Research Article Open Access

Journal of Modern Classical Physics
& Quantum Neuroscience

ISSN: 3068-4196

DOI: doi.org/10.63721/26JPQN0156

# Block Diagram Piezodrive for Nanophysics and Nanotechnology

**Afonin SM**

Ph.D., Senior Researcher, Associate Professor, National Research University of Electronic Technology, MIET, Moscow, Russia

**Citation:** *Afonin SM (2026) National Research University of Electronic Technology, MIET, Moscow, Russia. J. of Mod Phy & Quant Neuroscience 2(2), 1-8. WMJ/JPQN-156*

## *Abstract*

*The piezodrive is used in nanophysics and nanotechnology, scanning microscopy, delivery DNA, compound telescope, interferometer and adaptive optics. The method mathematical physics is used to construct the block diagram of the piezodrive from the equation of reverse piezo effect and its ordinary differential equation for nanophysics and nanotechnology. The matrix transfer function of the piezodrive is obtained. The block diagrams of the piezodrive with the back electromotive force at distributed and lumped parameters are determined for nanophysics and nanotechnology.*

***Corresponding author**: Afonin SM, Ph.D., Senior Researcher, Associate Professor, National Research University of Electronic Technology, MIET, Moscow, Russia.

**Submitted:** 11.03.2026 **Accepted**: 17.03.2026 **Published**: 15.04.2026

**Keyword:** Block diagram, Piezodrive, Nanophysics, Nanotechnology

## Introduction

The piezodrive is used for actuation of systems for nanophysics, nanotechnology, displacement and delivery DNA, compound telescope, interferometer, adaptive optics, scanning microscopy. This piezodrive is used to actuate or control nano mechanisms and convert electrical energy to mechanical energy at the nano displacement [1-17]. By method mathematical physics the block diagram of the piezodrive is determined for nanophysics and nanotechnology. The block diagram of the piezodrive is determined and show the transformation of electrical energy into mechanical energy in difference from Cady's and Mason's equivalent circuits [18-41]. The block diagram of the piezodrive for nanophysics and nanotechnology is determined with using the equation of reverse piezo effect and its linear ordinary second-order differential equation. From this set of equations for the block diagram of the piezodrive the matrix transfer function is determined [34-47]. For nanophysics and nanotechnology, the matrix transfer function of the piezodrive is obtained.

## Method

The parameters of the piezodrive for nanophysics and nanotechnology are obtained by method mathematical physics with using the equation the inverse piezo effect and its ordinary second-order differential equation.

The transverse inverse piezoeffect [1-10] is written as.

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

Block diagram of a nano piezo engine for nanobionics and longitudinal inverse piezo effect as

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

where $S_1$, $S_3$, $d_{31}$, $d_{33}$, $E_3$, $s^E_{11}$, $s^E_{33}$, $T_1$, $T_3$ are the relative deformation along axes 1 and 3, the transverse and longitudinal piezo modules, the electric field strength along axes 3, the elastic compliances at the transverse and longitudinal piezo effect at $E = \text{const}$ and the mechanical stress along axes 1 and 3.

Then the equation for the inverse piezo effect for the piezodrive has the general form [1 - 10]

$$S_i = s_{ij}^{\Psi}T_j + \nu_{\mathrm{mi}}\Psi_{\mathrm{m}},$$

here $s_{ij}^{\Psi} = \{s_{33}^{E}, s_{11}^{E}, s_{55}^{E}, s_{33}^{D}, s_{11}^{D}, s_{55}^{D} -$ the elastic compliances, $\nu_{mi} = \{d_{33}, d_{31}, d_{15}, g_{33}, g_{31}, g_{15} -$ the piezoelectric constant, $\Psi_m = \{E_3, E_3, E_1, D_3, D_3, D_1 -$ the control parameter: $E$ - electric field strength, $D$ - the electric induction, $\gamma$ - the coefficient of wave propagation, $i = 1, 2, \dots, 6$, $j = 1, 2, \dots, 6$, $m = 1, 2, 3$.

The ordinary second-order differential equation for the piezodrive in nanophysics and nanotechnology has the form [11−19]

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

## Block Diagram

By method mathematical physics the block diagram of the piezodrive is calculated for nanophysics and nanotechnology. The method mathematical physics is used to construct the block diagram of the piezodrive for nanophysics and nanotechnology from the equation of the reverse piezo effect and its ordinary differential equation.

The solution of the ordinary second-order differential equation the piezodrive for nanophysics and nanotechnology has the form

$$\Xi(x,p) = C\mathrm{e}^{-\gamma x} + B\mathrm{e}^{\gamma x}; \ \gamma = p/c^{\Psi} + \alpha$$

here $\Xi$ $(x,p)$- the Laplace transform of the displacement; $x$ - the coordinate; $p$ - the operator, the coefficient of propagation, $c^{\Psi}$- the speed of sound and $\alpha$ - the coefficient of damping.

Its coefficients $C$ and $B$ are derived

$$C = \frac{\Xi_1\mathrm{e}^{\gamma l} - \Xi_2}{2\mathrm{sh}(\gamma l)}; \ B = \frac{\Xi_2 - \Xi_1\mathrm{e}^{-\gamma l}}{2\mathrm{sh}(\gamma l)}.$$

This solution of the ordinary second-order differential equation the piezodrive for nanophysics and nanotechnology has the form

$$\Xi(x,p) = \frac{\Xi_1(p)\mathrm{sh}[\gamma(l-x)] + \Xi_2(p)\mathrm{sh}(\gamma x)}{2\mathrm{sh}(\gamma l)}.$$

The equations of the forces at the faces for the piezodrive are determined in the form

$$T_j(0,p)S_0 = F_1(\mathrm{p}) + M_1 p^2 \Xi_1(p) \quad \text{at } x=0;$$

$$T_j(l,p)S_0 = -F_2(\mathrm{p}) - M_2 p^2 \Xi_2(p) \quad \text{at } x=l.$$

The equations for the mechanical stresses at the faces for the piezodrive are derived

$$T_j(0,p) = \frac{1}{s_{ij}^{\Psi}} \frac{\mathrm{d}\Xi(x,p)}{\mathrm{dx}}\bigg|_{\mathrm{x=0}} - \frac{\nu_{mi}}{s_{ij}^{\Psi}} \boldsymbol{E_m}(p);$$

$$T_j(l,p) = \frac{1}{s_{ij}^{\Psi}} \frac{\mathrm{d}\Xi(x,p)}{\mathrm{dx}}\bigg|_{\mathrm{x=l}} - \frac{\nu_{mi}}{s_{ij}^{\Psi}} E_m(p).$$

We have the block diagram at the distributed parameters for the piezodrive in nanophysics and nanotechnology on Figure 1

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

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

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

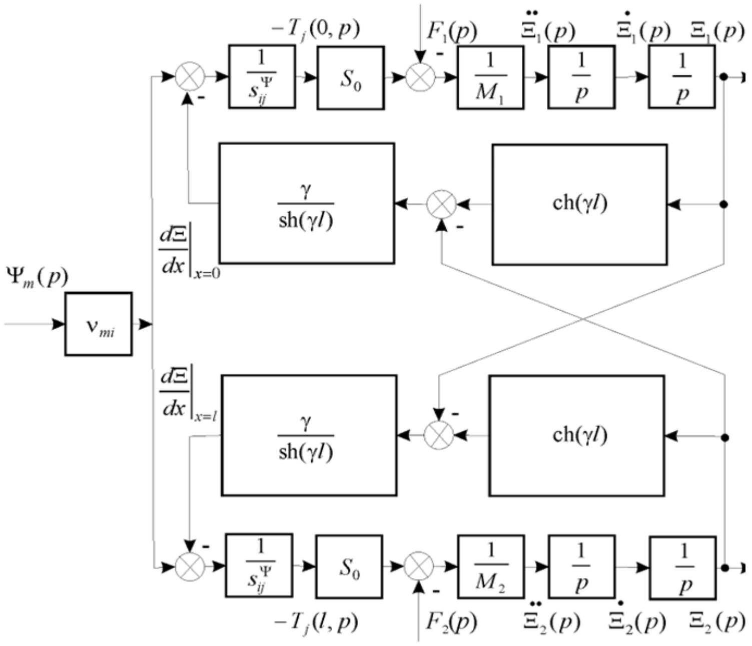

**Figure 1:** Block diagram piezodrive for nanophysics and nanotechnology.

From the block diagram at the distributed parameters for the piezodrive in nanophysics and nanotechnology on Figure 1 we have the equations

$$\Xi_1(p) = W_{11}(p)\Psi_m(p) + W_{12}(p)F_1(p) + W_{13}(p)F_2(p);$$

$$\Xi_2(p) = W_{21}(p)\Psi_m(p) + W_{22}(p)F_1(p) + W_{23}(p)F_2(p),$$

and the matrix equation for the piezodrive with its matrix transfer function

$$\begin{pmatrix} \Xi_1(p) \\ \Xi_2(p) \end{pmatrix} = \begin{pmatrix} W_{11}(p) & W_{12}(p) & W_{13}(p) \\ W_{21}(p) & W_{22}(p) & W_{23}(p) \end{pmatrix} \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix}$$

where the elements of the matrix are determined in the form

$$W_{11}(p) = \Xi_1(p)/\Psi_m(p) = -\frac{\mathrm{v}_{\mathrm{mi}}\left[M_2\chi_{ij}^{\Psi}p^2+\gamma\mathrm{th}(\gamma l/2)\right]}{A_{ij}}; \ \chi_{ij}^{\Psi} = s_{ij}^{\Psi}/S_0 ;$$

$$A_{ij} = M_1M_2\left(\chi_{ij}^{\Psi}\right)^2 p^4 + \{(M_1 + M_2)\chi_{ij}^{\Psi}/[c^{\Psi}\mathrm{th}(\gamma l)]\}p^3 +$$

$$+\left[(M_1 + M_2)\chi_{ij}^{\Psi}\alpha/\mathrm{th}(\gamma l) + 1/(c^{\Psi})^2\right]p^2 + 2\alpha p/c^{\Psi} + \alpha^2;$$

$$W_{21}(p) = \Xi_2(p)/\Psi_m(p) = \frac{\mathrm{v}_{\mathrm{mi}}\left[M_1\chi_{ij}^{\Psi}p^2+\gamma\mathrm{th}(\gamma l/2)\right]}{A_{ij}};$$

$$W_{12}(p) = \Xi_1(p)/F_1(p) = -\frac{\chi_{ij}^{\Psi}\left[M_2\chi_{ij}^{\Psi}p^2+\gamma\mathrm{th}(\gamma l/2)\right]}{A_{ij}};$$

$$W_{13}(p) = \Xi_1(p)/F_2(p) = W_{22}(p) = \Xi_2(p)/F_1(p) = \frac{\chi_{ij}^{\Psi}\gamma}{A_{ij}\mathrm{sh}(\gamma l)};$$

$$W_{23}(p) = \Xi_2(p)/F_2(p) = -\frac{\chi_{ij}^{\Psi}\left[M_1\chi_{ij}^{\Psi}p^2+\gamma\mathrm{th}(\gamma l/2)\right]}{A_{ij}}.$$

## Discussion

At inertial load the static absolute displacements for the piezodrive in nanophysics and nanotechnology are derived in the form

$$|\xi_1(\infty)| = d_{33}U\,(M_2 + m/2)/(M_1 + M_2 + m),$$

$$|\xi_2(\infty)| = d_{33}U\,(M_1 + m/2)/(M_1 + M_2 + m),$$

$$|\xi_1(\infty)| + |\xi_2(\infty)| = d_{33}U,$$

here $m, M_1$, $M_2$ are the masses of the piezo engine and loads. For the PZT piezodrive at $m \to 0$ at $d_{33}$= 0.4 nm/V, $U$=100 V, $M_1$=0.5 kg and $M_2$=2 kg we obtain the parameters $|\xi_1(\infty)|$=32 nm, $|\xi_2(\infty)|$=8 nm, $|\xi_1(\infty)|+|\xi_2(\infty)|$=40 nm.

For the piezodrive at the voltage control the electromechanical coupling coefficient has form

$$k_{mi} = \frac{d_{mi}}{\sqrt{s_{ij}^{E}\varepsilon_{mk}^{T}}}.$$

The negative feedback for the block diagram at the distributed parameters and voltage control of the piezodrive on Figure 2 has the form

$$U_{\dot{\Xi}\mathrm{a}}(p) = \frac{d_{mi}S_0R}{\delta s_{ij}^{E}}\dot{\Xi}_{\mathrm{a}}(p), \quad \mathrm{a} = 1,\ 2.$$

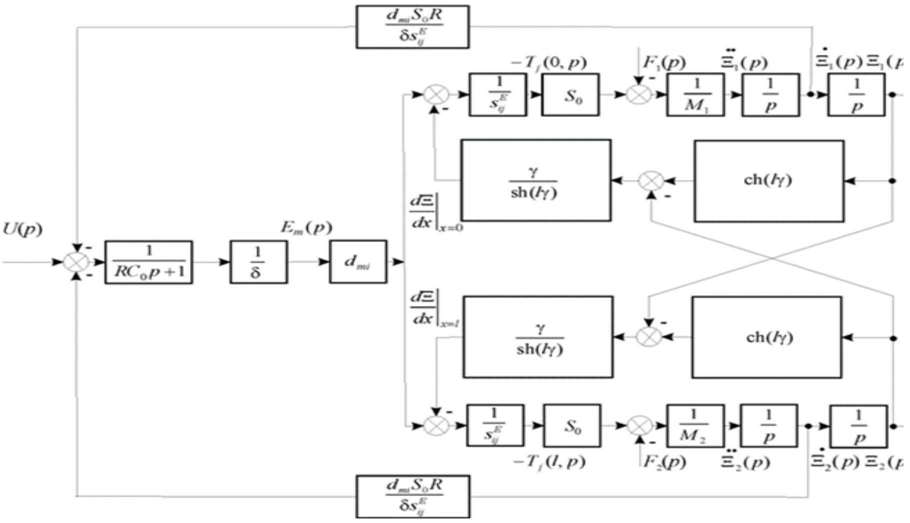

**Figure 2**: Block diagram piezodrive at voltage control and distributed parameters with negative feedbacks.

Let us consider the block diagrams with lumped parameters. For the piezodrive its block diagrams with lumped parameters at the voltage control are on Figure 3 and at the current control on Figure 4 for one fixed face of the piezodrive.

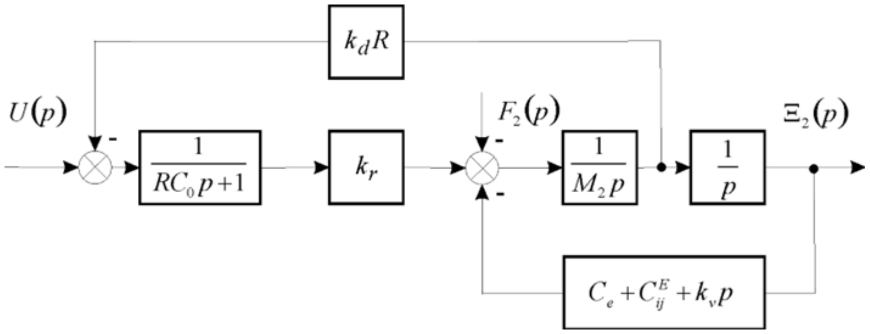

**Figure 3:** Block diagram piezodrive at one rigidly fixed face and voltage control for lumped parameters.

The coefficient $k_d$ is equal to the coefficient $k_r$ on Figure 3 and Figure 4

$$k_d = k_r = \frac{d_{mi}S_0}{\delta s_{ij}^{\Psi}},$$

where $\Psi=E,D$ are its upper indexes.

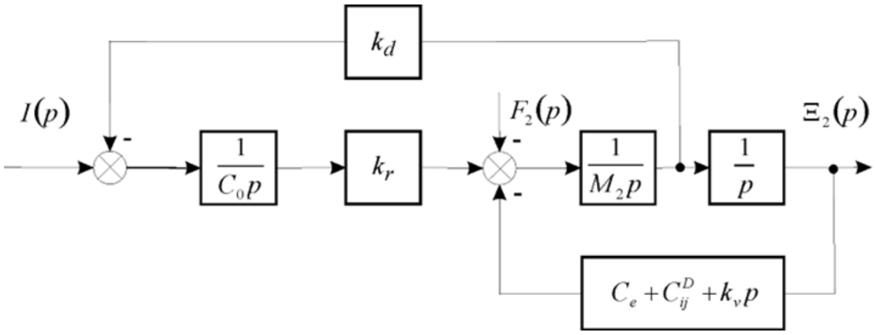

**Figure 4:** Block diagram piezo engine at current control and lumped parameters.

Therefore, we have the block diagrams for the piezodrive in nanophysics and nanotechnology.

## Conclusion

The block diagram for the piezodrive is determined for nanophysics and nanotechnology. The block diagram, the matrix transfer function of the piezodrive are derived. The numerical parameters of the piezodrive are determined. Its block diagrams with the back electromotive force at distributed and lumped parameters are derived for nanophysics and nanotechnology.

## References

1. Schultz J, Ueda J, Asada H (2017) Cellular Actuators. Butterworth-Heinemann Publisher, Oxford 382.
2. Afonin SM (2006) Absolute stability conditions for a system controlling the deformation of an elecromagnetoelastic transduser. Doklady Mathematics 74: 943-948. doi:10.1134/S1064562406060391.
3. Uchino K (1997) Piezoelectric actuator and ultrasonic motors. Boston, MA: Kluwer Academic Publisher 350.
4. Afonin SM (2005) Generalized parametric structural model of a compound elecromagnetoelastic transduser. Doklady Physics 50: 77-82. doi:10.1134/1.1881716.
5. Afonin SM (2008) Structural parametric model of a piezoelectric nanodisplacement transducer. Doklady Physics 53: 137-143, doi:10.1134/S1028335808030063.
6. Afonin SM (2006) Solution of the wave equation for the control of an elecromagnetoelastic transduser. Doklady Mathematics 73: 307-313, doi:10.1134/S1064562406020402.
7. Afonin SM (2025) Erratum to: Solution of the wave equation for the control of an elecromagnetoelastic transduser. Doklady Mathematics 111: 91. doi:10.1134/S1064562425010016.
8. Cady WG (1946) Piezoelectricity: An introduction to the theory and applications of electromechancial phenomena in crystals. McGraw-Hill Book Company, New York, London 806.
9. Mason W, editor (1964) Physical Acoustics: Principles and Methods. Part A. Methods and Devices. Academic Press, New York 1: 515.
10. Zhao C, Li Z, Xu F, Zhang H, Sun F, Jin J, Zhang X, Yang L (2024) Design of a novel three-degree-of-freedom piezoelectric-driven micro-positioning platform with compact structure. Actuators 13: 248. doi:10.3390/act13070248.
11. Zwillinger D (1989) Handbook of Differential Equations. Academic Press, Boston 673.
12. Afonin SM (2015) 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 225-242.
13. Afonin SM (2017) A structural-parametric model of electroelastic actuator for nano- and microdisplacement of mechatronic system. Chapter 8 in Advances in Nanotechnology. Volume 19. Eds. Bartul Z, Trenor J, Nova Science, New York 259-284.
14. Afonin SM (2025) Structural scheme of electroelastic engine micro and nano displacement for applied bionics and biomechanics. MOJ Applied Bionics and Biomechanics 9: 1-4. doi:10.15406/mojab.2025.09.00216.
15. Afonin SM (2018) Electromagnetoelastic nano- and microactuators for mechatronic systems. Russian Engineering Research 38: 938-944. doi:10.3103/S1068798X18120328.
16. Afonin SM (2017) Structural-parametric model electromagnetoelastic actuator nanodisplacement for mechatronics. International Journal of Physics 5: 9-15. doi:10.12691/ijp-5-1-27.
17. Afonin SM (2019) Structural-parametric model multilayer electromagnetoelastic actuator for nanomechatronics. International Journal of Physics 7: 50-57. doi:10.12691/ijp-7-2-3.
18. Afonin SM (2021) Calculation deformation of an engine for nano biomedical research. International Journal of Biomed Research 1: 1-4. doi:10.31579/IJBR-2021/028.
19. Afonin SM (2021) Precision engine for nanobiomedical research. Biomedical Research and Clinical Reviews 3: 1-5. doi:10.31579/2692-9406/051.
20. Afonin SM (2018) Structural-parametric model of electromagnetoelastic actuator for nanomechanics Actuators 7: 6. doi: 10.3390/act7010006.
21. Afonin SM (2019) Structural-parametric model and diagram of a multilayer electromagnetoelastic

actuator for nanomechanics. Actuators 8: 52. doi: 10.3390/act8030052.

22. Afonin SM (2018) Multilayer electromagnetoelastic actuator for robotics systems of nanotechnology, Proceedings of the 2018 IEEE Conference EIConRus 1698-1701. doi:10.1109/EIConRus.2018.8317432.
23. Afonin SM (2020) Optimal control of a multilayer electroelastic engine with a longitudinal piezoeffect for nanomechatronics systems. Applied System Innovation 3: 53. doi:10.3390/asi3040053.
24. Afonin SM (2021) Coded control of a sectional electroelastic engine for nanomechatronics systems. Applied System Innovation 4: 47. doi:10.3390/asi4030047.
25. Afonin SM (2020) Structural scheme actuator for nano research. COJ Reviews and Research 2: 1-3. doi:10.31031/COJRR.2020.02.000548.
26. Afonin SM (2018) Structural–parametric model electroelastic actuator nano- and microdisplacement of mechatronics systems for nanotechnology and ecology research. MOJ Ecology and Environmental Sciences 3: 306-309. doi:10.15406/mojes.2018.03.00104.
27. Afonin SM (2020) Deformation of electromagnetoelastic actuator for nano robotics system. International Robotics & Automation Journal 6: 84-86. doi:10.15406/iratj.2020.06.00205.
28. Afonin SM (2024) Correction of characteristics compound longitudinal piezodrive at elastic inertial load for nanorobotics research. International Robotics & Automation Journal 10: 103-106. doi:10.15406/iratj.2024.10.00291.
29. Afonin SM (2024) A multi-layer electro elastic drive for micro and nano robotics. International Robotics & Automation Journal 10: 73-76. doi:10.15406/iratj.2024.10.00286.
30. Afonin SM (2018) Electromagnetoelastic actuator for large telescopes. Aeronautics and Aerospace Open Access Journal 2: 270-272. doi:10.15406/aaoaj.2018.02.00060
31. Afonin SM (2019) Condition absolute stability of control system with electro elastic actuator for nano bioengineering and microsurgery. Surgery & Case Studies Open Access Journal 3: 307-309. doi:10.32474/SCSOAJ.2019.03.000165.
32. Afonin SM (2019) Piezo actuators for nanomedicine research. MOJ Applied Bionics and Biomechanics 3: 56-57. doi:10.15406/mojabb.2019.03.0009.
33. Afonin SM (2020) Multilayer piezo engine for nanomedicine research. MOJ Applied Bionics and Biomechanics 4: 30-31. doi:10.15406/mojabb.2020.04.00128.
34. Afonin SM (2021) Structural scheme of electromagnetoelastic actuator for nano biomechanics. MOJ Applied Bionics and Biomechanics 5: 36-39. doi:10.15406/mojabb.2021.05.00154.
35. Afonin SM (2019) A structural-parametric model of a multilayer electroelastic actuator for mechatronics and nanotechnology. Chapter 7 in Advances in Nanotechnology. Volume 22. Eds. Bartul Z, Trenor J, Nova Science, New York 169-186.
36. Afonin SM (2020) Electroelastic digital-to-analog converter actuator nano and microdisplacement for nanotechnology. Chapter 6 in Advances in Nanotechnology. Volume 24. Eds. Bartul Z, Trenor J, Nova Science, New York 205-218.
37. Afonin SM (2021) Characteristics of an electroelastic actuator nano- and microdisplacement for nanotechnology. Chapter 8 in Advances in Nanotechnology. Volume 25. Eds. Bartul Z, Trenor J, Nova Science, New York 251-266. doi:10.52305/TANO4731.
38. Afonin SM (2022) An absolute stability of nanomechatronics system with electroelastic actuator. Chapter 9 in Advances in Nanotechnology. Volume 27. Eds. Bartul Z, Trenor J, Nova Science, New York 183-198. doi:10.52305/YOPZ1532.
39. Afonin SM (2021) Rigidity of a multilayer piezoelectric actuator for the nano and micro range. Russian Engineering Research 41: 285-288. doi:10.3103/S1068798X21040031.
40. Afonin SM (2024). Structural scheme of an electromagnetoelastic actuator for nanotechnology research. Chapter 45 in Physics and Mechanics of New Materials and Their Applications. PHENMA 2023. Springer Proceedings in Materials. Volume 41. Eds. Parinov I A, Chang S H, Putri E P, Springer Cham 486-501. doi:10.1007/978-3-031-52239-0_45.
41. Afonin SM (2025) Structural model and scheme of a multilayer electromagnetoelastic actuator for nanotechnology. Chapter 45 in Physics and Mechanics of New Materials and Their Applications.

PHENMA 2024. Springer Proceedings in Materials. Volume 3. Eds. Parinov I.A., Chang S.H., Sohani, N., Gupta, V.K., Springer Cham 527-544. doi:10.1007/978-3-031-87677-6_45.

42. Afonin SM (2025) Structural scheme of electroelastic engine micro and nano displacement for applied bionics and biomechanics. MOJ Applied Bionics and Biomechanics 9: 1-4. doi:10.15406/mojab.2025.09.00216.
43. Afonin SM (2025) Multilayer and sectional nano piezo engine for applied bionics and biomechanics. MOJ Applied Bionics and Biomechanics 9: 59-62. doi:10.15406/mojabb.2025.09.00226.
44. Shevtsov SN, Soloviev AN, Parinov IA, Cherpakov AV, Chebanenko VA (2018) Piezoelectric Actuators and Generators for Energy Harvesting. Research and Development. Springer, Switzerland Cham 182. doi:10.1007/978-3-319-75629-5.
45. Akpinar M, Uzun B, Yayli MO (2024) Dynamics of a piezoelectric restrained nanowire in an elactic matrix. Mechanics of Solids 59: 2936-2959. doi:10.1134/S0025654424604713.
46. Nalwa HS (2019) Encyclopedia of Nanoscience and Nanotechnology. USA: American Scientific Publishers 25 Volumes.
47. Bhushan B., editor (2017) Springer Handbook of Nanotechnology. Germany: Springer, 1500 p., doi:10.1007/978-3-662-54357-3.