

Research Article

Structural Diagram of Piezodrive for Nanotechnology and Medical Science

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Abstract

The piezodrive is used for nanotechnology, medical science and precision engineering in adaptive optics, scanning microscopy for research DNA. The structural diagram of the piezodrive for nanotechnology, medical science, and precision engineering is determined with using the equation of the linear ordinary second-order differential equation and the equation for the reverse piezoeffect. The matrix transfer function of the piezodrive is obtained. The block diagrams of the piezodrive are determined for distributed and lumped parameters.

Introduction

Piezodrives are used in precision engineering, aerospace, machining, adaptive optics for optical manipulation, nano displacement for precision manipulation in medical science and nanotechnology [1]. The piezodrive is actuated precision mechatronics system and transfer electrical energy to mechanical energy. This piezodrive is used in scanning microscopy in nanotechnology and medical science for research on DNA [1 – 18]. With use physical mathematical method the structural diagram is obtained for the piezodrive. The structural diagram of the piezodrive is determined the transformation of electrical energy into mechanical energy in difference from Mason’s and Cady’s circuits [5– 36]. The structural diagram of the piezodrive is determined with using the equation of the linear ordinary second-order differential equation and the equation for the reverse piezoeffect [37 – 65]. From the set of the equations for the structural diagram its matrix transfer function is obtained.

Structural diagram

The piezodrive is calculated for nanotechnology, medical science, and precision engineering by physical mathematical method with used to construct the diagram of the piezodrive from the equations of the linear ordinary second-order and the reverse piezoeffect. The equation of the reverse piezoeffect has the form [1-18].

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

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Here S_i, T_j - the relative deformation and the mechanical stress, $s_{ij}^{\Psi} = \begin{cases} S_{33}^E, S_{11}^E, S_{55}^E \\ S_{33}^D, S_{11}^D, S_{55}^D \end{cases}$ the elastic compliances, $v_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \end{cases}$ the piezoelectric constant, $\Psi_m = \begin{cases} E_3, E_3, E_1 \\ D_3, D_3, D_1 \end{cases}$ the control parameter: E - electric field strength, D - the electric induction, γ - the coefficient of wave propagation, $i = 1, 2, \dots, 6, j = 1, 2, \dots, 6, m = 1, 2, 3$.

The second-order linear ordinary differential equation of the piezodrive [1-18] has the form

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

with its solution

$$\Xi(x, p) = C e^{-\gamma x} + B e^{\gamma x}$$

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

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

For two faces we have the equations of the forces

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

$$T_j(l, p) S_0 = F_2(p) + M_1 p^2 \Xi_2(p) \text{ for } x = l$$

and the equations of the mechanical stresses on two faces

$$T_j(0, p) = \frac{1}{s_{ij}^\psi} \frac{d\Xi(x, p)}{dx} \Big|_{x=0} - \frac{v_{mi}}{s_{ij}^\psi} E_m(p);$$

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

and the structural diagram of the piezdrive on Figure 1

$$\Xi_1(p) = \left[\frac{1}{(M_1 p^2)} \right] \left\{ \begin{array}{l} -F_1(p) + (1/\chi_{ij}^0) \\ \times [v_{mi} \Theta_m(p) - [\gamma / \text{sh}(\gamma l)] [\text{ch}(\gamma l) \Xi_1(p) - \Xi_2(p)]] \end{array} \right\},$$

$$\Xi_2(p) = \left[\frac{1}{(M_2 p^2)} \right] \left\{ \begin{array}{l} -F_2(p) + (1/\chi_{ij}^0) \\ \times [v_{mi} \Theta_m(p) - [\gamma / \text{sh}(\gamma l)] [\text{ch}(\gamma l) \Xi_2(p) - \Xi_1(p)]] \end{array} \right\},$$

Here $\chi_{ij}^\psi = S_{ij}^\psi / S_0$

From the structural diagram on Figure 1 we have the matrix transfer function.

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

Results and discussion

The static displacements of the longitudinal piezdrive at inertial load are obtained 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 piezdrive and loads. For the PZT longitudinal drive at $m \rightarrow 0$ at $d_{33} = 0.4 \text{ nm/V}, U = 100 \text{ V}, M_1 = 0.6 \text{ kg}$ and $M_2 = 2.4 \text{ kg}$ we obtain the parameters $\xi_1(\infty) = 32 \text{ nm}, \xi_2(\infty) = 8 \text{ nm}, \xi_1(\infty) + \xi_2(\infty) = 40 \text{ nm}$.

The static displacements of the shear piezdrive are determined in the form

$$\xi_1(\infty) = d_{15} U (b / \delta) (M_2 + m / 2) / (M_1 + M_2 + m)$$

$$\xi_2(\infty) = d_{15} U (b / \delta) (M_1 + m / 2) / (M_1 + M_2 + m)$$

$$\xi_1(\infty) + \xi_2(\infty) = d_{15} (b / \delta) U$$

here m, M_1, M_2 are the masses of the piezdrive and loads. For the PZT shear piezdrive at $d_{15} = 0.5 \text{ nm/V}, b = 10 \text{ mm}, \delta = 1 \text{ mm}, U = 100 \text{ V}, M_1 = 0.6 \text{ kg}$ and $M_2 = 2.4 \text{ kg}$ we obtain the parameters $\xi_1(\infty) = 400 \text{ nm}, \xi_2(\infty) = 100 \text{ nm}, \xi_1(\infty) + \xi_2(\infty) = 500 \text{ nm}$.

The static displacements of the transverse piezdrive are obtained

$$\xi_1(\infty) = d_{15} U (b / \delta) (M_2 + m / 2) / (M_1 + M_2 + m),$$

$$\xi_2(\infty) = d_{15} U (b / \delta) (M_1 + m / 2) / (M_1 + M_2 + m),$$

$$\xi_1(\infty) + \xi_2(\infty) = d_{15} (b / \delta) U,$$

here m, M_1, M_2 are the masses of the piezdrive and loads. For the PZT transverse piezdrive at $m \rightarrow 0$ at $d_{31} = 0.2 \text{ nm/V}, h = 10 \text{ mm}, \delta = 1 \text{ mm}, U = 100 \text{ V}, M_1 = 0.6 \text{ kg}$ and $M_2 = 2.4 \text{ kg}$ we obtain the parameters

$$\xi_1(\infty) = 160 \text{ nm}, \xi_2(\infty) = 40 \text{ nm}, \xi_1(\infty) + \xi_2(\infty) = 200 \text{ nm}.$$

For the piezdrive, the electromechanical coupling coefficient has the form

$$k_{mi} = d_{mi} / \sqrt{S_{ij}^E \epsilon_{mk}^T}$$

The structural diagram of the piezdrive at distributed parameters and voltage control with the negative feedback has the form Figure 2

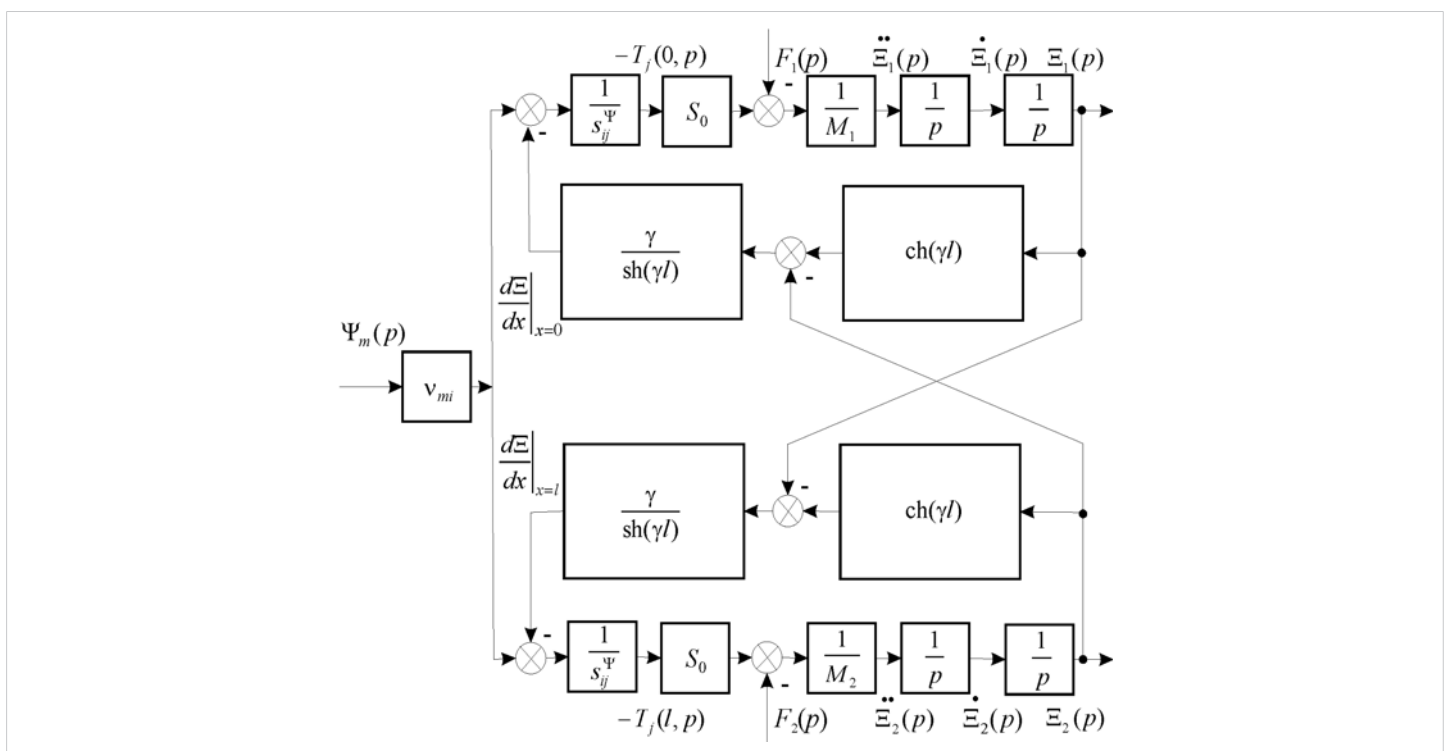


Figure 1: Structural diagram of piezdrive for nanotechnology, medical science and precision engineering

$$U_{\Xi_a}(p) = \frac{d_{mi} S_0 R_i}{\delta S_{ij}^E} \dot{\Xi}_a(p), \quad a = 1, 2$$

For the structural diagram of the piezodrive at one rigidly fixed face we have structural diagram with lumped parameters at voltage control on Figure 3.

The coefficient k_d equal coefficient k_r .

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

Here $\psi = E, D$ upper indexes:

E - at voltage control, D - at current control.

We have a structural diagram of the piezodrive with lumped parameters at current control on Figure 4.

The structural diagrams of the piezodrive are used for decision nano mechatronics systems in nanotechnology, medical science, and precision engineering.

Conclusion

The structural diagrams of the piezodrive at distributed and lumped parameters are determined for decision nano mechatronics system in nanotechnology, medical science and precision engineering. The structural diagrams and

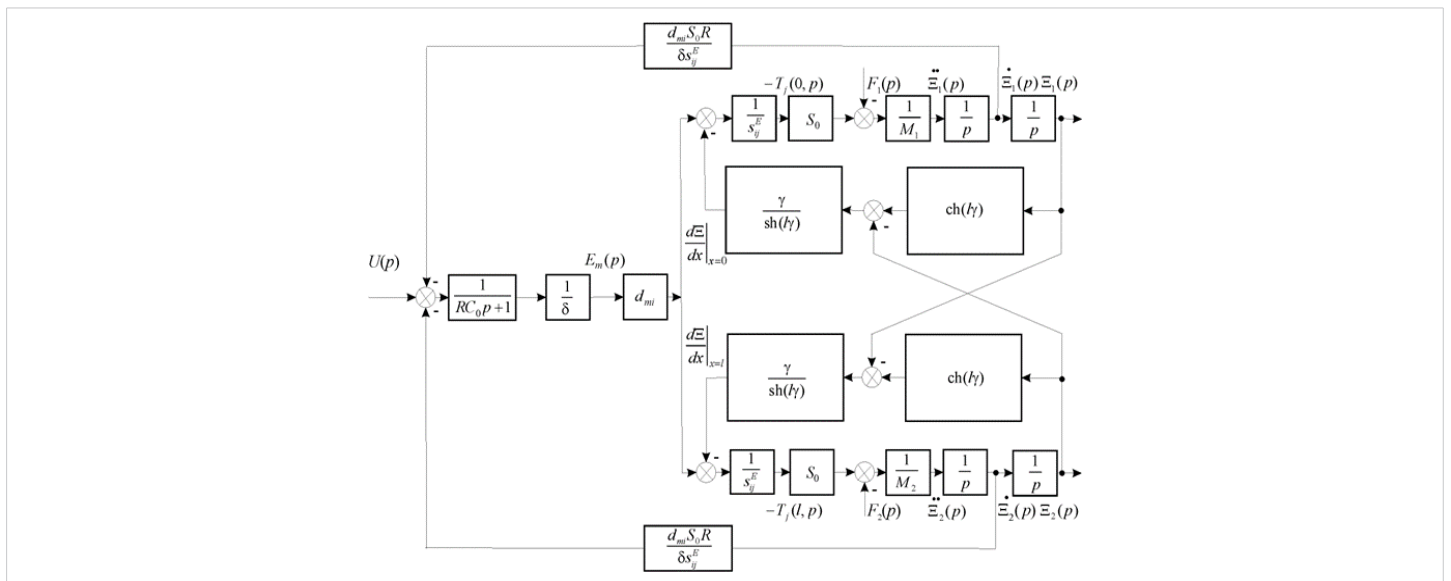


Figure 2: Structural diagram of piezodrive for voltage control at distributed parameters.

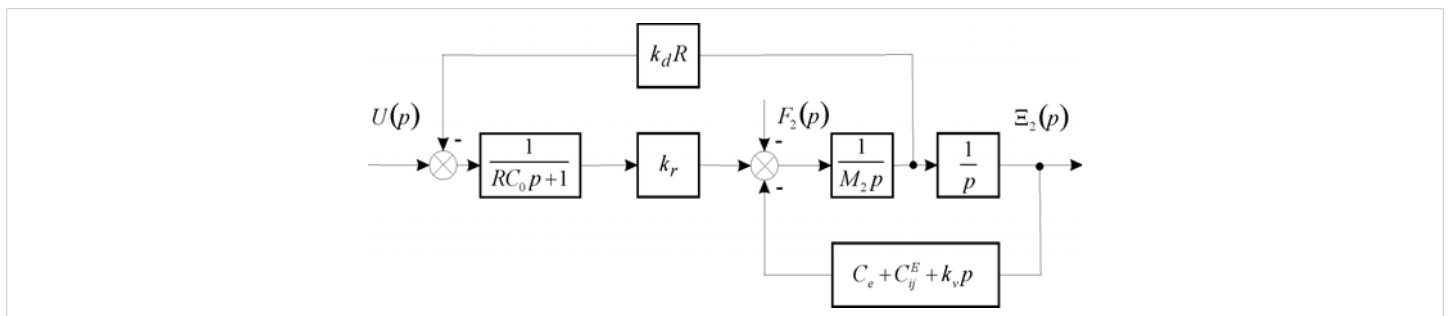


Figure 3: Structural diagram of piezodrive for voltage control at lumped parameters.

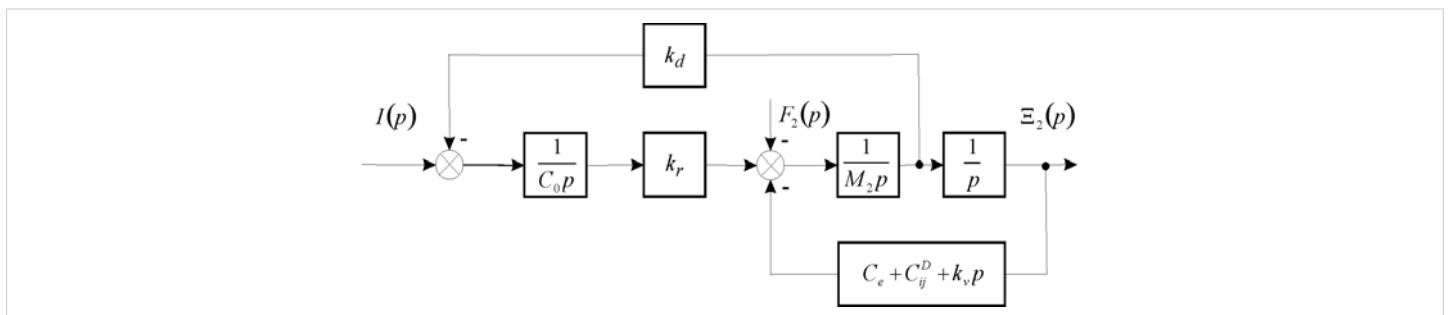


Figure 4: Structural diagram of piezodrive for current control at lumped parameters.

matrix transfer function of the piezodrive are used in nano mechatronics system. The numerical parameters of the piezodrives are determined.

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