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Structural model of a piezo engine for composite telescope

Abstract

The structural model of a piezo engine for composite telescope is constructed. This structural model clearly shows the conversion of electrical energy by a piezo engine into mechanical energy of the control element of a composite telescope. The structural scheme of a piezo engine is determined. For the control systems with a piezo engine its deformations are obtained in the matrix form. This structural model, structural scheme and matrix equation of a piezo engine are applied in calculation the parameters of the control systems for composite telescope.

Keywords: Piezo engine, Structural model, Structural scheme, Matrix equation, Deformation, Composite telescope

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Introduction

A piezo engine based on the piezoelectric effect is used in the control systems for composite telescope and adaptive optics.[1–14] A piezo engine is applied for precise adjustment, compensation the deformations of composite telescope and scanning microscope.[15–21] For decisions the displacements and the forces of a piezo engine in the control systems for composite telescope is used the structural model of a piezo engine. The structural model clearly shows the conversion of electrical energy by a piezo engine into mechanical energy of the control element of a composite telescope with using the physical parameters of a engine and its load.[16–28] The structural model and the structural scheme of a piezo engine for composite telescope are determined in difference from Cady's and Mason's electrical equivalent circuits of a piezo transducer.[7–28]

Structural scheme of a piezo engine

The matrix state equations [8, 11–17] of a piezo engine have the form

$$(D)=(d)(T)+(\varepsilon^T)(E)$$
$$(S)=(s^E)(T)+(d)^t(E)$$

where (D), (S), (T), (E) are the matrices of electric induction, relative deformation, mechanical field and electric field stresses, and t is transpose operator. For PZT engine the matrices have the form

$$(d)=\begin{pmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{15} & 0 & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 \end{pmatrix}$$

$$(d)^t=\begin{pmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{31} \\ 0 & 0 & d_{33} \\ 0 & d_{15} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$(\varepsilon^T)=\begin{pmatrix} \varepsilon_{11}^T & 0 & 0 \\ 0 & \varepsilon_{22}^T & 0 \\ 0 & 0 & \varepsilon_{33}^T \end{pmatrix}$$

$$(s^E)=\begin{pmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 \\ s_{12}^E & s_{11}^E & s_{13}^E & 0 & 0 & 0 \\ s_{13}^E & s_{13}^E & s_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{55}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(s_{11}^E - s_{12}^E) \end{pmatrix}$$

The equation of the reverse piezo effect [8–51] has the form

$$S_i = d_{mi}E_m + s_{ij}^E T_j$$

where m, i, j are axises.

For the longitudinal piezo engine on Figure 1 its parameters are determined in the form

$$\Delta\delta_{\max} = d_{33}E_3\delta = d_{33}U \;,\; F_{\max} = d_{33}E_3S_0/s_{33}^E$$

At d_{33} = $4\cdot10^{-10}$ m/V, E_3 = $0.8\cdot10^5$ V/m, δ = $2.5\cdot10^{-3}$ m, S_0 = $1.5\cdot10^{-4}$ m², s_{33}^E = $15\cdot10^{-12}$ m²/N its maximum values of deformation and force are received in the form $\Delta\delta_{\max}$ = 80 nm, $F_{\max}$ = 320 N with error 10%.

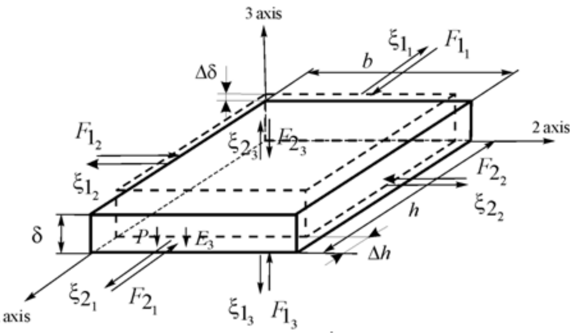

Figure 1 A piezo engine for composite telescope.

The differential equation for a piezo engine has the form[11–51]

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

where x, s, γ are coordinate, operator and coefficient.

Its solution has form

$$\Xi(x,s) = \{\Xi_1(s)\operatorname{sh}[(l-x)\gamma] + \Xi_2(s)\operatorname{sh}(x\gamma)\}/\operatorname{sh}(l\gamma)$$

For the stresses acting on two faces a piezo engine its transforms of Laplace have the form

$$T_j(0,s) = \frac{1}{s_{ij}^{\Psi}}\left.\frac{d\Xi(x,s)}{dx}\right|_{x=0} - \frac{d_{mi}}{s_{ij}^{\Psi}}\Psi_m(s)$$

$$T_j(l,s) = \frac{1}{s_{ij}^{\Psi}}\left.\frac{d\Xi(x,s)}{dx}\right|_{x=l} - \frac{d_{mi}}{s_{ij}^{\Psi}}\Psi_m(s)$$

where $\Psi = E$ or $\Psi = D$.

For the structural model and scheme of a piezo engine for composite telescope on Figure 2 its equations have the form

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

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

where $v_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15}\end{cases}$, $\Psi_m = \begin{cases} E_3, E_1 \\ D_3, D_1\end{cases}$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D\end{cases}$, $l = \{\delta, h, b$, $\gamma = \{\gamma^E, \gamma^D$, $c^{\Psi} = \{c^E, c^D$, $\chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0$, v_{mi} is the piezo coefficient.

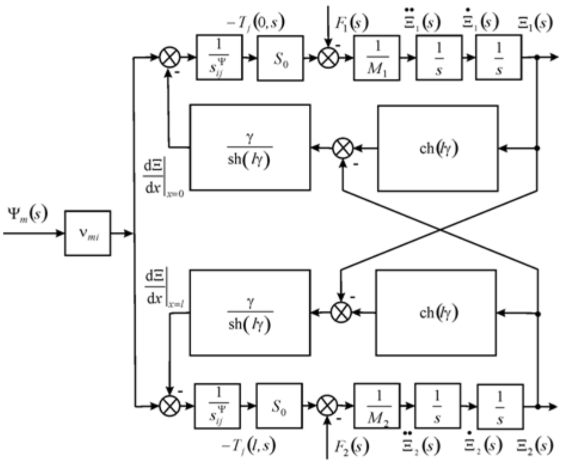

Figure 2 Structural scheme of a piezo engine for composite telescope.

Therefore, the matrix equation of a piezo engine has the form

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

The steady–state displacements of faces 1 and 2 for the longitudinal piezo engine have the form.

$$\xi_1(\infty) = d_{33}UM_2/(M_1 + M_2)$$

$$\xi_2(\infty) = d_{33}UM_1/(M_1 + M_2)$$

At $d_{33} = 4\cdot10^{-10}$ m/V, $U = 250$ V, $M_1 = 1$ kg and $M_2 = 4$ kg its displacements are obtained $\xi_1(\infty) = 80$ nm, $\xi_2(\infty) = 20$ nm, $\xi_1(\infty) + \xi_2(\infty) = 100$ nm with error 10%.

For the transverse piezo engine at elastic–inertial load the expression has the form

$$W(s) = \frac{\Xi(s)}{U(s)} = \frac{d_{31}h/\delta}{\left(1 + C_l/C_{11}^E\right)\left(T_t^2 p^2 + 2T_t\xi_t p + 1\right)}$$

$$T_t = \sqrt{M/\left(C_l + C_{11}^E\right)}, \quad \omega_t = 1/T_t$$

where C_l, C_{11}^E are the stiffness of load and engine, T_t, ξ_t, ω_t are the time constant, the attenuation coefficient and the conjugate frequency of the engine. At $M = 3$ kg, $C_l = 0.2\cdot10^7$ N/m, $C_{11}^E = 1\cdot10^7$ N/m its parameters are determined in the form the time constant $T_t = 0.5\cdot10^{-3}$ s and the conjugate frequency of the engine $\omega_t = 2\cdot10^3$ s^{-1} with error 10%.

Conclusion

The structural model of a piezo engine for composite telescope is obtained. The structural model clearly shows the conversion of electrical energy by a piezo engine into mechanical energy of the control element of a composite telescope using the physical parameters of a piezo engine and its load. The structural scheme of a piezo engine for composite telescope is determined.

The matrix equation of a piezo engine is received for the calculation its displacements and parameters. The structural model, the structural scheme and the matrix equation of a piezo engine are used in decisions of the control systems for composite telescope.

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None.

Conflicts of Interset

None.

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