

Schemes nano piezo engine for applied bionics

Abstract

The schemes with lumped parameters and distributed parameters of the nano piezo engine are constructed for applied bionics. The scheme of the nano piezo engine is founded by method mathematical physics. The displacement matrix of nano engine is determined.

Keywords: nano piezo engine, scheme, applied bionics

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Introduction

The nano piezo engine is used in applied bionics for nano positioning system, dampen mechanical vibrations, adaptive optics, ring quantum generator, scanning microscopy, works with DNA.¹⁻¹⁸ Its scheme is constructed by method mathematical physics for lumped parameters or distributed parameters of nano piezo engine.

Schemes

Let us consider the scheme of the nano piezo engine for lumped parameters. The scheme of nano piezo engine is determined by method mathematical physics with using the equation of the reverse piezo effect and the equations forces of engine in dynamics.¹⁶⁻⁵⁷

The equation of the reverse piezo effect has the form³⁻⁵⁹

$$S_i = d_{mi} E_m + s_{ij}^E T_j$$

here the indexes i, j, m and $S_i, E_m, T_j, d_{mi}, s_{ij}^E$ are the relative displacement, the strength electric field, the strength mechanical field, the piezo module, and the elastic compliance at $E = \text{const}$.

Than the Laplace transform general force $F(s)$ of the nano piezo engine is founded

$$F(s) = d_{mi} S_0 E_m(s) / s_{ij}^E$$

We have the transform general force by using the voltage $U_C(s) = U(s) / (RC_0 s + 1)$ on the piezo capacitor in the form

$$F(s) = \frac{d_{mi} S_0 U_C(s)}{\delta s_{ij}^E} = \frac{d_{mi} S_0 U(s)}{\delta s_{ij}^E (RC_0 s + 1)}$$

The Laplace transform general force of the nano piezo engine is written

$$F(s) = k_r U_C(s)$$

here k_r is the reverse coefficient in the form

$$k_r = \frac{d_{mi} S_0}{\delta s_{ij}^E}$$

The equation direct piezo effect has form³⁻⁴³

$$D_m = d_{mi} T_i + \varepsilon_{mk}^E E_k$$

here ε_{mk}^E is the permittivity.

Than the direct coefficient k_d is founded in the form

$$k_d = k_r = \frac{d_{mi} S_0}{\delta s_{ij}^E}$$

The Laplace transform voltage for the first feedback on the velocity of the second end is founded on Figure 1 in the form

$$U_d(s) = \frac{d_{mi} S_0}{\delta s_{ij}^E} \dot{\Xi}_2(s) R = k_d \dot{\Xi}_2(s) R$$

by using the Laplace transform velocity the second end $\dot{\Xi}_2$ of the nano engine.

The transform force at the second end $F_2(s)$ and the load force $F_l(s)$ are subtracted on Figure 1. The Laplace transform force for the second feedback has the form

$$F_l(s) = (C_e + C_{ij}^E + k_v s) \Xi_2(s)$$

here C_e, C_{ij}^E, k_v are the elastic load stiffness, the stiffness piezo engine, the coefficient of viscous friction. This Laplace transform the load force has form the sum of the elastic force and the viscous friction force.

The scheme for lumped parameters of the nano piezo engine is constructed on Figure 1 at the first fixed end, the elastic inertial load with the mass load M_2 and the voltage control.

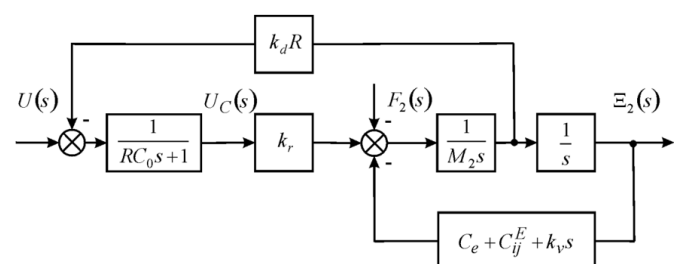


Figure 1 Scheme for lumped parameters nano engine.

The transfer function for lumped parameters of the nano engine on Figure 1 has the form

$$W(s) = \Xi_2(s) / U(s) = k_r / (a_3 p^3 + a_2 p^2 + a_1 p + a_0)$$

$$a_3 = RC_0 M_2, \quad a_2 = M_2 + RC_0 k_v$$

$$a_1 = k_v + RC_0 C_{ij}^E + RC_0 C_e + R k_r k_d, \quad a_0 = C_e + C_{ij}^E$$

At $R = 0$ the transfer function is founded in the form

$$W(s) = \Xi_2(s)/U(s) = k_{31}^U / (T_i^2 s^2 + 2T_i \xi_i s + 1)$$

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

$$T_i = \sqrt{M_2 / (C_e + C_{11}^E)}, \quad \omega_i = 1/T_i$$

At nano PZT engine $M_2 = 1$ kg, $C_e = 0.4 \cdot 10^7$ N/m, $C_{11}^E = 1.2 \cdot 10^7$ N/m its parameters are determined $T_i = 0.25 \cdot 10^{-3}$ s, $\omega_i = 4 \cdot 10^3$ s⁻¹.

At PZT drive $d_{31} = 0.2$ nm/V, $h/\delta = 20$, $C_e/C_{11}^E = 0.33$ its transfer coefficient is founded $k_{31}^U = 3$ nm/V.

Let us consider the scheme in general of the nano piezo engine for distributed parameters.

The scheme of nano engine is constructed by method mathematical physics with the equation of the reverse piezo effect and the equations forces in dynamics at the boundary conditions the differential equation of engine.

The ordinary differential equation of the nano piezo engine has form⁸⁻⁴⁹

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

here $\Xi(x, s)$, x , s , γ are the Laplace transform displacement, the coordinate, the parameter, the propagation coefficient and the general length $l = \{h, \delta, b\}$ the nano piezo engine, For the nano piezo engine at $x = 0$, $\Xi(0, s) = \Xi_1(s)$ and at $x = l$, $\Xi(l, s) = \Xi_2(s)$.

The solution of the ordinary differential equation has the form

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

and the boundary conditions are determined

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

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

The Laplace transform of the general force of the nano piezo engine has the form

$$F(s) = v_{mi} \Psi_m(s) / \chi_{ij}^\Psi$$

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

The general scheme and model for distributed parameters of the engine on Figure 2 are determined at voltage or current control

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

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

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

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

The general scheme for distributed parameters of the nano engine on Figure 2 is used in applied bionics and biomechanics.

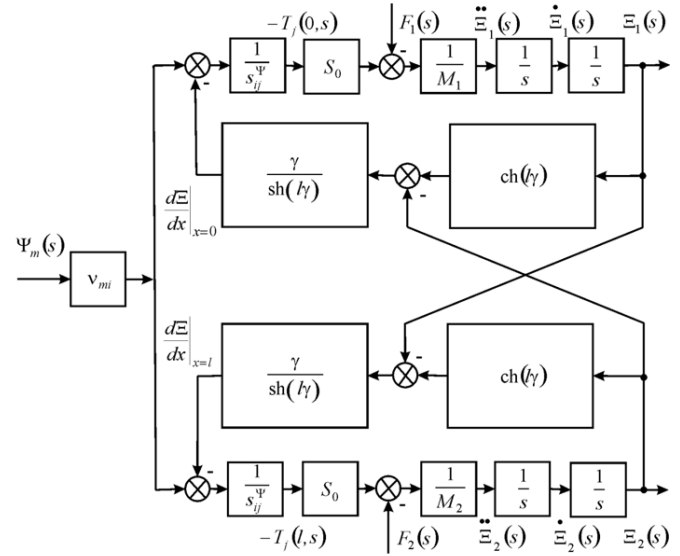


Figure 2 General scheme for distributed parameters nano piezo engine.

The displacement matrix has the form

$$\begin{pmatrix} \Xi_1(s) \\ \Xi_2(s) \end{pmatrix} = (W(s)) \begin{pmatrix} \Psi_m(s) \\ F_1(s) \\ F_2(s) \end{pmatrix}$$

$$(W(s)) = \begin{pmatrix} W_{11}(s) & W_{12}(s) & W_{13}(s) \\ W_{21}(s) & W_{22}(s) & W_{23}(s) \end{pmatrix}$$

with the transfer functions in the form

$$W_{11}(s) = \Xi_1(s) / \Psi_m(s) = v_{mi} [M_2 \chi_{ij}^\Psi s^2 + \gamma \text{th}(l\gamma/2)] / A_{ij}$$

$$W_{21}(s) = \Xi_2(s) / \Psi_m(s) = v_{mi} [M_1 \chi_{ij}^\Psi s^2 + \gamma \text{th}(l\gamma/2)] / A_{ij}$$

$$W_{12}(s) = \Xi_1(s) / F_1(s) = -\chi_{ij}^\Psi [M_2 \chi_{ij}^\Psi s^2 + \gamma / \text{th}(l\gamma)] / A_{ij}$$

$$W_{13}(s) = \Xi_1(s) / F_2(s) = W_{22}(s) = \Xi_2(s) / F_1(s) = [\chi_{ij}^\Psi \gamma / \text{sh}(l\gamma)] / A_{ij}$$

$$W_{23}(s) = \Xi_2(s) / F_2(s) = -\chi_{ij}^\Psi [M_1 \chi_{ij}^\Psi s^2 + \gamma / \text{th}(l\gamma)] / A_{ij}$$

$$A_{ij} = M_1 M_2 (\chi_{ij}^\Psi)^2 s^4 + \{(M_1 + M_2) \chi_{ij}^\Psi / [c^\Psi \text{th}(l\gamma)]\} s^3 +$$

here

$$+ [(M_1 + M_2) \chi_{ij}^\Psi \alpha / \text{th}(l\gamma) + 1 / (c^\Psi)^2] s^2 + 2\alpha s / c^\Psi + \alpha^2$$

The static displacements of the transverse engine are determined

$$\xi_1 = d_{31}(h/\delta)UM_2/(M_1 + M_2)$$

$$\xi_2 = d_{31}(h/\delta)UM_1/(M_1 + M_2)$$

At the transverse PZT engine $M_1 = 0.25$ kg, $M_2 = 1$ kg, $d_{31} = 0.2$ nm/V, $h/\delta = 10$, $U = 150$ V the static displacements are founded $\xi_1 + \xi_2 = 300$ nm and $\xi_1 = 240$ nm, $\xi_2 = 40$ nm.

Discussion

The nano piezo engine is used in applied bionics for scanning microscopy and adaptive optics. The structural scheme of the nano engine is determined. For the nano piezo engine the displacement matrix is constructed. The general schemes for engine are founded.

Conclusions

The schemes for lumped parameters and distributed parameters of the nano engine and its transfer functions are constructed by method mathematical physics. The displacement matrix and the transfer functions are determined for applied bionics.

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Conflicts of interest

The author declares that there is no conflict of interest.

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