



Measurement of thermal depolarization effects in piezoelectric coefficients of soft PZT ceramics via the frequency and direct methods



Jiri Fialka^{a,*}, Petr Benes^b, Lenka Michlovská^a, Stanislav Klusacek^a, Stanislav Pikula^b, Premysl Dohnal^b, Zdenek Havranek^a

^a CEITEC—Central European Institute of Technology, Brno University of Technology, Purkynova 123, Brno 612 00, Czech Republic

^b Department of Control and Instrumentation, Faculty of Electrical Engineering and Communication, Brno University of Technology, Technická 3082/12, Brno 616 00, Czech Republic

ARTICLE INFO

Article history:

Received 21 November 2015

Received in revised form 10 March 2016

Accepted 30 March 2016

Available online 19 April 2016

Keywords:

PZT ceramics

Piezoelectric charge coefficient

Curie temperature

Frequency method

Vibrometric method

ABSTRACT

Depolarization at high temperatures around the Curie point constitutes an important yet difficultly measurable material property of piezoelectric (PZT) ceramics. The common vibrometric technique (d_{33} meters) is not suitable for the measurement of temperature dependences, and therefore we used the frequency method to perform the desired procedures. The indicator selected to show the depolarization state in the piezoelectric ceramics consisted in the piezoelectric charge coefficient, whose value can be effectively measured via the above-mentioned frequency technique. The accuracy of the method was verified via comparing a d_{33} meter constructed by the authors (as described in this paper) and also by means of differently sized cylinders of ceramics NCE51, which are designed for longitudinal length modes. Based on the obtained results, we established a measurement methodology to exactly determine the value of the Curie point that corresponded to the phase transition to a cubic crystallographic structure. The experiment also confirmed the applicability of progressively controlled depolarization of PZT ceramics by high temperature in the range of between 350 and 370 °C, and it defined the temperature limits at which there occur irreversible changes of the piezoelectric properties of PZT ceramics. In the measured NCE51 material, the limit for irreversible changes was equal to 95% of the Curie temperature (368 °C).

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Piezoelectric ceramics are used as active elements in measurement techniques including, for example, ultrasonic distance sensors, acoustic emission sensors, sensors for crack detection, and high power applications. It is important to know the behavior of the ceramics during exposure to high temperatures near the Curie point, at which the depolarization of PZT elements regularly occurs.

The discussed knowledge of the relationship between parameters of PZT ceramics and temperature appears to be similarly significant in the designing of sensors and active elements by means of simulation and modeling systems, such as the COMSOL and ANSYS software; the said instruments constitute an interactive environment for the modeling and simulation of physical, mechanical, electrical, and other scientific problems. Material property dependences are usually not considered in these systems, and manufacturers do not list them in their data sheets. The heating of PZT ceramics to temperatures close to the Curie point nevertheless causes significant changes of material coefficients and may thus lead to partial or complete depolarization of the ceramics. The entire problem of the temperature dependence of piezoceramics is generally simplified by introducing a limit on the maximum working temperature.

Although the influences of temperature on piezoelectric coefficients and behavior around the Curie point were traditionally a marginal topic rarely discussed in specialized literature, they have recently become a problem of interest to a number of researchers and are currently analyzed in various papers [1–8]. The data related to ceramics NCE51 are not freely available, and only the Curie point value is indicated in this type of material.

Piezoelectricity, and thus also the individual material coefficients, are described in studies [9–13]. Methods for the measurement of material coefficients can be classified into two groups. The first group comprises techniques to determine the complete matrix of coefficients and includes the frequency method [14–17]; the matrix contains piezoelectric, elastic, and dielectric

* Corresponding author.

E-mail address: jiri.fialka@ceitec.vutbr.cz (J. Fialka).

coefficients. The second group then consists of methods for the direct measurement of concrete (mostly piezoelectric) coefficients, including the laser interferometer method based on the indirect piezoelectric effect [18–21] or the quasistatic technique applied in d_{33}/d_{31} meters and utilizing the direct piezoelectric effect [22].

The frequency method is currently the most popular approach to determining the complete matrix of coefficients of PZT ceramics. The procedure is described in the European standard EN50324 [23,24], which has been derived from the world standard CEI/IEC 60483: 1976 [25]; both these documents define the measurement techniques and sample dimension requirements in individual types of oscillation. At present, the frequency method involves the application of RLC meters, such as the HIOKI 3532 or the Agilent E4980A. More accurate measurement can be performed with impedance analyzers, for example the Agilent E4294A; this type has been conveniently replaced with the Keysight E4990A and the Wayne Kerr series 6500B. Generally, impedance analyzers allow direct display of the impedance and phase characteristics in real time. This advantage is often utilized in the reading of the resonance (f_r) and antiresonance (f_a) frequencies and enables us to monitor the influence of the clamping of the sample in the tweezers on the impedance characteristics. The drawback of the discussed method consists in the necessity to observe the required minimum proportions of the sample side dimensions for the measured oscillations.

Samples that do not satisfy this requirement are measured by means of direct methods, which usually facilitate the measurement of piezoelectric coefficients and include the laser interferometer technique described in papers [15,18]. The measurement utilizes the inverse piezoelectric effect, in which direct voltage is fed to the sample and a laser interferometer is used to measure the dimension changes. These dimension or displacement changes directly correspond to the magnitude of the exciting voltage. The input voltage, dimension changes, and range of the given interferometer can be used in the calculation of the piezoelectric charge coefficient. The measurement requires either an interferometer assembled from individual components or a full setup, for example the Polytec OFV5000 with a module measuring the displacement within a range of at least 50 nm V^{-1} . The main disadvantage of this approach lies in the necessity to shield the measuring device from external vibrations, which markedly affect the resulting charge coefficient value. Another drawback can be identified in the costly equipment found only in selected laboratories.

The method of direct measurement of the charge on a piezoelectric element during mechanical loading/unloading is based on the direct piezoelectric effect and can be split up into two variants. The first of these is described in paper [15] and uses a special device to calculate the charge coefficient. The piezoelectric element is loaded with a predefined force F in this structure. The charge is measured at piezoelectric unloading either directly by an electrometer (such as the Keithley 6517b) or the output from the piezoelectric element is led via a charge amplifier with a known transfer constant (mV pC^{-1}). The voltage corresponding to the acting force is measured at the output of the amplifier with a multimeter or a signal acquisition module, for example the NI9234.

The other variant exploiting the direct piezoelectric effect is often applied in devices referred to as “ d_{33}/d_{31} meters” [12,13,22]; the manufacturers include KCF Technologies, Sensor Technology Ltd., Piezotest (d_{33} PiezoMeter Systems), APC International (Wide-Range d_{33} Tester), HC Materials Corporation, and Concord Electroceramics Industries. Both the permanent excitation of the piezoelectric element by the defined force and the high repeatability are ensured due to the use of a vibration exciter and a reference force sensor.

None of the above-described approaches to the direct measurement of charge coefficients requires intensive shielding of the

Table 1

The dimensions and properties of the samples.

PZT type [–]	Labeling [–]	Diameter ($\varnothing$) [mm]	Thickness (t) [mm]	d_{33} coefficient $\times 10^{-12} [\text{C N}^{-1}]$
NCE51 no.01	$\varnothing 7.0 \times 15 \text{ mm}$	6.980	15.120	372
NCE51 no.02	$\varnothing 7.0 \times 14.5 \text{ mm}$	6.970	14.550	407
NCE51 no.03	$\varnothing 3.0 \times 5.7 \text{ mm}$	2.968	5.731	411
NCE51 no.04	$\varnothing 3.5 \times 14.5 \text{ mm}$	3.568	14.595	394
NCE51 no.05	$\varnothing 3.5 \times 20 \text{ mm}$	3.487	20.079	371

fixture from external vibrations, and conventional laboratory equipment can be employed to carry out the desired steps.

This paper presents a process of implementing the direct method and discusses the verification procedures related to the measurement conditions, namely the effects of the clamping force and the excitation frequency. The authors also compare the results obtained via the direct and the frequency methods and investigate whether the frequency method provides sufficient accuracy for measuring material coefficients of PZT ceramics at higher temperatures, or under circumstances that disallow any reliable use of the direct method.

2. Experiments

2.1. Materials

The cylindrical samples of soft piezoelectric ceramics with silver electrodes (or discs) were obtained from Noliac Ceramics. This commercial type of PZT ceramics with the general chemical formula $\text{Pb}(\text{Zr}_{0.52}\text{Ti}_{0.48})\text{O}_3$ was assigned the trade name NCE 51. The Curie temperature stated by the manufacturer equals to $360 \pm 18^\circ\text{C}$, and the value of the piezoelectric d_{33} coefficient at 25°C for the longitudinal length mode is equal to 443 pC N^{-1} with tolerances of $\pm 5\%$ [26]. The geometrical dimensions and labelling of individual samples are shown in Table 1. The samples were selected in such a manner that the proportions of height differ with respect to the cylinder base diameter. Different dimensions of the measured samples and various batches of the manufactured piezoceramics have a significant effect on the deviation in the d_{33} coefficient. At present, the manufacturing process is often fully automated, but even despite this, the actual production is still affected by biases in material coefficients of the ceramics. Thus, it cannot be guaranteed that, in the given type of the product, the resulting material coefficient values will always correspond to the reference values, which are usually obtained for a single concrete batch and dimension of the piezoelectric ceramics. The reference values of the piezoelectric charge coefficients (the d_{33} coefficient) were determined via the frequency method described in one of our previous publications [15].

2.2. Determination of the piezoelectric charge coefficients

2.2.1. Direct vibrometric measurement of the reference piezoelectric charge coefficients of the samples

Firstly, the relationship between the piezoelectric charge coefficient and the magnitude of the force F_3 acting vertically on the sample at the constant exciting frequency of 110 Hz was measured. The basic range of the set forces F_3 (from 0.1 N to 7 N) does not affect the charge coefficient significantly; any disruption of the integrity of the ceramics or, possibly, their complete destruction requires a pressure of tens or hundreds of MPa [27–29].

The configuration of the setup for direct measurement of the charge coefficient d_{33} by means of a laboratory d_{33} meter is shown in Fig. 1. The experimental setup was composed of a vibration exciter Brüel & Kjær (B&K) type 4809, with a reference force sensor B&K 8200 fixed to the vibrating centre of the exciter.

Download English Version:

<https://daneshyari.com/en/article/10629252>

Download Persian Version:

<https://daneshyari.com/article/10629252>

[Daneshyari.com](https://daneshyari.com)