Research article

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Multilayer and sectional nano piezo engine for applied bionics and biomechanics

Abstract

The multilayer nano piezo engine and sectional piezo engine are widely used for applied bionics and biomechanics in nano displacements for scanning microscopy and adaptive optics, compensating for vibrations, temperature and gravitational deformations. The parameters of nano engine are determined by using of mathematical physics method for the multilayer and sectional nano piezo engine with lumped parameters. The characteristics of the multilayer and sectional nano piezo engine are calculated. For static and dynamic regimes the characteristics and the parameters of the multilayer and the sectional nano piezo engine are founded. The transient characteristic for the nano displacement of the multilayer nano piezo engine is obtained. The mechanical and control characteristics of the sectional nano piezo engine are determined for applied bionics and biomechanics.

Keywords: multilayer nano piezo engine, nano displacement, elastic inertial load, time constant, sectional piezo engine, applied bionics and biomechanics

Volume 9 Issue 1 - 2025

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Received: June 13, 2025 | **Published:** June 27, 2025

Introduction

The nano piezo engine is applied in bionics, biomechanics and nanotechnology and nanoscience.[1–62] The multilayer nano piezo engine and sectional piezo engine are widely used for applied bionics and biomechanics in nano moving objects for scanning microscopy, adaptive optics, compensating for vibrations, temperature and gravitational deformations.[3,9,19,50,56–62] The parameters of nano engine are calculated by using of mathematical physics method for the multilayer and sectional nano piezo engine with lumped parameters. The characteristics of the multilayer and sectional nanopiezoelectric motor are determined.

Multilayer nano piezo engine

Systems for applied bionics and biomechanics with the multilayer longitudinal piezo engine of nano displacement solve problems of compensation of temperature and gravitational deformations, precise adjustment and correction of wave front by using adaptive optics and laser systems.[1–49]

The mathematic model[4–49] of the multilayer nano piezo engine with lumped parameters is constructed by using equation of the inverse longitudinal piezo effect

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

here $S_3, d_{33}, E_{33}, s_{33}^E, T_3$ 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 model of the multilayer nano piezo engine at its first fixed end, and its function at elastic inertial load in the form the second order oscillatory link. In static regime nano displacement Δl for the multilayer nano piezo engine has the form

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

here n, U are the number piezo layers, the voltage. At the multilayer nano PZT engine d_{33} = 0.4 nm/V, n = 10, U = 50 V, its nano displacement is founded Δl = 200 nm.

Let us consider the multilayer nano piezo engine as element of system with lumped parameters at inertial load,[4–49] here C_{33}^E is the rigidity of the multilayer piezo engine, M the mass of the inertial load.

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

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

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

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.

At the multilayer nano PZT engine at M = 1 kg, $C_{33}^E = 1.5 \cdot 10^7$ N/m the time constant T_t =0.26·10^-3^ s is founded.

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

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

here C_e is the rigidity of the elastic load.

For the multilayer nano PZT engine d_{33} = 0.4 nm/V, n = 10, U = 50 V, $C_e = 0.15 \cdot 10^7$ N/m, $C_{33}^E = 1.5 \cdot 10^7$ N/m are founded k_t = 3.64 nm/V and Δl =182 nm.

For the elastic inertial load are simultaneously the elastic load C_e and the inertial load M. The transfer function of the multilayer piezo engine with lumped parameters $W_{mlpe}(s)$ at elastic inertial load and its first fixed end has the form

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

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

$$T_t = \sqrt{M / \left(C_e + C_{33}^E\right)}, \omega_t = \sqrt{\left(C_e + C_{33}^E\right) / M}$$

At the multilayer nano PZT engine M = 1 kg, $C_e = 0.15 \cdot 10^7$ N/m,

$C_{33}^{E} = 1.5 \cdot 10^7$ N/m the time constant $T_t = 0.25 \cdot 10^{-3}$ s is founded.

The transient characteristic for the nano displacement of this multilayer piezo engine $\xi(t)$ at elastic inertial load has the form

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

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

Sectional nano piezo engine

In the sectional nano piezo engine there are N sections with the number n_k of the piezo layers in the k-th section. The sections of the piezo engine are mechanically connected in series, but electrically isolated. Than the piezo layers in the section are electrically connected in parallel and mechanically connected in series.

Let us consider the sectional nano piezo engine[49–62] at longitudinal piezo effect, consisting of n piezo layers united in N sections, and n_k number of piezo layers in the k-th section

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

and length of the k-th section

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

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

We obtain the total length of the sectional nano piezo engine in the form

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

The maximum nano displacement of the sectional piezo engine has the form

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

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

The nano displacement of the sectional nano piezo engine has the 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 nano displacement of the sectional piezo engine

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

here $n_s = \sum_{k=1}^{N} a_k 2^{k-1}$ is the number of the piezo layers of the sectional nano piezo engine, connected to the voltage source.

Let us consider the mechanical and control characteristics of the sectional nano piezo engine. The equation of the mechanical static characteristic of the sectional nano 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 after transformation

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

here $C_{33}^{E} = S_0 / \left(s_{33}^{E} l\right)$ is the rigidity of the sectional nano piezo engine.

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

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

$$\Delta l_{3\max} = d_{33} n_s U, \; F_{3\max} = d_{33} n_s U C_{33}^{E}$$

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 sectional nano piezo engine at the elastic load has the form

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

here k_t is the transfer coefficient of the sectional nano piezo engine.

Than the transfer function of the sectional nano piezo engine at elastic inertial load has the form

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

here

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

$$T_t = \sqrt{M / \left(C_e + C_{33}^{E}\right)}, \quad \omega_t = \sqrt{\left(C_e + C_{33}^{E}\right) / M}$$

The sectional nano piezo engine is determined for coded control in applied bionics and biomechanics.

Discussion

The model of the multilayer nano piezo engine with lumped parameters is obtained for applied bionics and biomechanics. The mechanical characteristic and the transient characteristic for the nano displacement of this multilayer piezo engine are founded.

Conclusion

The multilayer nano piezo engine and sectional piezo engine are widely used for applied bionics and biomechanics in nano moving objects for scanning microscopy and adaptive optics, compensating for vibrations and deformations. The parameters of the multilayer nano PZT engine are obtained. The parameters of nano engine are determined by using of mathematical physics method for the multilayer and sectional nano piezo engine with lumped parameters. The mechanical characteristic and transfer function of the multilayer and sectional nano piezo engine are founded.

Acknowledgments

None.

Funding

None.

Conflicts of interest

The author declares that there is no conflict of interest.

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