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Parallel and coded control of multi layered longitudinal piezo engine for nano biomedical research

Abstract

The multi-layer longitudinal piezo engine with parallel and coded control is used for nano biomedical research. The characteristics of the multi-layer longitudinal piezo engine with parallel and coded control are determined for nano biomedical research. The characteristics of the multi-layer longitudinal piezo engine are obtained by applied method of mathematical physics.

Keywords: Multi-layer longitudinal piezo engine, parallel and coded control, characteristics, biomedical research

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Afonin S.M.
National Research University of Electronic Technology MIET, Russia

Correspondence: Afonin SM, National Research University of Electronic Technology MIET, Moscow, Russia,
Email learner01@mail.ru

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Introduction

The use of the multi-layer longitudinal piezo engine for nano- and micro displacements is promising in nano biomedical research for the compensation of gravitational and temperature deformations, precise alignment,[1–10] Nano pumps, microsurgery, scanning microscopy, adaptive optics, interferometers.[8–38]

Increasing the range of displacement to tens of micrometers is achieved by using the multi-layer longitudinal piezo engine in the form the composite, stack or block piezo engine.[1–8]

At present the use of the multi-layer longitudinal piezo engine with parallel and coded control is relevant, which requires determining the characteristics of this piezo engine. The application of the multi-layer longitudinal piezo engine at coded control makes it possible to effectively use electromechanical digital-to-analog conversion proportional to the control code for nano- and microdisplacements.[11–34]

In contrast to the simple piezo engine the multi-layer longitudinal piezo engine in static without load has the range of the movement increased in n times, where n – the number of the piezo layers. The characteristics of the multi-layer longitudinal piezo engine for parallel and coded control are calculated by applied method of mathematical physics.

Characteristics multi-layer longitudinal piezo engine at parallel control

Structurally the multi-layer longitudinal piezo engine, depending on the manufacturing technology, can be made in the form: the composite piezo engine made of individual elastically pressed piezo plates; packaged or block piezo engine made of piezo plates sintered using silver paste; the composite piezo engine made of the piezo packages with elastic reinforcement; the glued multi-layer piezo engine made of the piezo plates; the multi-layer piezo engine with the layers by using thick-film or thin-film.[1–18]

The equation[3–6] of the inverse longitudinal piezo effect has the form

$$S_3 = d_{33}E_3 + s_{33}^E T_3$$

here $S_3, E_3, T_3, d_{33}, s_{33}^E$ – the relative displacement, the electric field stress, the mechanical stress, the piezo module, the elastic compliance with $E = \text{const}$, index 3 for 3 axis.

We have the equation of the mechanical characteristic at parallel control in the form $\Delta l = d_{33}nU - s_{33}^E Fl/S_0 = d_{33}nU - F/C_{33}^E$ and after the transformation we have the equation of the mechanical characteristic

$$\Delta l = \Delta l_{3\max}\left(1 - F/F_{3\max}\right)$$

$$\Delta l_{3\max} = d_{33}nU,\ F_{3\max} = d_{33}US_0/\left(s_{33}^E\delta\right)$$

here $l = n\delta$ – the length, $C_{33}^E = S_0/\left(s_{33}^E l\right)$ – the rigidity of the of the multi-layer longitudinal piezo engine, Δl – the displacement, F – the force. Let us consider the mechanical characteristic on Figure 1 of the multi-layer longitudinal piezo engine at parallel control from ceramic PZT.

The measurements of the mechanical characteristic were made on the Universal testing machine UMM-5 Russia in the range of working loads under mechanical stresses in the multi layered longitudinal piezo engine up to 100 MPa. At d_{33} = 0.4 nm/V, $n = 50$, $C_{33}^E = 2 \cdot 10^8$ N/m for 1) U = 50 V; 2) U = 100 V; 3) U = 150 V the parameters of the multi-layer longitudinal piezo engine from ceramic PZT are determined on Figure 1 in the form 1) $\Delta l_{3\max}$ = 1000 nm, $F_{3\max}$ = 200 N; 2) $\Delta l_{3\max}$ = 2000 nm, $F_{3\max}$ = 400 N; 3) $\Delta l_{3\max}$ = 3000 nm, $F_{\max}$ = 600 N. The discrepancy between the experimental data and the calculation results is 10%.

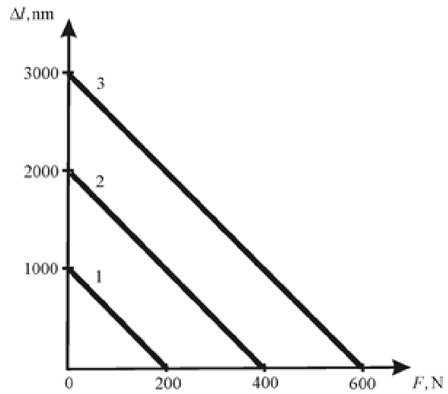

Figure 1 Mechanical characteristic of multi-layer longitudinal piezo engine at parallel control.

The displacement of the multi-layer longitudinal piezo engine at parallel control and elastic load on Figure 2 has the form

$$\Delta l = d_{33}nU - F/C_{33}^E$$

$$F = F_0 + C_a\Delta l + C_e\Delta l,\ F_0 = \sigma_a S_0$$

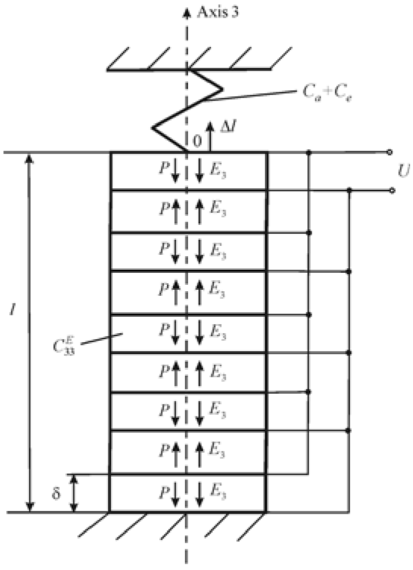

Figure 2 Multi-layer longitudinal piezo engines at parallel control and elastic load.

Here F_0 − the force of initial compression by the elastic element; σ_a − the mechanical stress of the initial reinforcement in the piezo engine; C_a − the rigidity of the reinforcing element; C_e − the load rigidity.

Consequently, the equation for the adjustment characteristic of the multi-layer longitudinal piezo engine at parallel control and elastic load has the form

$$\Delta l = \frac{d_{33}nU - \sigma_a l s_{33}^E}{1+\left(C_a+C_e\right)/C_{33}^E} = \frac{l\left(d_{33}E_3 - \sigma_a s_{33}^E\right)}{1+\left(C_a+C_e\right)/C_{33}^E}$$

For $\sigma_a = 0$ and $C_a = 0$ the equation the adjustment characteristic on Figure 3 of the multi-layer longitudinal piezo engine at parallel control and elastic load has the form

$$\Delta l = \frac{d_{33}nU}{1+C_e/C_{33}^E} = \frac{\Delta l_{3\max}}{1+C_e/C_{33}^E}$$

The adjustment characteristics on Figure 3 are determined by using electronic measuring system of displacement Model 214 Russia for the multi-layer longitudinal piezo engine from PZT for parallel control and elastic load at d_{33} = 0.4 nm/V, n = 25, C_{33}^E = 4 · 10[8] N/m, $C_a = 0$ for 1) $C_e = 0$; 2) C_e = 0.4 · 10[8] N/m with error 10%.

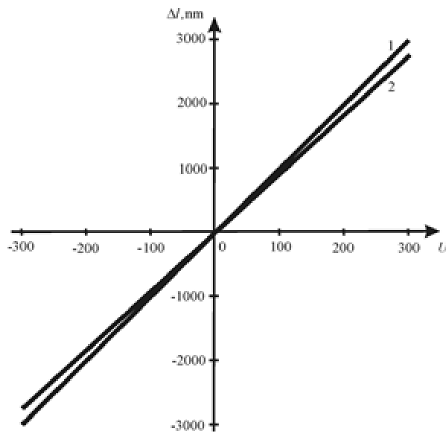

Figure 3 Adjustment characteristic at parallel control and elastic load.

Characteristics multi-layer longitudinal piezo engine at coded control

The length of the multi-layer longitudinal piezo engine at coded control has the form

$$l = \sum_{k=1}^{N} l_k = \left(2^N - 1\right)\delta$$

The maximum displacement of the multi-layer longitudinal piezo engine at coded control has the form

$$\Delta l_{\max} = d_{33}\left(2^N - 1\right)U = d_{33}nU$$

here $n = 2^N - 1$ is the number of the piezo layers.

In static conditions at the force $F = 0$ and the binary code $a_k = 0, 1$ we have displacement of the multi-layer longitudinal piezo engine at coded control in the form

$$\Delta l = \sum_{k=1}^{N} a_k \Delta l_k$$

Therefore, its displacement has the form

$$\Delta l = \sum_{k=1}^{N} a_k d_{33} 2^{k-1} U = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U$$

We have the mechanical characteristic at coded control[11–34] in the form $\Delta l = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U - s_{33}^E Fl/S_0 = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U - F/C_{33}^E$

after transformation, the normalized mechanical characteristic has the form

$$\Delta l/\Delta l_{3\max} = 1 - F/F_{3\max}$$

$$\Delta_{3\max} = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U, F_{3\max} = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)US_0 \Big/ \left(s_{33}^E l\right)$$

here $C_{33}^E = S_0/\left(s_{33}^E l\right)$.

Consequently, the equation for the adjustment characteristic of the multi-layer longitudinal piezo engine at coded control and elastic load on Figure 4 has the form

$$\Delta l = \frac{d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U}{1+\left(C_a+C_e\right)/C_{33}^E}$$

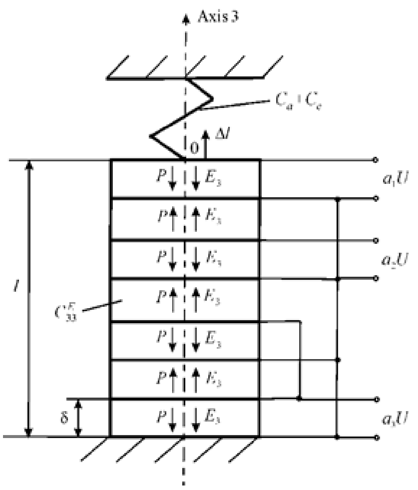

Figure 4 Multi-layer longitudinal piezo engines at coded control and elastic load.

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Therefore, the displacement of the multi-layer longitudinal piezo engine elastic load has the form

$$\Delta l = k_c U$$

here k_c is the coefficient

$$k_c = \begin{cases} \dfrac{d_{33} n}{1 + (C_a + C_e)/C_{33}^E} - \text{with parallel control}, \\ \dfrac{d_{33}\left(\sum\limits_{k=1}^{N} a_k 2^{k-1}\right)}{1 + (C_a + C_e)/C_{33}^E} - \text{with codedl control}. \end{cases}$$

The measurements of the parameters mechanical characteristic were made on the Universal testing machine UMM-5 Russia for the multi-layer longitudinal piezo engine from PZT for coded control at d_{33} = 0.4 nm/V, n = 7, $C_{33}^E = 8 \cdot 10^8$ N/m, and U = 200 V for 1) a_1 = 1, a_2 = 0, a_3 = 0; 2) a_1 = 1, a_2 = 1, a_3 = 0; 3) a_1 = 1, a_2 = 1, a_3 = 1. The maximum displacements and the maximum forces on Figure 5 are obtained 1) Δl_{max} = 80 nm, F_{max} = 64 N; 2) Δl_{max} = 240 nm, F_{max} = 192 N; 3) Δl_{max} = 560 nm, F_{max} = 448 N with error 10%.

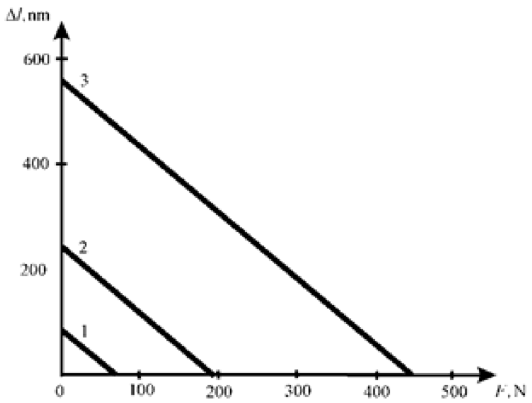

Figure 5 Mechanical characteristic at coded control.

Thus, the adjustment and mechanical characteristics of the multi-layer longitudinal piezo engine at parallel and coded control are found.

Discussion

Through the use of mathematical physics we have obtained the adjustment and mechanical characteristics of the multi-layer longitudinal piezo engine at parallel and coded control for nano biomedical research. The generalized adjustment and mechanical characteristics of the multi-layer longitudinal piezo engine at parallel and coded control are determined by using the equations of the inverse longitudinal piezo effect and the mechanical force.

Conclusion

The multi-layer longitudinal piezo engine is used in nano biomedical research for the compensation of gravitational and temperature deformations, scanning microscopy, adaptive optics. The characteristics of the multi-layer longitudinal piezo engine at parallel and coded control are obtained by using method of mathematical physics. The parameters and the characteristics of this multi-layer longitudinal piezo engines are determined.

The adjustment and mechanical characteristics in general of the multi-layer longitudinal piezo engine at parallel and coded control are found for nano biomedical research. Future works are planned to investigate the characteristics of multi-layer piezo engines in various applications.

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Conflicts of interest

The author declares that there is no conflict of interest.

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