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DETERMINATION OF THE PIEZOELECTRIC CHARGE CONSTANT D33 MEASURED BY THE LASER INTERFEROMETER AND FREQUENCY METHOD

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Abstract: *This paper compares the principal methods used for the piezoelectric charge constant measuring. Principles of three most commonly used measuring methods are described (frequency method, laser interferometry method and quasi-static method). Soft ceramic with production code PCM51 was used in the experiments. Piezoelectric charge coefficient d_{33} was measured. The values of the piezoelectric charge coefficient obtained by both methods were compared to the catalogue values of the piezoelectric ceramic. Both of the used methods are convenient. In comparison to the inteferometry method, the frequency method is lengthy and more demanding for the preparation of the samples, but it provides results with lower values variety.*

Key words: *charge constant, frequency method, interferometry method, piezoelectric, PZT*

1. INTRODUCTION

The piezoelectric charge constant d_{ij} is one of the constants describing the piezoelectric material behaviour. Various measuring methods are used to get the value of this coefficient. The following three measuring methods are used most often (Waanders et al., 1991 and Jaffe et al., 1971):

- Frequency method,
- Laser interferometry method,
- Quasi-static method.

The frequency method is used to obtain the piezoelectric charge coefficient in those cases, when the complete matrix of the material coefficients is needed. The result values strongly depend on the accuracy of reading of the resonance frequencies and other values needed for the calculation of all material constants. This is why the impedance analyser is used most often for this measuring method, because the analyzer assures high measuring accuracy. Impedance analyzers produced by Agilent E4294A and Wayne Kerr 65120B are the most used devices. The biggest disadvantage of the frequency method is in the need of production of a complete set of samples consisting of a disc, a plate and a cylinder made from piezoelectric material of one rank. The calculation that needs to be carried out for the frequency method corresponds to the European standard EN 50324-2 inferred from the world standard CEI/IEC 60483:1976.

Another possible method of measuring the piezoelectric charge constant is measuring with laser interferometry. This method is based on measuring the displacement deflection of the sample surface after the connection of voltage to the electrodes of the measured piezoelectric ceramics. This is why high resolution of the inteferometer is crucial and it should be in the range of units of nanometres. The main advantage of this method is the possibility of constant measurement in one sample of the piezoelectric material. The disadvantage of this laser interferometry method is its requirements for high accuracy in construction of the measuring device, since any minor iregularities or vibrations during the measurement strongly interfere with the accuracy of the obtained values. Interferometers with sufficient resolution are produced for example by Polytec, Lasertex, Agilent, SIOS and others.

Obtaining the piezoelectric charge constant by quasi-static method of measurement is the last of the described methods. There is no need of the costly process of establishing all the material constants and, similarly to the laser interferometry method, there is neither no need to produce a complete set of measured samples. The direct and the converse piezoelectric phenomenon have to be taken into account for these measurements. When the quasi-static method is used, so called "d_{31}/d_{33} meter" is used. Currently KCF Technologies (type PM350), HC Materials Corporation (type ZJ-6B) and Sensor Technology Ltd. (type SS01-01) produce these devices.

2. TECHNICAL REALISATION

Frequency method and laser interferometry method were confirmed in practice. The measurements were aimed to evaluate the advantages and the disadvantages of both of the used methods. The final values of the piezoelectric charge coefficient obtained by both methods were compared to the catalogue values of the piezoelectric ceramic.

2.1 Measured samples

The so called "soft" piezoelectric ceramics with former reference nr. PCM51, now ref. NCE51, produced by Noliac Ceramics s.r.o., was used for all experiments.

The sample dimensions need to be in accordance with the European standard EN 50324-1:2002, and the worldwide standard CEI/IEC 60483:1976. As only few samples are needed for the measurements and production of such a small number of samples would be extremely costly, the whole set was manufactured from a disc (EN 50324-1:2002 and CEI/IEC 60483:1976).

2.2 Frequency measurement method

Precise impedance analyzer Agilent 4294A with the Tweezers Contact Test Fixture 16334A connected directly to the impedance analyzer was used for the frequency method, for the connection scheme see Fig. 1.

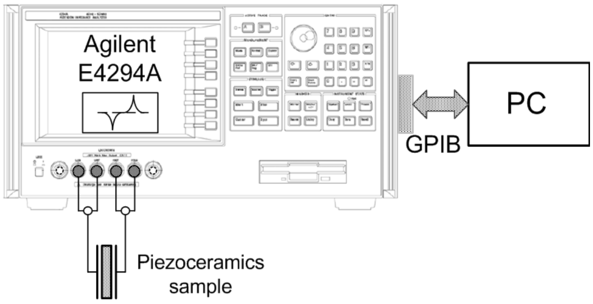

Fig. 1. Connection scheme for impedance characteristic measurement with impedance analyzer Agilent 4294A and measuring Tweezers Contact Test Fixture 16334A.

Automatic data reading from the device can be used and processed for example in an Excel file thanks to the device connection through the GPIB bus to a personal computer. Impedance analyser Agilent 4294A allows direct displaying of the impedance and phase characteristics on the device screen. Thanks to this, there is no problem with a possible confusion of the resonance and antiresonance frequency measuring double peak during this measurement, this problem can be noticed in devices, which do no allow displaying the characteristics directly during the measurements.

The calculations of single coefficients are listed in detail in the European standard EN 50324-2:2002. For this reason we mention only the final relation for the piezoelectric charge coefficient d_{33}, which was derived from the relations listed in the standard (EN 50324-2:2002).

The final relation for the d_{33} coefficient calculation, in which the initial measured values can be inserted, is:

$$d_{33} = \sqrt{C^T \cdot \frac{h}{\frac{\pi \cdot d^2}{4}} \cdot \frac{\pi}{2} \cdot \frac{f_r}{f_a} \cdot tan\left(\frac{\pi}{2} \cdot \frac{f_a - f_r}{f_a}\right) \cdot \frac{\frac{1}{4 \cdot \rho \cdot f_a^2 \cdot h^2}}{1 - \frac{\pi}{2} \cdot \frac{f_r}{f_a} \cdot tan\left(\frac{\pi}{2} \cdot \frac{f_a - f_r}{f_a}\right)}} \quad (1)$$

Where d_{33} is piezoelectric charge constant ($C.N^{-1}$ or $m.V^{-1}$), f_r is resonance frequency (Hz), f_a is antiresonance frequency (Hz), C^T is capacity measured at 1 kHz (F), h is thickness of the sample (m), d is diameter of the base (m), ρ is thickness of the sample material ($kg.m^{-3}$) and π is constant 3,1415… (-).

2.3 Laser interferometer measuring method

The piezoelectric charge coefficient was measured only once with this method, only on a cylinder from PCM51 material with the diameter Ød = 3,5 mm and height h = 20,1 mm, that is on the same sample as for measuring the material constants by the frequency method (Burianová et al. 1991). Measurement scheme is shown in Fig. 2.

The whole measuring set is fixed to an optical table, which is placed on a single base for maximum outer vibrations elimination. The valuation of the measurement is done by the output voltage signal shown on the oscilloscope Tektronix. From the process we can read the input voltage ΔU equalling to deviation caused by deviation from the voltage applied on the measured sample. The piezoelectric charge coefficient is calculated from the relation shown below, according to which the deviation increases with the gradually increasing voltage, in other words the height of the cylinder increases or decreases.

$$\Delta l = d_{33} U_{in} \Rightarrow d_{33} = \frac{\Delta l}{U_{in}} = \frac{50\left(nm \cdot V^{-1}\right) \cdot \Delta U(V)}{1000\,(V)} \qquad (2)$$

Where d_{33} is piezoelectric charge constant ($C.N^{-1}$ or $m.V^{-1}$), U_{in} is power supply voltage connected to the sample (V), ΔU is output voltage of the interferometer (V) for the interferometer sensitivity 50 ($nm.V^{-1}$) and Δl is change of length when power supply is connected (m).

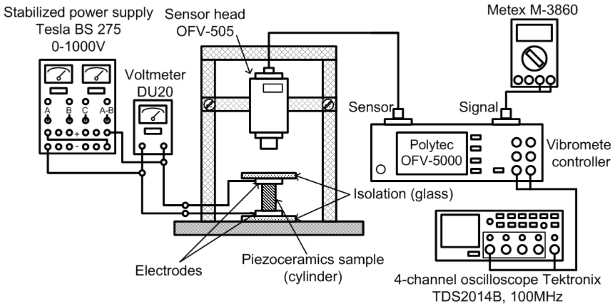

Fig. 2. Connection scheme for piezoelectric charge constant d_{33} measuring with laser interferometer Polytec OFV-5000.

3. RESULTS

	Sample 1	**Sample 2**	**Sample 3**
	d_{33} [$pm.V^{-1}$]	**d_{33} [$pm.V^{-1}$]**	**d_{33} [$pm.V^{-1}$]**
Values determined by the laser interferometry	449±6	397±2	451±8
Values determined by the resonance method	407±4	399±5	405±4
Value determined by the producer	425	425	425

Tab. 1. The resulting values of the measurements with interferometer and comparison to the values obtained by resonance measurement methods for the PCM51 material (cylinder Ød = 3,5 mm and h = 20,1 mm).

For the comparison of the measured and calculated values of the piezoelectric charge constant d_{33} with the values given by the producer three cylinders of the PCM51 measured ceramics were chosen. The calculated and the measured values of both methods are compared in the chart below in Tab. 1.

The error of the values of the coefficient d_{33} obtained by the frequency method is caused by the error of the measured input parameters for the material coefficient calculations. During the laser interferometry measurements the main source of inaccuracy is in the interference vibrations in the surroundings of the experimental workplace, which can be noticed as noise in the output interferometer signal. Micro-crack or lesser deviation in the dimensions of individual samples can have a big influence.

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