Research Article

Open Access

Step piezoengine for nano and micro bionics

Abstract

The parameters of the step piezoengine for nano and micro bionics, adaptive optics, laser systems, nanorobotics are obtained. The method mathematical physics are used. The transfer functions of the central piezoengine and piezolock are determined. The transfer functions for the step piezoengine for nano and micro bionics are investigated.

Keywords: step piezoengine, parameter, central piezoengine, piezolock, nano and micro bionics

Volume 10 Issue 1 - 2026

Afonin SM

National Research University of Electronic Technology, Russia

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

Received: February 27, 2026 | **Published:** March 13, 2026

Introduction

The step piezoengine is used for alignment and positioning in nano and micro bionics, adaptive optics, laser systems, nanorobotics. The step piezoengine is a piezomechanical device for converting electrical energy into mechanical energy and for actuating mechanisms and systems based on the piezoeffect[1–15] in the nanometer-to-millimeter range. Increasing the travel range to millimeters with the positioning error on the order of the nanometer is achieved by using the step piezoengine with the multilayer central piezoengine and piezolocks made of PZT ceramics.[16–27]

Method

The parameters of the step piezoengine are obtained by method mathematical physics with using the equation the inverse piezoeffect and the ordinary second-order differential equation.

The transverse inverse piezoeffect[1–12] is written as

$$S_1 = d_{31} E_3 + s_{11}^E T_1 ,$$

and longitudinal inverse piezoeffect - as

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

whereare $S_1, S_3, d_{31}, d_{33}, E_3, s_{11}^E, s_{33}^E, T_1, T_3$ the relative deformation along axes 1 and 3, the transverse and longitudinal piezomodules, the electric field strength along axes 3, the elastic compliances at the transverse and longitudinal piezoeffect and $E = \text{const}$, the mechanical stress along axes 1 and 3, then the equation for the inverse piezoeffect has the general form[1–12]

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

where S_i, d_{mi}, E_m, s_{ij}^E, T_j are the relative deformation, the piezomodule, the electric field strength, the elastic compliance at $E = \text{const}$, the mechanical stress, and the indexes $i, j = 1, 2, \dots, 6$; $m = 1, 2, 3, \dots, 6$.

The ordinary second-order differential equation for central piezoengine and the piezolock has the form[12–15]

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

where $\Xi(x,s)$, x, s, γ are the Laplace transform of the displacement, the coordinate, the transformation operator, the propagation coefficient.

Parameters of central piezoengine and piezolock

The expression for the Laplace transform of the relative deformation under the elastic inertial load has the form at $x = 0$, $\Xi_1(s) = \Xi(0,s) = 0$ and at $x = l$, $\Xi_2(s) = \Xi(l,s)$, we have at the one fixed end the solution of the ordinary differential equation of the piezoengine in the form

$$\Xi(x,s) = \Xi_2(s)\,\text{sh}(x\gamma)/\text{sh}(l\gamma) ,$$

where l is the length of the piezoengine.

The expression for the Laplace transform of the relative deformation under the elastic inertial load at $x = l$ has the form

$$d\Xi(x,s)/dx\big|_{x=l} = d_{mi} E_m(s) - s_{ij}^E M p^2 \Xi_2(s)/S_0 - s_{ij}^E C_e \Xi_2(s)/S_0 ,$$

where M, C_e, S_0 are the mass and the stiffness of the load, the cross-sectional area of the piezoengine.

Therefore, we have the expression in the form

$$\Xi_2(s)\gamma\,\text{cth}(l\gamma) + \Xi_2(s) s_{ij}^E M s^2/S_0 + \Xi_2(s) s_{ij}^E C_e/S_0 = d_{mi} E_m(s) .$$

Then the transfer function of the piezoengine with distributed parameters has the form

$$W_U(s) = \frac{\Xi_2(s)}{U(s)} = \frac{d_{mi} l/\delta}{Ms^2/C_p + l\gamma\,\text{cth}(l\gamma) + C_e/C_p} ,$$

where $C_p = \dfrac{S_0}{s_{ij}^E l}$, δ, $l = n\delta$, n are the stiffness of the piezoengine, the thickness of the piezolayer, the length of the piezoengine and the number of the piezolayers in the piezoengine.

The transfer function on the electric field strength for the multilayer longitudinal piezoengne for the central piezoengne or the piezolock of the step piezoengne in Figure 1 has the form

$$W_E(s) = \frac{\Xi_2(s)}{E_m(s)} = \frac{d_{33} n\delta}{Ms^2/C_p + l\gamma\,\text{cth}(l\gamma) + C_e/C_p} .$$

Then the transfer functionon the voltage for the multilayer longitudinal piezoengine with distributed parameters has the form

$$W_U(s) = \frac{\Xi_2(s)}{U(s)} = \frac{d_{33} n}{Ms^2/C_p + l\gamma\,\text{cth}(l\gamma) + C_e/C_p} .$$

The transfer function on the electric field strength for the multilayer longitudinal piezoengne for the central piezoengne or the piezolock of the step piezoengne in Figure 1 has the form.

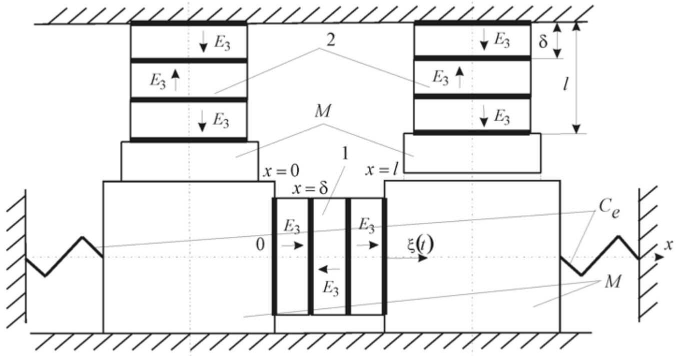

Figure 1 Step piezoengine: 1 – central piezoengine; 2 – piezolock.

Therefore, we obtain the steady state displacement of the free end of the multilayer central piezoengne in the form

$$\xi_2(\infty) = \frac{d_{33} n U_0}{1 + C_e/C_p} = k_U U_0 ,$$

where $k_U = \frac{d_{33} n}{1 + C_e/C_p}$ is the transmission coefficient on the voltage, $t \to \infty$ is the time, and U_0 is the voltage amplitude.

For the piezoelectric actuator made of PZT ceramics with the elastic inertial load at d_{33} = 0.4 nm/V, n = 8, $C_p = 2 \cdot 10^7$ N/m, $C_e = 0.5 \cdot 10^7$ N/m, U_0 = 100 V we obtain the transfer coefficient k_U = 2.56 nm/V and the steady state value $\xi_2(\infty)$ = 256 nm with the error 10 %.

Then, the transfer function $W_U(s)$ of the multilayer central piezoengne with the lumped parameters at the low matching circuit resistance $R \to 0$ and the elastic inertial load has the form

$$W_U(s) = \frac{\Xi_2(s)}{U(s)} = \frac{d_{33} n}{\left(1 + C_e/C_p\right)\left(T_t^2 s^2 + 2T_t \xi_t s + 1\right)} ,$$

$$W_U(s) = \frac{k_U}{T_t^2 s^2 + 2T_t \xi_t s + 1} ,$$

where $T_t = \sqrt{\frac{M}{C_e + C_p}}$ is the time constant for the oscillatory link.

For the PZT ceramic multilayer central piezoengne with the lumped parameters at the elastic inertial load $C_p = 2 \cdot 10^7$ N/m, $C_e = 0.5 \cdot 10^7$ N/m and M = 1 kg we have the const time $T_t = 0.2 \cdot 10^{-3}$ s with the error 10 %.

Taking into account the capacitance C_n of the multilayer central piezoengne and the high resistance $R >> 0$ of the matching circuit we have the time constant for the aperiodic link $T_a = RC_n$,

where

$$W_U(s) = \frac{\Xi_2(s)}{U(s)} = \frac{k_U}{T_a s + 1} ,$$

at $T_a >> T_t$.

For the PZT ceramic multilayer longitudinal central piezoengne at R = 20 kΩ, C_n = 1 μF we have the const time for the aperiodic link $T_a = 20 \cdot 10^{-3}$ s with the error 10 % and $T_a / T_t = 10$.

Displacement for step piezoengine

The amplitude step β of the step piezoengine is written as

$$\beta = \frac{n d_{33} U_0}{1 + C_e/C_p} = k_U U_0 .$$

Let us consider the time diagrams of the operation of the step piezoengne on Figure 2 and Figure 3, where T, T_1, t, τ are the period of the clocking pulses, the duration of the pulse, the time from the start of the movement and the time in the current step.

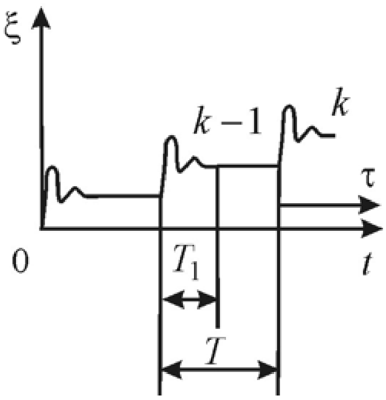

Figure 2 Time diagram step piezoengine in oscillatory mode.

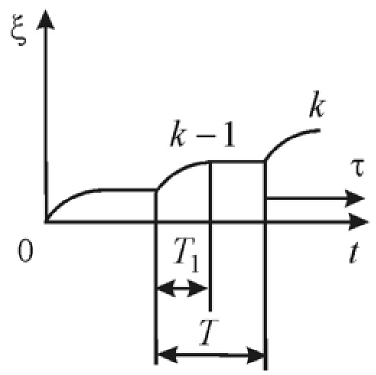

Figure 3 Time diagram step piezoengine in aperiodic mode**.**

For the central piezoengine in the oscillatory link mode at $R \to 0$ the displacement of the step piezoengine on k step Figure 2 is given as

$$\xi(\tau) = \beta \left\{ k - 1 + \left(1 - \frac{e^{-\frac{\xi_t \tau}{T_t}}}{\sqrt{1 - \xi_t^2}} \sin\left(\omega_t \tau + \phi_t\right) \right) \right\}.$$

For the central piezoengine in the oscillatory link mode at $R >> 0$ the displacement of the step piezoengine on k step Figure 3 is written as

$$\xi(\tau) = \beta \left\{ k - 1 + \left(1 - e^{-\tau/T_a}\right) \right\}.$$

Therefore, we have the parameters of the step piezoengine for nano and micro bionics.

Citation: Afonin SM. Step piezoengine for nano and micro bionics. *MOJ App Bio Biomech.* 2026;10(1):22–24. DOI: 10.15406/mojabb.2026.10.00238

Conclusion

The step piezoengine is used for alignment and positioning in nano and micro bionics, for adaptive optics and laser systems. Increasing the displacement range to millimeters with the positioning error on the order of the nanometer is achieved. The step piezoengine with the multilayer central piezoengine and piezolocks made of PZT ceramics and used due to its high rigidity and nano precision. The parameters of the step piezoengine for nano and micro bionics are determined. The transfer functions of the central piezoengine and piezolock are derived.

Acknowledgments

None.

Funding

None.

Conflicts of interest

The author declares that there is no conflict of interest.

References

1. Schultz J, Ueda J, Asada H. *Cellular actuators*. Butterworth-Heinemann Publisher, Oxford. 2017;382.
2. Afonin SM. Absolute stability conditions for a system controlling the deformation of an elecromagnetoelastic transduser. *Dokl Math*. 2006;74(3):943–948.
3. Uchino K. *Piezoelectric actuator and ultrasonic motors*. Boston, MA: Kluwer Academic Publisher. 1997;8:350.
4. Sun P, Xu Z, Jin L, et al. A novel piezo inertia actuator utilizing the transverse motion of two parallel leaf-springs. *Micromachines (Basel)*. 2023;14(5):954.
5. Afonin SM. Solution of the wave equation for the control of an elecromagnetoelastic transduser. *Dokl Math*. 2006;73(2):307–313.
6. Afonin SM. Erratum to: Solution of the wave equation for the control of an elecromagnetoelastic transduser. *Dokl Math*. 2025;111:91.
7. Cady WG. *Piezoelectricity: An introduction to the theory and applications of electromechancial phenomena in crystals*. McGraw-Hill Book Company, New York, London, 1946;806.
8. Mason W, editor. *Physical acoustics: Principles and methods.* Vol. 1. Part A. Methods and devices. Academic Press, New York, 1964;515.
9. Zhao C, Li Z, Xu F, et al. Design of a novel three-degree-of-freedom piezoelectric-driven micro-positioning platform with compact structure. *Actuators*. 2024;13(7):248.
10. Zwillinger D. *Handbook of differential equations*. Academic Press, Boston, 1989;673.
11. Afonin SM. *Structural-parametric model and transfer functions of electroelastic actuator for nano- and microdisplacement.* Chapter 9 in Piezoelectrics and Nanomaterials: Fundamentals, Developments and Applications. Ed. Parinov IA. Nova Science, New York. 2015;225–242.
12. Afonin SM. Structural scheme of electroelastic engine micro and nano displacement for applied bionics and biomechanics. *MOJ App Bio Biomech*. 2025;9(1):1–4.
13. Chang Q, Chen W, Zhang S, et al. Review on multiple-degree-of-freedom cross-scale piezoelectric actuation technology. *Adv Intell Syst*. 2024;6(6):2300780.
14. Afonin SM. Structural-parametric model of electromagnetoelastic actuator for nanomechanics. *Actuators*. 2018;7(1):6.
15. Afonin SM. Structural-parametric model and diagram of a multilayer electromagnetoelastic actuator for nanomechanics. *Actuators*. 2019;8(3):52.
16. Afonin SM. Optimal control of a multilayer electroelastic engine with a longitudinal piezoeffect for nanomechatronics systems. *Appl Syst Innov*. 2020;3(4):53.
17. Afonin SM. Coded control of a sectional electroelastic engine for nanomechatronics systems. *Appl Syst Innov*. 2021;4(3):47.
18. Afonin SM. Structural–parametric model electroelastic actuator nano- and microdisplacement of mechatronics systems for nanotechnology and ecology research. *MOJ Eco Environ Sci*. 2018;3(5):306–309.
19. Afonin SM. Deformation of electromagnetoelastic actuator for nano robotics system. *Int Rob Auto J*. 2020;6(2):84–86.
20. Afonin SM. Piezo actuators for nanomedicine research. *MOJ App Bio Biomech*. 2019;3(2):56–57.
21. Afonin SM. Structural scheme of electromagnetoelastic actuator for nano biomechanics. *MOJ App Bio Biomech*. 2021;5(2):36–39.
22. Afonin SM. DAC electro elastic engine for nanomedicine. *MOJ App Bio Biomech*. 2024;8(1):38–40.
23. Afonin SM. Multilayer and sectional nano piezo engine for applied bionics and biomechanics. *MOJ App Bio Biomech*. 2025;9(1):59–62.
24. Shevtsov SN, Soloviev AN, Parinov IA, et al. *Piezoelectric actuators and generators for energy harvesting*. Research and Development. Springer, Switzerland, Cham. 2018;182.
25. Akpinar M, Uzun B, Yayli MO. Dynamics of a piezoelectric restrained nanowire in an elactic matrix. *Mech Solids*. 2024;59(5): 2936–2959.
26. Nalwa HS, editor. *Encyclopedia of nanoscience and nanotechnology*. USA: American Scientific Publishers. 25 Volumes. 2019.
27. Afonin SM. Structural-parametric model of a piezoactuator for nanoscience and nanotechnology. *Eur J Appl Sci*. 2021;9(3):26–36.