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Structural-parametric model actuator of adaptive optics for composite telescope and astrophysics equipment

Abstract

In this paper, we obtained the structural-parametric model, the matrix transfer function, the static and dynamic characteristics of the multilayer electromagnetoelastic actuator of adaptive optics. It was designed the structural diagram of the multilayer electromagnetoelastic actuator of adaptive optics for composite telescope and astrophysics equipment in contrast to electrical equivalent circuits of the piezotransducer and the vibration piezomotor.

Keywords: multilayer electromagnetoelastic actuator, multilayer piezoactuator, structural diagram, matrix transfer function

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Introduction

For the adaptive optics of the composite telescope and the astrophysics equipment we used the multilayer electromagnetoelastic actuator nano and micro displacement with the piezoelectric, piezomagnetic, electrostriction, magnetostriction effects with the range of movement from nanometers to hundred of micrometers.[1–30] We received the structural-parametric model, the structural diagram of the multilayer electromagneto elastic actuator in contrast to the electrical equivalent circuits of the piezotransducer and the vibration piezomotor.[1–11] The matrix transfer function of the multilayer electromagnetoelastic actuator is calculated for the control system of the composite telescope or the interferometer.[14–32] We determined the structural-parametric model and the structural diagram of the multilayer actuator using the equation of the electromagnetoelasticity, the equivalent quadripole and the boundary conditions on the faces of the multilayer electromagneto elastic actuator.

Structural diagram of multilayer electromagnetoelastic actuator

We received the structural diagram of the multilayer electromagnetoelastic actuator of adaptive optics for composite telescope and astrophysics equipment in difference from Cady's and Mason's electrical equivalent circuits of the piezotransducer and the vibration piezomotor. In this work we used the method of the mathematical physics with Laplace transform for the structural-parametric model and the structural diagram of the multilayer electromagnetoelastic actuator for the adaptive optics of the composite telescope in astronomy.[8,14,19,29,30] We have the equation[8,9,11,24,29,31] of the electromagnetoelasticity in the form

$S_i = v_{mi}\Psi_m + s_{ij}^{\Psi}T_j$ where S_i is the relative displacement, v_{mi} is the coefficient of electromagnetoelasticity in the form d_{mi} piezomodule or magnetostrictive coefficient, Ψ_m is control parameter in variables: electric E_m, magnetic H_m field strengths or electric D_m induction, s_{ij}^{Ψ} is the elastic compliance with $\Psi = \text{const}$, T_j is the mechanical stress, i, j, m are the indexes.

For the multilayer electromagnetoelastic actuator we received the equation of the causes force in the form

$$F = v_{mi}S_0\Psi_m \Big/ s_{ij}^{\Psi}$$

where S_0 is the cross sectional area of the multilayer electromagnetoelastic actuator. The matrix the equivalent quadripole of the multilayer piezoactuator[29,31] has the form

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

where l is the length for longitudinal $l = n\delta$, for transverse $l = nh$ and for shift piezoeffect $l = nb$, for the piezolayer δ, h, b are the thickness, the height, the width, γ is the coefficient propagation.

We obtained the structural-parametric model and the structural diagram of the multilayer electromagnetoelastic actuator of adaptive optics for composite telescope and astrophysics equipment on Figure 1 from the equation of the force that causes deformation, the equivalent quadripole and the boundary conditions with the forces on faces of the actuator in the following form

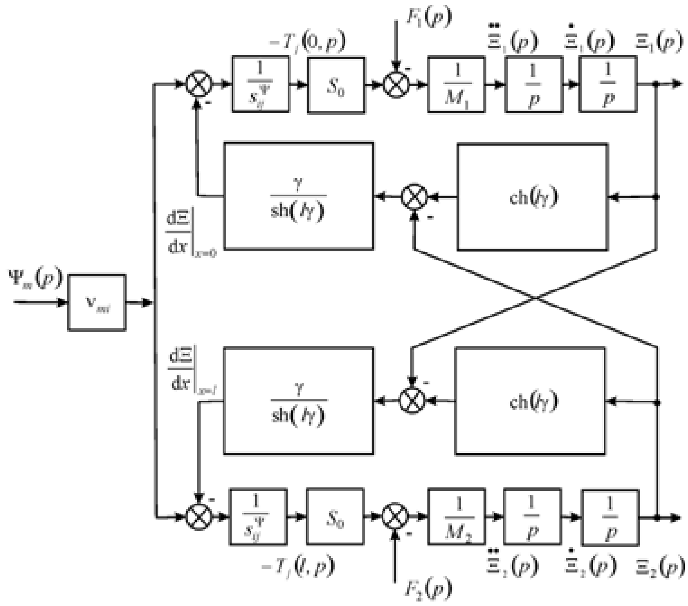

Figure 1 Structural diagram of multilayer electromagnetoelastic actuator for adaptive optics.

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

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

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

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

We have the matrix transfer function of the multilayer electromagnetoelastic actuator of adaptive optics for composite telescope and astrophysics equipment from the generalized structural-parametric model in the form

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

where $\left[\Xi(p)\right]$, $\left[W(p)\right]$, $\left[P(p)\right]$ are the matrixes of the displacements the faces, the transfer functions, the control parameters.

In the static we obtained displacements for $t \to \infty$ the faces of the voltage-controlled multilayer piezoactuator for the longitudinal piezoeffect and the inertial load at $m << M_1$, $m << M_2$, where m is the mass of the multilayer piezoactuator, M_1, M_2 are the load masses, and the forces on faces $F_1(t) = F_2(t) = 0$, in the following form

$$\xi_1(\infty) = \lim_{p \to 0} pW_{11}(p)\left(U/\delta\right)\big/ p = d_{33} nUM_2 \big/ \left(M_1 + M_2\right)$$

$$\xi_2(\infty) = \lim_{p \to 0} pW_{21}(p)\left(U/\delta\right)\big/ p = d_{33} nUM_1 \big/ \left(M_1 + M_2\right)$$

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

where U is the voltage.

For the multilayer piezoactuator at $d_{33} = 4 \cdot 10^{-10}$ m/V, n =16, U =100 V, M_1 =1 kg and M_2 =4 kg we obtained the static displacements of the faces the multilayer piezoactuator $\xi_1(\infty)$=512 nm, $\xi_2(\infty)$ =128 nm, $\xi_1(\infty) + \xi_2(\infty)$=640 nm.

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

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

$$T_t = \sqrt{M_2 / \left(C_e + C_{33}^E\right)}$$

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

where $\Xi_2(p)$, $U(p)$ are the Laplace transforms the displacement face and the voltage, T_t, ξ_t are the time constant and the damping coefficient, $C_{33}^E = S_0 / \left(s_{33}^E n\delta\right)$ is the rigidity of the multilayer piezoactuator for $E = \text{const}$.

At the elastic-inertial load for d_{33} =4·10^{-10} m/V, n =12, U =200V, M_2 =4 kg, C_{33}^E = 2·10^7 N/m, C_e =0.4·10^7 N/m we received the steady-state value of the displacement of the multilayer piezoactuator ξ_2 =800 nm and the time constant T_t =0.4·10^{-3} s.

Conclusion

The structural-parametric model, structural diagram and the matrix transfer function of the multilayer electromagnetoelastic actuator of adaptive optics for composite telescope and astrophysics equipment are obtained. The static and dynamic characteristics of the multilayer actuator are received with using the matrix transfer function of the multilayer electromagnetoelastic actuator.

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Conflicts of interest

The author declares there is no conflict of interest.

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