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Block diagram of a nano piezo engine for nanobionics

Abstract

A nano piezo engine is used in nanobionics, nanotechnology scanning microscopy, delivery DNA, adaptive optics of compound telescope. The block diagram of a nano piezo engine for nanobionics is determined with using the equation of reverse piezo effect and the linear ordinary second-order differential equation. The matrix transfer function of a nano piezo engine is obtained. The block diagrams of the piezo engine with the back electromotive force at distributed and lumped parameters are determined in nanobionics. The block diagrams of a piezo engine are illustrated the process of converting electrical energy into mechanical energy, as opposed to Cady's and Mason's equivalent circuits.

Keywords: block diagram, nano piezo engine, nanobionics

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Introduction

A nano piezo engine is used for actuation of systems for engine for nano displacement and delivery DNA in nanobionics. This piezo engine is used to actuate or control nano mechanisms and convert electrical energy into mechanical energy at the nanometric accuracy in laser systems, atomic force microscopes for nano displacement and compensation of vibration.[1–12] By method mathematical physics the block diagram of a nano piezo engine is determined for nanobionics. The block diagram of a nano piezo engine is determined and visually show the transformation of electrical energy into mechanical energy in difference from Cady's and Mason's electrical equivalent circuits.[6–12] The block diagram of a nano piezo engine for nanobionics is determined with using the equation of reverse piezo effect and the linear ordinary second-order differential equation. From the set of equations for the block diagram of a nano piezo engine the matrix transfer function is determined.[11–25] For nanobionics with a nano piezo engine its matrix transfer function is obtained.

Method

By method mathematical physics the block diagram of a nano piezo engine is calculated for nanobionics research. The method mathematical physics is used to construct the block diagram of a nano piezo engine from the equation of reverse piezo effect and its ordinary differential equation for nanobionics. This block diagram of a nano piezo engine visually shows the process for the transformation of the electrical energy into the mechanical in difference from Cady's and Mason's circuits.[6–12]

Block diagram

A nano piezo engine in the form piezo plate is used for nanobionics, scanning microscopy, adaptive optics. The piezo plate transforms electrical energy to mechanical energy with using inverse piezo effect. A nano piezo engines are used for nano displacements along the X, Y, Z axes. The characteristics of a nano piezo engine for nanobionics are obtained by method mathematical physics.[10–25]

Piezo materials from lead zirconate and titanate PZT type ceramics are used for the production of piezo engines. The piezo effect in PZT ceramics appears after polarization in the strong constant electric field.[12]

Let us consider the process of determination of the block diagram of a nano piezo for nanobionics. For obtained the block diagram of a nano piezo engine we have the equation of reverse piezo effect and the second-order linear ordinary differential equation. The equation of the reverse piezo effect[10–22] for the relative deformation has the form

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

here s_{ij}^{Ψ} – the elastic compliances, v_{mi} – the piezoelectric constant, Ψ_m – the control parameter: E – the electric field strength, D – the electric induction, i, j, k – indexes.

For the dynamic process in the block diagram of a nano piezo engine the differential equation is established[11]

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

here $\gamma^{\Psi} = \gamma$ – the coefficient of wave propagation.

The solution of this differential equation is obtained in the form

$$\Xi(x,p) = Ce^{-\gamma x} + Be^{\gamma x},$$

here $\Xi(x,p)$ is the Laplace transform of the displacement, x is the coordinate, p is the operator.

Accordingly, to solve the differential equation, the coefficients C and B are derived as follows

$$C = \left(\Xi_1 e^{\gamma l} - \Xi_2\right) / \left[2\text{sh}(\gamma l)\right], B = \left(\Xi_2 - \Xi_1 e^{-\gamma l}\right) / \left[2\text{sh}(\gamma l)\right].$$

For practical use, the solution to this differential equation can be expressed in the form

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

In general, the two equations for the forces acting on the two faces of a nano piezo engine can be derived as follows:

$$T_j(0,p) S_0 = F_1(p) + M_1 p^2 \Xi_1(p) \text{ at } x = 0;$$

$$T_j(l,p) S_0 = -F_2(p) - M_2 p^2 \Xi_2(p) \text{ at } x = l.$$

Accordingly, the two equations for mechanical stresses acting on the two faces of a nano piezo engine are determined

$$T_j(0,p) = \frac{1}{s_{ij}^{\Psi}} \frac{d\Xi_1(p)}{dx} - \frac{v_{mi}}{s_{ij}^{\Psi}} E_m(p);$$

$$T_j(l,p) = \frac{1}{s_{ij}^{\Psi}} \frac{d\Xi_2(p)}{dx} - \frac{v_{mi}}{s_{ij}^{\Psi}} E_m(p).$$

In general, we have the block diagram of a nano piezo engine at distributed parameters on Figure 1

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

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

here $\chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D \end{cases}$, $\nu_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \end{cases}$, $\Psi_m = \begin{cases} E_3, E_3, E_1 \\ D_3, D_3, D_1 \end{cases}$,
$l = \delta, h, b -$ length engine, $i = 1, 2, \ldots, 6$, $j = 1, 2, \ldots, 6$, $m = 1, 2, 3$.

Accordingly, from the block diagram of a nano piezo engine at distributed parameters on Figure 1 we have the equations

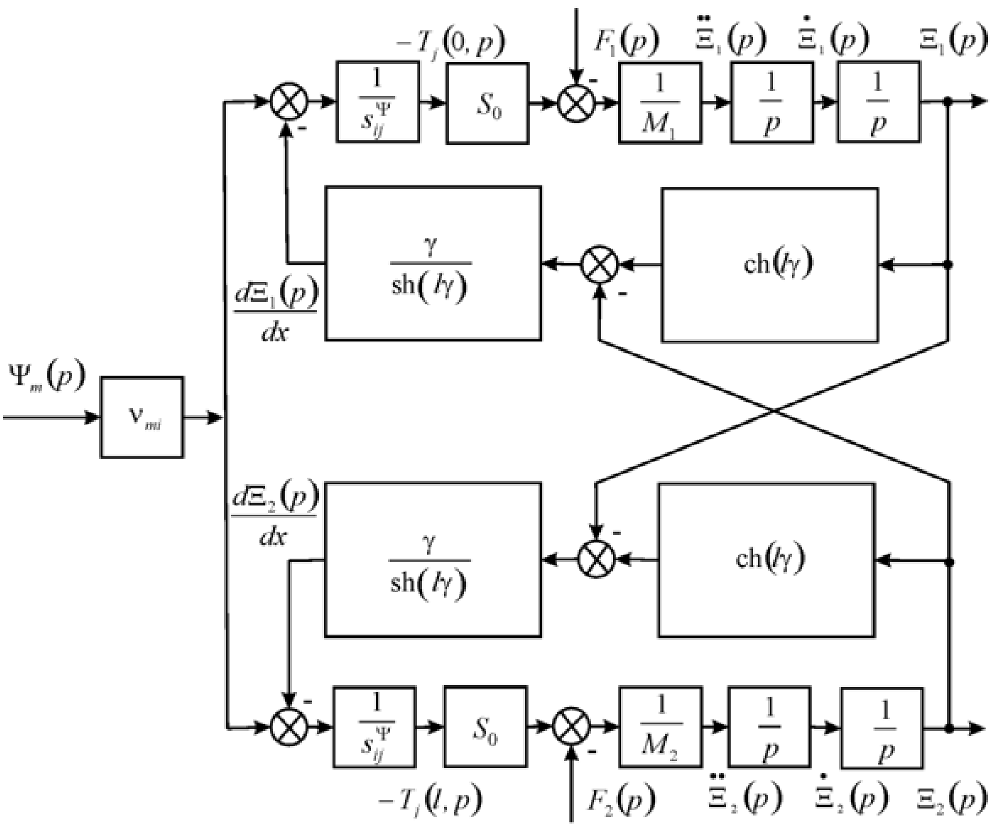

Figure 1 Block diagram nano piezo engine at distributed parameters for mechatronics.

$$\Xi_1(p) = W_{11}(p)\Psi_m(p) + W_{12}(p)F_1(p) + W_{13}(p)F_2(p);$$

$$\Xi_2(p) = W_{21}(p)\Psi_m(p) + W_{22}(p)F_1(p) + W_{23}(p)F_2(p),$$

with the matrix equation and the matrix transfer function in the form

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

here the transfer functions are established

$$W_{11}(p) = \Xi_1(p)/\Psi_m(p) = \nu_{mi}\left[M_2\chi_{ij}^{\Psi}p^2 + \gamma\mathrm{th}(\gamma l/2)\right]/A_{ij}; \chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0;$$

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

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

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

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

This transfer functions are used for the decision in the control systems for nanobionics.

Discussion

For the transition process in the steady end at inertial load the displacements of the longitudinal piezo engine are determined from the transfer functions in the form

$$\xi_1(\infty)=d_{33}U(M_2+m/2)/(M_1+M_2+m),$$
$$\xi_2(\infty)=d_{33}U(M_1+m/2)/(M_1+M_2+m),$$
$$\xi_1(\infty)+\xi_2(\infty)=d_{33}U,$$

here m,M_1,M_2 are the masses of the piezo engine and the loads. For t the longitudinal PZT engine for $m\to 0$ and $l/\delta=1$ at $d_{33}=0.4\,\mathrm{nm/V}$, $U=50\ \mathrm{V}$, $M_1=0.5\,\mathrm{kg}$ and $M_2=2\,\mathrm{kg}$ we obtain the steady parameters

$$\xi_1(\infty)=16\,\mathrm{nm},\xi_2(\infty)=4\,\mathrm{nm},\xi_1(\infty)+\xi_2(\infty)=20\,\mathrm{nm}.$$

At the steady end of the transient process under inertial load, the displacements of the transverse piezo engine are determined in the form

$$\xi_1(\infty)=d_{31}U(l/\delta)(M_2+m/2)/(M_1+M_2+m),$$
$$\xi_2(\infty)=d_{31}U(l/\delta)(M_1+m/2)/(M_1+M_2+m),$$
$$\xi_1(\infty)+\xi_2(\infty)=d_{31}U(l/\delta),$$

here m,M_1,M_2 are the masses of the piezo engine and the loads. For the transverse PZT engine for $m\to 0$ and $l/\delta=10$ at $d_{31}=0.2\,\mathrm{nm/V}$, $U=50\ \mathrm{V}$, $M_1=0.5\,\mathrm{kg}$ and $M_2=2\,\mathrm{kg}$ we obtain the steady parameters $\xi_1(\infty)=80\,\mathrm{nm}$, $\xi_2(\infty)=20\,\mathrm{nm}, \xi_1(\infty)+\xi_2(\infty)=100\,\mathrm{nm}.$

Let us consider the block diagram of a nano piezo engine at voltage control and distributed parameters with negative feedbacks from the direct piezo effect.[11] For piezo engine at voltage control the electromechanical coupling coefficient has form

$$k_{mi}=d_{mi}/\sqrt{s_{ij}^{E}\varepsilon_{mk}^{T}}.$$

Accordingly, the negative feedbacks from the direct piezo effect for block diagram at distributed parameters and voltage control of piezo engine on Figure 2 have the form

$$U_{\dot{\Xi}\mathrm{a}}(p)=\frac{d_{mi}S_0R}{\delta s_{ij}^{E}}\dot{\Xi}_{\mathrm{a}}(p),\mathrm{a}=1,2.$$

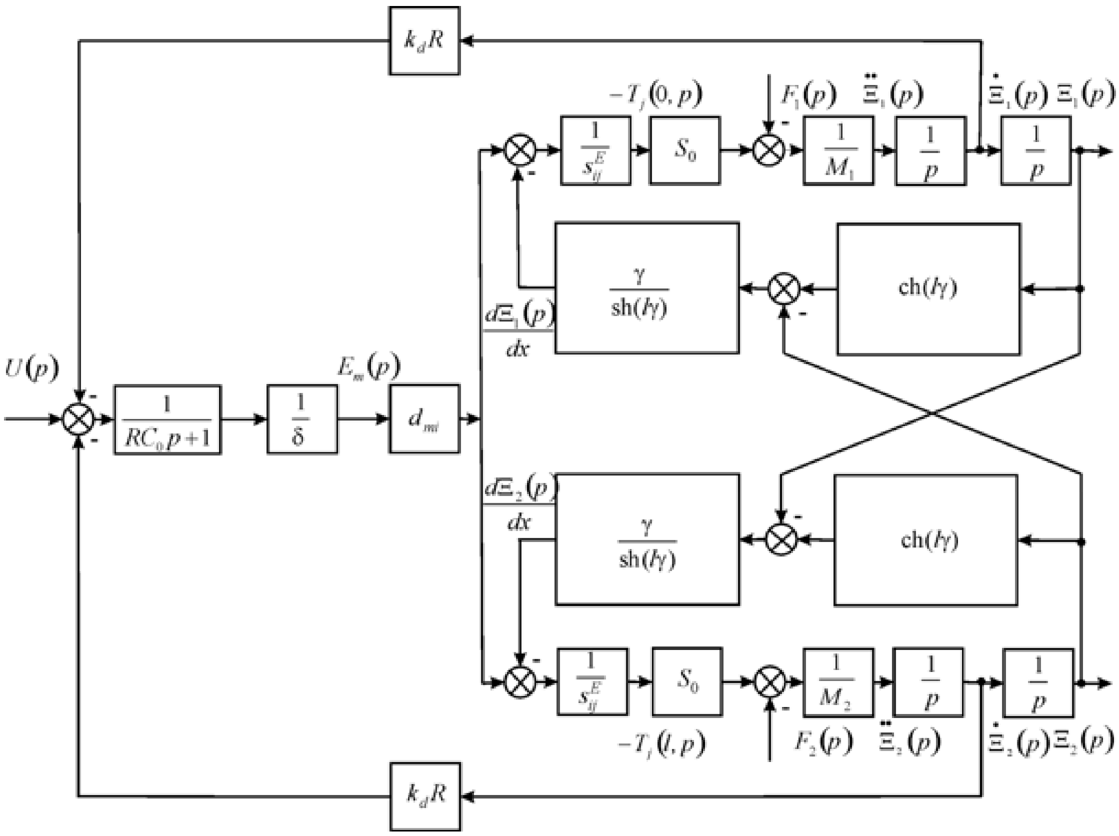

Figure 2 Block diagram nano piezo engine at voltage control and distributed parameters with negative feedbacks.

Let us consider the block diagram of a nano piezo engine at voltage and current control with lumped parameters and negative feedback from the direct piezo effect.

For a piezo engine at one rigidly fixed face we have the block diagram with lumped parameters at voltage control on Figure 3 and at current control on Figure 4.

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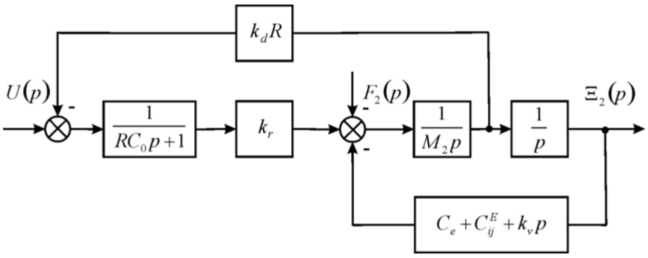

Figure 3 Block diagram piezo engine at voltage control and lumped parameters.

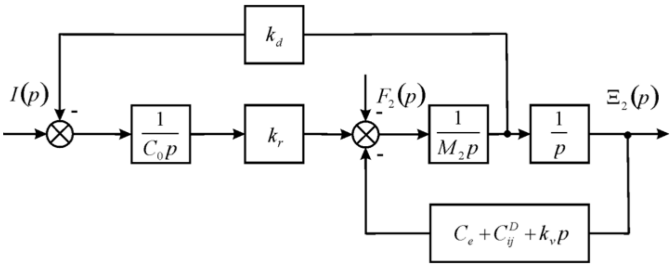

Figure 4 Block diagram piezo engine at current control and lumped parameters.

Accordingly, for a piezo engine at voltage and current control the coefficient k_d equal coefficient k_r [11]

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

here $\Psi = E, D$ upper indexes for the block diagrams: E - at voltage control, D - at current control.

The process of converting electrical energy into mechanical energy on the block diagrams are illustrated.

Conclusion

The block diagram of a nano piezo engine is determined for nanobionics. The block diagrams, matrix transfer function of a nano piezo engine are derived. This block diagrams of a nanopiezo engine are illustrated the process of converting electrical energy into mechanical energy, as opposed to Cady's and Mason's equivalent circuits. The numerical parameters of the piezo engine are determined. The block diagrams of the piezo engine with the back electromotive force at distributed and lumped parameters are derived for nanobionics.

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Conflicts of interest

The author declares that there is no conflict of interest.

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