Research Article
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Control of time constant for multilayer longitudinal piezo engine of nano displacement at elastic inertial load for nano physics and astronomy research

Abstract

The multilayer longitudinal piezo engine of nano displacement is used in laser systems for nano physics, nano mechatronics, and scanning microscopy, adaptive optics, for nano physics and astronomy research the multilayer engine is applied for compensation deformation, alignment, and autofocus. Image stabilization, precise adjustment of a composite telescope mirror, and correction of wave front by using flexible mirror. In static and dynamic regimes its characteristics are founded. The parameters of the multilayer engine of nano displacement in local control system with various negative feedbacks on the displacement and the acceleration are determined.

Keywords: Multilayer longitudinal piezo engine, Time constant, Nano displacement, Elastic inertial load, Nano physics, Astronomy research

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Afonin SM
National Research University of Electronic Technology, Russia

Correspondence: Afonin Sergey Mikhailovich, National Research University of Electronic Technology, MIET, 124498, Moscow, Russia

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Introduction

The multilayer longitudinal piezo engine of nano displacement is used for nano physics, nano mechatronics, astronomy research.[1–25] The multilayer engine is applied for nano physics and astronomy research for scanning microscopy, adaptive optics and laser systems, for compensation deformation, alignment, autofocus. Image stabilization.[3–52]

By using of mathematical physics method for the multilayer engine of nano displacement with lumped parameters at first fixed its end the parameters engine are determined. We are considering the multilayer longitudinal piezo engine of nano displacement at elastic inertial load in local control system for nano physics with various negative feedbacks on the displacement and the acceleration. The multilayer sectional longitudinal piezo engine under the coded control is determined.

Control of time constant for multilayer longitudinal piezo engine

Systems for astronomy research with the multilayer longitudinal piezo engine of nano displacement solve problems of compensation of temperature and gravitational deformations, precise adjustment of a composite telescope mirror, and correction of wave front by using flexible mirror.[1–40] The mathematic model[9–52] of the multilayer longitudinal piezo engine with lumped parameters is constructed by using the inverse longitudinal piezo effect equation

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

here S_3, d_{33}, E_3, s_{33}^E, T_3 are the relative deformation, the piezomodule, the strength electric field, the elastic compliances at $E = \text{const}$ the strength mechanic field for 3 axis.

We have the structural parametric model of the engine at its first fixed end[9–52] and its function at elastic inertial load in the form the second order oscillatory link. In static regime nano displacement Δl for multilayer longitudinal engine has the form

$$\Delta l = d_{33}nU = k_t U$$

here n, U are the number piezo layers, the voltage,

For PZT multilayer longitudinal engine d_{33} = 0.4 nm/V, n = 10, U = 50 V, its displacement is founded Δl = 200 nm. Let us consider multilayer longitudinal piezo engine of nano displacement as element of control system with lumped parameters at elastic inertial load,[18–22,40] where C_{33}^E is the rigidity of the multilayer longitudinal piezo engine, C_e is the rigidity of the elastic load, M the mass of the inertial load. The elastic inertial load has simultaneously the elastic load C_e and the inertial load M.

The model of the multilayer longitudinal piezo engine with lumped parameters is applied in this article for the structural scheme local control system the multilayer longitudinal piezo engine at negative feedback with piezo sensor in form its end multilayer piezo layer for nano physics and astronomy research.

In decisions control systems are used the transfer coefficient k_t and the time constant T_t of the multilayer longitudinal piezo engine with lumped parameters.[18–22] At the inertial load in dynamic regime the function of this engine $W_{mlpe}(s)$ has the form

$$W_{mlpe}(s) = \frac{\Xi(s)}{U(s)} = \frac{k_t}{T_t^2 s^2 + 2T_t\xi_t s + 1}$$

$$k_t = d_{33}n\,,\ T_t = \sqrt{M / C_{33}^E}$$

here $\Xi(s)$, $U(s)$, s, k_t, T_t are the transforms of Laplace the displacement and the voltage, the operator, the transfer coefficient and the time constant.

For the PZT multilayer longitudinal engine at M = 1 kg, C_{33}^E =1.5·10⁷ N/m the time constant T_t =0.26·10⁻³ s is founded.

At elastic load for the multilayer longitudinal piezo engine its nano displacement Δl has the form

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

For the PZT multilayer longitudinal engine d_{33} = 0.4 nm/V, n = 10, U = 50 V, C_e = 0.15·10⁷ N/m, C_{33}^E = 1.5·10⁷ N/m are founded k_t = 3.64 nm/V and Δl =182 nm. The transfer function of the multilayer engine with lumped parameters $W_{mlpe}(s)$ at elastic inertial load and its first fixed end has the form

$$W_{mlpe}(s)=\frac{\Xi(s)}{U(s)}=\frac{k_t}{T_t^2 s^2+2T_t\xi_t s+1}$$

$$k_t=d_{33}n/\left(1+C_e/C_{33}^E\right),\; T_t=\sqrt{M/\left(C_e+C_{33}^E\right)}$$

At the multilayer PZT engine M = 1 kg, C_e = 0.15·10^7 N/m, C_{33}^E = 1.5·10^7 N/m the time constant T_t =0.25·10^{-3} s is founded. The transient characteristic for the displacement of this multilayer longitudinal piezo engine $\xi(t)$ at elastic inertial load has the form

$$\xi(t)=k_t U_m\left(1-\frac{e^{-\frac{\xi_t t}{T_t}}}{\sqrt{1-\xi_t^2}}\sin\left(\omega_t t+\varphi_t\right)\right)$$

here U_m, ω_t, φ_t are the amplitude voltage, the circular frequency, the phase.

The structural scheme local control system for the multilayer longitudinal piezo engine at negative feedback with piezo sensor and its first fixed end with piezo sensor in form its end multilayer piezo layer is constructed in the form on Figure 1. For the negative feedback on the displacement is determined in control system the form $\mathrm{W_{nfcs}}(\mathrm{s})=\mathrm{k_d}$ (Figure 1), the time constant of the multilayer longitudinal piezo engine is corrected in this local control system. Corrected time constant of the multilayer longitudinal piezo engine in local control system with negative feedback on the displacement is determined in the form

$$T_{td}=\frac{T_t}{\sqrt{1+k_t k_d}}$$

here T_{td}, k_d are the time constant of the multilayer engine in control systems with the negative displacement feedback and the coefficient of the displacement sensor.

For the negative acceleration feedback the in control system in the form $W_{nfcs}(s)=k_a s^2$ (Figure 1) the corrected time constant has the form

$$T_{ta}=T_t\sqrt{1+k_t k_a/T_t^2}$$

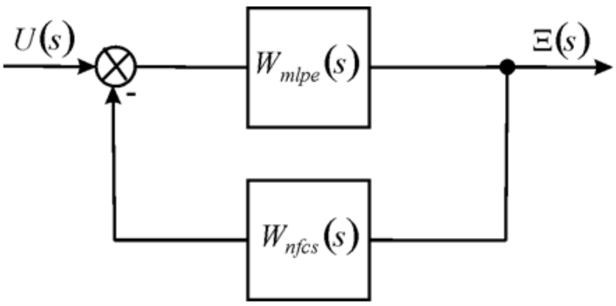

Figure 1 Structural scheme local control system of multilayer longitudinal piezo engine

here T_{ta}, k_a are the corrected time constant and the coefficient of the acceleration sensor.

For negative feedback on the displacement and the acceleration in the form $W_{nfcs}(s)=k_d+k_a s^2$ in Figure 2 the corrected time constant has the form

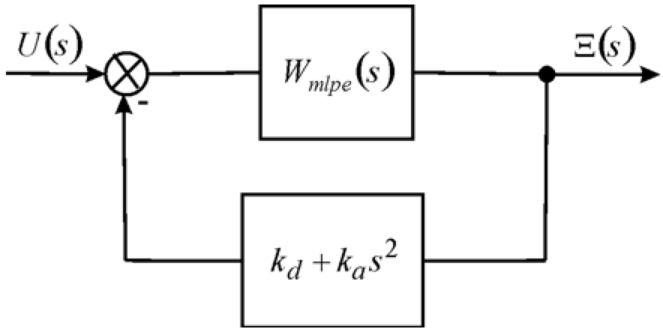

Figure 2 Structural scheme local control system of multilayer longitudinal piezo engine with negative feedbacks on displacement and acceleration

$$T_{tda}=T_t\sqrt{\frac{1+k_t k_a/T_t^2}{1+k_t k_d}}$$

Than $1+k_t k_a/T_t^2=1+k_t k_d$, $k_a/T_t^2=k_d$, $T_{tda}=T_t$

At $1+k_t k_a/T_t^2>1+k_t k_d$, $k_a/T_t^2>k_d$, $T_{tda}>T_t$

At $1+k_t k_a/T_t^2<1+k_t k_d$, $k_a/T_t^2<k_d$, $T_{tda}<T_t$

The parameters of the multilayer longitudinal piezo engine for nano displacement with lumped parameters in local control system with various negative feedbacks on the displacement and the acceleration are determined. For the multilayer piezo engine of nano system in practice the error of the hysteresis deformation can be more 20 %, then the error position more 20 %. In classic researches on Preisach model of hysteresis was used compensation hysteresis with the error to 5% with used the polynomial and hiperbolic functions and sign function.[34–38]

For the corrections hysteresis at the error to 5% we used multilayer sectional piezo engine with code control of sections with the stability voltage for two end voltage and the stability two end main loops of hysteresis with the error to 5 %. In the multilayer sectional piezo engine there are N sections with the number n_k of the piezo layers in the k -th section. Accordingly, the sections of the piezo engine are mechanically connected in series, but electrically isolated. The piezo layers in the section are electrically connected in parallel and mechanically in series.

The equation of the inverse piezo effect[9–52] for the multilayered piezo engine has the form

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

where S_i is the relative deformation of the multilayered piezo engine along the axis i, T_j is the mechanical tension in the piezo engine along the axis, E_m is the electric field strength along the axis m, s_{ij}^E is the elastic compliance with $E=\mathrm{const}$, d_{mi} is the piezomodule, i, j = 1, 2, ..., 6, m = 1, 2, 3 are the indexes.

Let us consider the multilayer sectional longitudinal piezo engine,[9–12] consisting of n piezolayers united in N sections, and n_k number of piezo layers in the k -th section

$$n_k=2^{k-1}$$

length of the k -th section

$$l_k=2^{k-1}\delta$$

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here $k = 1, 2, ..., N$, $l_1 = \delta$ is the length of the first section.

We obtain the total length of the multilayer sectional longitudinal piezo engine

$$l = \sum_{k=1}^{N} l_k = \left(2^N - 1\right)\delta$$

The maximum displacement of the multilayer sectional longitudinal piezo engine has the form

$$\Delta l_{\max} = d_{33}(2^N - 1)U = d_{33} n U$$

here $n = 2^N - 1$ is the number of the piezo layers in the multilayer sectional longitudinal piezo engine.

The displacement of the multilayer sectional longitudinal piezo engine has form.

$$\Delta l = \sum_{k=1}^{N} a_k \Delta l_k$$

here $a_k \in \{0; 1\}$ are digits of the binary code..

Than this displacement

$$\Delta l = \sum_{k=1}^{N} a_k d_{33} 2^{k-1} U = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right) U = d_{33} n_s U$$

here $n_s = \sum_{k=1}^{N} a_k 2^{k-1}$ is the number of the piezo layers of the

multilayer sectional longitudinal piezo engine connected to the voltage source.

Let us consider the mechanical and control characteristics of the multilayer sectional longitudinal piezo engine with the code control. The equation of the mechanical static characteristic of the multilayer sectional longitudinal piezo engine has the form

$$\Delta l = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right) U - s_{33}^E F l / S_0$$

and

$$\Delta l = d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right) U - F / C_{33}^E$$

here $C_{33}^E = S_0 / (s_{33}^E l)$ is the rigidity of the multilayer sectional longitudinal piezo engine.

The equation the mechanical static characteristic of the multilayer sectional longitudinal piezo engine has the form

$$\Delta l = \Delta l_{3\max}\left(1 - F / F_{3\max}\right)$$

$$\Delta l_{3\max} = d_{33} n_s U, \quad F_{3\max} = \frac{d_{33} n_s U S_0}{s_{33}^E l}$$

here $\Delta l_{3\max}$ is the maximum displacement along the axis 3, $F_{3\max}$ is the maximum force along the axis 3,

The adjustment characteristic of the multilayer sectional longitudinal piezo engine at the elastic has the form

$$\Delta l = \frac{d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right) U}{1 + \frac{C_e}{C_{33}^E}} = k_t U$$

here k_t is the transfer coefficient of the of the multilayer sectional longitudinal piezo engine under the code control.

Than the transfer function of the multilayer longitudinal piezo engine under coded control has the form

$$W(s) = \frac{\Xi(s)}{U(s)} = \frac{d_{33} \sum_{k=1}^{N} a_k 2^{k-1}}{\left(1 + \frac{C_e}{C_{33}^E}\right)(T_t^2 s^2 + 2T_t \xi_t s + 1)}$$

and

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

here

$$k_t = \frac{d_{33}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)}{1 + \frac{C_e}{C_{33}^E}}, \quad T_t = \sqrt{M / (C_e + C_{33}^E)}$$

The multilayer sectional longitudinal piezo engine under the code control is determined for nano physics and astronomy research.

Discussion

The model of the multilayer longitudinal piezo engine with lumped parameters for the structural scheme local control system the multilayer longitudinal piezo engine at negative feedback with piezo sensor is obtained for nano physics and astronomy research. The corrected time constants of the multilayer longitudinal piezo engine in local control systems are founded by using negative feedbacks on the displacement and the acceleration.

Conclusion

The multilayer longitudinal piezo engine is used for nano physics, nano mechatronics, scanning microscopy, astronomy research, adaptive optics, autofocus. Image stabilization, precise adjustment of the composite telescope mirror, and correction of wave front by using flexible mirror. The parameters of the PZT multilayer longitudinal engine with lumped parameters are obtained.

The transfer functions and the time constants of the multilayer longitudinal engine are determined. The corrected time constant of the multilayer longitudinal piezo engine with lumped parameters for local control system at negative feedbacks on the displacement and the acceleration are determined for nano physics and astronomy research.

For the corrections hysteresis in nano physics and astronomy research we used multilayer sectional piezo engine under the code control of the sections with the stability two end voltage and the stability two end main loops of hysteresis in the sections.

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