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Research Article

Structural Scheme A Piezoengine Nanodisplacement for Biomedical Science and Research

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Abstract

The structural scheme a piezo engine nano displacement is obtained for biomedical science and research. The structural structural scheme a piezo engine nano displacement is constructed by method mathematical physics. In biomedical science and research, the nano displacements are determined.

Keywords: Piezo engine, Structural scheme, Nano displacement, Biomedical research

Introduction

The structural scheme a piezo engine nano displacement is constructed for biomedical science and research [1-23]. A piezoengine is used in scanning microscopy, microsurgery, damping vibration, adaptive optics system for biomedical science and research [24-64].

Method

For the structural sheme a piezoengine is used method of mathematical physics with the solution the reverse piezoeffect equation [3-39] and its differential equation

at the voltage control

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

at the current the control

$$S_i = g_{mi}D_m + s_{ij}^D T_j$$

here S_i, E_m, D_m, T_j, d_{mi}, g_{mi}, s_{ij}^E, s_{ij}^D are the relative displacement, the electric field strength, the electric induction, the mechanical field strength, piezomodules, the elastic compliances, and the low indexes i, j, m.

The ordinary differential equation of piezoengine [8-60] is written

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

here $\Xi(x,s)$, x, s, γ are the transform of the displacement, its coordinate and parameter, the propagation coefficient and the general length $l = \{ l, \delta, b$ of piezoengine nanodisplacement.

Structural Scheme

For the longitudinal piezoengine the solution of its differential equation is determined

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

The system boundary conditions for the longitudinal piezoengine has the form

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

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

The transform of the force causes displacement for the longitudinal piezoengine has the form

$$F(s)=\frac{d_{33}S_0E_3(s)}{s_{33}^E}$$

here S_0 is cross sectional area.

Its longitudinal reverse coefficient

$$k_r=\frac{F(s)}{U(s)}=\frac{d_{33}S_0}{\delta s_{33}^E}$$

The structural model of the longitudinal piezoengine has the form

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

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

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

For the shif piezoengine the solution of its differential equation is determined

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

The system of conditions for the shift piezoengine has the form

$$T_5(0,s)=\frac{1}{s_{55}^E}\frac{\mathrm{d}\Xi(x,s)}{\mathrm{d}x}\bigg|_{x=0}-\frac{d_{15}}{s_{55}^E}E_1(s)$$

$$T_5(b,s)=\frac{1}{s_{55}^E}\frac{\mathrm{d}\Xi(x,s)}{\mathrm{d}x}\bigg|_{x=b}-\frac{d_{15}}{s_{55}^E}E_1(s)$$

The transform of the force causes displacement for the shift piezoengine has the form

$$F(s)=\frac{d_{15}S_0E_3(s)}{s_{55}^E}$$

Its shif reverse coefficient

$$k_r=\frac{F(s)}{U(s)}=\frac{d_{15}S_0}{\delta s_{55}^E}$$

The structural model of the shift piezoengine has the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{55}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{15}E_1(s)-\left[\gamma/\mathrm{sh}(b\gamma)\right]\\ \times\left[\mathrm{ch}(b\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{55}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{15}E_1(s)-\left[\gamma/\mathrm{sh}(b\gamma)\right]\\ \times\left[\mathrm{ch}(b\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{55}^E=s_{55}^E/S_0$$

For the transverse piezoengine the solution of its differential equation is obtained

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

here $\Xi_1(s)$, $\Xi_2(s)$, are the transforms its end displacements.

The system boundary conditions for the transverse piezoengine has the form

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

$$T_1(h,s)=\frac{1}{s_{11}^E}\frac{\mathrm{d}\Xi(x,s)}{\mathrm{d}x}\bigg|_{x=h}-\frac{d_{31}}{s_{11}^E}E_3(s)$$

The transform of the force causes displacement for the transverse piezoengine has the form

$$F(s)=\frac{d_{31}S_0E_3(s)}{s_{11}^E}$$

The transverse reverse coefficient has the form

$$k_r=\frac{F(s)}{U(s)}=\frac{d_{31}S_0}{\delta s_{11}^E}$$

The structural model of the transverse piezoengine has the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{11}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{31}E_3(s)-\left[\gamma/\mathrm{sh}(h\gamma)\right]\\ \times\left[\mathrm{ch}(h\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{11}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{31}E_3(s)-\left[\gamma/\mathrm{sh}(h\gamma)\right]\\ \times\left[\mathrm{ch}(h\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

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

In general the equation of inverse piezoeffect [3-41] has the form

$$S_i=\nu_{mi}\Psi_m+s_{ij}^{\Psi}T_j$$

here $\Psi_m=E_m,D_m$ is control parameter at the voltage or current control.

The system boundary conditions for a piezoengine is determined

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

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

The transformation of force causes displacement has the form

$$F(s)=\frac{\nu_{mi}S_0\Psi_m(s)}{s_{ij}^{\Psi}}$$

The general structural scheme a piezoengine a piezoengine a piezoengine on Figure 1 and its model for biomedical science and research has the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{ij}^{\Psi}\right)^{-1}\\ \times\left[\begin{array}{l}\nu_{mi}\Psi_m(s)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\\ \times\left[\mathrm{ch}(l\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{ij}^{\Psi}\right)^{-1}\\ \times\left[\begin{array}{l}\nu_{mi}\Psi_m(s)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\\ \times\left[\mathrm{ch}(l\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

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

Here

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

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

(Figure 1)

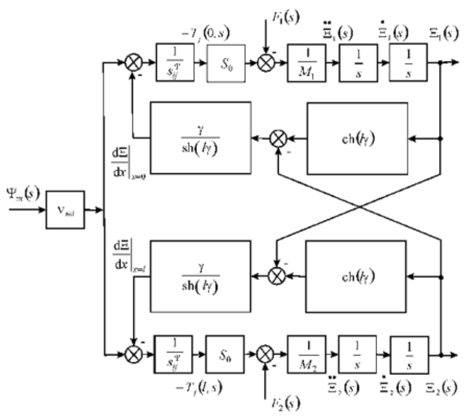

Figure 1: General scheme piezoengine for biomedical science and research.

The displacement matrix is founded

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

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

here its functions

$$W_{11}(s)=\Xi_1(s)/\Psi_m(s)=\nu_{mi}\left[M_2\chi_{ij}^{\Psi}s^2+\gamma\,\mathrm{th}(l\gamma/2)\right]/A_{ij}$$

$$A_{ij}=M_1M_2\left(\chi_{ij}^{\Psi}\right)^2s^4+\left\{\left(M_1+M_2\right)\chi_{ij}^{\Psi}/\left[c^{\Psi}\mathrm{th}(l\gamma)\right]\right\}s^3+$$
$$+\left[\left(M_1+M_2\right)\chi_{ij}^{\Psi}\alpha/\mathrm{th}(l\gamma)+1/\left(c^{\Psi}\right)^2\right]s^2+2\alpha s/c^{\Psi}+\alpha^2$$

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

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

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

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

Then static longitudinal displacements at the voltage control for biomedical science and research have the form

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

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

At the PZT engine d_{33} = 0.4 nm/V, U = 150 V, M_1 = 1 kg, M_2 = 4 kg its displacements are determined ξ_1 = 48 nm, ξ_2 = 12 nm, $\xi_1+\xi_2$ = 60 nm at 10% error.

The equation of the direct piezoeffect of piezoengine for the voltage control has the form [8-60].

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

here k is the index, ε_{mk}^{E} is the permittivity.

Its direct coefficient

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

The transform of the voltage for the feedback on Figure 2 at the voltage control of piezoengine has the form for two its ends

$$U_d(s)=\frac{d_{mi}S_0R}{\delta s_{ij}^{E}}\dot{\Xi}_n(s)=k_dR\dot{\Xi}_n(s),\ n=1,2$$

(Figure 2)

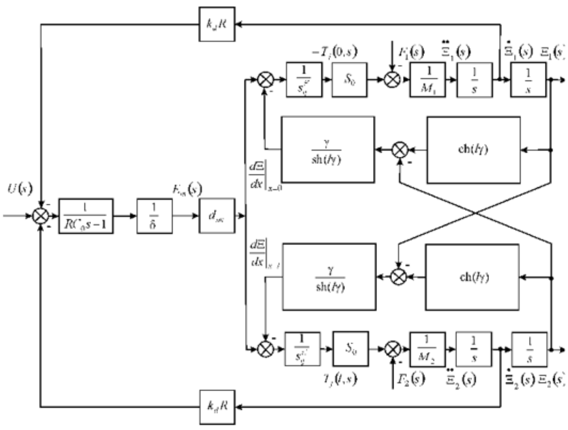

Figure 2: Scheme engine with feedbacks at voltage control for biomedical science and research.

The mechanical characteristic of piezoengine has the form

$$S_i(T_j)\big|_{\Psi=\mathrm{const}}=\nu_{mi}\Psi_m\big|_{\Psi=\mathrm{const}}+s_{ij}^{\Psi}T_j$$

The adjustment characteristic

$$S_i(\Psi_m)\big|_{T=\mathrm{const}}=\nu_{mi}\Psi_m+s_{ij}^{\Psi}T_j\big|_{T=\mathrm{const}}$$

The mechanical characteristic of transverse piezoengine has the form

$$\Delta h=\Delta h_{\max}(1-F/F_{\max})$$

$$\Delta h_{\max}=d_{31}E_3h,\ F_{\max}=d_{31}E_3S_0/s_{11}^{E}$$

At the PZT engine d_{31} = 0.2 nm/V, E_3 = 0.5·10[5] V/m, h = 2.5·10-2 m, S_0 = 1.5·10[-5] m[2], s_{11}^{E} = 15·10[-12] m[2]/N the maximum displacement and force are determined $\Delta h_{\max}$ = 250 nm and $F_{\max}$ = 10 N at 10% error.

The relative displacement a piezoengine at elastic load has the form

$$\frac{\Delta l}{l}=\nu_{mi}\Psi_m-\frac{s_{ij}^{\Psi}C_e}{S_0}\Delta l$$

$$F=C_e\Delta l$$

The adjustment characteristic a piezoengine has the form

$$\Delta l=\frac{\nu_{mi}l\Psi_m}{1+C_e/C_{ij}^{\Psi}}$$

The scheme the piezoengine at the voltage control on Figure 3 is determined for first fixed end and elastic inertial load (Figure 3).

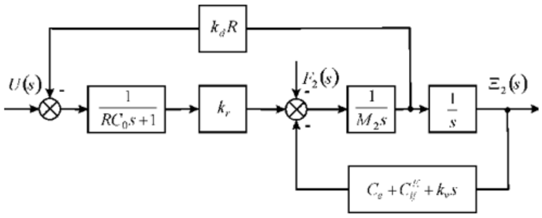

Figure 3: Scheme engine with feedbacks at voltage control for biomedical science and research.

Its function at the voltage control for fixed first end and elastic inertial load Figure 3 has the form

$$W(s)=\Xi_2(s)/U(s)=k_r/\left(a_3p^3+a_2p^2+a_1p+a_0\right)$$

$$a_3=RC_0M_2,\quad a_2=M_2+RC_0k_v$$

$$a_1=k_v+RC_0C_{ij}+RC_0C_e+Rk_rk_d,\quad a_0=C_e+C_{ij}$$

For $R=0$ its function has the form

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

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

$$T_t=\sqrt{M_2/\left(C_e+C_{11}^E\right)},\quad \omega_t=1/T_t$$

At the PZT engine M_2 = 1 kg, C_e = 0.1.10^7 N/m, C_{11}^E = 1.5.10^7 N/m its time constant is obtained T_t = 0.25.10^-3 s at 10% error. At d_{31} = 0.2 nm/V, h/δ = 20, C_e/C_{11}^E = 0.05 the coefficient is determined k_{31}^U = 3.8 nm/V at 10% error.

Discussion

A piezoengine is used for biomedical science and research in system adaptive optics and scanning microscopy, microsurgery. At using method mathematical physics the structural scheme, a piezoengine is constructed. Its displacement matrix is founded. The schemes with the feedbacks at the voltage control are determined.

Conclusions

The general structural scheme a piezoengine is obtained. The displacement matrix is founded. The parameters of PZT engine at the voltage control are determined for biomedical science and research in system adaptive optics and scanning microscopy, microsurgery.

Conflicts of Interest

None.

Acknowledgements

None.

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