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Structural-Parametric Model and Structural Diagram of Electromagnetoelastic Actuator for Nanoscience

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ABSTRACT

The structural-parametric model, the structural diagram and the matrix transfer function, the characteristics of the electromagnetoelastic actuator for the nanoscience are determined. The generalized structural diagram, the generalized matrix transfer function for the electromagnetoelastic actuator nanodisplacement are obtained from its structural-parametric model.

Keywords: *Electromagnetoelastic actuator, Structural-parametric model, Piezoactuator, Electromagnetoelasticity, Structural diagram, Matrix transfer function.*

INTRODUCTION

At present the electromagnetoelastic actuator with the piezoelectric, piezomagnetic, electrostriction, magnetostriction effects is used in the control system for the nanoscience in the scanning sensing microscopy [1 − 8].

For control system in the nanoscience the structural-parametric model, the structural diagram, matrix transfer function, the static and dynamic characteristics of the actuator are calculated [9 − 18].

The structural-parametric model, the structural diagram and matrix transfer function the electromagnetoelastic actuator based on the electromagnetoelasticity make it possible to describe the dynamic and static properties of the electromagnetoelastic actuator for the nanoscience with regard to its physical parameters and external load [19 − 23].

STRUCTURAL DIAGRAM OF ACTUATOR

Let us consider the structural-parametric model, the structural diagram of the electromagnetoelastic actuator for the nanoscience in contrast Cady and Mason electrical equivalent circuits. The method of the mathematical physics with Laplace transform is applied for the solution the wave equation, for the determination the structural diagram of the electromagnetoelastic actuator for the nanoscience [1 − 18].

For the electromagnetoelastic actuator the generalized equation [8, 11] of the electromagnetoelasticity has the form

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

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, $\Psi_m = \{E_m, D_m, H_m$ is the control parameter, E_m is the electric field strength for the voltage control along axis m, D_m is the electric induction for the current control along axis m, H_m for magnetic field strength control along axis m, T_j is the mechanical stress along axis j, ν_{mi} is the electromagnetoelastic coefficient or the electromagnetoelastic module, for example, the piezoelectric module, s_{ij}^{Ψ} is the elastic compliance for the control parameter $\Psi = \text{const}$, and the indexes i= 1, 2, … , 6; j = 1, 2, … , 6; m = 1, 2, 3. The main size of the electromagnetoelastic actuator is determined us the working length $l = \{\delta, h, b$ for the actuator or for the piezoactuator in following form the thickness, the height and the width for the longitudinal, transverse and shift piezoeffect.

For the construction the structural diagram of electroelastic actuator in nanotechnology is used the wave equation for the wave propagation in a long line with damping but without distortions. With using Laplace transform is obtained the linear ordinary second-order differential equation with the parameter p. Correspondingly the original problem for the partial differential equation of hyperbolic type using the Laplace transform is reduced to the simpler problem [8, 18] for the linear ordinary differential equation

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

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

The structural-parametric model and the generalized structural diagram [7, 14] of the electromagnetoelastic actuator on Figure 1 are determined, using the method of the mathematical physics with Laplace transform for the solution of the wave equation, the boundary conditions and the equation of the electromagnetoelasticity, in the form

$$\begin{aligned}
&\Xi_1(p) = \left[1/\left(M_1 p^2\right)\right] \times \\
&\times \left\{-F_1(p) + \left(1/\chi_{ij}^{\Psi}\right)\left[\nu_{mi}\Psi_m(p) - \left[\gamma/\mathrm{sh}(l\gamma)\right]\left[\mathrm{ch}(l\gamma)\Xi_1(p) - \Xi_2(p)\right]\right]\right\} \\
&\Xi_2(p) = \left[1/\left(M_2 p^2\right)\right] \times \\
&\times \left\{-F_2(p) + \left(1/\chi_{ij}^{\Psi}\right)\left[\nu_{mi}\Psi_m(p) - \left[\gamma/\mathrm{sh}(l\gamma)\right]\left[\mathrm{ch}(l\gamma)\Xi_2(p) - \Xi_1(p)\right]\right]\right\}
\end{aligned} \qquad (3)$$

where $\nu_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \\ d_{33}, d_{31}, d_{15} \end{cases}$, $\Psi_m = \begin{cases} E_3, E_1 \\ D_3, D_1 \\ H_3, H_1 \end{cases}$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D \\ s_{33}^H, s_{11}^H, s_{55}^H \end{cases}$,

$c^{\Psi} = \begin{cases} c^E \\ c^D \\ c^H \end{cases}$, $\gamma = \begin{cases} \gamma^E \\ \gamma^D \\ \gamma^H \end{cases}$, $l = \begin{cases} \delta \\ h \\ b \end{cases}$, $\chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0$,

ν_{mi} is the electromagnetoelastic coefficient, $\Psi_m = \{E_m, D_m, H_m\}$ is the control parameter, E_m is the electric field strength for the voltage control along axis *m*, D_m is the electric induction for the current control along axis *m*, H_m for magnetic field strength control along axis *m*, s_{ij}^{Ψ} is the elastic compliance, d_{mi} is the piezomodule at the voltage-controlled piezoactuator or the magnetostrictive coefficient for the magnetostrictive actuator, g_{mi} is the piezomodule at the current-controlled piezoactuator, S_0 is the cross section area, M_1, M_2 are the mass on the faces of the actuator, $\Xi_1(p)$, $\Xi_2(p)$ and $F_1(p)$, $F_2(p)$ are the Laplace transforms of the appropriate displacements and the forces on the faces 1, 2.

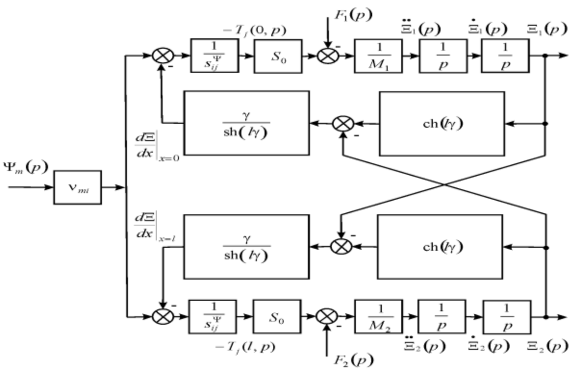

Figure1. *Generalized structural diagram of electromagnetoelastic actuator for nanoscience.*

The structural-parametric model and the structural diagrams of the voltage-controlled or current-controlled piezoactuator are determined from the structural-parametric model of the electromagnetoelastic actuator.

Matrix Transfer Function of Actuator

The matrix transfer function of the electromagnetoelastic actuator is deduced [8, 18] from its the structural-parametric model (3) in the form

$$(\Xi(p)) = (W(p))(P(p)) \qquad (4)$$

$$(\Xi(p)) = \begin{pmatrix} \Xi_1(p) \\ \Xi_2(p) \end{pmatrix},$$

$$(W(p)) = \begin{pmatrix} W_{11}(p) & W_{12}(p) & W_{13}(p) \\ W_{21}(p) & W_{22}(p) & W_{23}(p) \end{pmatrix},$$

$$(P(p)) = \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix}$$

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

For the voltage-controlled the piezoactuator at the transverse piezoeffect we have the control parameter $\Psi_m = E_3$. The transfer functions of the voltage-controlled the piezoactuator at the transverse piezoeffect are determined in the form

$$W_{11}(p)=\Xi_1(p)/E_3(p)=d_{31}\left[M_2\chi_{11}^E p^2+\gamma \mathrm{th}(h\gamma/2)\right]/A_{11}$$

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

$$A_{11}=M_1M_2\left(\chi_{11}^E\right)^2p^4+\left\{(M_1+M_2)\chi_{11}^E/\left[c^E\mathrm{th}(h\gamma)\right]\right\}p^3+$$
$$+\left[(M_1+M_2)\chi_{11}^E\alpha/\mathrm{th}(h\gamma)+1/\left(c^E\right)^2\right]p^2+2\alpha p/c^E+\alpha^2$$

$$W_{21}(p)=\Xi_2(p)/E_3(p)=d_{31}\left[M_1\chi_{11}^E p^2+\gamma \mathrm{th}(h\gamma/2)\right]/A_{11}$$

$$W_{12}(p)=\Xi_1(p)/F_1(p)=-\chi_{11}^E\left[M_2\chi_{11}^E p^2+\gamma/\mathrm{th}(h\gamma)\right]/A_{11}$$

$$W_{13}(p)=\Xi_1(p)/F_2(p)=$$
$$=W_{22}(p)=\Xi_2(p)/F_1(p)=\left[\chi_{11}^E\gamma/\mathrm{sh}(h\gamma)\right]/A_{11}$$

$$W_{23}(p)=\Xi_2(p)/F_2(p)=-\chi_{11}^E\left[M_1\chi_{11}^E p^2+\gamma/\mathrm{th}(h\gamma)\right]/A_{11}$$

The transfer function of the voltage-controlled transverse piezoactuator is obtained from (4) for the elastic-inertial load at $M_1\to\infty$, $m \ll M_2$ and the approximation the hyperbolic cotangent by two terms of the power series in the form

$$W(p)=\Xi_2(p)/U(p)=k_t/\left(T_t^2p^2+2T_t\xi_t p+1\right) \qquad (5)$$

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

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

$$\xi_t=\alpha h^2C_{11}^E/\left(3c^E\sqrt{M_2\left(C_e+C_{11}^E\right)}\right)$$

where $U(p)$ is the Laplace transform of the voltage on the plates of the piezoactuator, k_t is the transfer coefficient, T_t is the time constant. ξ_t is the damping coefficient of the piezoactuator. Therefore for the transverse piezoactuator with the elastic-inertial load at $d_{31}=2\cdot10^{-10}$ m/V, $h/\delta=20$, $M_2=1$ kg, $C_{11}^E=2.4\cdot10^7$ N/m, $C_e=0.1\cdot10^7$ N/m we obtain values the transfer coefficient $k_t=3.84$ nm/V and the time constant of the piezoactuator $T_t=0.2\cdot10^{-3}$ c.

The matrix transfer function of the actuator are calculated for control systems with the actuator in the nanoscience.

Conclusions

The structural-parametric model, the structural diagram, the matrix transfer function and the characteristics of the electromagnetoelastic actuator for the nanoscience are determined.

The generalized structural diagram, the matrix transfer function of the electromagnetoelastic actuator make it possible to describe the dynamic and static properties of the actuator with regard to its physical parameters, external load.

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