Measurement System for Determining Piezoelectric Charge Coefficient

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Abstract— The paper focuses on a system of direct measurement of piezoelectric charge coefficient. The created system is based on quasistatic method when harmonic force signal is applied to the examined piezoelectric material. A program in the programming environment LabVIEW was created for control, measurement, and processing. Thanks to the universality of this system from the perspective of hardware, this system offers higher levels of modularity than d_{33} meters available on the market.

Keywords— piezoelectric effect, piezoelectric charge coefficient, quasistatic method, Berlincourt method, dynamic method

1. INTRODUCTION

Determining the parameters of piezoelectric materials is an integral part of the design of applications using these materials. It is necessary to know the exact properties of the behavior of materials in given applications, and in addition, each application may place different requirements on the piezoelectric material used. The piezoelectric charge coefficient is an important parameter for the selection of a suitable piezoelectric material as an actuator. Furthermore, it is one of the parameters evaluated during control measurements in the production of piezoelectric materials [1].

Not only one but several different experimental methods are given to determine the piezoelectric coefficients. When choosing a method, several factors must be taken into account, such as the size and shape of the sample, available laboratory equipment and more. Examples of possible methods are direct methods and frequency method. [2].

Within the direct methods of measuring the piezoelectric charge coefficient, it is possible either to use dedicated instruments for measuring charge coefficients called d_{33} meters or to create your measurement system based on appropriate standards. However, the standards contain basic instructions and do not standardize measurement methods.

This work aims to create a system for measuring piezoelectric charge coefficient using laboratory equipment that can replace d_{33} meters and which can offer higher levels of modularity than these instruments available on the market. In practice, the dedicated instruments are manufactured for measuring d_{33} and d_{31}, but in this case, a device was created only for measuring the parameter d_{33}. For d_{31} it would be necessary to measure on the electrodes perpendicular to the applied force.

2. QUASISTATIC METHOD

The measurement of the charge induced by mechanical stress or the so-called Berlincourt / quasi-static / dynamic method is the manufacturer's most widely used method for measuring the polarity and piezoelectric charge coefficient d_{33} [3]. Compared to the frequency method, the quasistatic method is not limited by the shape and dimensions of the specimen [2].

The piezoelectric charge constant is determined through measurement of the electrical response of the material under the action of an on-off or dynamic external force. Description of the quasi-static method leads into two methods based on the direct or inverse piezoelectric effect. That is, to measure charge or deflection. In this case, a method based on a direct phenomenon is used where the charge is measured depending on the excitation force. The method based on the direct phenomenon is described in [4] and the method based on the inverse phenomenon in [5].

European and American standards dealing with measuring methods for determining the coefficients of piezoelectric materials, namely EN50324-2 and IEEE Std 176-1987, describe this method in general. These standards do not specify exactly how the measurement takes place. The determination of the charge constant can therefore take place in two ways. Either through comparison of the generated charge with the force signal that the measured piezoelectric element stresses, or through comparison of the generated charge with the charge that is generated by a piezoelectric element with known parameters [3] [4].

Calculation of charge coefficient d_{33} when determining with force measurement [3]:

$$d_{33} = \frac{Q_3}{F_3} \; [\mathrm{C \cdot N^{-1}}], [\mathrm{m \cdot V^{-1}}] \tag{1}$$

where Q_3 denotes generated charge of the measured element in the coordinate direction 3 and F_3 is the magnitude of the loading force in the coordinate direction 3.

The charge coefficient d_{33} is mentioned in the equations and the description of the method, but this method is not limited to only this direction. The method can be used to measure charge coefficients in other directions, for example d_{13}, d_{31}, and d_{15}. The only changes in such cases are a change in the settling of the sample and further addition of measuring electrodes to other corresponding sides of the material under examination.

3. MEASUREMENT SYSTEM

As was mentioned before, created system of measurement shown in Fig. 1 is based on the quasi-static method when the piezoelectric charge coefficient is determined through comparison of the generated charge with the dynamic force signal that the measured piezoelectric element stresses. This dynamic force has shape of a sinusoid with static frequency of 110 Hz and with user-configurable amplitude. This frequency was chosen for several reasons. Firstly, it fulfills the requirements mentioned in standard *EN50324-2* which states that frequency should be in limits between 20 and 1000 Hz [3]. Secondly, this frequency is commonly used in dedicated d_{33} meters and thirdly, it is not a signal of 50 Hz or its higher harmonics, so the signal is separable from noise from the electrical network thanks to spectral analysis [6]. Furthermore, the dynamic force was chosen because it eliminates the influence of the pyroelectric effect on the measurement [2].

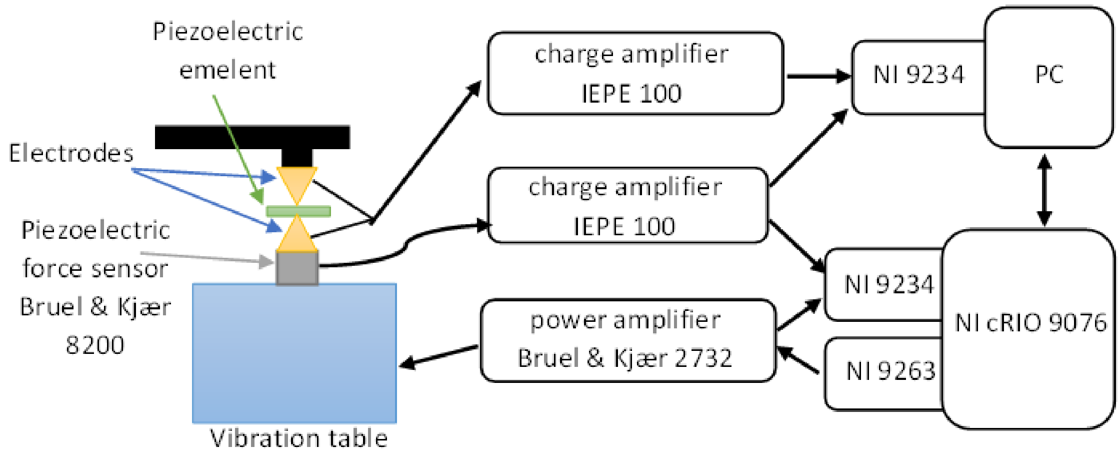

Figure 1: System devices diagram

From the devices seen in Fig. 1, only the voltage output module NI 9263, the acquisition modules NI 9234 and the CompactRIO controller NI cRIO 9076 have to be these exact types. Other devices can be replaced by other devices and their parameters alter in the control program. Thanks to this, the system of measurement offers high levels of modularity and flexibility from the perspective of available laboratory equipment.

The control software for this system is divided into two connected programs in the programming environment LabVIEW. The first program running on the CompactRIO controller NI cRIO 9076 is in charge of generating the required force signal through altering the power supply to the vibration table and in charge of safety controls to protect the hardware from possible damage. Thanks to the integrated controller NI cRIO-9076, constant control and its independence from the system resources of the computer from which the measurement is started is ensured.

Although this separation of programs creates inefficiency in the usage of hardware, i.e. more modules are needed, this configuration avoids possible problems with accessing results of measurements which are stored in TDMS file. Both programs could be united and run-on integrated controller, but it would increase the required user's knowledge and experiences with integrated controllers.

The dynamic force signal within the measuring system is created by the action of the vibrating armature of the vibrating table on the structure ensuring the prestressing of the force. A measured piezoelectric element is connected between copper point electrodes which are placed on the vibrating armature and the structure. Furthermore, a force sensor is placed between the vibrating armature and the lower electrode to provide feedback for the program ensuring vibration control.

The second program which is running on the computer is ensuring data acquisition and data saving. The data acquisition is started when the program in CompactRIO controller transmits information that the RMS value of the force signal stabilizes at the value entered by the user with a maximum error of 0,5%.

From the measured waveforms of the force and charge from the tested piezoelectric element the amplitude spectrums are determined to obtain the amplitudes of the frequency component 110 Hz. Thanks to the use of the fast Fourier transform, and thus the spectral analysis, the calculation is not subject to error due to the presence of the 50 Hz harmonic component and its higher harmonics, which enter the measurement from the electrical network. To determine the amplitude of the required component as accurately as possible, the properties of the windows were used in the calculation of the fast Fourier transform, namely the Flat top window, which is optimal for the most accurate calculation of the amplitudes of the harmonic components of the signals. Thanks to the use of windows, the occurrence of spectral leakage is also prevented, i.e. the formation of non-existent frequency signal components in the spectrum.

4. RESULTS AND DISCUSSION

The functionality of the system was tested on a set composed of multiple samples of soft piezoceramics NCE51 of different dimensions and shapes with piezoelectric charge coefficient d_{33} = 443 pC·N^{-1} ± 5%. This value of charge coefficient is stated by the producer for this material, but the actual value varies in different batches and is also dependent on the polarization of the specimen and his age. The measured results and reference values, i.e. values of piezoelectric charge coefficient measured by d_{33} meter ZJ-3C, are shown in Table 1 and Table 2.

Table 1: Measured d_{33} of soft piezoceramics NCE51 in the direction of polarization

dimensions [mm]	25x5x0,5	Ø3x5,7	Ø3,5x14	Ø20x2	Ø18x2	Ø16x2	Ø10x2
shape	thin plate	cylinder	cylinder	thin disc	thin disc	thin disc	thin disc
d_{33} [pC·N^{-1}] (reference)	500	462	368	452	474	460	459
d_{33} [pC·N^{-1}]	453	440	343	417	472	440	437
δ_r [%]	10,4	5,0	7,3	8,4	0,4	4,5	5,0

Table 2: Measured d_{33} of soft piezoceramics NCE51 in the opposite direction than polarization

dimensions [mm]	25x5x0,5	Ø3x5,7	Ø3,5x14	Ø20x2	Ø18x2	Ø16x2	Ø10x2
shape	thin plate	cylinder	cylinder	thin disc	thin disc	thin disc	thin disc
d_{33} [pC·N^{-1}] (reference)	478	463	370	452	476	459	465
d_{33} [pC·N^{-1}]	447	443	352	419	463	436	443
δ_r [%]	6,9	4,5	5,1	7,9	2,8	5,3	5,0

Note that the piezoelectric charge coefficient should not be affected by flipping the sample, i.e. affected by polarization direction. But the coefficient is not constant on the whole area of the samples so changes of the gripping point can influence the measured value. The differences between the charge coefficient of the same sample can be most probably attributed to this phenomenon.

5. CONCLUSION

For determining piezoelectric charge coefficient system of measurement based on the quasi-static method was created. This system thanks to adjustable parameters offers high degrees of modularity from the hardware perspective. The consequence is a system suitable for determining various effects on the measurement such as the shape of electrodes and which can be put together from common laboratory equipment instead of acquiring a special device called d_{33} meter. Furthermore, the system includes various precautions for ensuring safety of used devices, such as protection against current overexcitation of the vibrating table, to ensure that the equipment will not be damaged even when the system is used by less skilled operators.

This system was tested on a set of soft piezoceramics NCE51 with various shapes and dimensions, the results can be found in Table 1 and Table 2. Measured values are compared with reference piezoelectric charge coefficients which were determined with d_{33} meter ZJ-3C. The largest measurement error was determined for the sample in the shape of a thin plate with dimensions 25x5x0,5 mm. For the rest of the samples values of relative deviations are between 0,4 % and 8,4 %. It is worth noting that values of the piezoelectric charge coefficient determined by this measurement system are lower than reference values determined by d_{33} meter. Some error can be attributed to the fact that change of location of the gripping point influence the measured value. Furthermore, the generation of force contributes to the measurement error due to small changes of the effective value of the force signal during measurement, i.e. errors of the effective value of force signal are tolerated up to 0,5%.

Based on the results of testing measurements, it can be concluded that the created measurement system gives similar results as dedicated instruments for determining piezoelectric charge coefficients and offers an alternative to purchasing d_{33} meters for measurements that do not require high levels of accuracy.

REFERENCES

[1] *Piezoelectric ceramics: principles and applications*. Mackeyvill: APC International, 2002. ISBN 09-718-7440-9.

[2] *IEEE Standard on Piezoelectricity*. IEE Standart 176-1987. New York, USA: The Institute of Electrical and Electronics Engineers, Inc, 1988.

[3] EN 50324-2. *Piezoelectric properties of ceramic materials and components - Part 2: Methods of measurement*. Brusel: CENELEC, 2002.

[4] WAANDERS, J.W. *Piezoelectric Ceramics: Properties and Applications*. 1. Philips Components, 1991, 91 s. OCLC: 45085184.

[5] HUANG, Zhaorong, Qi ZHANG, Silvana CORKOVIC, Robert DOREY a Roger W. WHATMORE. Comparative Measurements of Piezoelectric Coefficient of PZT Films by Berlincourt, Interferometer, and Vibrometer Methods. *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control* [online]. 2006, 53(12), 2490-2523 [cit. 2022-03-10]. ISSN 0885-3010, doi:10.1109/TUFFC.2006.175

[6] STEWART, Mark, Will BATTRICK a Markys CAIN. *Measurement Good Practice Guide No. 44: Measuring Piezoelectric d33 coefficients using the Direct Method* [online]. Teddington, Middlesex, United Kingdom: National Physical Laboratory, 2001 [cit. 2022-03-06]. ISSN 1368-6550, https://eprintspublications.npl.co.uk/2768/1/mgpg44.pdf