Parametric Structural Schematic Diagram of Electroelastic Actuator for Nanodisplacement

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Abstract

The parametric structural schematic diagram of the electroelastic actuator or the piezoactuator is determined in contrast the electrical equivalent circuit Cady or Mason types for the calculation of the piezoelectric transmitter and receiver, the vibration piezomotor with the mechanical parameters in form the velocity and the pressure. The structural diagram of electroelastic actuator is obtained with the mechanical parameters the displacement and the force. In this work the method of mathematical physics is used. The transfer functions of the electroelastic actuator are determined. The generalized structural-parametric model, the generalized parametric structural schematic diagram, the generalized matrix equation for the electroelastic actuator nanodisplacement are obtained. The deformations of the electroelastic actuator for the nanotechnology are described by the matrix equation.

Keywords: Electroelastic actuator, Piezoactuator, Parametric structural schematic diagram, Transfer function.

Introduction

The electroelastic actuator based on the electro elasticity in the form the piezoelectric, piezomagnetic, electrostriction effects is used for the nanodisplacement in the nanotechnology [1-8]. Piezoactuator is the piezomechanical device intended for the actuation of the mechanisms, the systems or the management based on the piezoelectric effect, converts the electrical signals into the mechanical movement and the force [1,6,7]. Piezoactuator for nanodisplacement is used in the scanning tunneling microscopes, the scanning force microscopes, the atomic force microscopes [1-16]. The parametric structural schematic diagram of the electroelastic actuator on the piezoelectric, piezomagnetic, electrostriction effects, for example, the piezoactuator is determined in contrast electrical equivalent circuit for the calculation of the piezoelectric transmitter and receiver, the vibration piezomotor with the mechanical parameters in form the velocity and the pressure [2,9,10]. The parametric structural schematic diagram of the electroelastic actuator is obtained with the mechanical parameters the displacement and the force. The parametric structural schematic diagram, the generalized structural-parametric model, the generalized matrix equation for the actuator are obtained in the matrix form in general from the wave equation of the actuator and the equation of the electro elasticity.

Objective and Methods

The objective of this work is to obtain the parametric structural schematic diagram of the electroelastic actuator with the mechanical parameters the displacement and the force. The method of mathematical physics is applied for the solution of the wave equation of the electroelastic actuator with using the Laplace transform.

Results

Parametric structural schematic diagram

As the result of the joint solution of the wave equation of the electro elastic actuator for nanodisplacement with the Laplace transform, the equation of electro elasticity and the boundary conditions on the two loaded working surfaces of the actuator, we obtain the parametric structural schematic diagram of the electroelastic actuator [8,12].

The generalized equation of electro elasticity [8, 10, 16] has following form.

$$S_i = v_{mi}\Psi_m(t) + s_{ij}^{\Psi} T_j(x,t) \tag{1}$$

where $S_i = \partial \xi(x,t)/\partial x$ is the relative displacement along axis i of the cross section of the piezoactuator or the piezoplate, $\Psi_m = \{E_m, D_m$ is the control parameter E for the voltage control, D for the current control along axis m, T_j is the mechanical stress along axis j, v_{mi} is the coefficient of electro elasticity, for example, piezomodule, s_{ij}^{Ψ} is the elastic compliance for control parameter Ψ=const, indexes i, j = 1,2, ... , 6; m = 1,2,3. The main size or the working length $l = \{\delta, h, b$ for the piezo actuator, respectively, the thickness, the height and the width for the longitudinal, transverse and shift piezoeffect.

For calculation of the electroelastic actuator nanodisplacement is used the wave equation [8,10,16] for the wave propagation in a long line with damping but without distortions. After Laplace transform is obtained the linear ordinary second-order differential equation with the parameter p, where the original problem for the partial differential equation of hyperbolic type using the Laplace transform is reduced to the simpler problem [8,11,12] for the linear ordinary differential equation.

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

with its solution

$$\Xi(x,p) = Ce^{-x\gamma} + Be^{x\gamma} \tag{3}$$

where $\Xi(x,p)$ is the Laplace transform of the displacement of the section of actuator, $\gamma = p/c^{\Psi} + \alpha$ is the propagation coefficient, c^{Ψ} is the sound speed for Ψ=const, α is the damping coefficient, C and B are constants.

From (1) and (2), the boundary conditions on loaded surfaces, the strains along the axes the system of equations for the generalized structural-parametric model and the generalized parametric structural schematic diagram are determined for Figure 1 of the electroelastic actuator with the output parameters the Laplace transform for the displacements $\Xi_1(p)$, $\Xi_2(p)$ for the faces of the actuator nanodisplacement for the nanotechnology in the form

$$\Xi_1(p) = \left[1/(M_1 p^2)\right] \times$$
$$\times \left\{ -F_1(p) + (1/\chi_{ij}^{\Psi}) \left[v_{mi}\Psi_m(p) - \left[\gamma/\text{sh}(l\gamma)\right] \left[\text{ch}(l\gamma)\Xi_1(p) - \Xi_2(p)\right]\right]\right\} \tag{4}$$

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

where $\chi_{ij}^{\Psi} = \dfrac{s_{ij}^{\Psi}}{S_0}$, $v_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15}\end{cases}$, $\Psi_m = \begin{cases} E_3, E_3, E_1 \\ D_3, D_3, D_1 \end{cases}$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D \end{cases}$,

$l = \{\delta, h, b$, $c^{\Psi} = \{c^E, c^D$, $\gamma^{\Psi} = \{\gamma^E, \gamma^D$,

v_{mi} is the coefficient of the electro elasticity, for example, d_{mi} is the piezomodule, g_{mi} is the piezomodule for the current-controlled piezoactuator, S_0 is the cross section area and M_1, M_2 are the displaced mass on the faces of the electroelastic actuator, $F_1(p)$, $F_2(p)$ are the Laplace transform of the forces on the faces. Figure 1 shows the generalized parametric structural schematic diagram of the electroelastic actuator corresponding to the set of equations (4) for the Laplace transform of the displacements of the faces.

The generalized structural scheme and the generalized transfer functions of the electro elastic actuator for nanodisplacement are obtained from the generalized structural parametric model of the actuator.

Transfer functions

The transfer functions of the electroelastic actuator nanodisplacement are determined from its generalized structural-parametric model, considering the generalized equation of electroelasticity, its wave equation and the equation of the forces on its faces. The generalized transfer functions of the of the electroelastic actuator are; the ratio of the Laplace transform of the displacement of the face actuator and the Laplace transform of the control parameter or the force at zero initial conditions [8,12].

The Laplace transforms of displacements for two faces of the actuator are dependent from the Laplace transforms of the general parameter of control and forces on two faces and are written in the matrix form. From equation (4) for the Laplace transforms of the displacements of two faces of the actuator yields the matrix equation in the following form

From (5) the static displacement of the faces the actuator $\xi_1(\infty)$ and $\xi_2(\infty)$ can be written in the form

$$\begin{pmatrix} \Xi_1(p) \\ \Xi_2(p) \end{pmatrix} = \begin{pmatrix} W_{11}(p) & W_{12}(p) & W_{13}(p) \\ W_{21}(p) & W_{22}(p) & W_{23}(p) \end{pmatrix} \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix} \tag{5}$$

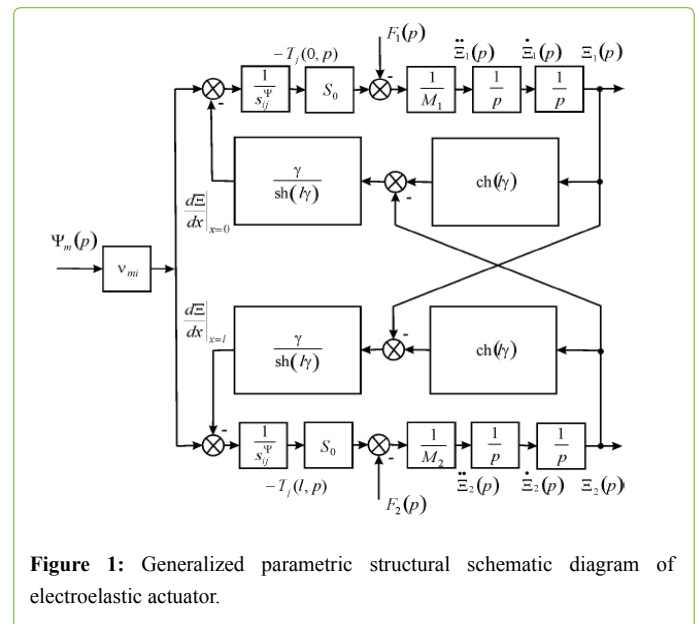$$\xi_1(\infty) = \lim_{t\to\infty} \xi_1(t) = \frac{v_{mi} l \Psi_{m0}(M_2 + m/2)}{M_1 + M_2 + m} \tag{6}$$

Figure 1: Generalized parametric structural schematic diagram of electroelastic actuator.

$$\xi_2(\infty) = \lim_{t \to \infty} \xi_2(t) = \frac{v_{mi} l \Psi_{m0}(M_1 + m/2)}{M_1 + M_2 + m} \qquad (7)$$

$$\xi_1(\infty) + \xi_2(\infty) = \lim_{t \to \infty}(\xi_1(t) + \xi_2(t)) = v_{mi} l \Psi_{m0} \qquad (8)$$

where m is the mass of the electroelastic actuator, M_1, M_2 are the load masses. For $d_{33} = 4 \times 10^{-10}$ m/V, $U = 50$ V, $M_1 = 1$ kg and $M_2 = 4$ kg we obtain the static displacements of the faces of the piezoactuator or the piezoplate $\xi_1(\infty) = 16$ nm, $\xi_2(\infty) = 4$ nm, $\xi_1(\infty) + \xi_2(\infty) = 20$ nm.

The matrix transfer functions of the electroelastic actuator for nanodisplacement are determined for the control systems in the nanotechnology.

Discussion

We obtain the generalized parametric structural schematic diagram and generalized structural-parametric model of the electroelastic actuator for nanodisplacement in the nanotechnology. From generalized structural-parametric model of the electroelastic actuator after algebraic transformations we obtain the transfer functions of the electroelastic actuator.

The parametric structural schematic diagrams, the structural-parametric models of the piezoactuator for the transverse, longitudinal, shift piezoelectric effects are determined from the generalized structural-parametric model of the electroelastic actuator for nanodisplacement.

Conclusion

The generalized parametric structural schematic diagram and the generalized structural-parametric model of the electroelastic actuator nanodisplacement are constructed for the nanotechnology with the mechanical parameters the displacement and the force from the solution of the wave equation, the equations of the electro elasticity and the deformations along the axes with using the Laplace transform. The deformations of the electroelastic actuator for the nanotechnology are described by the matrix equation for the transfer functions of the actuator.

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