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Short Communication

Structural Diagram of Electro Magneto Elastic Actuator Nano Displacement for Material Science

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Abstract

For control system in the scanning tunneling microscope and the adaptive optics for nanotechnology and material science we drew structural-parametric model, the structural diagram and the matrix transfer function, the characteristics of the electro magneto elastic actuator for nano displacement. In this work, we have the generalized structural diagram, the generalized matrix transfer function of the electro magneto elastic actuator.

Keywords: Structural diagram; Structural-parametric model; Electro magneto elastic actuator; Piezo actuator; Matrix transfer function

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Introduction

For nanotechnology and material science is promising for use mechatronics systems with electromechanical actuators based on electro magneto elasticity. The electro magneto elastic actuator nano displacement with the piezoelectric, piezomagnetic, electrostriction, magnetostriction effects is used in the control system in the scanning tunneling microscope, the atomic force microscope and the adaptive optics [1-30].

For control system of nanotechnology and material science we receive structural-parametric model, the structural diagram, the matrix transfer function and the characteristics of the electro magneto elastic actuator [9-29].

Structural diagram and matrix transfer function

The method of the mathematical physics with Laplace transform we have to build the structural diagram of the electro magneto elastic actuator for nanotechnology and material science. The structural diagram of the electro magneto elastic actuator nano displacement for material science is difference from Cady and Mason electrical equivalent circuits [1-18].

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. With Laplace transform the original problem for the partial differential equation of hyperbolic type using the Laplace transform is reduced to the simpler problem [8,13,14,18] for the linear ordinary differential equation

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

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

In general, the equation of the electro magneto elasticity [8,11] has the following form

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

where $S_i = \partial\xi(x,t)/\partial x$ is the relative displacement along axis *i* of the cross-section of the actuator, *t* is the time, *x* is the coordinate, $\Psi_m = \{E_m, D_m, H_m$ 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 electro magneto elastic coefficient, s_{ij}^{Ψ} is the elastic compliance for the control parameter $\Psi = \text{const}$, i, j, m are the indexes.

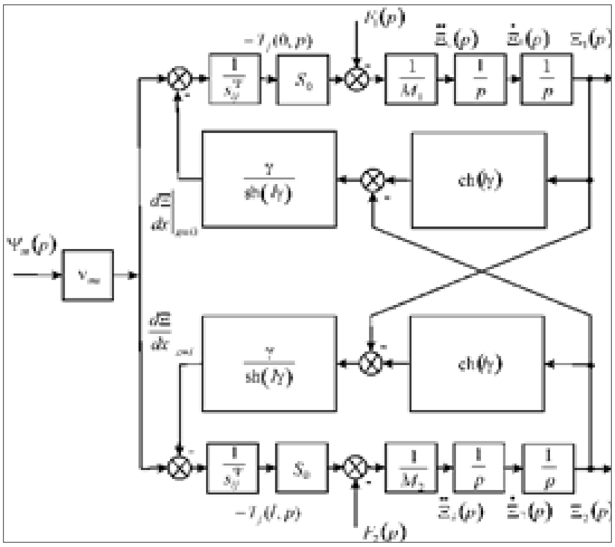

Figure 1: Generalized structural diagram of electro magneto elastic actuator.

The generalized structural-parametric model and the generalized structural diagram [7,8,14] of the electro magneto elastic actuator for nano displacement on Figure 1 are obtained by the method of the mathematical physics with solution of the wave equation, the equation of the electro magneto elasticity, the boundary conditions in the form

$$\Xi_1(p) = \left[1/(M_1 p^2)\right]\times$$

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

$$\Xi_2(p) = \left[1/(M_2 p^2)\right]\times$$

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

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

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

ν_{mi} is the electro magneto elastic coefficient, d_{mi} is the piezo module at the voltage-controlled piezo actuator or the magnetostrictive coefficient for the magnetostrictive actuator, g_{mi} is the piezo module at the current-controlled piezo actuator, s_{ij}^{Ψ} 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.

In this work, we have the working length $l = \delta, h, b$ for the piezo actuator in the form the thickness, the height and the width for the longitudinal, transverse and shift piezo effect.

Let us consider the matrix transfer function of the electro magneto elastic actuator [8,18] obtained from the structural-parametric model in the form

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

where $(\Xi(p))$ is the matrix of the Laplace transforms of the displacements for the faces of the electro magneto elastic actuator, $(W(p))$ is the matrix transfer function, $(P(p))$ the matrix of the Laplace transforms of the control parameters.

We receive the transfer function of the voltage-controlled transverse piezo actuator for the elastic-inertial load at $M_1 \to \infty$, $m \ll M_2$ for the approximation the hyperbolic cotangent by two terms of the power series in the form

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

$$k_t = (d_{31}h/\delta)/(1 + C_e/C_{11}^E), \quad T_t = \sqrt{M_2/(C_e + C_{11}^E)}$$

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

Where $U(p)$ is the Laplace transform of the voltage on the piezo actuator, k_t, T_t, ξ_t are the transfer coefficient, the time constant and the damping coefficient of the piezo actuator.

For the transverse piezo actuator from piezo ceramics PZT with one fixed face and the elastic-inertial load at $M_1 \to \infty$, $m \ll M_2$ for d_{31} = 2.5·10^{-10}m/V, h/δ =20, U =60 V, M_2=1kg, C_{11}^E =2·10^{7}N/m, C_e =0.5·10^{7}N/m we obtain the steady-state value of displacement $\xi_2(\infty)$ =240nm, values the transfer coefficient k_t =4 nm/V and the time constant of the piezo actuator T_t=0.2·10^{-3}s. The discrepancy between the experimental data and calculation results is 5%.

The matrix transfer function of the electro magneto elastic actuator is calculated for control system of the deformation the electro magneto elastic actuator.

Conclusion

For nanotechnology and material science we obtain the generalized structural diagram of the electro magneto elastic actuator for nano displacement with the mechanical parameters the displacement and the force in the difference from Cady and Mason electrical equivalent circuits. From the structural diagram, the matrix transfer function of the electro magneto elastic actuator we have the dynamic and static characteristics of the actuator with regard to physical parameters and external load.

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