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Multilayer Electro Magneto Elastic Actuator for Nanomechanics

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Abstract

In this paper, we consider the generalized structural diagram of the multilayer electro magneto elastic actuator or the multilayer piezo actuator for the nanomechanics in contrast to Cady and Mason?s electrical equivalent circuits for the calculation of the piezo transmitter and receiver, the vibration piezo motor. From the solution of the general equation of the electro magneto elasticity, the matrix equation for the equivalent quadripole of the multilayer electro magneto elastic actuator, and its boundary conditions we receive the generalized structuralparametric model, the structural diagram and matrix transfer function of the multilayer actuator.

Index terms— multilayer electro magneto elastic actuator, multilayer piezo actuator, equivalent quadripole, structural diagram, structural-parametric model.

1 Introduction

t present, we use the multilayer electro magneto elastic actuator on the piezoelectric, piezomagnetic, electrostriction, and magnetostriction effects for precise alignment in the range of movement from nanometers to tens of micrometers in nanomechanics systems for nanotechnology and adaptive optics. We receive the parametric structural schematic diagram of the multilayer piezo actuator for nanomechanics in contrast to Cady and Mason's electrical equivalent circuits for the calculation of the piezo transmitter, the piezo receiver, and the vibration piezo motor **??**1 -12]. The parametric structural schematic diagram of the multilayer electro magneto elastic actuator is obtained with the mechanical parameters of displacement and force **??**14 ?20].The piezo actuator use for actuation of mechanisms, systems, or management based on the piezo effect, and convert electrical signals into mechanical movement or force. The investigation of the static and dynamic characteristics of the multilayer piezo actuator is necessary for the calculation of nanomechatronics systems. We apply multilayer piezo actuator in nanotechnology for scanning tunneling microscopy and atomic force microscopy **??**6 ? 32].

2 II. Parametric Structural Schematic Diagram

In this paper, we have the parametric structural schematic diagram and the matrix transfer function of the multilayer electro magneto elastic actuator for the nanomechanics from its the structural-parametric model. In general, the equation for the electro magneto elasticity of the multilayer electro magneto elastic actuator [12,14,16,31] has the form ( ) ( )t , x T s t S j ij m mi i ? + ? ? =**(1)**

where( ) x t , x S i ? ? ? =

is the relative displacement along axis i of the cross-section of the actuator, therefore, we obtainH , D , E = ?

the generalized control parameter in the form m E in Figure 1 for the voltage control, m D for the current control, m H for the magnetic field strength control along axis m, j T is the mechanical stress along axis j, mi ? is the coefficient of electro magneto elasticity, for example, mi d piezo module or magnetostriction coefficient, ? ij s is the elastic compliance with const = ? , For example, we consider the matrix equation for the Laplace transforms of the forces and the displacements [16] at the input and output ends of k the piezo layer of the multilayer piezo actuator from n the piezo layers. We drew the equivalent T-shaped quadripole of k the piezo layer in Figure 2. ? are the Laplace transforms of the displacements at input and output ends of k the piezo layer in Figure 2.( ) ( ) ( ) ( ) p Z p Z Z p F k k inp k 1 2 2 1 + ? + ? + ? = (2) ( ) ( ) ( ) ( ) p Z Z p Z p F k k out k 1 2 1 2 + ? + + ? ? = ? where ( ) ? ?? ? = ij s S Z th 0 1 , ( ) ?? ? = ? sh

Accordingly, we have for Figure 2 the Laplace transforms the following system of the equations for k the piezo layer in the form( ) ( ) ( ) p Z Z Z p F Z Z p F k out k inp k 1 2 1 1 2 1 2 1 + ? ? ? ? ? ? ? ? ? + + ? ? ? ? ? ? ? ? ? + = ? (3) ( ) ( ) ( ) p Z Z p F Z p k out k k 1 2 1 1 1 1 + ? ? ? ? ? ? ? ? ? + + = ?

the matrix equation for k the piezo layer ( ) ( ) [ ] ( ) ( ) ? ? ? ? ? ? ? ? = ? ? ? ? ? ? ? ? ? + p p F M p[ ] ? ? ? ? ? ? ? ? ? ? ? ? ? + ? ? ? ? ? ? ? ? ? + + = ? ? ? ? ? ? = 2 1 2 1 1 1 2 1 22 21 12 11 1 1 2 1 Z Z Z Z Z Z Z m m m m M (5)

Where ( )?? = + = = ch 1 2 1 22 11 Z Z m m , ( ) ?? = ? ? ? ? ? ? ? ? + = sh 2 0 1 1 1 12 Z Z Z Z m , ()0 2 21 sh 1 Z Z m ?? = = , ? ? = ij s S Z 0 0

For the multilayer piezo actuator the Laplace transforms the displacement The force on the output face for the k the piezo layer equal in magnitude and opposite in direction to the force on the input face for k+1 the piezo layer( ) ( ) p F p F inp k out k 1 + ? =**(6)**

From equation (**??**) the matrix equation for n the piezo layers( ) ( ) [ ] ( ) ( ) ? ? ? ? ? ? ? = ? ? ? ? ? ? ? ? + p p F M p p F n out n n inp 1 1 1 (7)

with the matrix of the multilayer piezo actuator Figure 1 a in the form [ ] ( ) ( ) ( ) ( ) ? ? ? ? ? ? ? ? ? ? ?? ?? ?? ?? = n Z n n Z n M n ch sh sh ch 0 0

Accordingly, in general, the matrix for the equivalent quadripole of the multilayer electro magneto elastic actuator Figure 1 a-? has the following form[ ] ( ) ( ) ( ) ( ) ? ? ? ? ? ? ? ? ? ? ? ? = l Z l l Z l M n ch sh sh ch 0 0

Therefore, we have from the equation (**??**) the equivalent quadripole of the multilayer piezo actuator on Figure 1 a-? for the longitudinal piezo effect with length of the multilayer piezo actuator ? = n l , for the transverse piezo effect with nh l = , for the shift piezo effect with nb l = , where b , h , ? are the thickness, the height, the width for k the piezo layer.

Equations of the forces acting on the faces of the multilayer piezo actuator at 0 = x , ( ) ( ) ( ) p p M p F S p , T j 1 2 1 1 0 0 ? + = (8) at l x = , ( ) ( ) ( ) p p M p F S s , l T jd , d , d g , g , g d , d , d v mi , ? ? ? ? ? = ? 1 3 1 3 1 3 H , H D , D E , E m , ? ? ? ? ? = ? H H H D D D E E E ij s ,? ? ? ? ? = ? H D E c c c c , ? ? ? ? ? ? ? ? = ? H D E , ? ? ? ? ? ? = nb nh n l . ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? = ? ? p p l l p p F p M p m mi ij 2 1 1 2 1 1 ch sh 1 1 (10) ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? = ? ? p p l l p p F p M p m mi ij 1 2

3 S s E E = ?

The structural-parametric model of the multilayer piezo actuator for the transverse piezo effect has the form For the shift piezo effect the Laplace transform of the caused force The structural-parametric model of the multilayer piezo actuator for the shift piezo effect has the form We drew the structural schematic diagram of the actuator from the generalized structural-parametric model of the multilayer electro magneto elastic actuator for the nanomechanics.( ) ( ) E s p E S d p F 55 1 0 15 = (**15**) 0 55 55 S s E E = ? ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? ? = ? p p l l p E d p F p M p E 2 1 3 33 33 1 2 1 1 ch sh 1 1 (12) ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? ? = ? p p l l p E d p F p M p E 1 2 3 33 33 2 2 2 2 ch sh 1 1 ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? ? = ? p p l l p E d p F p M p E 2 1 3 31 11 1 2 1 1 ch sh 1 1 (14) ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? ? = ? p p l l p E d p F p M p E 1 2

4 III.

5 Matrix Transfer Function

From equation (10) we receive the matrix transfer function of the multilayer electro magneto elastic actuator with n the layers in the following form Therefore, in general, we have the matrix transfer function of the multilayer electro magneto elastic actuator in the form ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( )? ? ? ? ? ? ? ? ?? ? ? ? ? ? ? = ? ? ? ? ? ? ? ? ? p F p F p p W p W p W p W p W p( ) [ ] ( ) [ ] ( ) [ ] p P p W p = ? (18) ( ) [ ] ( ) ( ) ? ? ? ? ? ? ? ? = ? p p p 2 1 ( ) [ ] ( ) ( ) ( ) ( ) ( ) ? ? ? ? ? ? ? = p W p W p W p W p W p W p W( ) ( ) ( ) ( ) ( ) [ ] ij ij mi m A l p M p p p W 2 th 2 2 1 11 ? ? + ? ? = ? ? = ? 0 S s ij ij ? ? = ? ( ) ( ) ( ) [ ] { } ( ) ( ) ( ) [ ] 2 2 2 2 1 3 2 1 4 2 2 1 2 1 th th ? + ? + + ? ? ? + + ? ? + + ? = ? ? ? ? ? ? c p p c l M M p l c M M p M M A ij ij ij ij ( ) ( ) ( ) ( ) [ ] ij ij ij m A l p M p p p W 2 th 2 1 2 21 ? ? + ? ? = ? ? = ? ( ) ( ) ( ) ( ) [ ] ij ij ij A l p M p F p p W ? ? + ? ? ? = ? = ? ? th 2 2 1 1 12 ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ij ij A l p F p p W p F p p W ? ? ? = ? = = ? = ? sh 1 2 22 2 1 13 ( ) ( ) ( ) ( ) [ ] ij ij ij A l p M p F p p W ? ? + ? ? ? = ? = ? ? th 2 1 2 2 23

We receive the generalized parametric structural schematic diagram and the generalized matrix transfer function from the generalized structural-parametric model of the multilayer electro magneto elastic actuator to calculate its static and dynamic characteristics for the nanomechanics. Let us consider, for example, the voltage-controlled multilayer piezo actuator for the longitudinal piezo effect with the inertial load1 M m « , 2 M m « and ( ) ( ) 0 2 1 = = t F t F

and the static displacements of its faces in the following form( ) ( ) ( )( ) p U p pW t m p t ? = ? = ? ? ? ? ? ? ? 11 0 0 1 1 lim lim thus ( ) ( ) 2 1 2 33 1 M M M nU d m + = ? ? and ( ) ( ) ( )( ) p U p pW t m p t ? = ? = ? ? ? ? ? ? ? 21 0 0 2 2 lim lim thus ( ) ( ) 2 1 1 33 2 M M M nU d m + = ? ?

where m U is the amplitude of the voltage, m is the mass of the multilayer piezo actuator, = 480 nm. We derive the transfer function with concentrated parameters of the multilayer piezo actuator for the longitudinal piezo effect with the voltage control for the elastic-inertial load and one fixed face and its structural diagram in Figure **??**.( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? ? = ? p p l l p E d p F p M p E 2 1 1 15 55 1 2 1 1 ch sh 1 1 (16) ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? × ? + ? ? ? ? ? ? ? = ? p p l l p E d p F p M p E 1 2 1 15 55 2 2 2 2 ch sh 1 1 ( ) ( ) ( ) (

) ( ) The discrepancy between the experimental data and calculation results is no more than 5%.1

IV.

6 Results and Discussions

We have the equations for the generalized structural-parametric model and the generalized structural diagram of the multilayer electro magneto elastic actuator. We receive the matrix transfer functions and the structural diagram of the multilayer electro magneto elastic actuator from the set of equations describing the structural parametric model of the multilayer actuator for the nanomechanics. The solution of the matrix equation for the equivalent quadripole of the multilayer electro magneto elastic actuator with the Laplace transform is used for the construction the structural diagram of the multilayer actuator.

As a result of the joint solution of the general equation of electro magneto elasticity, the matrix equation for the equivalent quadripole of the multilayer electro magneto elastic actuator, and its boundary conditions we receive the generalized structuralparametric model and the generalized structural diagram of the multilayer actuator.

7 V. ONCLUSION

We consider the generalized structuralparametric model, the structural diagram and the matrix transfer function of the multilayer electro magneto elastic actuator for the nanomechanics. We receive the structural diagram of the multilayer piezo actuator for the transverse, longitudinal, and shift piezo effects.

From the general equation of electro magneto elasticity, the force that causes the deformation, the system of the equations for the equivalent quadripole of the multilayer actuator, and the forces on its faces, we obtain generalized structural-parametric model and generalized structural diagram of the multilayer electro magneto elastic actuator for the nanomechanics. [1] [2] [3]

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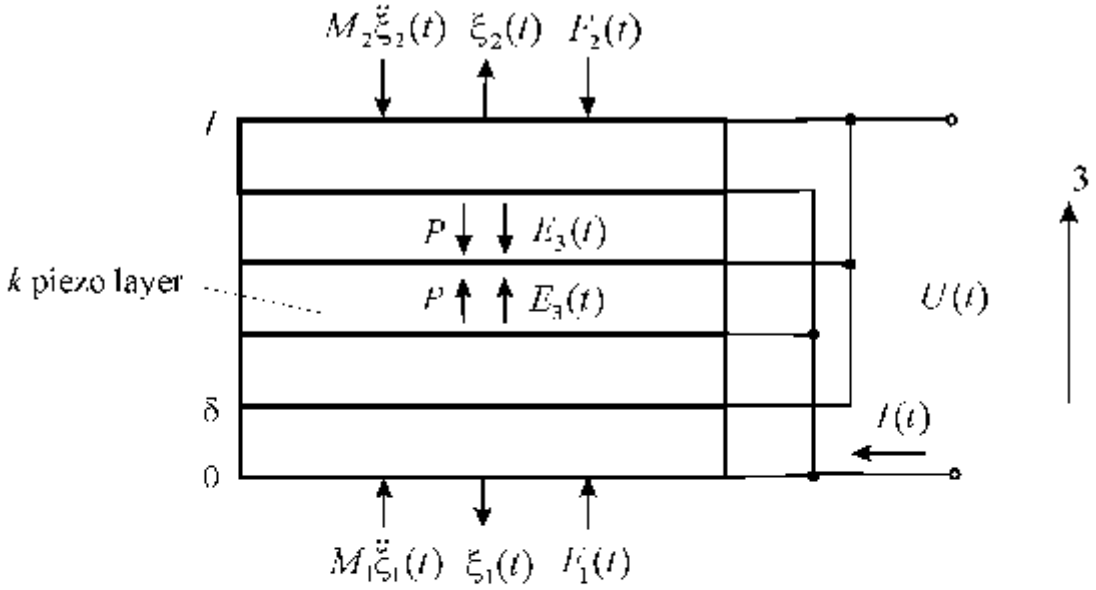
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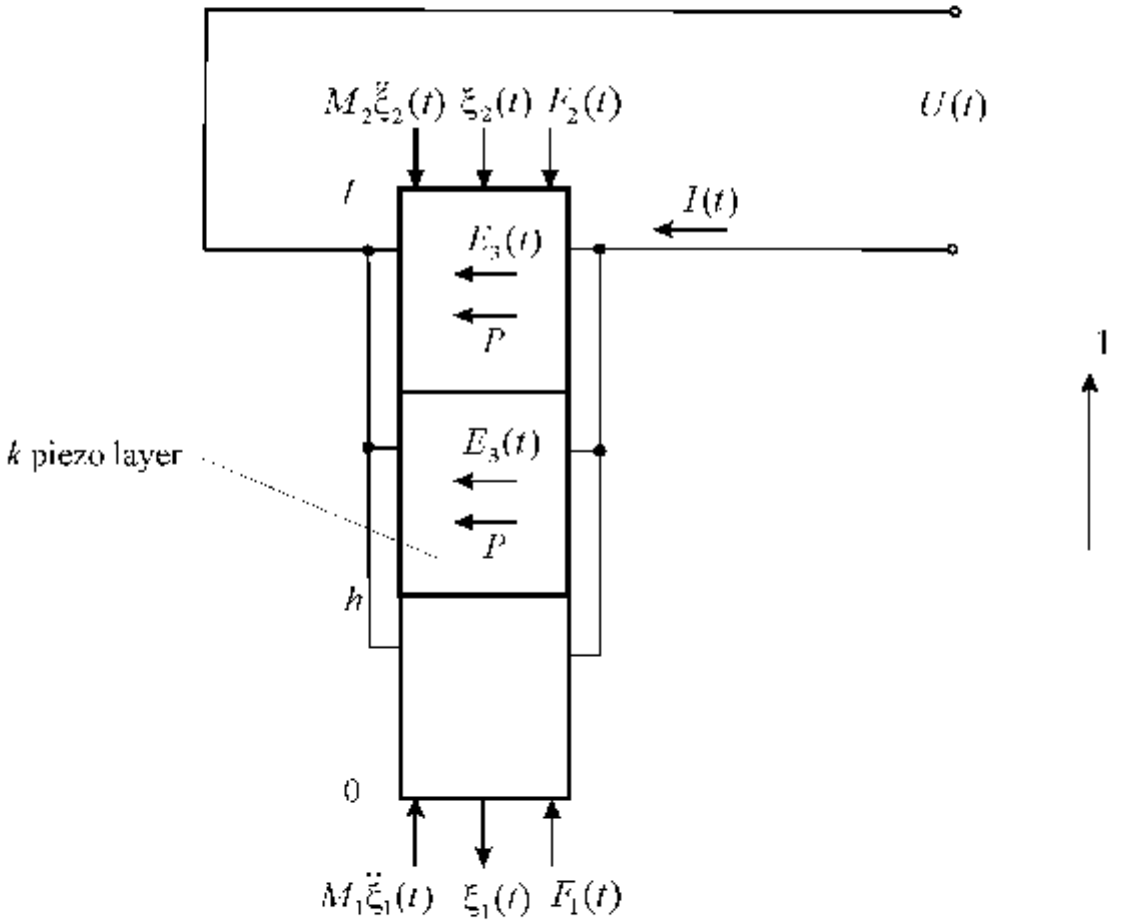
a)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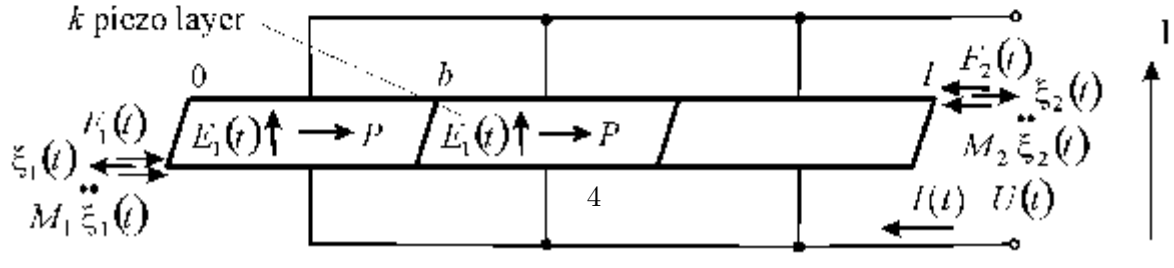
b)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4
I(t) U(t)

c)

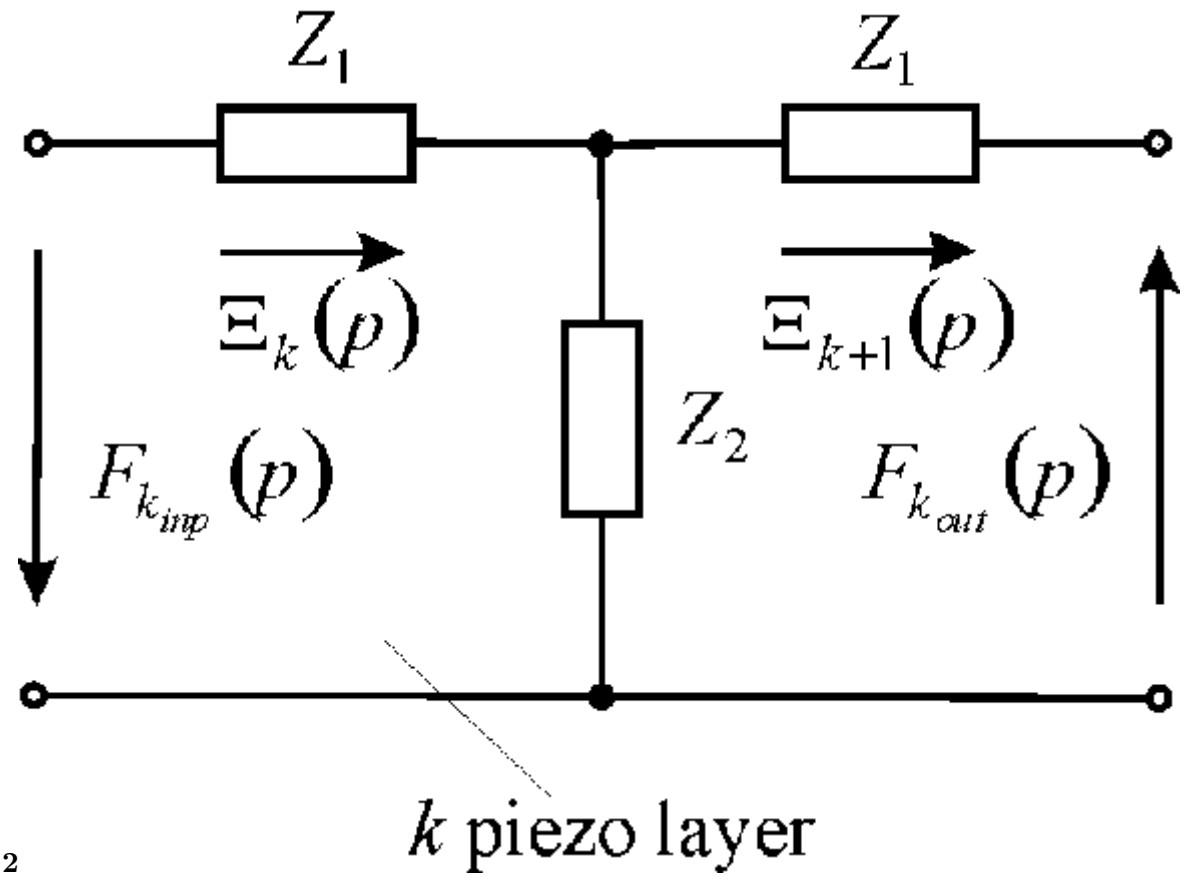

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Figure 2: Figure 2 :

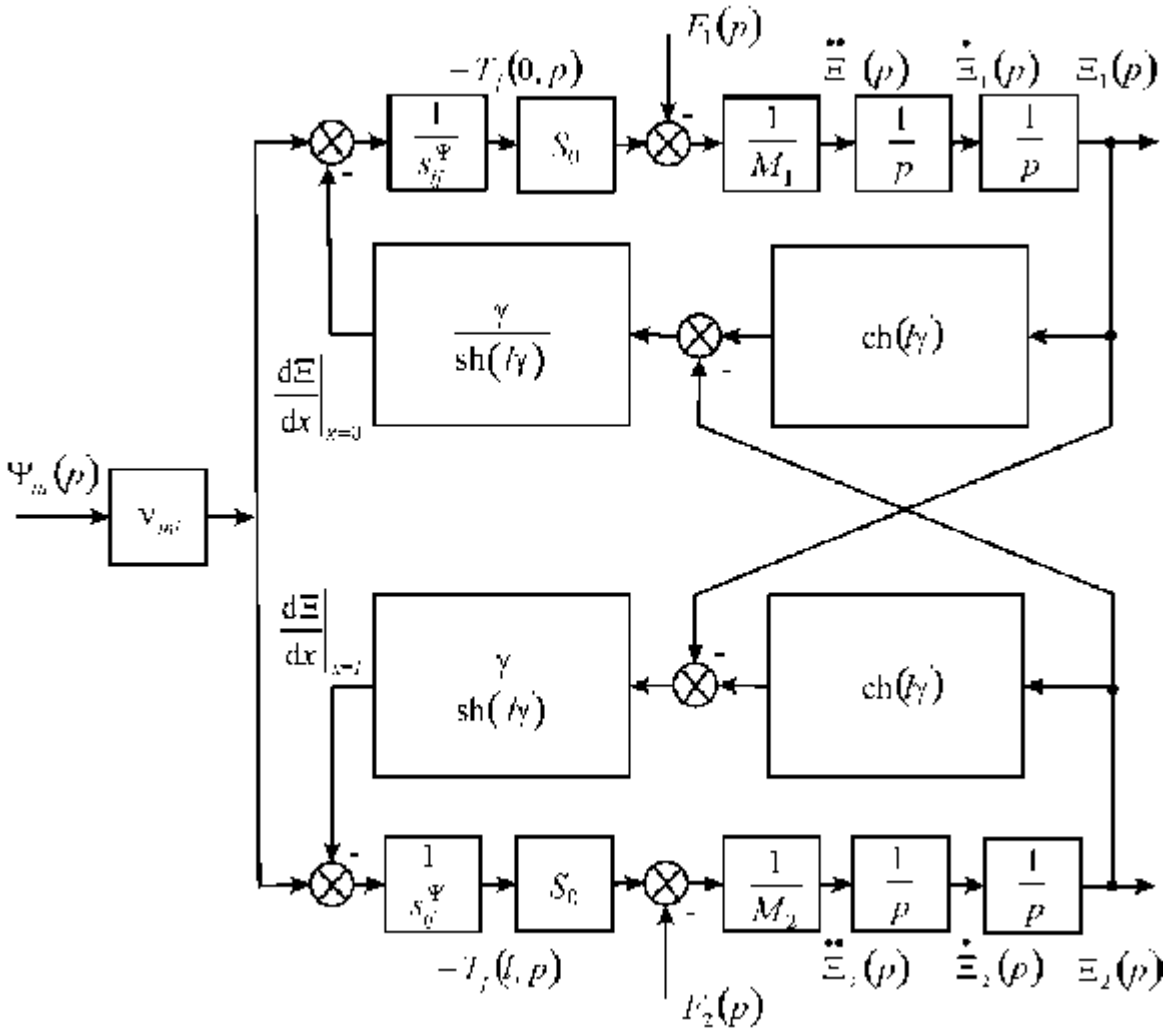

Figure 3:

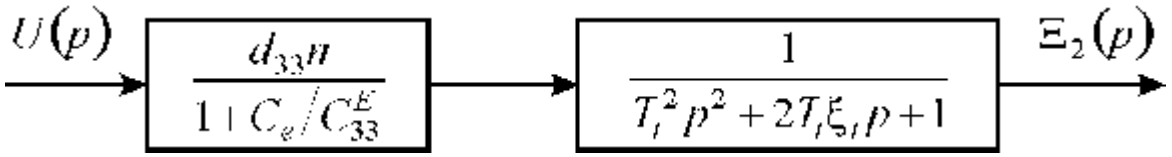

Figure 4:

[IEEE/ASME Transactions on Mechatronics] , 1109/TMCH.20. *IEEE/ASME Transactions on Mechatronics* 15 (5) p. 770.

[S1028335808030063] , / S1028335808030063 .

[S1068798x11090036] , / S1068798x11090036 .

[Bartul et al.] , Z Bartul , J Trenor , Nova Science . New York. p. .

[Tmech ()] , / Tmech . 2009.2034973.

[Schultz et al. ()] , J Schultz , J Ueda , H Asada . 2017. Oxford. 382. (Cellular Actuators. Butterworth-Heinemann Publisher)

[Afonin ()] 'A structural-parametric model of electroelastic actuator for nanoand microdisplacement of mechatronic system'. S M Afonin . *Advances in nanotechnology*, 2017. 19.

[Afonin ()] 'Absolute stability conditions for a system controlling the deformation of an elecromagnetoelastic transduser'. S M Afonin . 10.1134/S1064562406060391. *Doklady mathematics* 2006. 74 (3) p. .

[Afonin ()] 'Block diagrams of a multilayer piezoelectric motor for nanoand microdisplacements based on the transverse piezoeffect'. S M Afonin . 10.1134/S1064230715020021. *Journal of computer and systems sciences international* 2015. 54 (3) p. .

[Afonin ()] 'Deformation, fracture, and mechanical characteristics of a compound piezoelectric transducer'. S M Afonin . *Mechanics of solids* 2003. 38 (6) p. .

[Afonin ()] 'Design static and dynamic characteristics of a piezoelectric nanomicrotransducers'. S M Afonin . 10.3103/S0025654410010152. *Mechanics of solids* 2010. 45 (1) p. .

[Karpelson et al. ()] 'Driving high voltage piezoelectric actuators in microrobotic applications'. M Karpelson , G-Y Wei , R J Wood . 10.1016/j.sna.2011.11.035. *Sensors and Actuators A: Physical* 2012. 176 p. .

[Afonin ()] 'Elastic compliances and mechanical and adjusting characteristics of composite piezoelectric transducers'. S M Afonin . 10.3103/S0025654407010062. *Mechanics* 2007. 42 (1) p. .

[Afonin ()] 'Electroelasticity problems for multilayer nano-and micromotors'. S M Afonin . doi:10. *Russian engineering research* 2011. 31 (9) p. .

[Afonin ()] 'Electromagnetoelastic nano-and microactuators for mechatronic systems'. S M Afonin . *Russian Engineering Research* 2018. 38 (12) p. .

[Afonin ()] 'Electromechanical deformation and transformation of the energy of a nano-scale piezomotor'. S M Afonin . 10.3103/S1068798X11070033. *Russian engineering research* 2011. 31 (7) p. .

[Yang and Tan ()] 'Equivalent circuit modeling of piezoelectric energy harvesters'. Y Yang , Tan . *Journal of intelligent material systems and structures* 2009. 20 (18) p. .

[Afonin ()] 'Generalized parametric structural model of a compound elecromagnetoelastic transduser'. S M Afonin . 10.1134/1.1881716. *Doklady physics* 2005. 50 (2) p. .

[Zwillinger ()] *Handbook of Differential Equations*, D Zwillinger . 1989. Boston: Academic Press. 673.

[Ueda et al. ()] *Large effectivestrain piezoelectric actuators using nested cellular architecture with exponential strain amplification mechanisms*, J Ueda , T Secord , H H Asada . 10.1109/TMECH.2009.2034973. 2010.

[Afonin ()] 'Multilayer electromagnetoelastic actuator for robotics systems of nanotechnology'. S M Afonin . 10.1109/EIConRus.2018.8317432. *Proceedings of the 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, (the 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)) 2018. p. .

[Afonin ()] 'Nano-and micro-scale piezomotors'. S M Afonin . 10.3103/S1068798X12060032. *Russian engineering research* 2012. 32 (7-8) p. .

[Afonin ()] 'Optimal control of a multilayer submicromanipulator with a longitudinal piezo effect'. S M Afonin . 10.3103/S1068798X15120035. *Russian engineering research* 2015. 35 (12) p. .

[Afonin ()] 'Parametric block diagram and transfer functions of a composite piezoelectric transducer'. S M Afonin . *Mechanics of solids* 2004. 39 (4) p. .

[Afonin ()] 'Parametric structural diagram of a piezoelectric converter'. S M Afonin . *Mechanics of solids* 2002. 37 (6) p. .

[Part A. Methods and Devices ()] *Part A. Methods and Devices*, (New York) 1964. Academic Press. 1.

[Cady ()] *Piezoelectricity: An introduction to the theory and applications of electromechancial phenomena in crystals*, W G Cady . 1946. New York, London: McGraw-Hill Book Company. 806.

[Afonin ()] 'Solution of the wave equation for the control of an elecromagnetoelastic transduser'. S M Afonin . 10.1134/S1064562406020402. *Doklady mathematics* 2006. 73 (2) p. .

[Bhushan B (ed.) ()] *Springer Handbook of Nanotechnology*, 10.1016/j.engstruct.2014.11.025. Bhushan B (ed.) 2004. Berlin, New York: Springer. p. 1222.

[Przybylski ()] *Static and dynamic analysis of a flextensional transducer with an axial piezoelectric actuation, Engineering structures*, J Przybylski . 10.1016/j.engstruct.2014.11.025. 2015. 84 p. .

[Afonin ()] 'Static and dynamic characteristics of a multy-layer electroelastic solid'. S M Afonin . 10.3103/S0025654409060119. *Mechanics* 2009. 44 (6) p. .

[Afonin ()] 'Structural parametric model of a piezoelectric nanodisplacement transduser'. S M Afonin . doi:10. *Doklady physics* 2008. 53 (3) p. .

[Afonin ()] 'Structural-parametric model and transfer functions of electroelastic actuator for nanoand microdisplacement'. S M Afonin . *Piezoelectrics and Nanomaterials: Fundamentals, Developments and Applications. Ed. Parinov IA. Nova Science*, (New York) 2015. p. .

[Afonin ()] 'Structural-parametric model electromagnetoelastic actuator nanoand microdisplacement for precision engineering'. S M Afonin . *Precision Engineering. Engineering and Technology* 2016. 3 (6) p. .

[Afonin ()] 'Structural-parametric model electromagnetoelastic actuator nanodisplacement for mechatronics'. S M Afonin . 10.12691/ijp-5-1-27. *International Journal of Physics* 2017. 5 (1) p. .

[Afonin ()] 'Structural-parametric models and transfer functions of electromagnetoelastic actuators nano-and microdisplacement for mechatronic systems'. S M Afonin . 10.11648/j.ijtam.20160202.15. *International Journal of Theoretical and Applied Mathematics* 2016. 2 (2) p. .