Electro Magneto Elastic Actuator for Nanomedical Research

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Introduction

The electro magneto elastic actuator with the piezoelectric, piezomagnetic, electrostriction, magnetostriction effects is used for nanomedical research in the scanning tunneling microscopy [1-9]. For control system of the deformation of the electro magneto elastic actuator its structural diagram, transfer function, characteristics are calculated [9-18]. The structural diagram and matrix transfer function the electro magneto elastic actuator is applied to describe the dynamic and static characteristics of the electro magneto elastic actuator for nanomedical research with regard to its physical parameters and external load [14-28].

Aim

The aim of this work is to construct the structural diagram and the matrix transfer function of the electro magneto elastic actuator for control systems of nanomedical research.

Method

The method of mathematical physics is used to solve the wave equation with the Laplace transform for obtain the structural diagram, the matrix transfer function, the characteristics of the electro magneto elastic actuator for nanomedical research.

Results

We constructed the structural diagram and the matrix transfer function of the electro magneto elastic actuator. The structural diagram of the electro magneto elastic actuator is difference from Cady and Mason electrical equivalent circuits. The method of the mathematical physics we used for the determination the structural diagram of electro magneto elastic actuator for nanomedical research. The generalized equation [8,11,18,26] of the electro magneto elasticity has the form

$$S_i = v_m \Psi_m(t) + s_y^y T_j(x, t) \quad (1)$$

where $S_i = \partial \xi(x, t) / \partial x$ is the relative displacement along axis i of the cross section of the actuator, $\Psi_m = \{E_m, D_m, H_m\}$ 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 , v_m is the electro magneto elastic coefficient or the electro magneto elastic module, s_y^y is the elastic compliance for the control parameter $\Psi = const$, the indexes $i = 1, 2, \dots, 6$; $j = 1, 2, \dots, 6$; $m = 1, 2, 3$. For the piezoactuator its main size length is determined $l = \delta, h, b$ in the form the thickness, the height and the width for the longitudinal, transverse and shift piezoeffect. In the foundation the structural diagram actuator is used decision with Laplace transform the wave equation for the wave propagation in the long line with damping but without distortions. We obtained with using Laplace transform the linear ordinary second-order differential equation with the parameter p [8,14,18].

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

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 $\Psi = const$, α is the damping coefficient.

Figure 1: Generalized structural diagram of electro magneto elastic actuator for nanomedical research.

We determined the generalized structural-parametric model, the generalized structural diagram [7,8,14] of the actuator on (Figure 1) by the method of the mathematical physics with using the equation of the electro magneto elasticity and the boundary conditions in the following form

$$\begin{aligned}\Xi_1(p) &= [1/(M_1 p^2)] \times \{-F_1(p) + (1/x_{ij}^w)[v_{mi}\Psi(p) - [\gamma/sh(l\gamma)][ch(l\gamma)\Xi_1(p) - \Xi_2(p)]]\} \\ \Xi_2(p) &= [1/(M_2 p^2)] \times \{-F_2(p) + (1/x_{ij}^w)[v_{mi}\Psi(p) - [\gamma/sh(l\gamma)][ch(l\gamma)\Xi_2(p) - \Xi_1(p)]]\} \quad (3) \\ v_{mi} &= \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \end{cases}, \Psi_m = \begin{cases} E_3, E_1 \\ D_3, D_1, S_{ij}^w \\ H_3, H_1 \end{cases} = \begin{cases} S_{33}^E, S_{11}^E, S_{55}^E \\ S_{33}^D, S_{11}^D, S_{55}^D \\ S_{33}^H, S_{11}^H, S_{55}^H \end{cases}, \\ c^w &= \begin{cases} c^E \\ c^D, \gamma \\ c^H \end{cases}, \gamma = \begin{cases} \gamma^E \\ \gamma^D, l \\ \gamma^H \end{cases}, l = \begin{cases} \delta \\ h, x_{ij}^w = s_{ij}^w / s_0 \\ b \end{cases}\end{aligned}$$

Where v_{mi} is the electro magneto elastic coefficient, d_{mi} is the piezomodule or the magnetostrictive coefficient, g_{mi} is the piezomodule, S_{ij}^w is the elastic compliance, S_0 is the cross section area M_1, M_2 are the mass on two faces of the actuator, $\Xi_1(p), \Xi_2(p)$ and $F_1(p), F_2(p)$, are the Laplace transforms of the displacements and the forces on two faces. The structural diagrams of the magnetostrictive actuator or piezoactuator are determined from the generalized structural diagram of the electro magneto elastic actuator. We obtained the matrix transfer function of the electro magneto elastic actuator [8,18] from the structural-parametric model (3) in the form

$$\begin{aligned}(\Xi(p)) &= (W(p))(P(p)) \\ (\Xi(p)) &= \begin{pmatrix} \Xi(p) \\ \Xi(p) \end{pmatrix}, (W(p)) = \begin{pmatrix} W_{11}(p)W_{12}(p)W_{13}(p) \\ W_{21}(p)W_{22}(p)W_{23}(p) \end{pmatrix} \quad (4) \\ (P(p)) &= \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix}\end{aligned}$$

where $\Xi(p)$ is the matrix of the Laplace transforms of the displacements for the faces of the actuator, $(W(p))$ is the matrix transfer function, $(P(p))$ the matrix of the Laplace transforms of the control parameter and the forces. We calculated the matrix transfer function of the electro magneto elastic actuator for control system of nanomedical research. We obtained the transfer function of the transverse piezoactuator with one fixed face for the elastic-inertial load from (4) at $M \rightarrow \infty, m \ll M_2$, in the form

$$\begin{aligned}W(p) &= \Xi_2(p)/U(p) = K_t / (T_t^2 p^2 + 2T_t \xi_t p + 1) \\ K_t &= (d_{31}h/\delta) / (1 + C_e/C_{11}^E), T_t = \sqrt{M_2 / (1 + C_e/C_{11}^E)} \quad (5) \\ \xi_t &= \alpha h^2 C_{11}^E / 3C^E \sqrt{M_2 (c_e + c_{11}^E)}\end{aligned}$$

where $U(p)$ is the Laplace transform of the voltage on the piezoactuator; k_t is the transfer coefficient, T_t is the time constant. ξ_t is the damping coefficient of the piezoactuator. For the transverse piezoactuator with one fixed face for the elastic-inertial load at $d_{31} = 2.4 \cdot 10^{-10} \text{ m/V}$, $h/\delta = 0$, $M_2 = 1 \text{ kg}$, $C_{11}^E = 3.10^7 \text{ N/m}$, $C_e = 0.6 \cdot 10^7 \text{ N/m}$ we obtain values the transfer coefficient $K_t = 2 \text{ nm/V}$ and the time constant of the piezoactuator $T_t = 0.17 \cdot 10^{-3} \text{ s}$.

Summary

We obtained the structural diagram and the matrix transfer function of the electro magneto elastic actuator for control systems of nanomedical research.

Conclusion

We constructed the generalized structural diagram of the electro magneto elastic actuator for nanomedical research with the mechanical parameters the displacement and the force in the difference from Cady and Mason electrical equivalent circuits. The generalized structural diagram, the matrix transfer function and the characteristics of the electro magneto elastic actuator are determined for describe the dynamic and static characteristics of the actuator in control systems.

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