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An Engine for Nano Material Science

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Abstract

The application of an electro elastic engine in the form the piezoelectric or electrostriction engine is promising for nano material science, nanotechnology, adaptive optics. The piezo engine is used for precise matching in tunel microscope for the compensation of temperature and gravitational deformations. Investigating the characteristics of an electro elastic engine of nano and micrometric movements is used for the calculation of nano mechatronics systems. The piezo engine is the piezo mechanical device for actuate or control mechanisms and systems by using the piezo effect and to convert electrical energy into mechanical energy. The nanometric accuracy of nano mechatronics systems is provided by the piezo engine. In nanotechnology, photonics, and adaptive optics, these control systems with an electro elastic engine are used for aligning the mirrors of laser optics and for combining and scanning in the atomic-force microscope. The transfer functions of an electro elastic engine for nano displacement with the transverse, longitudinal, shear, piezo effects are obtained. The effects of the geometric and physical parameters of an electro elastic engine and external load on its dynamic characteristics are determined. For nano material science the structural model of an engine is obtained. For an engine its matrix equation of the deformations is obtained. In the structural model of an engine its energy transformation is clearly. The characteristics of an engine are received.

Keywords

Piezoelectric engine, Electro elastic engine, Deformation, Structural model, Characteristic, Nano material science

1. Introduction

For control system of nano material science an engine on piezoelectric or electrostrictive effect is applied [1-3]. In the structural model of an engine its energy transformation is clearly [3-5]. The piezoelectric engine is used for precise deformations for nano material science in tunnel microscopy, interferometry and adaptive optics [4-12].

2. Structural model an engine

For a piezoelectric engine the system equations [1-9] 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, piezoelectric module, strength mechanical field, dielectric constant, strength electric field, relative deformation, elastic compliance, transposed piezoelectric module.

For PZT engine its matrixes coefficients

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

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

The relative deformation of the longitudinal PZT engine [1-9] is received

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

where d_{33} is longitudinal piezoelectric 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.

For the longitudinal PZT engine in the mechanical characteristic its maximums values of deformation $\Delta\delta_{\max}$ and force $F_{\max}$ are obtained

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

At d_{33} = $4{\cdot}10^{-10}$ m/V, S_0 = $1.5{\cdot}10^{-4}$ m^2, δ = $2.5{\cdot}10^{-3}$ m, s_{33}^E = $15{\cdot}10^{-12}$ m^2/N, E_3 = $1.5{\cdot}10^5$ V/m for the longitudinal PZT engine are obtained $\Delta\delta_{\max}$ = 150 nm and $F_{\max}$ = 600 N on Figure 1 with error 10%.

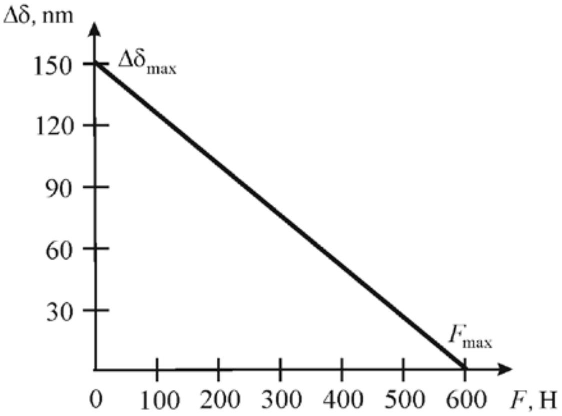

Figure 1. Mechanical characteristic an engine for nano material science.

The deformation from the force $\Delta l(F)$ of an engine in form of the mechanical characteristic is determined

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

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 piezoelectric module, E_m is strength of electric field for *m* axis, $l = \{\ \delta, h, b$ is the length, s_{ij}^E is the elastic compliance, S_0 is the area of an engine.

The differential equation of an engine [2-10] has the form

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

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

here s, $\Xi(x,s)$, x, γ, α are the parameter of transform, the Laplace transform of its deformation, the coordinate, the propagation and attenuation coefficients.

For the transverse PZT engine its deformations

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

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

The decision of differential equation has the form

$$\Xi(x,s) = \left\{\Xi_1(s)\operatorname{sh}\left[(h-x)\gamma\right] + \Xi_2(s)\operatorname{sh}(x\gamma)\right\}/\operatorname{sh}(h\gamma)$$

The Laplace transforms of forces on its faces are received

$$T_1(0,s)S_0 = F_1(s) + M_1 s^2 \Xi_1(s) \quad \text{for} \quad x = 0$$

$$T_1(h,s)S_0 = -F_2(s) - M_2 p^2 \Xi_1(s) \quad \text{for} \quad x = h$$

where F_1, F_2, M_1, M_2 are the forces and the masses on the faces.

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

$$T_1(0,s) = \left(s_{11}^E\right)^{-1} \left.\frac{d\Xi(x,s)}{dx}\right|_{x=0} - d_{31}\left(s_{11}^E\right)^{-1} E_3(s)$$

$$T_1(h,s) = \left(s_{11}^E\right)^{-1} \left.\frac{d\Xi(x,s)}{dx}\right|_{x=\delta} - d_{31}\left(s_{11}^E\right)^{-1} E_3(s)$$

For the transverse PZT engine its structural model is obtained

$$\Xi_1(s) = \left(M_1 s^2\right)^{-1}\left\{-F_1(s) + \left(\chi_{11}^E\right)^{-1}\begin{bmatrix} d_{31}E_3(s) - \left[\gamma/\operatorname{sh}(h\gamma)\right] \\ \times\left[\operatorname{ch}(h\gamma)\Xi_1(s) - \Xi_2(s)\right]\end{bmatrix}\right\}$$

$$\Xi_2(s) = \left(M_2 s^2\right)^{-1}\left\{-F_2(s) + \left(\chi_{11}^E\right)^{-1}\begin{bmatrix} d_{31}E_3(s) - \left[\gamma/\operatorname{sh}(h\gamma)\right] \\ \times\left[\operatorname{ch}(h\gamma)\Xi_2(s) - \Xi_1(s)\right]\end{bmatrix}\right\}$$

$$\chi_{11}^E = s_{11}^E/S_0$$

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

At electro elastic coefficient v_{mi} and length l of an engine the Laplace transforms of stresses on its faces in form the system of the equations is obtained

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

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

For nano material science the structural model of an engine on Figure 2 is received

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

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

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

where $\nu_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \end{cases}$, $\Psi_m = \begin{cases} E_3, E_1 \\ D_3, D_1 \end{cases}$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D \end{cases}$, $l = \{ \delta, h, b$, $\gamma = \{\gamma^E, \gamma^D$, $c^{\Psi} = \{ c^E, c^D$.

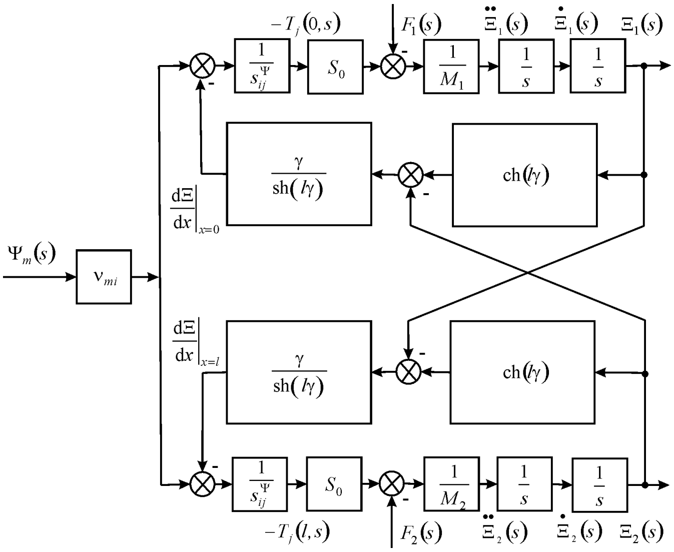

Figure 2. Structural scheme an engine for nano material science.

The structural scheme an engine on Figure 2 is used for decision of its deformations for nano material science in tunnel microscopy and adaptive optics.

3. Characteristics an engine

The matrix of deformations an engine for nano material science has the form

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

The steady-state deformations its faces are written

$$\xi_1 = d_{mi}\Psi_m l\left(M_2 + m/2\right)/\left(M_1 + M_2 + m\right)$$

$$\xi_2 = d_{mi}\Psi_m l\left(M_1 + m/2\right)/\left(M_1 + M_2 + m\right)$$

where m is the mass of an engine.

At $m << M_1$ and $m << M_2$ the steady-state deformations the faces of the longitudinal PZT engine are received

$$\xi_1 = d_{33}UM_2/\left(M_1 + M_2\right)$$

$$\xi_2 = d_{33}UM_1/\left(M_1 + M_2\right)$$

At d_{33} = 4·10^{-10} m/V, M_1 = 1 kg, M_2 = 4 kg, U = 150 V the steady-state deformations ξ_1 = 48 nm, ξ_2 = 12 nm and $\xi_1 + \xi_2$ = 60 nm and error 10%.

At elastic-inertial load the steady-state deformation of the transverse PZT engine is determined

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

At d_{31} = 2.2·10^{-10} m/V, h/δ = 20, C_l / C_{11}^E = 0.1, for the transverse PZT engine is received the transverse transfer coefficient k_{31}^E = 4 nm/V.

The transfer equation of this engine for elastic-inertial load is obtained

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

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

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

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

At M = 2.5 kg, C_l = 0.1·10^7 N/m C_{11}^E = 1·10^7 N/m the parameters of the transverse PZT engine are determined T_t = 0.48·10^{-3} s, ω_t = 2.1·10^3 s^{-1} with error 10%.

Therefore, the transfer equation of an engine for elastic-inertial load has form

$$W(s) = \frac{\Xi(s)}{U(s)} = k_{mi}^E \Big/ \left(T_t^2 p^2 + 2T_t \xi_t p + 1 \right)$$

$$k_{mi}^E = d_{mi} \left(l/\delta \right) \Big/ \left(1 + C_l / C_{ij}^E \right), \ T_t = \sqrt{M \Big/ \left(C_l + C_{ij}^E \right)}$$

where k_{mi}^E, C_{ij}^E are the transfer coefficient and the stiffness of an engine

4. Conclusions

For nano material science the structural model an electro elastic engine is determined. Its structural scheme is obtained. The matrix of deformations of an engine is constructed. The characteristics of an engine are received.

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