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An Engine for Nanomedicine and Nanotechnology

Afonin SM*

National Research University of Electronic Technology, MIET, Russia

***Corresponding author:** Afonin Sergey Mikhailovich, National Research University of Electronic Technology, MIET, 124498, Moscow, Russia, Email: learner01@mail.ru

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Abstract

For nanomedicine and nanotechnology the structural model of an engine is determined. The structural scheme of an engine is constructed. For an engine its matrix equation of the deformations is received for the decision of control systems. The parameters and characteristics of an engine are obtained.

Keywords: Piezo Engine; Electro Elastic Engine; Structural Model and Scheme; Parameter; Characteristic; Nanomedicine and Nanotechnology

Introduction

For control system of nanomedicine and nanotechnology an engine on piezoelectric or electrostrictive effect is applied [1-9]. For the structural schema of an engine its energy transformation is clearly [4-16]. The piezo engine is used for precise movements in adaptive optics and microscopy [11-26].

Structural Model and Scheme

The equations [8-50] of an electro elastic engine have form

$$(D)=(d)(T)+(\varepsilon^T)(E)$$

$$(S)=(s^E)(T)+(d)^t(E)$$

where (D), (d), (T), (ε^T), (E), (S), (s^E), $(d)^t$ are matrixes electric induction, piezo coefficient, strength mechanical field, dielectric constant, strength electric field, relative displacement, elastic compliance, transposed piezo coefficient.

For PZT engine its matrixes coefficients

$$(d)=\begin{pmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{15} & 0 & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 \end{pmatrix}$$

$$(\varepsilon^T)=\begin{pmatrix} \varepsilon_{11}^T & 0 & 0 \\ 0 & \varepsilon_{22}^T & 0 \\ 0 & 0 & \varepsilon_{33}^T \end{pmatrix}$$

$$(s^E)=\begin{pmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 \\ s_{12}^E & s_{11}^E & s_{13}^E & 0 & 0 & 0 \\ s_{13}^E & s_{13}^E & s_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{55}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & 2\left(s_{11}^E - s_{12}^E\right) \end{pmatrix}$$

The equation of the mechanical characteristic of an engine is obtained

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

where $\Delta l_{max} = d_{mi}E_m l$ at $F = 0$ and $F_{max} = d_{mi}E_m S_0 / s_{ij}^E$ at $\Delta l = 0$, d_{mi} is the piezo module, E_m is strength of electric field for m axis, s_{ij}^E is the elastic compliance, l is the length, S_0 is the area of an engine.

For the longitudinal PZT engine its relative displacement [8-18] is written

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

where d_{33} is longitudinal piezo module, E_3 is strength electric field for 3 axis, s_{33}^E is elastic compliance, T_3 is strength mechanical field for 3 axis.

In the mechanical characteristic of the longitudinal PZT engine for nanomedicine and nanotechnology its maximums values of displacement $\Delta\delta_{max}$ and force F_{max} are determined

$$\Delta\delta_{max} = d_{33}\delta E_3 = d_{33}U, \quad F_{max} = d_{33}S_0E_3 / s_{33}^E$$

At E_3 = 0.75·10^5 V/m, d_{33}= 4·10^{-10} m/V, S_0 = 1.5·10^{-4} m^2, δ = 2.5·10^{-3} m, s_{33}^E = 15·10^{-12} m^2/N for the longitudinal PZT engine are obtained $\Delta\delta_{max}$ = 75 nm, F_{max} = 300 N on Figure 1 with error 10%.

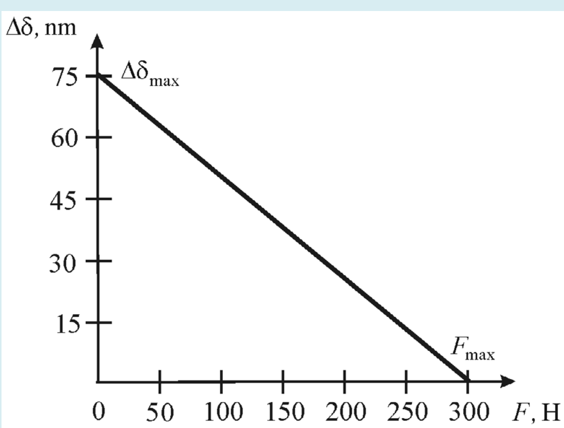

Figure 1: Mechanical characteristic an engine.

Also for the mechanical characteristic of the transverse PZT engine its maximums values

$$\Delta h_{max} = d_{31}E_3 h = d_{31}Uh/\delta, \quad F_{max} = d_{31}E_3S_0 / s_{11}^E$$

At $E_3 = 1.2\cdot10^5$ V/m, $d_{31} = 2\cdot10^{-10}$ m/V, $h = 1\cdot10^{-2}$ m, $\delta = 0.5\cdot10^{-3}$ m, $S_0 = 1\cdot10^{-5}$ m^2, $S_{11}^E = 12\cdot10^{-12}$ m^2/N for the transverse PZT engine are received $\Delta h_{max} = 240$ nm, $F_{max} = 20$ N.

The differential equation of an engine [8-50] is written

$$\frac{d^2\Xi(x,s)}{dx^2} - \gamma^2\Xi(x,s) = 0$$

$$\gamma = s/c^E + \alpha$$

here s, $\Xi(x,s)$, x, γ are the parameter, the Laplace transform of its displacement, the coordinate and the coefficient.

For the longitudinal PZT engine its displacements

$$\Xi(0,s) = \Xi_1(s) \text{ for } x = 0$$

$$\Xi(\delta,s) = \Xi_2(s) \text{ for } x = \delta$$

The decision of differential equation is determined

$$\Xi(x,s) = \{\Xi_1(s)\mathrm{sh}[(\delta\text{-}x)\gamma] + \Xi_2(s)\mathrm{sh}(x\gamma)\} / \mathrm{sh}(\delta\gamma)$$

Also the Laplace transforms of forces on its faces are received

$$T_3(0,s)S_0 = F_1(s) + M_1 s^2\Xi_1(s) \text{ for x=0}$$

$$T_3(\delta,s)S_0 = -F_2(s) - M_2 s^2\Xi_2(s) \text{ for x=}\delta$$

where F_1, F_2, M_1, M_2 are the forces, the masses.

The Laplace transforms of the mechanical stresses for the longitudinal PZT engine are obtained

$$T_3(0,s) = (s_{33}^E)^{-1}\left.\frac{d\Xi(x,s)}{dx}\right|_{x=0} - d_{33}(s_{33}^E)^{-1}E_3(s)$$

$$T_3(\delta,s) = (s_{33}^E)^{-1}\left.\frac{d\Xi(x,s)}{dx}\right|_{x=\delta} - d_{33}(s_{33}^E)^{-1}E_3(s)$$

Therefore, the structural model of the longitudinal PZT engine is determined

$$\Xi_1(s) = (M_1s^2)^{-1}\left\{-F_1(s) + (\chi_{33}^E)^{-1}\left[\begin{array}{l} d_{33}E_3(s) - [\gamma/\mathrm{sh}(\delta\gamma)] \\ \times[\mathrm{ch}(\delta\gamma)\Xi_1(s) - \Xi_2(s)] \end{array}\right]\right\}$$

$$\Xi_2(s) = (M_2s^2)^{-1}\left\{-F_2(s) + (\chi_{33}^E)^{-1}\left[\begin{array}{l} d_{33}E_3(s) - [\gamma/\mathrm{sh}(\delta\gamma)] \\ \times[\mathrm{ch}(\delta\gamma)\Xi_2(s) - \Xi_1(s)] \end{array}\right]\right\}$$

$$\chi_{33}^{E} = s_{33}^{E} / S_0$$

where $\Xi_1(s), \Xi_2(s)$ are the Laplace transforms of its displacements.

Also the system of the equations for the Laplace transforms of stresses an engine is written

$$T_j(0,s) = (s_{ij}^{\Psi})^{-1} \left. \frac{d\Xi(x,s)}{dx} \right|_{x=0} - v_{mi} (s_{ij}^{\Psi})^{-1} \Psi_m(s)$$

$$T_j(l,s) = \left(s_{ij}^{\Psi}\right)^{-1} \left. \frac{d\Xi(x,s)}{dx} \right|_{x=l} - v_{mi} \left(s_{ij}^{\Psi}\right)^{-1} \Psi_m(s)$$

where v_{mi} is electro elastic coefficient, l is length.

The structural model of an engine Figure 2 for nanomedicine and nanotechnology is determined

$$\Xi_1(s) = (M_1 s^2)^{-1} \left\{ -F_1(s) + (\chi_{ij}^{\Psi})^{-1} \begin{bmatrix} v_{mi} \Psi_m(s) - [\gamma/\mathrm{sh}(l\gamma)] \\ \times [\mathrm{ch}(l\gamma) \Xi_1(s) - \Xi_2(s)] \end{bmatrix} \right\}$$

$$\Xi_2(s) = (M_2 s^2)^{-1} \left\{ -F_2(s) + (\chi_{ij}^{\Psi})^{-1} \begin{bmatrix} v_{mi} \Psi_m(s) - [\gamma/\mathrm{sh}(l\gamma)] \\ \times [\mathrm{ch}(l\gamma) \Xi_2(s) - \Xi_1(s)] \end{bmatrix} \right\}$$

$$\chi_{ij}^{\Psi} = s_{ij}^{\Psi} / S_0$$

where $v_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \end{cases}, \quad \Psi_m = \begin{cases} E_3, E_1 \\ D_3, D_1 \end{cases},$

$s_{ij}^{\Psi} = \begin{cases} s_{33}^{E}, s_{11}^{E}, s_{55}^{E} \\ s_{33}^{D}, s_{11}^{D}, s_{55}^{D} \end{cases}, \quad l = \{\delta, h, b, \quad \gamma = \{\gamma^E, \gamma^D, \quad c^{\Psi} = \{c^E, c^D.$

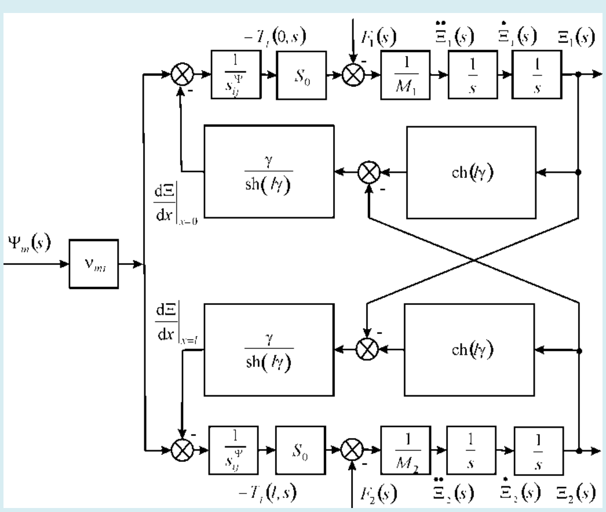

Figure 2: Scheme an engine.

The structural scheme on Figure 2 is used for decision of deformations an engine for system of nanomedicine and nanotechnology.

Parameters and characteristics

Therefore, the matrix of the deformations an engine for nanomedicine and nanotechnology is determined

$$\begin{pmatrix} \Xi_1(s) \\ \Xi_2(s) \end{pmatrix} = \begin{pmatrix} W_{11}(s) & W_{12}(s) & W_{13}(s) \\ W_{21}(s) & W_{22}(s) & W_{23}(s) \end{pmatrix} \begin{pmatrix} \Psi_m(s) \\ F_1(s) \\ F_2(s) \end{pmatrix}$$

The steady-state movements its faces are written

$$\xi_1 = d_{mi} \Psi_m l M_2 / (M_1 + M_2)$$

$$\xi_2 = d_{mi} \Psi_m l M_1 / (M_1 + M_2)$$

The steady-state movements the faces of the longitudinal PZT engine are received

$$\xi_1 = d_{33} U M_2 / (M_1 + M_2)$$

$$\xi_2 = d_{33} U M_1 / (M_1 + M_2)$$

At U = 125 V, M_1 = 1 kg, M_2 = 4 kg, d_{33}= 4·10^{-10} m/V the steady-state movements ξ_1 = 40 nm, ξ_2 = 10 nm and $\xi_1 + \xi_2 = 50$ nm and error 10%.

The transfer equation of the transverse PZT engine for elastic-inertial load is determined

$$W(s) = \frac{\Xi(s)}{U(s)} = \frac{k_{31}^{E}}{T_t^2 s^2 + 2T_t \xi_t s + 1}$$

$$k_{31}^{E} = d_{31}(h/\delta) / (1 + C_l / C_{11}^{E})$$

$$T_t = \sqrt{M / (C_l + C_{11}^{E})}, \quad \omega_t = 1 / T_t$$

where k_{31}^{E} is the transverse transfer coefficient, C_l, C_{11}^{E} are the stiffness for load, engine, T_t, ξ_t, ω_t are the time constant, the attenuation coefficient, the conjugate frequency of the engine.

At $C_l = 0.1 \cdot 10^7$ N/m, $C_{11}^E = 1 \cdot 10^7$ N/m, $M = 2$ kg the parameters of the transverse PZT engine are obtained $T_t = 0.43 \cdot 10^{-3}$ s, $\omega_t = 2.3 \cdot 10^3$ s^{-1} with error 10%.

The steady-state movement of the transverse PZT engine at elastic-inertial load is determined

$$\Delta h = \frac{d_{31}(h/\delta)U}{1 + C_l / C_{11}^E} = k_{31}^E U$$

At $h/\delta = 20$, $C_l / C_{11}^E = 0.1$, $d_{31} = 2 \cdot 10^{-10}$ m/V for the transverse PZT engine is received the transverse transfer coefficient $k_{31}^E = 3.6$ nm/V.

Conclusions

For control system the structural model an electro elastic engine is obtained. Its structural scheme is determined. The matrix of deformations an engine is constructed. The parameters and characteristics of an engine are obtained.

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