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Research Article

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Multilayer Electro Magneto Elastic Actuator for Nano Science and Engineering

Afonin SM*

National Research University of Electronic Technology, MIET, Moscow, Russia

***Corresponding author**
Afonin SM, National Research University of Electronic Technology, MIET, Moscow, Russia; E-Mail: learner01@mail.ru

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Abstract
We obtained the structural diagram of the multilayer electromagnetoelastic actuator for nano science and engineering in contrast to electrical equivalent circuits of the piezotransmitter and piezoreceiver, the vibration piezomotor. In this work the structural-parametric model, the structural diagram and the matrix transfer function of the multilayer electromagnetoelastic actuator for nano science and engineering are determined.

Keywords: Multilayer Electro Magneto Elastic Actuator, Multilayer Piezo Actuator, Deformation, Structural Diagram, Matrix Transfer Function

Introduction
The multilayer electro magneto elastic actuator nano and micro displacement with the piezoelectric, piezomagnetic, electrostriction, magnetostriction effects is used in the control system for nano science and engineering in scanning tunneling microscopy, atomic force microscopy and adaptive optics in the range of movement from few nanometers to tens of micrometers [1-32]. We received the structural diagram of the multilayer electro magneto elastic actuator in contrast to electrical equivalent circuits of the piezotransmitter and piezoreceiver, the vibration piezomotor [1-11]. We used the equation of the electro magneto elasticity, the equivalent quadripole and the boundary conditions of the multilayer electro magneto elastic actuator for the structural-parametric model and the structural diagram of the multilayer actuator [8-31]. In the work the matrix transfer function of the multilayer actuator are determined from its structural-parametric model.

Structural diagram
For nano science and engineering we determined the structural diagram of the multilayer electro magneto elastic actuator in difference from Cady and Mason electrical equivalent circuits of the piezotransducer. We used the method of the mathematical physics with Laplace transform for the determination the structural-parametric model and the structural diagram of the multilayer electro magneto elastic actuator for nano science and engineering [8, 14, 23].

In general the equation of the electro magneto elasticity has the following form [8, 9, 11, 23]

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

where S_i is the relative deformation, ν_{mi} is the coefficient of electro magneto elasticity: d_{mi} piezomodule or magnetostrictive coefficient, Ψ_m is control parameter in the form of electric E_m, magnetic H_m field strengths or electric D_m induction, s_{ij}^{Ψ} is the elastic compliance with Ψ=const, T_j is the mechanical stress, *i, j, m* are the indexes.

We obtained for the structural-parametric model of the multilayer electro magneto elastic actuator the Laplace transform of the causes force in the form

$$F(p) = \nu_{mi} S_0 \Psi_m(p) / s_{ij}^{\Psi}$$

where is the cross sectional area of the multilayer electro magneto elastic actuator.

In general we have the matrix the equivalent quadripole of the multilayer electro magneto elastic actuator in the form

$$[M]^n = \begin{bmatrix} \mathrm{ch}(l\gamma) & Z_0\mathrm{sh}(l\gamma) \\ \dfrac{\mathrm{sh}(l\gamma)}{Z_0} & \mathrm{ch}(l\gamma) \end{bmatrix}$$

where l is length of the multilayer actuator in the form for the longitudinal piezoeffect $l=n\delta$, for the transverse piezo effect $l=nh$, for the shift piezoeffect $l=nb$, are the thickness, the height, the width for the piezolayer.

We have the system of the equations for the generalized structural-parametric model and the generalized structural diagram of the multilayer electro magneto elastic actuator on Figure 1.

In the work we received the generalized structuralparametric model of the multilayer electro magneto elastic actuator in result analysis the equation of the force that causes deformation from the equation of the electro magneto elasticity, the equivalent quadripole and the boundary conditions equations with the forces on faces of the actuator in the following form

$$\Xi_1(p)=\left[1/\left(M_1p^2\right)\right]\times\left\{-F_1(p)+\left(1/\chi_{ij}^{\Psi}\right)\left[\nu_{mi}\Psi_m(p)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\times\left[\mathrm{ch}(l\gamma)\Xi_1(p)-\Xi_2(p)\right]\right]\right\}$$

$$\Xi_2(p)=\left[1/\left(M_2p^2\right)\right]\times\left\{-F_2(p)+\left(1/\chi_{ij}^{\Psi}\right)\left[\nu_{mi}\Psi_m(p)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\times\left[\mathrm{ch}(l\gamma)\Xi_2(p)-\Xi_1(p)\right]\right]\right\}$$

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

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

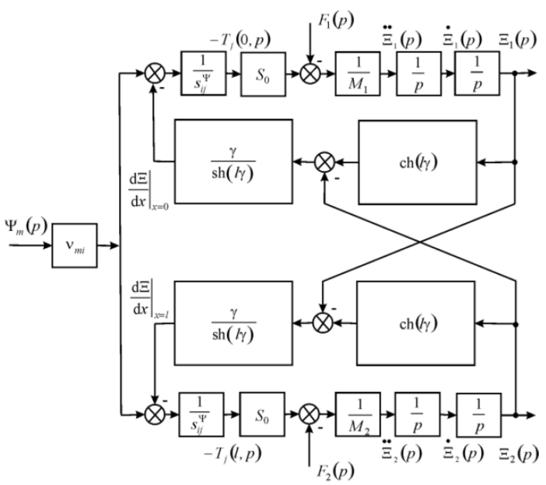

Figure 1: Generalized structural diagram of multilayer electro magneto lastic actuator for nano science and engineering

From the generalized structural-parametric model we have the matrix transfer function of the multilayer electro magneto elastic actuator in the form

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

$$[\Xi(p)]=\begin{bmatrix}\Xi_1(p)\\\Xi_2(p)\end{bmatrix},\ [W(p)]=\begin{bmatrix}W_{11}(p)&W_{12}(p)&W_{13}(p)\\W_{21}(p)&W_{22}(p)&W_{23}(p)\end{bmatrix}$$

$$[P(p)]=\begin{bmatrix}\Psi_m(p)\\F_1(p)\\F_2(p)\end{bmatrix}$$

where $[\Xi(p)]$ is the-matrix of the displacements the faces, $[W(p)]$ is the matrix transfer function, $[P(p)]$ is the matrix of the control parameters.

We determined at $t\to\infty$ the static displacements the faces of the voltage-controlled multilayer piezo actuator for the longitudinal piezo effect and the inertial load at $m \ll M_1$, $m \ll M_2$, where m is the mass of the multilayer piezo actuator, M_1, M_2 are the load masses, and the forces on faces $F_1(t) = F_2(t)=0$, in the form

$$\xi_1(\infty)=\lim_{p\to0}pW_{11}(p)(U/\delta)/p=d_{33}nUM_2/(M_1+M_2)$$

$$\xi_2(\infty)=\lim_{p\to0}pW_{21}(p)(U/\delta)/p=d_{33}nUM_1/(M_1+M_2)$$

$$\xi_1(\infty)+\xi_2(\infty)=d_{33}nU$$

where U is the voltage.
At $d_{33} = 4\cdot10^{-10}$ m/V, $n = 4$, U= 50 V, M_1 = 1.5 kg and M_2 = 6 kg we obtained the static displacements of the faces the multilayer piezo actuator $\xi_1(\infty)$ = 64 nm, $\xi_2(\infty)$ = 16 nm, $\xi_1(\infty)+\xi_2(\infty)$= 80 nm.

We received transfer function of the multilayer piezoactuator at longitudinal piezoeffect with one fixed face and voltage control at the elastic-inertial load $m \ll M_2$ for nano science and engineering in the following form

$$W(p)=\frac{\Xi_2(p)}{U(p)}=\frac{d_{33}n}{\left(1+C_e/C_{33}^E\right)\left(T_t^2p^2+2T_t\xi_tp+1\right)}$$

$$T_t=\sqrt{M_2/\left(C_e+C_{33}^E\right)},\ \xi_t=\alpha(n\delta)^2C_{33}^E\Big/\left(3c^E\sqrt{M_2\left(C_e+C_{33}^E\right)}\right)$$

where $\Xi(p)$, $U(p)$ are the Laplace transforms the displacement face and the voltage, T_t, ξ_t are the time constant and the damping coefficient, $C_{33}^E=S_0/\left(s_{33}^En\delta\right)$ is the rigidity of the multilayer piezoactuator for E=const.

For the multilayer electromagnetoelastic actuator of nano science and engineering with the elastic-inertial load for $d_{33} = 4\cdot10^{-10}$ m/V, n = 12, U = 50 V, M_2 = 4 kg, C_{33}^E = $2\cdot10^7$ N/m, C_e = $0.4\cdot10^7$ N/m we received values the steady-state value of displacement face ξ_2= 200 nm and the time constant $T_t = 0.4\cdot10^{-3}$ s.

Conclusions

In this work we obtained for nano science and engineering the generalized structural diagram of the multilayer electro magneto elastic actuator with the mechanical parameters in the form the displacement and the force in the difference from Cady and Mason electrical equivalent circuits.

The generalized structural-parametric model, generalized structural diagram and the matrix transfer function of the multilayer electro magneto elastic actuator for nano science and engineering are received.

The static and dynamic characteristics of the multilayer electro magneto elastic actuator with using the matrix transfer function of the actuator are determined.

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