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An actuator nano and micro displacements for composite telescope in astronomy and physics research

Abstract

We obtained the deformation, the structural diagram, the transfer functions and the characteristics of the actuator nano and micro displacements for composite telescope in astronomy and physics research. The mechanical and regulation characteristics of the actuator are received.

Keywords: actuator nano and micro displacements, piezo actuator, deformation, transfer function, regulation characteristic, mechanical characteristic, nano and micro displacements, composite telescope

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Introduction

The electromagnetoelastic actuator nano and micro displacements at the piezoelectric, electrostriction, magnetostriction, piezomagnetic effects is used for the control system the adaptive optics of the composite telescope and the interferometer. The multilayer actuator is increased the range of the displacement from nm to tens microns.[6–31] The structural model and the structural diagram of the multilayer actuator are determined by using the equation of the electromagnetoelasticity, the differential equation and the boundary conditions of the actuator. The piezo actuator is applied in adaptive optics for composite telescope, laser systems, interferometry, scanning microscopy, nano manipulators for physics and astronomy research The electromagnetoelastic actuator is provided displacement from 1 nm to 20 µm, force 10-1000 N, response 1-10 ms.[11–31]

Deformation and structural diagram of actuator

The structural diagram of the actuator for composite telescope is obtained in difference from Cady's and Mason's electrical equivalent circuits of the piezo transducer. Electromagnetoelasticity equation has the form of the equation of reverse effect for the deformation of the actuator

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

where S_i, ν_{mi}, Ψ_m, s_{ij}^{Ψ}, T_j are the relative deformation; the module; the control parameter; the elastic compliance; the mechanical stress.[10–25] The second order linear ordinary differential equation for the actuator.[10–25,28] has the form

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

where $\Xi(x,p)$ is transform of Laplace the displacement, p, γ, x are the parameter of transform, the propagation coefficient, the coordinate. For the structural diagram on Figure 1 and the structural model of the actuator for composite telescopes in astronomy and physics research the system of equations has the form

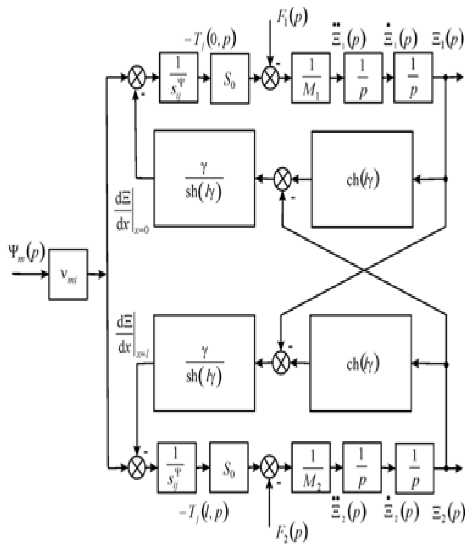

Figure 1 Structural diagram of actuator for composite telescopes in astronomy and physics research.

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

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

where $\chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0$, $\nu_{mi} = \left\{ \begin{array}{l} d_{33}, d_{31}, d_{15} \\ d_{33}, d_{31}, d_{15} \end{array} \right.$, $\Psi_m = \left\{ \begin{array}{l} E_3, E_1 \\ H_3, H_1 \end{array} \right.$, $s_{ij}^{\Psi} = \left\{ \begin{array}{l} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^H, s_{11}^H, s_{55}^H \end{array} \right.$, E, H are the strengths of the electric and magnetic fields.

Therefore, the system of the equations for the structural model of the actuator has the form

$$\Xi_1(p)=\left(1/\left(M_1p^2\right)\right)\times\left\{\begin{array}{l}-F_1(p)+C_{ij}^{\Psi}l\\ \times\left[\begin{array}{l}\nu_{mi}\Psi_m(p)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\\ \times\left[\mathrm{ch}(l\gamma)\Xi_1(p)-\Xi_2(p)\right]\end{array}\right]\end{array}\right\};$$

$$\Xi_2(p)=\left(1/\left(M_2p^2\right)\right)\times\left\{\begin{array}{l}-F_2(p)+C_{ij}^{\Psi}l\\ \times\left[\begin{array}{l}\nu_{mi}\Psi_m(p)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\\ \times\left[\mathrm{ch}(l\gamma)\Xi_2(p)-\Xi_1(p)\right]\end{array}\right]\end{array}\right\},$$

where $C_{ij}^{\Psi}=S_0/\left(s_{ij}^{\Psi}l\right)=1/\left(\chi_{ij}^{\Psi}l\right)$ is the stiffness of actuator.

The matrix equation of the actuator has 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 electromagnetoelasticity equation at $F=C_e\Delta l$ the regulation characteristic of the actuator has the form

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

where C_e, F are stiffness and force of the load. Therefore, the regulation characteristic of the actuator has the form:

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

$$C_{ij}^{\Psi}=S_0/\left(s_{ij}^{\Psi}l\right),\ k_{mi}^{\Psi}=d_{mi}\,l/\left(1+C_e/C_{ij}^{\Psi}\right),$$

where C_{ij}^{Ψ}, k_{mi}^{Ψ} are the stiffness and the transfer coefficient of the actuator. The transfer function with lumped parameter of the actuator[7,11–30] has the form:

$$W(p)=\Xi(p)/\Psi_m(p)=k_{mi}^{\Psi}/\left(T_t^2p^2+2T_t\xi_tp+1\right),$$

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

where $\Xi(p)$, $\Psi_m(p)$ are the transforms of the displacement and the control parameter, T_t, ξ_t are the time constant and the damping coefficient of the actuator, M is the load mass. The transfer function with lumped parameter of the transverse piezo actuator[7,11–30] has the form

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

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

where $U(p)$ is the Laplace transform of the voltage and k_{31}^{U} is the transfer coefficient. At d_{31}=2·10^{-10} m/V, l/δ =12, M =1 kg, C_{11}^{E} =3.4·10^{7} N/m, C_e=0.2·10^{7} N/m the transfer coefficient k_{31}^{U} =2.27 nm/V and the time constant T_t =0.17·10^{-3} s are obtained for the transverse piezo actuator from ceramic PZT.

From the electromagnetoelasticity equation at elastic load the regulation characteristic of the multilayer longitudinal piezo actuator is obtained in the following form

$$\Delta l=\frac{d_{33}nU}{1+C_e/C_{33}^{E}}=k_{33}^{U}U,$$

$$k_{33}^{U}=d_{33}n/\left(1+C_e/C_{33}^{E}\right),\ l=n\delta,$$

where k_{33}^{U} is the transfer coefficient.

For the multilayer longitudinal piezo actuator from ceramic PZT at d_{33} =4·10^{-10} m/V, n =6, C_{33}^{E} =4·10^{7} N/m, C_e =0.2·10^{7} N/m, U =100 V are received k_{33}^{U} =2.29 nm/V and Δl =229 nm.

The mechanical characteristic of the actuator has form $S_i(T_j)$ or $\Delta l(F)$ and the regulation line of actuator has form $S_i(\Psi_m)$ or $\Delta l(U)$. The mechanical characteristic is obtained in the following form

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

The regulation characteristic of the actuator has the form

$$S_i\big|_{T=\mathbf{const}}=d_{mi}E_m+s_{ij}^{E}T_j\big|_{T=\mathbf{const}}.$$

The mechanical characteristic of the actuator has the form

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

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

where $\Delta l_{\max}$ is the maximum displacement for $F=0$ and $F_{\max}$ is the maximum force for $\Delta l=0$.

The maximum displacement and the maximum force of the transverse piezo actuator on Figure 2 have the form

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

At d_{31} =2·10^{-10} m/V, E_3= 2·10^{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 parameters of the transverse piezo actuator are found $\Delta h_{\max}$ =1000 nm and $F_{\max}$ =40 N. The discrepancy between the experimental data for the piezo actuators and the calculation results is 10%.

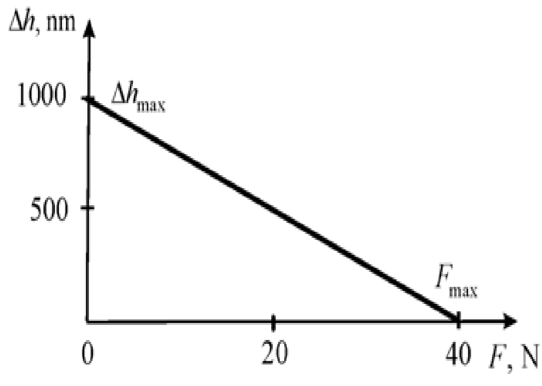

Figure 2 Mechanical characteristic of transverse piezo actuator for composite telescopes in astronomy and physics research.

Conclusion

The regulation characteristic, the transfer function and the structural diagram of the actuator nano and micro displacements are obtained for composite telescope in astronomy and physics research.

The mechanical and regulation characteristics of the actuator nano and micro displacements are found for nano manipulators in physics and astronomy research. The mechanical characteristic of actuator and its maximum displacement and maximum force are obtained. For the elastic load the regulation characteristics of the electromagnetoelastic actuator and the multilayer piezo actuator are calculated.

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None.

Conflicts of interest

The author declares there is no conflict of interest.

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