UTILIZATION OF THE LASER INTERFEROMETER FOR THE MEASUREMENT OF PIEZOELECTRIC CHARGE CONSTANT D_{31} AND D_{33}

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Abstract: Principle of one nowadays most commonly used measuring methods have been described, laser interferometry method. This method was practically applied to piezoelectric ceramic samples. The paper describes the production of the piezoelectric ceramic samples of defined measures according to current regulation. Soft ceramic with production code PCM51 was used in the experiments. Piezoelectric charge coefficient d_{31} and d_{33} was measured. The final values of the piezoelectric charge coefficient gained by laser interferometry method were compared to the catalogue values of the piezoelectric ceramic. The measurements were aimed to evaluate the advantages and the disadvantages of used method.

Keywords: piezoelectric charge constant, laser interferometer, piezoelectric ceramics

1. INTRODUCTION

When designing the piezoelectric actuators and sensors it is important to know the catalogue values of the used material. One of the constants describing the piezoelectric material behaviour is the piezoelectric charge constant d_{ij}. More measuring methods are used to get the value of this coefficient. Currently the following three measuring methods are used most often, frequency method, laser interferometry method and quasi-static method [1], [2].

All of the mentioned methods are used frequently, as they provide high accuracy of the measurements. Their common disadvantage is that of the need of using specialised and accurate measuring devices.

The frequency method is used to gain the piezoelectric charge coefficient in those cases, when the complete matrix of the material coefficients has to be known. 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, because the analyser assures high measuring accuracy. Impedance analysers produced by Agilent and Wayne Kerr are the most used ones, Agilent E4294A and Wayne Kerr 65120B respectively. The appliances differ in the sensitivity and frequency range. The calculation needed 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 [4], [5].

A second possible method of measuring the piezoelectric charge constant is by 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 interferometer is crucial and it should be in the range of units of nanometres. This solution is currently the most used one in laboratory conditions. The main reason is the high price of the interferometer and high demand for isolating the measuring centre from any parasitic vibrations. Laser interferometry is used when measuring the piezoelectric charge coefficient d_{31} and d_{33}.

The disadvantage of this laser interferometry method is its high requirements for accuracy in construction of the measuring device, since any minor irregularities 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 many others [3].

The last used method is obtaining the piezoelectric charge constant by quasi-static method of measurement. There is no need of the costly process of establishing all the material constants and similarly to the laser interferometry method. The direct and the converse piezoelectric phenomenon have to be taken in to account for the measurements. For obtaining the piezoelectric charge constant the tested sample is compared to reference sample of a known d_{ij} piezoelectric coefficient. 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. All devices mentioned above can measure both d_{33} and d_{31} coefficients, other types are designed to measure only the d_{33} coefficient, the main difference is the price [1], [5].

2. MEASUREMENT

2.1. MEASURED SAMPLES

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

The measured samples had to be manufactured before the measurements and calculations. The sample dimensions need to be in accordance with the European standard EN 50324-1:2002, and the worldwide standard CEI/IEC 60483: 1976 [4], [5].

As only few samples are needed for the measurements and production of such a small number of samples would be extremely costly, a disc was chosen and the whole set was manufactured from this disc. This disc was firstly lapped abraded by a flat grinding, this way a thinner disc of the same diameter was obtained. From this thin disc a cylinder was produced by cutting out a prism from the disc and then it was abraded cylindrically. For later comparison of the charge constant value d_{33}, it is good to keep some prisms of square base and of the same height as the cylinder. The samples produced in this way need to be polished on the surface for good contact of the silver electrodes that it is for the best possible conductivity between the ceramics and the metal.

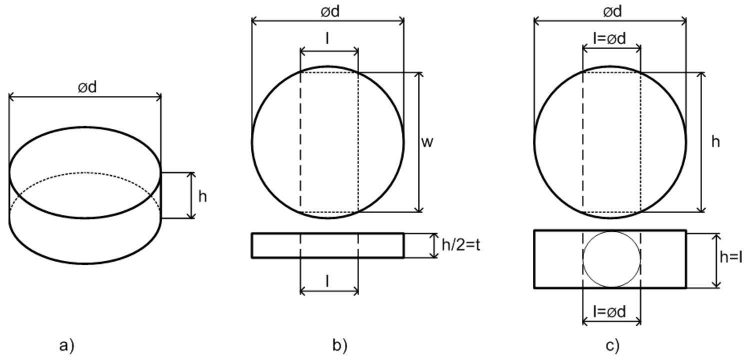


Figure 1: Process of production of the samples for parameters measuring, where a) is the original disc, b) is the production of the thin disc, c) is the production of cylinder.

Since neither the European, nor the world standard gives the exact dimensions of the piezoelectric samples designated for measuring the material coefficients, it was necessary to choose those dimensions, which are within the range cited by both standards and which allow the calculation of the constants and which were as well possible to produce without any major problem. The real dimensions of the measured samples according to the diagram in Figure 1, are cited in Table 1.

Sample and dimension	**Ød-diameter**	**h-thickness**	**l-length**	**w-width**
	[mm]	**[mm]**	**[mm]**	**[mm]**
Thin disc	30,0	2,0	-	-
Thin plate	-	2,0	4,0	25,0
Cylinder	3,5	20,1	-	-

Table 1: Real dimensions of samples for complete set of piezoelectric material calculation

2.2. LASER INTERFEROMETER MEASURING METHOD

The piezoelectric charge coefficient was measured only once with this method, on a cylinder and thin plate from PCM51 material. Measurement set-up is shown in Figure 2. During the measurements, the measured sample was isolated by a glass plate of dimensions 99x99x2mm, on which there was fixed reflection label for better quality of reflexed optical signal of the interferometer. The weight of the isolation glass plate was not calculated during the coefficient calculations. The whole measuring set is fixed to an optical table, which is placed on a single base for maximum outer vibrations elimination. The task of the single base is to control the vibrations, which were caused by the evaluating devices, but also other environment conditions, for example any movement in the room and outside the room. These interferences can be considered the major error influencing the measurements [3].

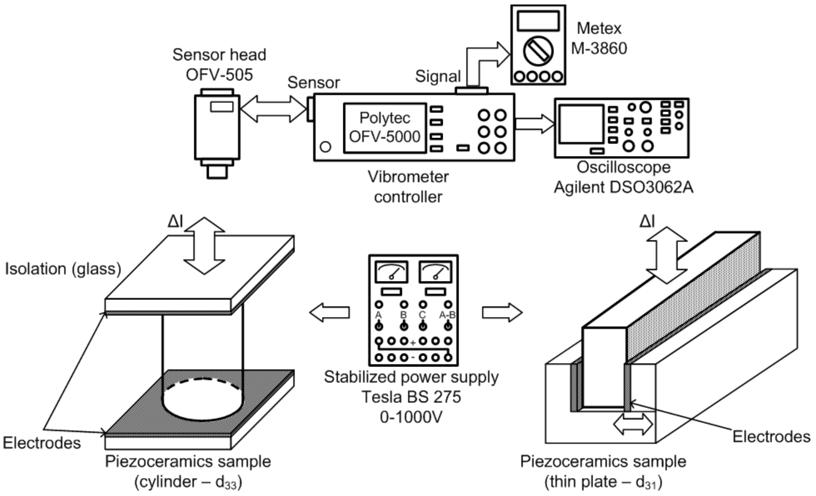
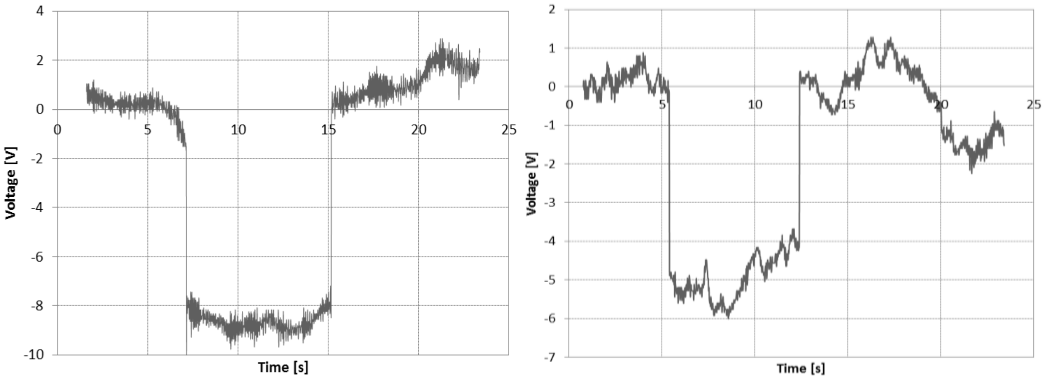


Figure 2 : Connection scheme for piezoelectric charge constant d_{33} and d_{31} measurement with laser interferometer Polytec OFV-5000 and sensor head OFV-505

The devices used for this experiment can be divided into several groups, when the main part was formed by the laser interferometer Polytec OFV-5000 together with the vibrometer sensor head head OFV-505. Velocity decoder VD-06 with measuring range of 50 $mm \cdot s^{-1} \cdot V^{-1}$ at 350 kHz and displacement decoder DD-500 with measuring range of 0,05 $\mu m \cdot V^{-1}$ at 350 kHz were used for this measurement. The light source of the vibrometer sensor head OFV-505 is a helium neon laser and wavelength is 633 nm. The stand-off distance is measured from the front side of the focusing ring and the optimal stand-off distances are at 234mm+(n·l)mm, where n=0;1;2… and l=204mm±1mm. By using short range front lenses OFV-SR for the sensor head the vibrometer can by optimally adapted to stand-off distances from 60mm to 5m [6], [7].

The oscilloscope Agilent Technologies DSO3062A designed for measurement the resulting voltage signal from the interferometer was used. The quality of the signal from the sensor head IFV-505 was controlled by Metex M-3860 voltmeter. For driving the measured sample stabilized power supply Tesla BS 275 is used, which allows to reach 0-1000 V on output. The used voltmeter, oscilloscope and stabilized power supply are not the main parts of the connection and can be therefore replaced by other devices with similar characteristics.

The valuation of the measurement is done by the output voltage signal shown on the oscilloscope Agilent DSO3062A. The example of gained dependence is shown on the (Figure 3a and 3b), 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 interferometer sensitivity was set on 50 $nm \cdot V^{-1}$. The measurement was started with the voltage connected to the sample. This voltage was later disconnected; this is shown as the first descent on the shown process. After the stabilization of the process, the voltage was connected again, this way a second major change was caused, both the major changes, changes during the short-circuit of the electrodes and during the reconnection of the voltage, should equal. The resulting value of the piezoelectric charge constant equals to the relation of dimension change and the connected voltage.



a) b)

Figure 3: The output signal from the interferometer Polytec OFV-5000 shown on the oscilloscope Agilent DSO3062A – measured values for a) cylinder - d_{33} and b) thin plate - d_{31} (characteristics drawn in the Excel program)

The piezoelectric charge coefficient is calculated from the relation shown below, according to which the deviation is increasing with the gradually increasing voltage, that is the height of the cylinder is increasing or decreasing [1].

$$\begin{gathered}\Delta l = d_{33} U_{in} \Rightarrow d_{33} = \frac{\Delta l}{U_{in}} = \frac{50\left(nm \cdot V^{-1}\right) \cdot \Delta U(V)}{1000(V)} \\ \Delta l = d_{31} U_{in} \Rightarrow d_{31} = \frac{\Delta l}{U_{in}} = \frac{50\left(nm \cdot V^{-1}\right) \cdot \Delta U(V)}{1000(V)}\end{gathered} \tag{1}$$

Where	U_{in}	is the power supply voltage connected to the sample (V)
	ΔU	the output voltage on the interferometer (V)
	Δl	change of length when power supply is connected (m)
	d_{33}, d_{31}	the piezoelectric charge constant ($C.N^{-1}$ or $m.V^{-1}$)

2.3. RESULTS

For the comparison of the measured and calculated values of the piezoelectric charge constant d_{31} and d_{33} with the values given by the producer two samples of the PCM51 measured ceramics were chosen. Ten measurements were done on these two samples, for any accidental error exclusion. The calculated and the measured values of method are compared in the chart below, where a difference can be noted in comparison to the values given by the producer of the ceramics.

			Sample	**Sample 1**	**Sample 2**
Values determined by the laser interferometry	**d_{33}**	**[pm.V^{-1}]**	cylinder	449±32	451±33
	$-d_{31}$	**[pm.V^{-1}]**	thin plate	234±46	261±48
Values determined by the resonance method	**d_{33}**	**[pm.V^{-1}]**	cylinder	407±4	405±4
	$-d_{31}$	**[pm.V^{-1}]**	thin plate	198±6	203±7
Value determined by the producer	**d_{33}**	**[pm.V^{-1}]**	cylinder	425	425
	$-d_{31}$	**[pm.V^{-1}]**	thin plate	200	200

Table 2: The resulting values of the measurements with interferometer and comparison to the values obtained by resonance measurement methods for the PCM51 material,

3. CONSLUSION

From the resulting values we can see that the calculated value obtained from the resonance method is lower than the value obtained from laser interferometry measurements. 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. Neither the value given by the producer can be taken as clearly correct value, as the batch of the piezoelectric ceramics is the main influence on the deviation in the resulting values. A great influence can be of micro-fissures or lesser deviation in the dimensions of individual samples.

4. ACKNOWLEDGEMENTS

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