Research Article
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Characteristics electroelastic engine for nanobiomechanics

Abstract

We received the characteristics of the electroelastic engine for nanobiomechanics. We obtained the mechanical and control characteristics of the electroelastic engine. We investigated the regulation characteristic of the multilayer piezo engine for the elastic load.

Keywords: electroelastic engine, piezo engine; mechanical and control characteristics, nanobiomechanics

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Afonin SM
National Research University of Electronic Technology, Russia

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

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Introduction

The electroelastic engine with the piezoelectric or electrostriction effect for nanobiomechanics is used in nanomanipulator, scanning microscopy, nanopump. The use of the electroelastic engine is promising in the equipment of nanobiotechnology, microelectronics and nanotechnology. The electroelastic engine is the electromechanical device for actuating and controlling mechanisms, systems with the conversion of electrical signals into mechanical displacements and forces.[1–5] The piezo engine is used for nanoscale motion in interferometry, scanning microscopy, adaptive optics, laser systems, focusing and image stabilization systems, vibration damping, micromanipulation in cells. The electroelastic engine is provided range of movement from nanometers to microns, loading capacity up to 1000 N, fast response 1-10 ms. The multilayer electroelastic engine is designed to increase the range of movement up to tens of microns.[6–29]

Characteristics engine

Let us consider the characteristics of the electroelastic engine with fixe one face in the form the mechanical characteristic and the control characteristic are used in the calculation of the control system for nanobiomechanics with using the parameters of its load. From the equation of the electroelasticity[6,7,10–28] we receive the mechanical characteristic of the electroelastic engine for nanobiomechanics in form the characteristic $S_i(T_j)$ - the relative displacement from the mechanical stress or $\Delta l(F)$ - the displacement from the force at $E = \text{const}$. We have the mechanical characteristic in the following form

$$S_i\big|_{E=\mathbf{const}} = d_{mi} E_m\big|_{E=\mathbf{const}} + s_{ij}^E T_j ,$$

where S_i, d_{mi}, E_m, s_{ij}^E, T_j are the relative displacement, the electroelastic module or the piezo module, the electric field strength, the elastic compliance, the mechanical stress.

The control characteristic of the electroelastic engine for nanobiomechanics is the characteristic in the form $S_i(E_m)$ - the relative displacement from the electric field strength or $\Delta l(U)$ - the displacement from the voltage at $T = \text{const}$. We have the control characteristic in the form

$$S_i\big|_{T=\mathbf{const}} = d_{mi} E_m + s_{ij}^E T_j\big|_{T=\mathbf{const}} .$$

For the mechanical characteristic of the electroelastic engine with controlling voltage we get the following equation

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

where $\Delta l_{\max}$ is the maximum displacement for $F = 0$ and $F_{\max}$ is the maximum force for $\Delta l = 0$.

The maximum displacement of the electroelastic engine is written as the expression

$$\Delta l_{\mathbf{max}} = d_{mi} E_m l ,$$

where l is the length of the engine. This length of the engine is equal to the thickness with the longitudinal piezo effect, the height with the transverse piezo effect and the width with the shear piezo effect. For the maximum mechanical stress of the electroelastic engine with controlling voltage we have the equation

$$T_{\mathbf{j\,max}} = d_{mi} E_m / s_{ij}^E .$$

The maximum force of the electroelastic engine is written as the expression

$$F_{\mathbf{max}} = T_{\mathbf{j\,max}} S_0 = d_{mi} E_m S_0 / s_{ij}^E ,$$

where S_0 is the cross sectional area of the engine.

For the engine with the transverse piezo effect and we obtain the maximum displacement and the maximum force in the form

$$\Delta l_{\mathbf{max}} = d_{31} E_3 l ,$$

$$F_{\mathbf{max}} = d_{31} E_3 S_0 / s_{11}^E .$$

At d_{31} =2·10^{-10} m/V, E_3 =6·10^5 V/m, l =2·10^{-2} m, S_0 =1·10^{-5} m^2, s_{11}^E = 15·10^{-12} m^2/N for the piezo engine with the transverse piezo effect from piezo ceramic PZT are received the maximum displacement $\Delta l_{\max}$ = 2.4 μm and fhe maximum force $F_{\max}$ = 80 N (Figure 1).

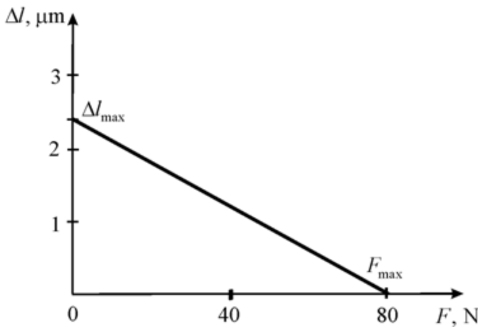

Figure 1 Mechanical characteristic of piezo engine with transverse piezo effect for nanobiomechanics.

For the regulation characteristic of the electroelastic engine with elastic force $F = C_e \Delta l$ we have equation

$$\frac{\Delta l}{l} = d_{mi} E_m - \frac{s_{ij}^E C_e}{S_0} \Delta l \ ,$$

We get the displacement of the electroelastic engine for elastic load in the form the regulation characteristic

$$\Delta l = \frac{\left(d_{mi}\, l/\delta\right) U}{1 + C_e / C_{ij}^E} \ ,$$

$$U = E_m \delta \ , \ C_{ij}^E = S_0 \Big/ \left(s_{ij}^E l\right),$$

where U is the voltage, δ is the thickness, C_{ij}^E is stiffness of the electroelastic engine at $E = \text{const}$.

For the multilayer piezo engine with the longitudinal piezo effect we obtain the regulation characteristic in the following form

$$\Delta l = \frac{d_{33} n U}{1 + C_e / C_{33}^E} = k_{33}^E U \ ,$$

$$l = n\delta \ , \ k_{33}^E = d_{33} n \Big/ \left(1 + C_e / C_{33}^E\right),$$

where k_{33}^E is the transfer coefficient at $E = \text{const}$.

At $d_{33} = 4 \cdot 10^{-10}$ m/V, $n = 16$, $C_{33}^E = 1.5 \cdot 10^7$ N/m, $C_e = 0.3 \cdot 10^7$ N/m, $U = 90$ V for the multilayer piezo engine with the longitudinal piezo effect from ceramic PZT are received the transfer coefficient $k_{33}^E = 5.33$ nm/V and the displacement $\Delta l = 480$ nm on Figure 2. The discrepancy between the experimental data for the piezo engines and the calculation results is 10%. We received the regulation characteristic of the multilayer piezo engine for the elastic load.

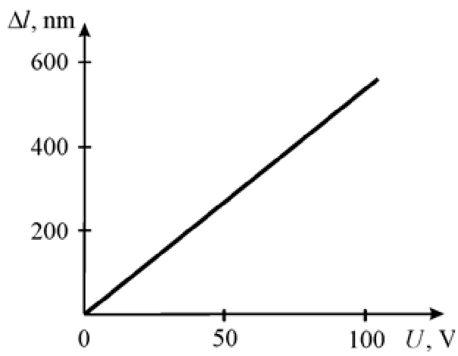

Figure 2 Regulation characteristic of multilayer piezo engine with longitudinal piezo effect for elastic load in nanobiomechanics.

Conclusion

The mechanical and control characteristics of the electroelastic engine are used in the calculation of the control system for nanobiomechanics. The mechanical characteristic of the electroelastic engine with controlling voltage is received with used the maximum displacement and the maximum force of the engine. The regulation characteristic of the electroelastic engine is obtained for the elastic load.

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Conflicts of interest

The authors declare, that there is no conflict of interest.

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