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Electromagnetoelastic Actuator for Nano Physics and Optics Sciences

Afonin SM

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

ABSTRACT

The regulation and mechanical characteristics of the electromagnetoelastic actuator are obtained for control systems in nano physics and optics sciences for scanning microscopy, adaptive optics and nano biomedicine. The piezo actuator is used for nano manipulators. The matrix transfer function of the electromagnetoelastic actuator is received for nano physics and optics sciences.

***Corresponding author**

Afonin SM, National Research University of Electronic Technology, MIET, Moscow, Russia, Email: learner01@mail.ru

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Introduction

The electromagnetoelastic actuator at the piezoelectric or electrostriction effect is used for nano physics and optics sciences [1-15]. The electromagnetoelastic actuator is the electromechanical device for actuating and controlling mechanisms, systems with the conversion of electrical signals into mechanical displacements and forces. The electromagnetoelastic actuator is provided range of movement from nanometers to ten microns, force 1000 N, response 1-10 ms [16-34].

Characteristics of Actuator

Characteristics of actuator are used in the calculation of nano mechatronics control systems for nano physics and optics sciences. From the electromagnetoelasticity equation [7, 11-32] the relative deformation of electromagnetoelastic actuator at elastic force has the form

$$\frac{\Delta l}{l} = d_{mi}\Psi_m - \frac{s_{ij}^{\Psi} C_e}{S_0}\Delta l \,,$$

$$F = C_e \Delta l \,,$$

where $l, \Delta l, d_{mi}, \Psi_m, S_{ij}^{\Psi}, C_e, S_0$ are the length, the deformation or displacement of the electromagnetoelastic actuator, the electromagnetoelastic module or the piezo module, the electric or magnetic field strength, the elastic compliance at Ψ = const, stiffness of the load, the area of the actuator, *i, j, m* are the indexes. The regulation characteristic of the actuator at elastic force has the form

$$\Delta l = \frac{d_{mi} l \Psi_m}{1 + C_e / C_{ij}^{\Psi}} \,,$$

$$C_{ij}^{\Psi} = S_0 / \left(s_{ij}^{\Psi} l\right),$$

where C_{ij}^{Ψ} is stiffness of the electromagnetoelastic actuator at Ψ = const. Therefore, the regulation characteristic for the transverse piezo actuator for the elastic load has the form

$$\Delta l = \frac{\left(d_{31} l/\delta\right) U}{1 + C_e / C_{11}^{E}} = k_{31}^{U} U \,,$$

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

where k^{U}_{31} is the transfer coefficient for voltage. For the piezo actuator from ceramic PZT at $=2.10^{-10}$ m/V, $l/\delta = 20$, $C_{11}{}^{E} = 2 \cdot 10^7$ N/m, $C_e = 0.5 \cdot 10^7$ N/m, U = 25 V we obtain values the transfer coefficient for voltage k^{U}_{31} = 3.2 nm/V and the displacement Δl = 80 nm.

The mechanical characteristic of the electromagnetoelastic actuator has the form

$$\Delta l = \Delta l_{\max}\left(1 - F/F_{\max}\right),$$

where $\Delta l_{\max}$ is the maximum displacement for F=0 and $F_{\max}$ is the maximum force for Δl=0. The maximum displacement and the maximum force for the piezo actuator with the transverse piezo effect have the form

$$\Delta l_{\max} = d_{31} E_3 l \,,$$

$$F_{\max} = d_{31} E_3 S_0 / s_{11}^{E} \,.$$

At $d_{31} = 2 \cdot 10^{-10}$ m/V, $E_3 = 1.5 \cdot 10^5$ V/m, $l = 2 \cdot 10^{-2}$ m, $S_0 = 1 \cdot 10^{-5}$ m^2, $s_{11}{}^{E} = 15 \cdot 10^{-12}$ m^2/N the maximum displacement $\Delta l_{\max}$ = 600 nm and the maximum force $F_{\max}$ = 20 N are received for the mechanical characteristic of the transverse piezo actuator from ceramic PZT.

The second order linear ordinary differential equation has the form

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

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where $\Xi(x, p)$ is the Laplace transform of the displacement of the electromagnetoelastic actuator; C and B are the coefficients; x is the coordinate; p is the Laplace operator; $\gamma = p/c^{\Psi} + \alpha$ is the wave propagation coefficient; c^{Ψ} is the speed of sound in the actuator at Ψ =const ; α is the attenuation coefficient.

From solution this second order linear ordinary differential equation and the electromagneto elasticity equation the system of the equations for the structural model and diagram on Figure 1 of the electromagnetoelastic actuator are obtained for nano physics and optics sciences

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

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

$$\text{where } \chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0, \quad d_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ d_{33}, d_{31}, d_{15} \end{cases}, \quad \Psi_m = \begin{cases} E_3, E_1 \\ H_3, H_1 \end{cases},$$

$$s_{ij}^{\Psi} = \begin{cases} s_{33}^{E}, s_{11}^{E}, s_{55}^{E} \\ s_{33}^{H}, s_{11}^{H}, s_{55}^{H} \end{cases}, \quad \gamma = \begin{cases} \gamma^{E} \\ \gamma^{H} \end{cases}.$$

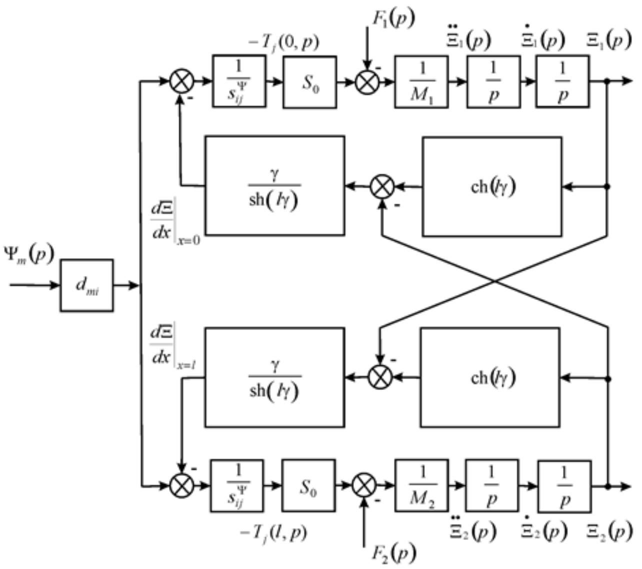

Figure1: Structural diagram of electromagnetoelastic actuator for nano physics and optics sciences

After the transformation the structural model of the electromagnetoelastic actuator the system of the equations for the Laplace transform of the displacements of two faces of the actuator has the form

$$\Xi_1(p) = W_{11}(p)\Psi_m(p) + W_{12}(p)F_1(p) + W_{13}(p)F_2(p),$$

$$\Xi_2(p) = W_{21}(p)\Psi_m(p) + W_{22}(p)F_1(p) + W_{23}(p)F_2(p).$$

The matrix equation with the matrix transfer function of the electromagnetoelastic actuator has the form

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

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

Therefore, the transfer functions of the electromagnetoelastic actuator in the form of the elements in the matrix transfer function are written in the form

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

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

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

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

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

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

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

The transfer function for voltage with lumped parameter of the transverse piezo actuator [7, 11-32] with fixe one face for the elastic-inertial load has the form

$$W(p) = \Xi(p)/U(p) = k_{31}^{U}/\left(T_t^2p^2 + 2T_t\xi_t p + 1\right)$$

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

where $\Xi(p)$, $U(p)$ are the Laplace transforms of the displacement and the voltage, T_t, ξ_t are the time constant and the damping coefficient of the piezo actuator, M is the load mass. At d_{31} = $2\cdot10^{-10}$ m/V, = 20, M =1 kg, $C_{11}^{E} = 2\cdot10^7$ N/m, $C_e = 0.5\cdot10^7$ N/m values the transfer coefficient for voltage k_{31}^{U} = 3.2 nm/V and the time constant of the piezo actuator $T_t = 0.2\cdot10^{-3}$ s are obtained for the transverse piezo actuator with the elastic-inertial load. The discrepancy between the experimental and calculation data for the piezo actuator is 10%.

Conclusions

The regulation characteristic and the matrix transfer function of the electromagnetoelastic actuator are received for nano physics and optics sciences. The maximum displacement and the maximum force are obtained for the mechanical characteristic of the actuator.

The transfer functions of the electromagnetoelastic actuator in the form of the elements in the matrix transfer function are obtained for control system. The characteristics of the actuator are used for the calculation the control system for nano physics and optics sciences.

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