

The study of mechanical effect on the characteristics of the PZT-system piezoelectric elements

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Abstract. The paper examines the characteristics of the piezoengine by the method of glancing collisions under the conditions of the moving scheme with mobile connections. The research results of the values’ changes of the PZT materials’ electrophysical parameters and their structural composition are represented. In the course of the research, the voltage boundary values, occurring during glancing collision of the inclined piezoceramic transducer, have been obtained.

1. Introduction

There is an active development of power engineering in the past 30 years in the world. At the end of the XX century a great interest of the humanity was focused on a large amount of electricity generation to cover the increasing needs of population and industry. However, with the advent of the new Millennium, there is an active development of small generations: microelectronics, automated manufacturing, robotics, precision engineering, where an important role is given to the accuracy of movement, assembly, etc. Special attention should be devoted to the high- frequency piezoelectric transducers’ region on the basis of which the piezoengines, used as the industrial drives of linear displacement, are constructed, [1-3]. The constructions and materials, applied in piezoelectric motors do not always correspond to the movement accuracy and quality requirements.

Piezoelectric transducers are based on the use of the phenomenon of the direct and inverse piezoelectric effect and are made from materials based on lead zirconate-titanate (PZT) with various structural modifications. When the direct piezoelectric effect is used, a polarization charge on the piezoelectric surface is observed; the transducers have a mechanical input and an electrical output. Electrical polarization, associated with the surface charge, increases linearly relative to mechanical stress as a first approximation [4, 5]. In the process of the inverse piezoelectric effect, the change of the piezoelectric length is observed, but the transducer has an electrical input and mechanical output.

The most important element of a piezoengine is a piezoelectric element, the choice of which should be based on the maximum efficiency achievement requirement. The application of the scheme with direct and glancing collision, the velocity of which is a fraction of a second, is absolutely actual in precision engineering. When these schemes are used, the quality of piezoelectric elements is characterized by the following main parameters, adopted in Russia and abroad [6, 7]:

K_{33}^T (e_{33}^T/e_0) – relative permittivity;

$\tan \delta$ – loss-angle tangent at frequency of 1 kHz in weak fields;

T_c (T_k) – Curie temperature point;



$K_p, K_{33}, K_{31}, K_{15}$ – electromechanical coupling coefficients;

$d_{33} - d_{31} d_{15}$ – piezoelectric modules;

g_{33}, g_{31}, g_{15} – electric voltage factors;

Y_{11}^E, Y_{33}^E – Young's moduli;

N_L, N_T, N_R – frequency constants;

S_{11}^E, S_{33}^E – the elasticity parameter;

r – density;

Q_m – the mechanical quality factor.

The most important parameters are dielectric permittivity $K_{33}^T (e_{33}^T/e_0)$, as a measure of the piezoelectric element capacity, and piezoelectric moduli $d_{33} - d_{31}, d_{15}$, determining the value of the electric charge on the piezoelectric electrodes when the force is applied [8,9].

The aim of the article is to study the influence of the mechanical effect on the characteristics of the piezoelectric element and to determine the optimal material for piezoelectric motors.

2. Materials and methods

To conduct the study, concerning an assessment of the mechanical effects impact, the authors of the article have chosen the most common piezoelectric materials, based on PZT: PZT-19, PZT-19M, PZTtBS-1. Special disc blanks with a diameter of 15 mm and a thickness of 2 mm were made from the abovementioned materials. The mechanical effect was performed on the laboratory setup, depicted in figure 1.

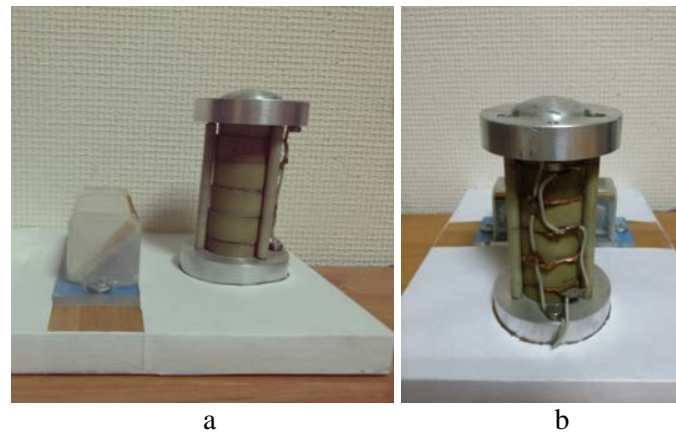


Figure 1. The laboratory setup: a – the side view, b – the back view

Figure 2 shows a scheme of the investigated piezoelectric motor with thickness δ with electrodes deposited on two parallel faces [8-12].

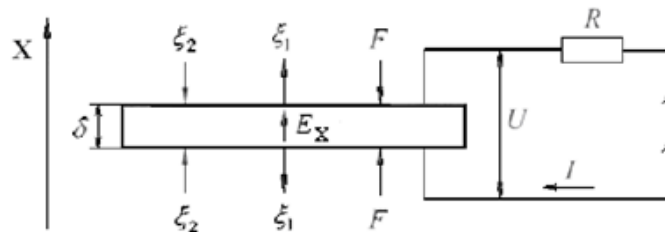


Figure 2. The piezoelectric motor scheme: ξ_1, ξ_2 – plate faces displacement under tension and compression; F – external forces; E_x – electric field intensity; U – electrodes' plate voltage; I – current, R – load.

The inverse piezo effect equation for the longitudinal fluctuations under the voltage control has the following view [12-16]:

$$S_x = d_x E_x(t) + \varepsilon_x T_x, \quad (1)$$

where S_x – the piezoplate strain rate in direction X; ξ – x plate section displacement; d_{33} – the piezoelectric modulus under the longitudinal plate polarization.

The force equation, influencing the piezoplate, is represented in the following way:

$$T_x S_0 = F + \frac{m \partial S_x}{\partial t}, \quad (2)$$

where F – external force, applied to the piezoelectric element; m – piezoengine's moving mass.

The dynamic load with a pressure range from 2 to 5 N/cm² was applied to the element from the selected materials to assess the mechanical effect influence upon the piezoelectric element characteristics. Also, in the process of the study, the electrophysical properties at the temperature change from '−60°' to '+60°' have been estimated.

3. Results and Discussion

As a result of mechanical effect, the following data, represented in table 1, 2 and in figure 3 have been obtained.

Table 1. Electrophysical parameters of piezoelectric materials

Parameter	Symbol	PZT-19	PZT-19M	PZTtBS-1
Relative permittivity	$\varepsilon_{33}^T/\varepsilon_0$	1650	1850	4100
Loss-angle tangent at frequency	tg	0.0300	0.0250	0.0270
Electromechanical coupling coefficients	$K_p/K_{31}/K_{33}$	0.56/0.29/0.64	0.62/0.35/0.72	0.65/0.38/0.73
Piezoelectric modules	D_{31}/d_{33}	155/360	184/410	289/600
Mechanical quality factor	Q_m	90	90	50
Curie temperature point;	T_c	290	300	170
Density	ρ	7.60	7.60	7.30

When there is a change of the piezoelectric element temperature, the following electrophysical parameters have been obtained. The results are given in table 2.

Table 2. The change temperature and electrophysical parameters of piezoelectric materials

Material	Effecting factor		Electrophysical parameters change, %		
	Lower temperature of the agent (limiting)	Elevated temperature of the agent (limiting)	$\varepsilon_{33}^T/\varepsilon_0$	d_{31}	V_1^E
PZT-19	− 60°	+ 60°	± 10.0	± 10.0	± 2.0
PZT-19M			± 10.0	± 10.0	± 2.0
PZTtBS-1			± 10.0	± 10.0	± 2.0

The temperature gradient and electrophysical parameters changes comparison has shown that material PZT-19 is much less susceptible to the temperature fluctuations and is suitable for the use in the middle and Northern latitudes.

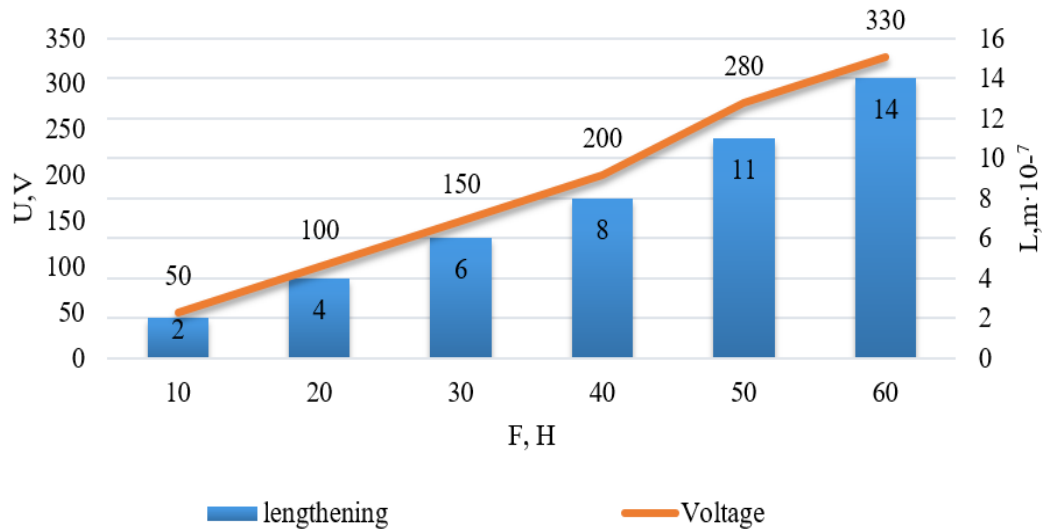


Figure 3. Extension and the external load for different values of the resulting voltage.

The graph shows that the resulting voltage at the ends of the electrodes increases almost linearly with the increasing of the applied load. The extension of the piezoelectric element being tested also increases almost linearly.

The comparative analysis of the electrophysical parameters, given in figure 4, shows the presence of significant advantages of the PZT-19M.

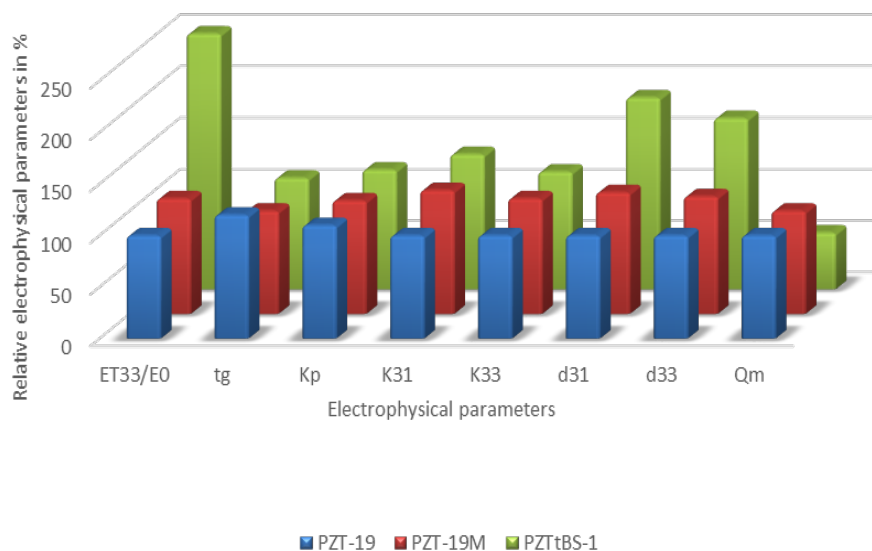


Figure 4. Comparative analysis of electrophysical parameters.

4. Conclusion

The calculation of the piezoelectric motor characteristics was carried out for the scheme of the movable link by the glancing collisions method. As a result, a range of the impact forces values that occur under the conditions of vibrations of the high frequency piezoelectric transducer has been

received. Thus, the conducted researches allowed us to reveal the dependence of the output power of the piezoelectric motor on the material under low mechanical loads and the behavior trends of the piezoelectric constants. The best material for piezoelectric motors is PZTtBS-1.

References

- [1] Haiyan C, Xiaobo G and Zhongyan M 2002 *J. Materials Chemistry and Physics* **75** 202
- [2] Iula A and Pappalardo M 2003 *J. Ultrasonics* **42** 291
- [3] Karimli T I 2016 *Inter. Collec.of Scien. Pap.* **1(52)** 69
- [4] Vullers R J M, Schaijk R, Doms I, Hoof C V and Mertens R 2009 *J. Solid-State Elect.* **53** 684–693
- [5] Schwankl M, Rübner M, Singer R F and Körner C 2013 *J. Proc. Mater. Sci.* **2** 166
- [6] Komarov V P, Peresadchenko A N, Bushnaya A N and Khrebtov A O 2014 *J. Scien. works of DonNTU* **2(23)** 60
- [7] Semenistaya T V, Petrov V V and Ladigina A A 2014 *J. Izvestiya SFedU. Eng. Sc.* **4** 213
- [8] Neubauer M and Wallaschek J 2013 *J. Mech.l Sys.s and Sign. Proces.* **36(1)** 36
- [9] Rupitsch J S, Ilg J, Sutor A and Lerch R 2011 *J. Proc.Eng.* **25** 1441
- [10] Ivanov A A 2014 *J. Trans. of NSTU n.a. R.E. Alexeev* **5(102)** 61
- [11] Jiao Q, Shifeng H, Yuesheng X, Hudong J, Dongyu X and Xin C 2014 *J. Ceram. Inter.* **40(8)** 13019
- [12] Du G, Liang R, Wang J, Wang L, Zhang W, Wang G and Dong X 2013 *J. Ceram. Inter.* **39 (8)** 9299
- [13] Cross J S, Shinozakia K, Yoshiokaa T, Tanakaa J, Kimb S H, Moriokac H and Saito K 2010 *J. Mater Sci. and Eng: B* **173 (1)** 18
- [14] Wang D, Rocks S A and Dorey R A 2009 *J. of the Europ. Ceram. Soc.* **29 (6)** 1147
- [15] Wang Z, Miao J and Chee W T 2009 *J. Sens. and Actuat. A: Phys.* **149(2)** 277
- [16] Takechi S, Onishi T, Minami S, Miyachi T, Fujii M, Hasebe N, Mori K, Nogami K, Ohashi H, Sasaki S, Shibata H, Iwai T, Grün E, Srama R and Okada N 2008 *J. Planet. and Spac. Sci.* **56 (9)** 1309