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Calculation of the deformation of an electromagnetoelastic actuator for composite telescope and astrophysics equipment

Abstract

In this paper we have determined the deformation of an electromagnetoelastic actuator for composite telescope and astrophysics equipment. In the visibility of energy conversion the structural schema of an electromagnetoelastic actuator has a difference from Cady and Mason electrical equivalent circuits of a piezo vibrator. The matrix equation and the matrix transfer function of an electromagnetoelastic actuator are received.

Keywords: electromagnetoelastic actuator, piezo actuator, deformation, structural schema, matrix equation

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Introduction

In astrophysics research an electromagnetoelastic actuator in the form of piezo engine or magnetostriction actuator is used for composite telescope, astrophysics equipment and adaptive laser system.[1–6] The piezo actuator is applied for optical–mechanical device, adaptive optics system, fiber–optic system, scanning microscopy.[5–14] For an electromagnetoelastic actuator the electromagnetoelasticity equation and the ordinary differential equation of the second order are solved to obtain the structural schema of an actuator. In the visibility of energy conversion the structural schema of an electromagnetoelastic actuator has a difference from Cady and Mason electrical equivalent circuits of a piezo vibrator. By applying the methods of electromagnetoelasticity the structural schema of an electromagnetoelastic actuator for composite telescope and astrophysics equipment is obtained.[4–12]

Deformation of engine

The equation electromagnetoelasticity of an electromagnetoelastic actuator for composite telescope and astrophysics equipment[1–30] has the form

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

where S_i, d_{mi}, Ψ_m, s_{ij}^{Ψ} and T_j are the relative deformation, the module, the control parameter or the intensity of field, the elastic compliance, and the mechanical intensity.

In static the mechanical characteristic[3–44] of an electromagnetoelastic actuator has the form

$$S_i\big|_{\Psi=\text{const}} = d_{mi}\Psi_m\big|_{\Psi=\text{const}} + s_{ij}^{\Psi} T_j$$

the regulation characteristic an actuator has the form

$$S_i\big|_{T=\text{const}} = d_{mi}\Psi_m + s_{ij}^{\Psi} T_j\big|_{T=\text{const}}$$

The mechanical characteristic of an electromagnetoelastic actuator has the form

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

$$\Delta l_{\max} = d_{mi}\Psi_m l \, , \; F_{\max} = d_{mi}\Psi_m S_0 / s_{ij}^{\Psi}$$

For the the transverse piezo actuator after transforms the maximum values of deformation and force have the form

$$\Delta h_{\max} = d_{31}E_3 h \, , \; F_{\max} = d_{31}E_3 S_0 \big/ s_{11}^{E}$$

At d_{31} = 2·10^{-10} m/V, E_3 = 1·10^5 V/m, h = 2.5·10^{-2} m, S_0 = 1.5·10^{-5} m^2, s_{11}^{E} = 15·10^{-12} m^2/N the maximum values of deformation and force for the transverse piezo actuator are found $\Delta h_{\max}$ = 500 nm and $F_{\max}$ = 20 N.

The regulation characteristic at elastic load of an electromagnetoelastic actuator for composite telescope and astrophysics equipment is obtained in the form

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

The equation of the deformation at elastic load of an electromagnetoelastic actuator for composite telescope and astrophysics equipment has the form

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

After transforms the equation of the deformation at elastic load for the transverse piezo actuator has the form

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

where k_{31}^{U} is the transfer coefficient.

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At $d_{31} = 2 \cdot 10^{-10}$ m/V, $h/\delta = 16$, $C_{11}^{E} = 2.8 \cdot 10^{7}$ N/m, $C_e = 0.4 \cdot 10^{7}$ N/m, $U = 150$ V the transfer coefficient and the deformation of the transverse piezo actuator are obtained $k_{31}^{U} = 2.8$ nm/V and $\Delta h = 420$ nm. Theoretical and practical parameters of the piezo actuator are coincidences with an error of 10%.

The ordinary differential equation of the second order for an electromagnetoelastic actuator for composite telescope and astrophysics equipment has the form[4–37]

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

$$\gamma = p/c^{\Psi} + \alpha$$

where $\Xi(x,p)$, p, γ, c^{Ψ}, α are the transform of Laplace for displacement, the operator of transform, the coefficient of wave propagation, the speed of sound and the coefficient of attenuation,

The decision of the ordinary differential equation of the second order for an electromagnetoelastic actuator has the form

$$\Xi(x,p) = Ce^{-x\gamma} + Be^{x\gamma}$$

The coefficients C, B have the form

$$C = \left(\Xi_1 e^{l\gamma} - \Xi_2\right)/\left[2\operatorname{sh}(l\gamma)\right]$$

$$B = \left(\Xi_2 - \Xi_1 e^{-l\gamma}\right)/\left[2\operatorname{sh}(l\gamma)\right]$$

where $\Xi_1(p)$, $\Xi_2(p)$ are the transforms Laplace of displacements for faces 1 and 2 for an actuator.

In dynamic the system of the equations for the transforms Laplace of forces on faces of an electromagnetoelastic actuator is received[10–42]

$$M_1 p^2 \Xi_1(p) + F_1(p) = S_0 T_j(0,p)$$

$$-M_2 p^2 \Xi_2(p) - F_2(p) = S_0 T_j(l,p)$$

where M_1, M_2, $F_1(p)$, $F_2(p)$, $T_j(0,p)$, $T_j(l,p)$, S_0 are the masses of the loads, the transforms Laplace of forces and stress on faces 1 and 2, the area of an actuator.

The system of the equations the transforms Laplace of stresses on faces of an actuator has the form

$$T_j(0,p) = \frac{1}{s_{ij}^{\Psi}}\frac{d\Xi(0,p)}{dx} - \frac{d_{mi}}{s_{ij}^{\Psi}}\Psi_m(p)$$

$$T_j(l,p) = \frac{1}{s_{ij}^{\Psi}}\frac{d\Xi(l,p)}{dx} - \frac{d_{mi}}{s_{ij}^{\Psi}}\Psi_m(p)$$

After transforms the system of the equations for the structural schema on Figure 1 and model of an electromagnetoelastic actuator for composite telescope and astrophysics equipment has the form

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

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

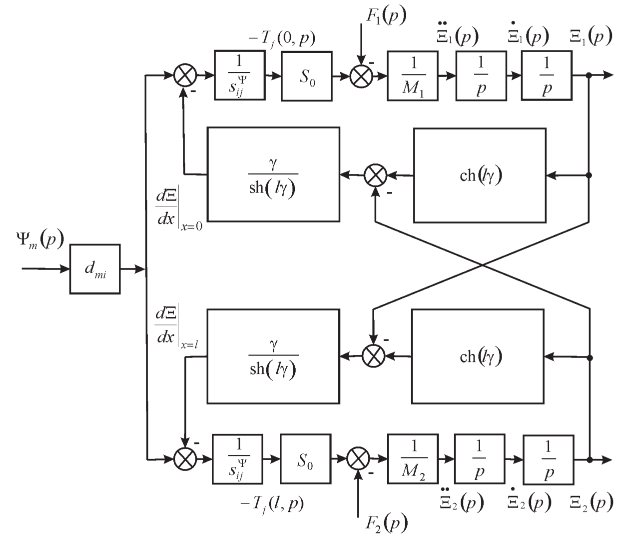

Figure 1 Structural schema of an electromagnetoelastic actuator for composite telescope and astrophysics equipment.

where $\chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0$, $d_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ d_{33}, d_{31}, d_{15} \end{cases}$, $\Psi_m = \begin{cases} E_3, E_1 \\ H_3, H_1 \end{cases}$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^{E}, s_{11}^{E}, s_{55}^{E} \\ s_{33}^{H}, s_{11}^{H}, s_{55}^{H} \end{cases}$, $\gamma = \begin{cases} \gamma^{E} \\ \gamma^{H} \end{cases}$, E and H are the intensity of electric field and the intensity of magnetic field in an actuator.

The structural schema of an electromagnetoelastic actuator replaces Cady and Mason electrical equivalent circuits.[5–10]

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

$$\begin{pmatrix} \Xi_1(p) \\ \Xi_2(p) \end{pmatrix} = \begin{pmatrix} W_{11}(p) & W_{12}(p) & W_{13}(p) \\ W_{21}(p) & W_{22}(p) & W_{23}(p) \end{pmatrix} \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix}$$

From the matrix equation of an electromagnetoelastic actuator at the inertial load the steady–state deformations in the form $\xi_1(\infty)$, $\xi_2(\infty)$ of an actuator have the form

$$\xi_1(t)\big|_{t\to\infty} = \xi_1(\infty) = d_{mi}\Psi_m l M_2/(M_1 + M_2)$$

$$\xi_2(t)\big|_{t\to\infty} = \xi_2(\infty) = d_{mi}\Psi_m l M_1/(M_1 + M_2)$$

Therefore, after transforms the steady–state deformations of the transverse piezo actuator at the inertial load have the form

$$\xi_1(\infty) = d_{31}(h/\delta)UM_2/(M_1 + M_2)$$

$$\xi_2(\infty) = d_{31}(h/\delta)UM_1/(M_1 + M_2)$$

Therefore, at $d_{31} = 2 \cdot 10^{-10}$ m/V, $h/\delta = 20$, $U = 250$ V, $M_1 = 2$ kg and $M_2 = 8$ kg the deformations of the transverse piezo actuator

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are received $\xi_1\left(\infty\right)$ = 800 nm, $\xi_2\left(\infty\right)$ = 200 nm, $\xi_1\left(\propto\right)+\xi_2\left(\propto\right)$ = 1000 nm.

Conclusion

In the article the deformation of an electromagnetoelastic actuator for composite telescope and astrophysics equipment is obtained. The structural schema of an electromagnetoelastic actuator is shown. In the visibility of energy conversion the structural schema of an electromagnetoelastic actuator has a difference from Cady and Mason electrical equivalent circuits of a piezo vibrator. From the equation electromagnetoelasticity and the ordinary differential equation of the second order the structural schema of an electromagnetoelastic actuator is received. The matrix equation and the matrix transfer function of an electromagnetoelastic actuator for composite telescope and astrophysics equipment are found.

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Conflicts of interest

Author declares there is no conflict of interest.

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