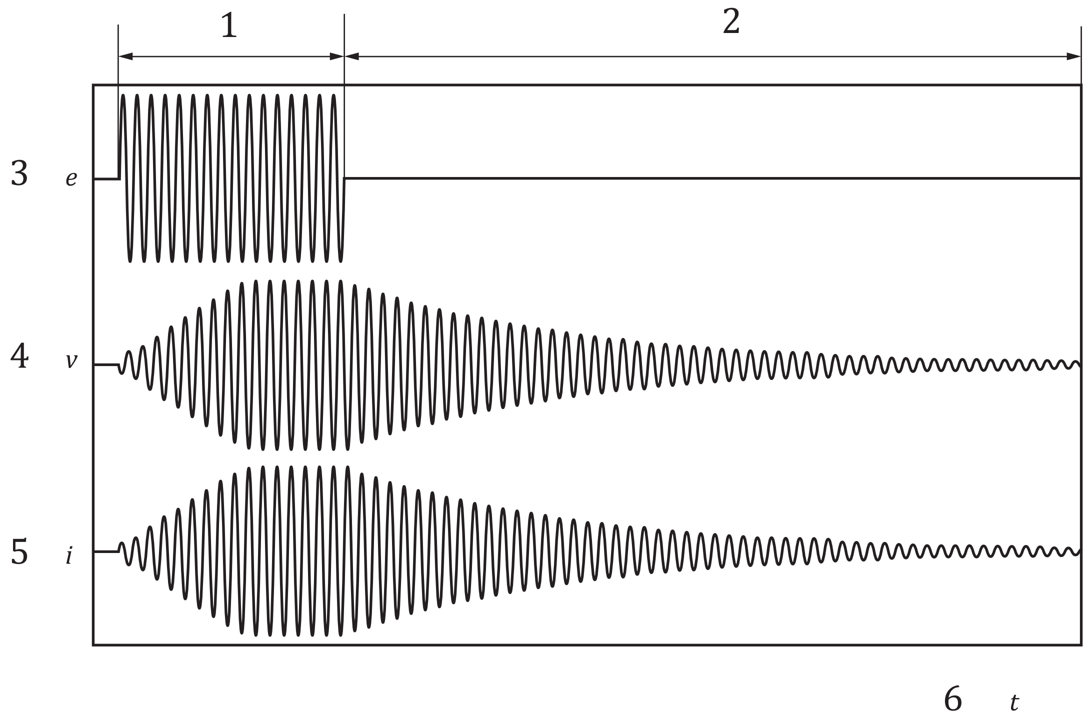
ϕ_{i} Initial phase of current

Φ_{v} Initial phase of vibration velocity

ρ Density determined in 7.2 (kg/m^3)

5 Principle

A voltage *e* near the resonance frequency of a piezoelectric fine ceramic resonator is applied to driving voltage then reduced to 0, placing the electrical terminals in a shorted state ($e = 0$, see Figure 1).



Key

1 burst drive
2 short circuited
3 voltage
4 vibration velocity
5 current
6 time

Figure 1 — Waveform of vibration velocity and current during burst voltage driving of a piezoelectric fine ceramic resonator

The decay waveforms of vibration velocity v and current i when electrical terminals are shorted (e = 0) after burst driving decay with a mechanical resonance frequency are shown in Formula (1) and Formula (2) (see Figure 1).

$$v = V_0 \varepsilon^{-\beta_v t} \sin(2\pi f_{rv} t + \varphi_v) \tag{1}$$

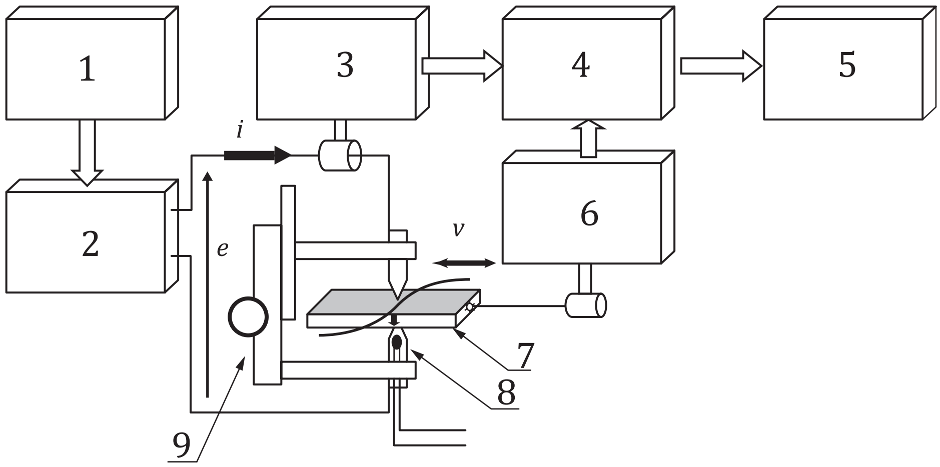
$$i = I_0 \varepsilon^{-\beta_i t} \sin(2\pi f_{ri} t + \varphi_i) \tag{2}$$

β_v and β_i, and likewise f_{rv} and f_{ri}, can be taken as nearly the same values, but considering that this is a measurement analysis concerning mechanical vibration level, β_v is used as a decay constant and f_{rv} is used as a resonance frequency. In a large amplitude range, various other factors can also produce other frequency components. Consequently, only a first (fundamental) resonance frequency component is extracted from the decay waveform of the vibration velocity and the current when electrical terminals are shorted; the amplitude of the vibration velocity V_1, the amplitude of current I_1, resonance frequency f_{rv1} and decay constant β_{v1} in a selected schedule are measured and calculated, and these values are used to calculate the required constants at a selected vibration velocity. A voltage is applied only for a brief duration, and it then drops to 0 V, meaning that the electrical field applied to elements after electrical terminals are shorted and is also deemed zero, and since driving is only for a brief duration, measurements can be made under conditions where temperature change attributable to vibration loss is negligible, and piezoelectric characteristics can be evaluated in a vibrational stress load environment free from the effects of external electrical fields and temperature[1–10].

6 Measurement equipment

6.1 General

This clause details the apparatus used for measurement. Figure 2 also presents a simplified schematic of the measurement apparatus. A calibrated apparatus is used in measurement.



Key

1 function generator

2 power amplifier

3 current probe

4 digital storage oscilloscope

5 numerical analysis software

6 vibration velocity meter

7 test piece

8 thermocouple

9 test piece holder

Figure 2 — Simplified schematic of measurement apparatus

6.2 Function generator

The function generator shall output a sine wave greater than the first (fundamental) resonance frequency of the piezoelectric fine ceramic resonator, and allow the setting of its drive duration (burst driving).

6.3 Power amplifier

The power amplifier shall be capable of providing power amplification for sine waves at least two times greater than the first (fundamental) resonance frequency of a piezoelectric fine ceramic resonator, as well as four-quadrant output. The power amplifier should provide peak amplitudes of 200 V or more and 1 A or more for output voltage and current, respectively, and output impedance should be 0,5 Ω or less.

6.4 Vibration velocity meter

The vibration velocity meter shall be capable of measurement in a frequency range up to roughly five times the first (fundamental) resonance frequency of a piezoelectric fine ceramic resonator, in a vibration velocity range of approximately 0,01 m/s to 2 m/s. The vibration velocity meter shall also be calibrated.

6.5 Current probe

The current probe shall be capable of measurement in a frequency range up to roughly five times the first (fundamental) resonance frequency of a piezoelectric fine ceramic resonator (material) and allow measurement of current in a range of approximately 1 mA to 1 A. The current probe shall also be calibrated.

6.6 Digital storage oscilloscope

The digital storage oscilloscope shall be capable of recording waveforms at a sampling frequency at least 10 times greater than the first (fundamental) resonance frequency of a piezoelectric fine ceramic and shall allow output of wave form data as numerical data. The oscilloscope should also allow recording of 1 s or more waveform data and have excellent y-axis resolution.

6.7 Test piece holder

The test piece holder shall have at its tip a pair of electrode pins measuring 1 mm or less in diameter and be capable of using these structures to sandwich and hold the upper and lower electrode surfaces of a piezoelectric fine ceramic resonator at a single point of contact on each surface.

NOTE 1 Providing the holder with a mechanism that has a Z-stage to move the upper pin vertically allows easy mounting of test pieces.

NOTE 2 If a thermocouple is installed inside the lower electrode pin, the temperature of a piezoelectric fine ceramic resonator can be measured easily.

6.8 Numerical analysis software (numerical analyser)

Numerical analysis software shall allow frequency analysis of waveform data and extraction of selected frequency components. The software shall also allow calculation of instantaneous frequency values and instantaneous amplitude values.

7 Specimens

7.1 Test piece form

A piezoelectric fine ceramic resonator is used as a test piece and has a form described as X (length, 43 ± 0,2 mm), Y (width, 7 ± 0,2 mm) and Z (thickness, 1 ± 0,05 mm), and an electrode surface described as length × width. Test pieces are also polarized in the orientation of their thickness.

To interface with laser light properly, laser-reflective surfaces (either of two surfaces comprising width × thickness) should be mirror-polished.

7.2 Measurement of test piece density

Test piece mass M is measured (weighing) in 1 mg units. Density ρ (kg/m^3) is then calculated from volume calculated on the basis of values described in 7.1, and rounded to four significant digits.

7.3 Measurement of characteristics values

Principal constants are measured in advance, for example test piece resonance frequency f_0, mechanical quality factor Q_m, elastic constant s_{11} and piezoelectric constant d_{31}.

NOTE EM-4501 is a useful reference on measurement methods for individual constants.

