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Review Article

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Electro Magneto Elastic Actuator for Nanoscience

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Abstract

The mathematical model, the structural scheme, the matrix transfer function, the characteristics of the electro magneto elastic actuator is obtained. The transfer functions of the magneto elastic actuator are described the characteristics of the actuator with regard to its physical parameters and external load.

Keywords: Electro magneto elastic actuator, Piezo actuator, Mathematical model, Structural scheme.

Introduction

The electro magneto elastic actuator on the piezoelectric, electrostriction, magneto striction effects is used [1-6].

The mathematical model, the structural scheme and the transfer functions of the electromagneto elastic actuator are calculated for designing the control mechatronics [4-11].

The mathematical model, the structural scheme and the matrix transfer function the electro magneto elastic actuator based on the magneto elastic elasticity make it possible to describe the dynamic and static properties of the electro magneto elastic actuator with regard to its physical parameters and external load [12-23].

Structural scheme

The method of the mathematical physics with the Laplace transform is applied for the solution the wave equation. The structural scheme of the electro magneto elastic actuator is changed from Cady and Mason electrical equivalent circuits [7-8].

The equation of the electro magneto elasticity has the following form [6, 8, 12].

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

where S_i is the relative displacement along axis i of the cross section of the piezo 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 is the magnetic field strength for the magneto control along axis m, T_j is the mechanical stress along axis j, ν_{mi} is the electro magneto elastic module, for example, the piezo module, s_{ij}^{Ψ} is the elastic compliance for the control parameter Ψ = const , and the indexes i= 1, 2, … , 6; j= 1, 2, … , 6; m= 1, 2, 3. The main size along axis i for the electro magneto elastic actuator is determined us the working length $l=\{\delta, h, b\}$ in form the thickness, the height or the width for the longitudinal, transverse or shift piezo effect.

For the construction the structural scheme of the electro magneto elastic actuator is used the wave equation for the wave propagation in the long line with damping but without distortions [8, 10, 14]. With using Laplace transform is obtained the linear ordinary second-order differential equation. The problem for the partial differential equation of hyperbolic type using the Laplace transform is reduced to the simpler problem for the linear ordinary differential equation [6, 8, 14].

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

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

Using method of the mathematical physics with the Laplace transform for the solution of the equation of the electro magneto elasticity, the wave equation, the boundary conditions, the mathematical model and the structural scheme of the electro magneto elastic actuator on Figure 1 are determined in the following form [6, 12, 23].

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

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

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

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

v_{mi} is the electro magneto elastic module, $\Psi_m = \{E_m, D_m, H_m\}$ is the control parameter in the form the electric field strength, the electric induction or the magnetic field strength along axis m, s_{ij}^{Ψ} is the elastic compliance, d_{mi} is the piezo module at the voltage-controlled piezo actuator or the magneto strictive coefficient for the magneto strictive actuator, g_{mi} is the piezo module at the current-controlled piezo actuator, S_0 is the cross section area, M_1, M_2 are the mass of the loads 1, 2, $\Xi_1(p)$, $\Xi_2(p)$ and $F_1(p)$, $F_2(p)$ and, are the Laplace transforms of the appropriate displacements and the forces on the faces1, 2.

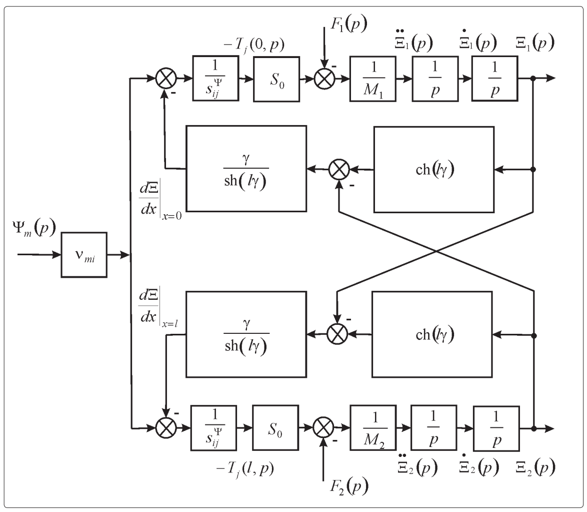

Figure 1: Structural scheme of electro magneto elastic elastic actuator for nano and micro manipulators of nanoscience

The structural schemes of the voltage controlled or current controlled piezo actuator are obtained from its mathematical model.

Matrix transfer function

The matrix transfer function of the electro magneto elastic actuator is derived from its mathematical model in the following form [6, 17, 20].

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

where $(\Xi(p))$ is the column-matrix of the Laplace transforms of the displacements for the faces 1, 2of the electro magneto elastic 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 faces 1, 2.

The transfer functions of the electro magneto elastic actuator are

$$W_{11}(p)=\Xi_1(p)/\Psi_m(p)=\nu_{mi}\left[M_2\chi_{ij}^{\Psi}p^2+\gamma\,\mathrm{th}(l\gamma/2)\right]/A_{ij}\,,$$

$$\chi_{ij}^{\Psi}=s_{ij}^{\Psi}/S_0\,,$$

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

$$W_{21}(p)=\Xi_2(p)/\Psi_m(p)=\nu_{ij}\left[M_1\chi_{ij}^{\Psi}p^2+\gamma\,\mathrm{th}(l\gamma/2)\right]/A_{ij}\,,$$

$$W_{12}(p)=\Xi_1(p)/F_1(p)=-\chi_{ij}^{\Psi}\left[M_2\chi_{ij}^{\Psi}p^2+\gamma/\mathrm{th}(l\gamma)\right]/A_{ij}\,,$$

$$W_{13}(p)=\Xi_1(p)/F_2(p)=$$
$$W_{22}(p)=\Xi_2(p)/F_1(p)=\left[\chi_{ij}^{\Psi}\gamma/\mathrm{sh}(l\gamma)\right]/A_{ij}\,,$$

$$W_{23}(p)=\Xi_2(p)/F_2(p)=-\chi_{ij}^{\Psi}\left[M_1\chi_{ij}^{\Psi}p^2+\gamma/\mathrm{th}(l\gamma)\right]/A_{ij}\,.$$

The transfer function of the voltage controlled piezo actuator under the transverse piezo effect with one fixed the end is obtained for the elastic inertial load at, $M_1\to\infty$, $m_a << M_2$ has form

$$W(p)=\frac{\Xi_2(p)}{U(p)}=\frac{d_{31}h/\delta}{\left(1+C_e/C_{11}^E\right)\left(T_t^2p^2+2T_t\xi_tp+1\right)}$$

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

where $U(p)$ is the Laplace transforms of the voltage, T_t is the time constant and ξ_t is the damping coefficient of the piezo actuator, m_a is the mass of the piezo actuator.

For the voltage controlled piezo actuator from the piezo ceramics PZT under the transverse piezo effect with one fixed the end, the elastic inertial load $M_1\to\infty$, $m_a << M_2$ and the input voltage U_m=100 V for $d_{31} = 2.5\cdot10^{-10}$ m/V, h/δ =20, M_2 = 4 kg, C^E_{11} =$2\cdot10^7$ N/m, C_e=$0.5\cdot10^7$ N/m, are obtained the values ξ_m = 400nm, T_t = $0.4\cdot10^{-3}$ s.

For calculations the control mechatronics systems in the nanoscience, the nanotechnology, the nano biology, the microsurgery with the electro magneto elastic actuator its transfer functions are obtained.

Conclusions

The mathematical model, the structural scheme and the transfer functions of the electro magneto elastic actuator are described the characteristics of the electro elastic actuator with regard to its physical parameters, external load.

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