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Piezoactuator of nanodisplacement for astrophysics

Abstract

The structural scheme of a piezoactuator is obtained for astrophysics. The matrix equation is constructed for a piezoactuator. The characteristics of a piezoactuator are received for astrophysics.

Keywords: piezoactuator, structural scheme, nanodisplacement, characteristic, astrophysics

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Introduction

For the control system in astrophysics a piezoactuator of the nanodisplacement is applied in very large telescope, interferometer and orbital telescope.[1–9] The energy conversion is clearly for the structural scheme of a piezoactuator.[10–16] A piezoactuator is used for the nanodisplacement in adaptive optics and telescopes.[17–26]

Structural scheme and characteristics

The equations[27–35] of the piezoeffects have form

$$(D)=(d)(T)+\left(\varepsilon^T\right)(E)$$

$$(S)=\left(s^E\right)(T)+(d)^t(E)$$

where (D), (d), (T), $\left(\varepsilon^T\right)$, (E), (S), $\left(s^E\right)$, $(d)^t$ are matrixes of electric induction, piezomodule, strength mechanical field, dielectric constant, strength electric field, relative displacement, elastic compliance, transposed piezomodule. The matrixes coefficients we have for a PZT piezoactuator.[36–52]

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

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

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

The equation of the mechanical characteristic is written for a piezoactuator

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

where $\Delta l_{\max}=d_{mi}E_m l$ for $F=0$ and $F_{\max}=d_{mi}E_m S_0/s_{ij}^E$ for $\Delta l=0$, l is the length, S_0 is the area of a piezoactuator.

For the longitudinal piezoactuator the relative displacement[8–21] is written

$$S_3=d_{33}E_3+s_{33}^E T_3$$

where d_{33} is the longitudinal piezomodule.

In the mechanical characteristic of the longitudinal piezoactuator for astrophysics the maximums values of the displacement $\Delta\delta_{\max}$ and the force $F_{\max}$ are determined

$$\Delta\delta_{\max}=d_{33}\delta E_3=d_{33}U\ ,\ F_{\max}=d_{33}S_0E_3/s_{33}^E$$

At $E_3 = 1.5\cdot10^{5}$ V/m, $d_{33} = 4\cdot10^{-10}$ m/V, $S_0 = 1.5\cdot10^{-4}$ m^2, $\delta = 2.5\cdot10^{-3}$ m, $s_{33}^E = 15\cdot10^{-12}$ m^2/N for the longitudinal piezoactuator are obtained $\Delta\delta_{\max} = 150$ nm, $F_{\max} = 600$ N with error 10%.

Therefore, for the mechanical characteristic of the transverse piezoactuator we have its maximums values

$$\Delta h_{\max}=d_{31}E_3h=d_{31}Uh/\delta\ ,F_{\max}=d_{31}E_3S_0/s_{11}^E$$

At $E_3 = 2.4\cdot10^{5}$ V/m, $d_{31} = 2\cdot10^{-10}$ m/V, $h = 1\cdot10^{-2}$ m, $\delta = 0.5\cdot10^{-3}$ m, $S_0 = 1\cdot10^{-5}$ m^2, $s_{11}^E = 12\cdot10^{-12}$ m^2/N the parameters are received $\Delta h_{\max} = 480$ nm, $F_{\max} = 40$ N.

The differential equation of a piezoactuator[12–52] is written

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

here $\Xi(x,s)$, s, x, γ are the Laplace transform of the displacement, the parameter, the coordinate and the propagation factor.

The nanodisplacements are obtained for the longitudinal piezoactuator

$$\Xi(0,s)=\Xi_1(s)\ \text{for}\ x=0$$

$$\Xi(\delta,s)=\Xi_2(s)\ \text{for}\ x=\delta$$

The decision of the differential equation is determined

$$\Xi(x,s)=\left\{\Xi_1(s)\mathrm{sh}\left[(\delta-x)\gamma\right]+\Xi_2(s)\mathrm{sh}(x\gamma)\right\}/\mathrm{sh}(\delta\gamma)$$

Taking into account the boundary conditions for two faces, we obtain the system of the equations for the structural model of the longitudinal piezoactuator.

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{-F_1(s)+\left(\chi_{33}^E\right)^{-1}\begin{bmatrix} d_{33}E_3(s)-[\gamma/\mathrm{sh}(\delta\gamma)] \\ \times[\mathrm{ch}(\delta\gamma)\Xi_1(s)-\Xi_2(s)]\end{bmatrix}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{-F_2(s)+\left(\chi_{33}^E\right)^{-1}\begin{bmatrix} d_{33}E_3(s)-[\gamma/\mathrm{sh}(\delta\gamma)] \\ \times[\mathrm{ch}(\delta\gamma)\Xi_2(s)-\Xi_1(s)]\end{bmatrix}\right\}$$

$$\chi_{33}^E=s_{33}^E/S_0$$

where $\Xi_1(s)$, $\Xi_2(s)$ are the Laplace transforms of the displacements for two faces.

We have the system of the equations for the structural model of the transverse piezoactuator

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{-F_1(s)+\left(\chi_{11}^E\right)^{-1}\begin{bmatrix} d_{31}E_3(s)-[\gamma/\mathrm{sh}(h\gamma)] \\ \times[\mathrm{ch}(h\gamma)\Xi_1(s)-\Xi_2(s)]\end{bmatrix}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{-F_2(s)+\left(\chi_{11}^E\right)^{-1}\begin{bmatrix} d_{31}E_3(s)-[\gamma/\mathrm{sh}(h\gamma)] \\ \times[\mathrm{ch}(h\gamma)\Xi_2(s)-\Xi_1(s)]\end{bmatrix}\right\}$$

$$\chi_{11}^E=s_{11}^E/S_0$$

Therefore, we have the system of the equations for the structural model of the shift piezoactuator in the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{-F_1(s)+\left(\chi_{55}^E\right)^{-1}\begin{bmatrix} d_{15}E_1(s)-[\gamma/\mathrm{sh}(b\gamma)] \\ \times[\mathrm{ch}(b\gamma)\Xi_1(s)-\Xi_2(s)]\end{bmatrix}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{-F_2(s)+\left(\chi_{55}^E\right)^{-1}\begin{bmatrix} d_{15}E_1(s)-[\gamma/\mathrm{sh}(b\gamma)] \\ \times[\mathrm{ch}(b\gamma)\Xi_2(s)-\Xi_1(s)]\end{bmatrix}\right\}$$

$$\chi_{55}^E=s_{55}^E/S_0$$

The system of the equations for the structural model of a piezoactuator is determined for Figure 1.

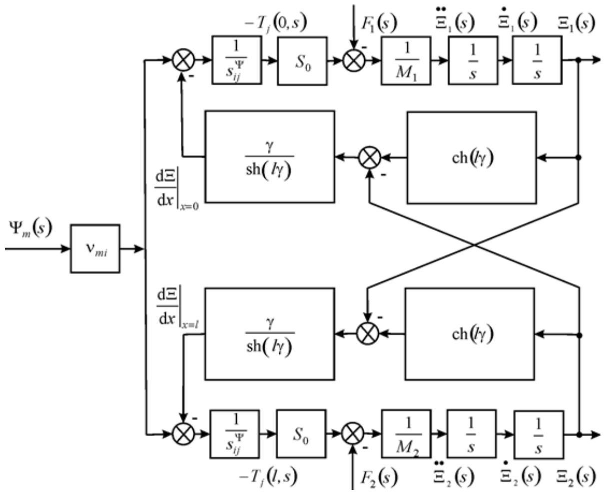

Figure 1 Structural scheme of piezoactuator.

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{-F_1(s)+\left(\chi_{ij}^{\Psi}\right)^{-1}\begin{bmatrix} \nu_{mi}\Psi_m(s)-[\gamma/\mathrm{sh}(l\gamma)] \\ \times[\mathrm{ch}(l\gamma)\Xi_1(s)-\Xi_2(s)]\end{bmatrix}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{-F_2(s)+\left(\chi_{ij}^{\Psi}\right)^{-1}\begin{bmatrix} \nu_{mi}\Psi_m(s)-[\gamma/\mathrm{sh}(l\gamma)] \\ \times[\mathrm{ch}(l\gamma)\Xi_2(s)-\Xi_1(s)]\end{bmatrix}\right\}$$

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

where

$$\nu_{mi}=\begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15}\end{cases}$$

$$\Psi_m=\begin{cases} E_3, E_3, E_1 \\ D_3, D_3, D_1\end{cases}$$

$$s_{ij}^{\Psi}=\begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D\end{cases}$$

$$l=\{\delta, h, b$$

$$\gamma=\{\gamma^E, \gamma^D$$

$$c^{\Psi}=\{c^E, c^D$$

The structural scheme on Figure 1 is used for the decision of a piezoactuator in astrophysics. The matrix of the nanodisplacement of a piezoactuator 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 nanodisplacements are written for two faces of a piezoactuator

$$\xi_1=d_{mi}\Psi_m lM_2/(M_1+M_2)$$
$$\xi_2=d_{mi}\Psi_m lM_1/(M_1+M_2)$$

The steady-state nanodisplacements are obtained for two faces of the longitudinal piezoactuator

$$\xi_1=d_{33}UM_2/(M_1+M_2)$$
$$\xi_2=d_{33}UM_1/(M_1+M_2)$$

At U = 75 V, M_1 = 1 kg, M_2 = 4 kg, d_{33}= 4·10^{-10} m/V the steady-state nanodisplacements are determined ξ_1 = 24 nm, ξ_2 = 6 nm and $\xi_1+\xi_2$ = 30 nm with error 10%.

The transfer equation of the transverse piezoactuator is determined at one the fixed face and the elastic-inertial load

$$W(s)=\frac{\Xi(s)}{U(s)}=\frac{k_{31}^E}{T_t^2s^2+2T_t\xi_t s+1}$$

$$k_{31}^E=d_{31}(h/\delta)/\left(1+C_l/C_{11}^E\right)$$

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

where k_{31}^E is the transfer coefficient, C_l, C_1^E are the stiffness for the load and the transverse piezoactuator, T_t, ξ_t, ω_t are the time constant, the attenuation coefficient, the conjugate frequency.

At C_l = 0,2·10^7 N/m, C_{11}^E = 1.4·10^7 N/m, M = 2 kg the parameters are obtained T_t = 0.354·10^{-3} s, ω_t = 2.8·10^3 s^{-1} with error 10%.

The steady-state nanodisplacement of the transverse piezoactuator is written for elastic-inertial load.

$$\Delta h=\frac{d_{31}(h/\delta)U}{1+C_l/C_{11}^E}=k_{31}^E U$$

At $h/\delta = 20$, $C_l/C_{11}^E = 0.14$, $d_{31} = 2\cdot10^{-10}$ m/V the transfer coefficient of the transverse piezoactuator is received $k_{31}^E = 3.5$ nm/V with error 10%.

Conclusions

The structural scheme of a piezoactuator is constructed for astrophysics. The matrix of the nanodisplacement of a piezoactuator is obtained. The characteristics of a piezoactuator are determined.

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Conflict of interest

The Authors declares that there is no Conflict of interest.

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