

Structural-Parametric Model of a Piezoactuator for Nanoscience and Nanotechnology

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ABSTRACT

The decision of wave equation, the structural-parametric model, the structural diagram, the transfer functions of a piezoactuator for nanoscience and nanotechnology are determined. Effects of geometric and physical parameters of a piezoactuator and the external load on its dynamic characteristics are determined. The structural diagram and the transfer functions of a piezoactuator for the transverse, longitudinal, shift piezoelectric effects are obtained from the structural-parametric model of a piezoactuator in contrast to Cady's and Mason's electrical equivalent circuits of a piezotransducer. For calculation of the mechatronics systems for nanoscience and nanotechnology with a piezoactuator its the structural diagram and the transfer functions are obtained. The generalized structural diagram of a piezoactuator is constructed.

Keywords: Decision wave equation, Structural-parametric model, Structural diagram, Piezoactuator, Nanoscience, Nanotechnology, Deformation, Transfer function.

INTRODUCTION

For nanoscience, nanobiology, nanotechnology, adaptive optics of large compound telescope and antenna satellite telescope is promising use a piezoactuator in mechatronics systems. Piezoactuator is piezomechanical device intended for actuation of mechanisms, systems or its management based on the piezoelectric effect with the convention electrical signals into mechanical movement and force [1 – 7]. The problem of building the structural diagram of a piezoactuator is solved in contrast to use Cady's and Mason's electrical equivalent circuits of a piezotransducer [7 – 14].

In the work consider building the structural-parametric model of a piezoactuator, representing the system of equations with the electromechanical parameters of a piezoactuator describes the structure a piezoactuator and conversion the energy electric field into mechanical energy and the corresponding displacements and forces at its ends. By solving the wave equation with allowance methods of mathematical physics using Laplace transform and the equation of piezoelectric effect, the boundary conditions on working faces of a piezoactuator, the strains along the coordinate axes, it is possible to construct a structural-parametric model of a piezoactuator. The transfer functions, the structural diagram of a piezoactuator are obtained from its structural-parametric model [2 – 14].

Piezoactuator for nano- and micrometric movements operates based on the inverse piezoeffect, in which the motion is achieved due to its deformation, when an external electric voltage is applied. Piezoactuator is used for scanning tunneling microscope, scanning force microscope, atomic force microscope [9 – 18]. The use of a piezoactuator solves the problems of the precise alignment and the compensation of temperature and gravitational deformations in equipment. The characteristics a piezoactuator are received for the calculation of mechatronics systems in nanotechnology.

DECISION WAVE EQUATION AND STRUCTURAL-PARAMETRIC MODEL OF A PIEZOACTUATOR

The structural diagram and the transfer functions of a piezoactuator for nanoscience and nanotechnology are obtained from the structural-parametric model a piezoactuator with the mechanical parameters the displacement and the force [7–14]. The deformation of a piezoactuator on Figure 1 corresponds to its stressed state, therefore in the piezoactuator there are six stress components $T_1, T_2, T_3, T_4, T_5, T_6$, where the components T_1, T_2, T_3 are related to extension-compression stresses along the coordinate axes 1, 2 and 3 and T_4, T_5, T_6 - to shear stresses.

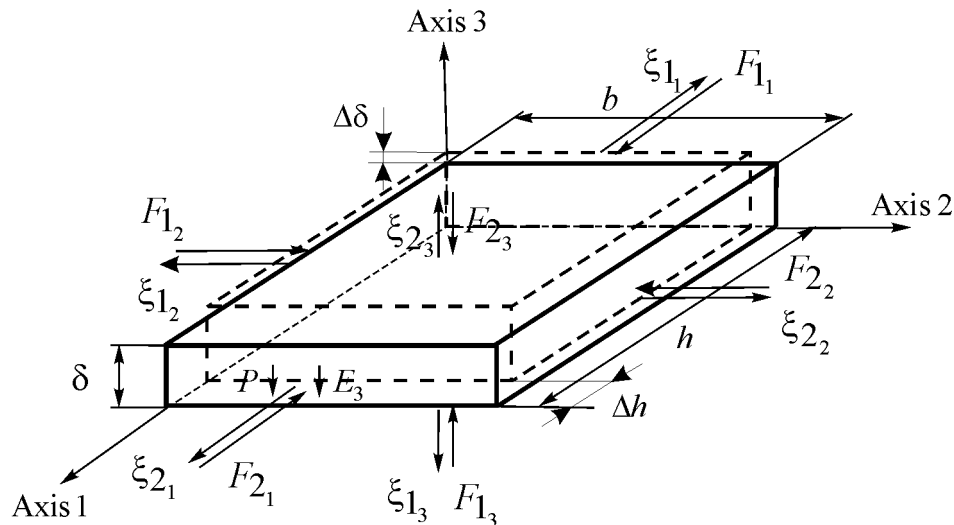


Figure 1. Kinematic diagram of a piezoactuator for nanoscience and nanotechnology

The matrix state equations [7–18] connecting the electric and elastic variables for the polarized piezoceramics have the form:

$$(S) = (s^E)(T) + (d)^T(E), \quad (1)$$

$$(D) = (d)(T) + (\epsilon^T)(E), \quad (2)$$

where the first equation describes the inverse piezoelectric effect, and the second equation depicts the direct piezoelectric effect, (S) is the column matrix of relative deformations, (D) is the column matrix of electric induction along the coordinate axes, (T) is the column matrix of mechanical stresses, (E) is the column matrix of electric field strength along the coordinate axes, (s^E) is the elastic compliance matrix for $E = \text{const}$, (ϵ^T) is the matrix of dielectric constants

for $T = \text{const}$, $(d)^T$ is the transposed matrix of the piezoelectric modules. In polarized piezoceramics from lead zirconate titanate PZT for a piezoactuator there are five independent components $s_{11}^E, s_{12}^E, s_{13}^E, s_{33}^E, s_{55}^E$ in the elastic compliance matrix, three independent components d_{33}, d_{31}, d_{15} in the transposed matrix of the piezomodules, three independent components $\varepsilon_{11}^T, \varepsilon_{22}^T, \varepsilon_{33}^T$ in the matrix of dielectric constants.

In general of the inverse piezoelectric effect for the piezoactuator [1 – 35] is obtained in the form

$$S_i = v_{mi} \Psi_m + s_{ij}^\Psi T_j, \quad (3)$$

where S_i is the relative displacement of a piezoactuator, v_{mi} is the piezoelectric module: d_{mi} for the d -form of the equation or g_{mi} for the g -form of the equation, Ψ_m is the control parameter in the form E_m the electric field strength or D_m the electric induction, s_{ij}^Ψ is the elastic compliance at $\Psi = \text{const}$, T_j is the mechanical stress, $i, j = 1, 2, \dots, 6$, $m = 1, 2, 3$ are the indexes.

For a piezoactuator at the longitudinal piezoelectric effect δ is thickness and the electrodes deposited on its faces perpendicular to axis 3, the area of which is equal to S_0 . The direction of the polarization axis P taken as the direction of axis 3. The equation of the inverse longitudinal piezoelectric effect [7 – 18] has the form

$$S_3 = d_{33} E_3 + s_{33}^E T_3, \quad (4)$$

where S_3 is the relative displacement of a piezoactuator at longitudinal piezoelectric effect, d_{33} is the longitudinal piezomodule, $E_3 = U/\delta$ is the electric field strength along axis 3, U is the voltage between the electrodes of a piezoactuator, s_{33}^E is the elastic compliance along axis 3 at $E = \text{const}$, and T_3 is the mechanical stress along axis 3 on Figure 1. For a piezoactuator at the transverse piezoelectric effect h is height. The equation of the inverse transverse piezoelectric effect [7 – 18] has the form

$$S_1 = d_{31} E_3 + s_{11}^E T_3, \quad (5)$$

where S_1 is the relative displacement of a piezoactuator at transverse piezoelectric effect, d_{31} is the transverse piezomodule, s_{11}^E is the elastic compliance along axis 1 at $E = \text{const}$, and T_1 is the mechanical stress along axis 1 on Figure 1. For a piezoactuator at the shift piezoelectric effect b is width. The direction of the polarization axis P taken as the direction of axis 1. The equation of the inverse shift piezoelectric effect [7 – 18] has the form

$$S_5 = d_{15} E_1 + s_{55}^E T_5, \quad (6)$$

where S_5 is the relative displacement of a piezoactuator at shift piezoelectric effect, d_{15} is the shift piezomodule, E_1 is the electric field strength along axis 1, s_{55}^E is the elastic compliance at $E = \text{const}$, and T_5 is the mechanical shift stress.

For constructing the structural parametric model of a piezoactuator at longitudinal piezoelectric effect the wave equation using Laplace transform, the equation of the inverse longitudinal piezoeffect, the equation of forces acting on the faces are solved. By using Laplace transform the original problem solution for the partial differential hyperbolic equation of type is reduced to the simpler problem for the ordinary linear differential equation second order [12 – 18]. Calculations of a piezoactuator are performed with using the wave equation [7 – 14], describing the wave propagation in a long line with damping but without distortions in the form

$$\frac{1}{(c^E)^2} \frac{\partial^2 \xi(x,t)}{\partial t^2} + \frac{2\alpha}{c^E} \frac{\partial \xi(x,t)}{\partial t} + \alpha^2 \xi(x,t) = \frac{\partial^2 \xi(x,t)}{\partial x^2} \quad (7)$$

where $\xi(x,t)$ is the displacement of the section, x is the coordinate, t is time, c^E is the sound speed at $E = \text{const}$, α is the damping coefficient. The differential equation of a piezoactuator is solved by using the Laplace transform to the wave equation at zero initial conditions. Therefore, in general the ordinary linear differential equation second order of a piezoactuator [7 – 34] has the form

$$\frac{d^2 \Xi(x,s)}{dx^2} - \gamma^2 \Xi(x,s) = 0 \quad (8)$$

$$\gamma = s/c^\Psi + \alpha \quad (9)$$

where $\Xi(x,s)$, x , s , γ , c^Ψ , α are the Laplace transform of the displacement a piezoactuator, the coordinate, the Laplace operator; the wave propagation coefficient; the speed of sound at $\Psi = \text{const}$; the attenuation coefficient. Solution this differential equation has the form

$$\Xi(x,p) = Ce^{-x\gamma} + Be^{x\gamma}, \quad (10)$$

where C , B are the coefficients. For a piezoactuator at longitudinal piezoelectric effect the Laplace transforms of the displacements faces 1 and 2 have form

$$\begin{aligned} \Xi(0,s) &= \Xi_1(s) \quad \text{for } x=0, \\ \Xi(\delta,s) &= \Xi_2(s) \quad \text{for } x=\delta. \end{aligned} \quad (11)$$

The coefficients C and B have the form

$$C = (\Xi_1 e^{\delta\gamma} - \Xi_2) / (2\text{sh}(\delta\gamma)), \quad B = (\Xi_2 - \Xi_1 e^{-\delta\gamma}) / (2\text{sh}(\delta\gamma)). \quad (12)$$

Therefore, the solution (10) has form

$$\Xi(x,s) = \{\Xi_1(s)\text{sh}[(\delta-x)\gamma] + \Xi_2(s)\text{sh}(x\gamma)\} / \text{sh}(\delta\gamma). \quad (13)$$

The system of the equations for the Laplace transforms for the forces on faces of a piezoactuator is found in the form

$$T_3(0,s)S_0 = F_1(s) + M_1s^2\Xi_1(s) \quad \text{for } x=0, \quad (14)$$

$$T_3(\delta,s)S_0 = -F_2(s) + M_2s^2\Xi_2(s) \quad \text{for } x=\delta,$$

where $T_3(0,s)$, $T_3(\delta,s)$, S_0 , M_1 , M_2 are the Laplace transforms of the mechanical stresses, determined from the equation of the inverse longitudinal piezoelectric effect, the area of a piezoactuator, and the masses of loads.

The system of the equations the Laplace transforms of the mechanical stresses on the faces of a piezoactuator at longitudinal piezoelectric effect is obtained from (4) at $x=0$ and $x=\delta$ in the form

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

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

The system of equations (15) for the structural-parametric model and the structural diagram of a piezoactuator for longitudinal piezoelectric effect has the form

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

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

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

Therefore, in general the system of the equations is denoted for the faces of a piezoactuator

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

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

where l the length of a piezoactuator has follow form: at the longitudinal piezoelectric effect δ the thickness, at the transverse piezoelectric effect h the height, at the shift piezoelectric effect b the width. From (10), (17) the coefficients C and B have the form

$$C = (\Xi_1 e^{l\gamma} - \Xi_2)/(2\text{sh}(l\gamma)), \quad B = (\Xi_2 - \Xi_1 e^{-l\gamma})/(2\text{sh}(l\gamma)). \quad (18)$$

Therefore, the solution (10) has the form

$$\Xi(x,s) = \{\Xi_1(s)\text{sh}[(l-x)\gamma] + \Xi_2(s)\text{sh}(x\gamma)\}/\text{sh}(l\gamma). \quad (19)$$

The system of the equations the Laplace transform for the forces on faces is determined in the form

$$T_j(0,s)S_0 = F_1(s) + M_1s^2\Xi_1(s) \quad \text{for } x=0, \quad (20)$$

$$T_j(l, s)S_0 = -F_2(s) - M_2 s^2 \Xi_2(s) \quad \text{for } x = l,$$

where S_0 is the area of a piezoactuator.

The system of the equations for the Laplace transform of the mechanical stresses on the faces of a piezoactuator is obtained from (3) at $x=0$ and $x=l$ in the form

$$\begin{aligned} T_j(0, s) &= \frac{1}{s_{ij}^\Psi} \frac{d\Xi(x, s)}{dx} \Big|_{x=0} - \frac{d_{mi}}{s_{ij}^\Psi} \Psi_m(s), \\ T_j(l, s) &= \frac{1}{s_{ij}^\Psi} \frac{d\Xi(x, s)}{dx} \Big|_{x=l} - \frac{d_{mi}}{s_{ij}^\Psi} \Psi_m(s). \end{aligned} \quad (21)$$

Therefore, for the longitudinal, transverse and shift deformations the system of the equations for the generalized structural-parametric model and the generalized structural diagram of a piezoactuator on Figure 2 has the form

$$\begin{aligned} \Xi_1(s) &= \left[\frac{1}{(M_1 s^2)} \right] \left\{ -F_1(s) + \left(\frac{1}{\chi_{ij}^\Psi} \right) \right. \\ &\quad \left. \times \left[d_{mi} \Psi_m(s) - [\gamma / \text{sh}(l\gamma)] [\text{ch}(l\gamma) \Xi_1(s) - \Xi_2(s)] \right] \right\}, \\ \Xi_2(s) &= \left[\frac{1}{(M_2 s^2)} \right] \left\{ -F_2(s) + \left(\frac{1}{\chi_{ij}^\Psi} \right) \times \right. \\ &\quad \left. \times \left[d_{mi} \Psi_m(s) - [\gamma / \text{sh}(l\gamma)] [\text{ch}(l\gamma) \Xi_2(s) - \Xi_1(s)] \right] \right\}, \end{aligned} \quad (22)$$

where $\chi_{ij}^\Psi = s_{ij}^\Psi / S_0$, $v_{mi} = \begin{Bmatrix} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \end{Bmatrix}$, $\Psi_m = \begin{Bmatrix} E_3, E_1 \\ D_3, D_1 \end{Bmatrix}$, $s_{ij}^\Psi = \begin{Bmatrix} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D \end{Bmatrix}$, $l = \{\delta, h, b\}$, $\gamma = \{\gamma^E, \gamma^D\}$, $c^\Psi = \{c^E, c^D\}$, and Ψ is the control parameter for a piezoactuator in the form E for voltage control and D for current control.

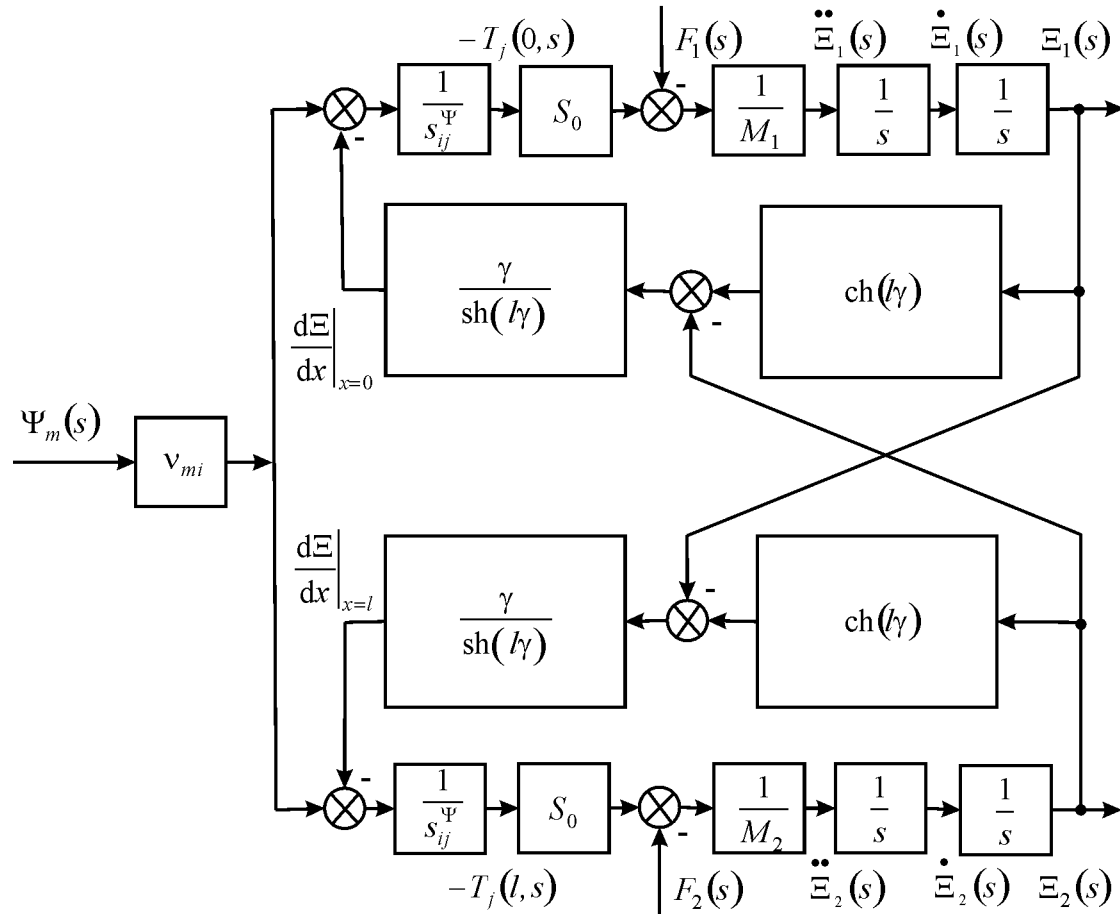


Figure 2. Generalized structural diagram of a piezoactuator for nanoscience and nanotechnology

Therefore, in general the matrix equation with the matrix transfer function of a piezoactuator has the form

$$(\Xi(s)) = (W(s))(P(s)), \quad (23)$$

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

where $(\Xi(s))$ is the column-matrix of the Laplace transforms of the displacements, $(W(s))$ is the matrix transfer function, $(P(s))$ is the column-matrix of the Laplace transforms of the control parameter and the forces.

In general the matrix equation for the displacements of a piezoactuator is determined in the form

$$\begin{pmatrix} \Xi_1(s) \\ \Xi_2(s) \end{pmatrix} = \begin{pmatrix} W_{11}(s) & W_{12}(s) & W_{13}(s) \\ W_{21}(s) & W_{22}(s) & W_{23}(s) \end{pmatrix} \begin{pmatrix} \Psi_m(s) \\ F_1(s) \\ F_2(s) \end{pmatrix}, \quad (24)$$

where $W_{11}(s)$, $W_{12}(s)$, $W_{13}(s)$, $W_{21}(s)$, $W_{22}(s)$, $W_{23}(s)$ are the transfer functions of a piezoactuator in the following form

$$\begin{aligned} W_{11}(s) &= \Xi_1(s)/\Psi_m(s) = v_{mi} [M_2 \chi_{ij}^\Psi s^2 + \gamma \text{th}(l\gamma/2)] / A_{ij}, \\ W_{21}(s) &= \Xi_2(s)/\Psi_m(s) = v_{mi} [M_1 \chi_{ij}^\Psi s^2 + \gamma \text{th}(l\gamma/2)] / A_{ij}, \\ W_{12}(s) &= \Xi_1(s)/F_1(s) = -\chi_{ij}^\Psi [M_2 \chi_{ij}^\Psi s^2 + \gamma / \text{th}(l\gamma)] / A_{ij}, \\ W_{13}(s) &= \Xi_1(s)/F_2(s) \\ &= W_{22}(s) = \Xi_2(s)/F_1(s) = [\chi_{ij}^\Psi \gamma / \text{sh}(l\gamma)] / A_{ij}, \\ W_{23}(s) &= \Xi_2(s)/F_2(s) = -\chi_{ij}^\Psi [M_1 \chi_{ij}^\Psi s^2 + \gamma / \text{th}(l\gamma)] / A_{ij}, \\ \chi_{ij}^\Psi &= s_{ij}^\Psi / S_0, \\ A_{ij} &= M_1 M_2 (\chi_{ij}^\Psi)^2 s^4 + \left\{ (M_1 + M_2) \chi_{ij}^\Psi / [c^\Psi \text{th}(l\gamma)] \right\} s^3 \\ &+ \left\{ (M_1 + M_2) \chi_{ij}^\Psi \alpha / \text{th}(l\gamma) + 1 / (c^\Psi)^2 \right\} s^2 + 2\alpha s / c^\Psi + \alpha^2. \end{aligned} \quad (25)$$

Let us find the static displacements the faces of a piezoactuator in a stationary regime for inertial load at $\Psi_m(t) = \Psi_m \cdot 1(t)$, $F_1(t) = F_2(t) = 0$ and at $m \ll M_1$, $m \ll M_2$. Then the static displacements of the faces piezoactuator have the form

$$\xi_1(\infty) = \lim_{t \rightarrow \infty} \xi_1(t) = \lim_{s \rightarrow 0} s W_{11}(s) \Psi_m / s = d_{mi} l \Psi_m M_2 / (M_1 + M_2) \quad (26)$$

$$\xi_2(\infty) = \lim_{t \rightarrow \infty} \xi_2(t) = \lim_{s \rightarrow 0} s W_{21}(s) \Psi_m / s = d_{mi} l \Psi_m M_1 / (M_1 + M_2) \quad (27)$$

$$\xi_1(\infty) + \xi_2(\infty) = \lim_{t \rightarrow \infty} (\xi_1(t) + \xi_2(t)) = d_{mi} l \Psi_m \quad (28)$$

where m , M_1 , M_2 are the mass of a piezoactuator and the masses of loads.

The static displacements the faces of a piezoactuator for longitudinal piezoelectric effect and inertial load at $E_3(t) = (U/\delta) \cdot 1(t)$, $F_1(t) = F_2(t) = 0$ and $m \ll M_1$, $m \ll M_2$ have the following form

$$\xi_1(\infty) = \lim_{t \rightarrow \infty} \xi_1(t) = \lim_{s \rightarrow 0} s W_{11}(s) (U/\delta) / s = d_{33} U M_2 / (M_1 + M_2) \quad (29)$$

$$\xi_2(\infty) = \lim_{t \rightarrow \infty} \xi_2(t) = \lim_{s \rightarrow 0} s W_{21}(s) (U/\delta) / s = d_{33} U M_1 / (M_1 + M_2) \quad (30)$$

$$\xi_1(\infty) + \xi_2(\infty) = \lim_{t \rightarrow \infty} (\xi_1(t) + \xi_2(t)) = d_{33} U \quad (31)$$

At $d_{33} = 0.4 \text{ nm/V}$, $U = 200 \text{ V}$, $M_1 = 1 \text{ kg}$ and $M_2 = 4 \text{ kg}$ the static displacements of the faces of a piezoactuator with longitudinal piezoelectric effect from piezoceramics PZT are obtained $\xi_1(\infty) = 64 \text{ nm}$, $\xi_2(\infty) = 16 \text{ nm}$, $\xi_1(\infty) + \xi_2(\infty) = 80 \text{ nm}$.

The static displacements the faces of a piezoactuator for the transverse piezoelectric effect and inertial load at $U(t) = U \cdot 1(t)$, $E_3(t) = (U/\delta) \cdot 1(t)$ and $F_1(t) = F_2(t) = 0$ and $m \ll M_1$, $m \ll M_2$ have the form

$$\xi_1(\infty) = \lim_{t \rightarrow \infty} \xi_1(t) = \lim_{s \rightarrow 0} s W_{11}(s) (U/\delta) / s = d_{31} (h/\delta) U M_2 / (M_1 + M_2) \quad , \quad (32)$$

$$\xi_2(\infty) = \lim_{t \rightarrow \infty} \xi_2(t) = \lim_{s \rightarrow 0} p W_{21}(s) (U/\delta) / s = d_{31} (h/\delta) U M_1 / (M_1 + M_2) \quad , \quad (33)$$

$$\xi_1(\infty) + \xi_2(\infty) = \lim_{t \rightarrow \infty} (\xi_1(t) + \xi_2(t)) = d_{31} (h/\delta) U \quad . \quad (34)$$

At $d_{31} = 0.2 \text{ nm/V}$, $h/\delta = 20$, $U = 150 \text{ V}$, $M_1 = 1 \text{ kg}$ and $M_2 = 4 \text{ kg}$ are received the static displacement of the faces of a piezoactuator with transverse piezoelectric effect from piezoceramics PZT $\xi_1(\infty) = 480 \text{ nm}$, $\xi_2(\infty) = 120 \text{ nm}$, $\xi_1(\infty) + \xi_2(\infty) = 600 \text{ nm}$.

The transfer function for the lumped parameters of a piezoactuator at transverse piezoelectric effect with one fixed face has the form

$$W(s) = \frac{\Xi_2(s)}{U(s)} = \frac{d_{31} h/\delta}{(1 + C_e/C_{11}^E) (T_t^2 s^2 + 2T_t \xi_t s + 1)} \quad , \quad (35)$$

$$T_t = \sqrt{M_2 / (C_e + C_{11}^E)} \quad , \quad \xi_t = \alpha h^2 C_{11}^E / \left(3c^E \sqrt{M(C_e + C_{11}^E)} \right) \quad , \quad C_{11}^E = S_0 / (s_{11}^E h) = 1 / (\chi_{11}^E h)$$

where h , δ , T_t , ξ_t are the height, the thickness, the time constant and the attenuation coefficient of a piezoactuator. At $d_{31} = 0.2 \text{ nm/V}$, $h/\delta = 20$, $M_2 = 4 \text{ kg}$, $C_{11}^E = 2 \cdot 10^7 \text{ N/m}$, $C_e = 0.2 \cdot 10^7 \text{ N/m}$, $U = 55 \text{ V}$ for a piezoactuator at the transverse piezoelectric effect from ceramic PZT with one rigidly fixed face are obtained the time constant $T_t = 0.43 \cdot 10^{-3} \text{ s}$ and the static displacement $\Delta h = \xi_2(\infty) = 200 \text{ nm}$. Theoretical and practical parameters of a piezoactuator are coincidences with an error of 10%.

CONCLUSION

The decision of the wave equation, the structural-parametric model, the structural diagram, the transfer functions of a piezoactuator for nanoscience and nanotechnology are obtained using Laplace transform. The structural diagram and the transfer functions of a piezoactuator for the transverse, longitudinal, shift piezoelectric effects are determined from its structural-parametric model.

The structural diagram of a piezoactuator is received with the mechanical parameters in the form the displacement and the force. The structural diagram of a piezoactuator is used for the reflection its transformation of electrical energy into mechanical energy in contrast to Cady's and Mason's electrical equivalent circuits of a piezotransducer. The static characteristics of a piezoactuator are obtained for mechatronics systems in nanoscience and nanotechnology.

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