Electromagnetelastic Actuator for Nanomechanics

SM Afonin[1]

[1] National Research University of Electronic Technology (MIET)

Received: 10 December 2017 Accepted: 31 December 2017 Published: 15 January 2018

Abstract

From the structural-parametric model of the electromagnetoelastic actuator we obtain the parametric structural schematic diagram and the matrix transfer function, the characteristics of the electromagnetoelastic actuator for the nanomechanics. The generalized parametric structural schematic diagram, the matrix transfer function of the electromagnetoelastic actuator is described with using its physical parameters and external load.

Index terms — electromagnetoelastic actuator; structural-parametric model; nanodisplacement; piezoactuator; parametric structural schematic diagram

1 I. Introduction

he electromagnetoelastic actuator for piezoelectric, piezomagnetic, electrostriction, magnetostriction effects is used for the precise adjustment in the nanomechanics, the nanotechnology, the adaptive optics **??**1 ?32]. The piezoactuator on the inverse piezoeffect is serves for the actuation of mechanisms or the management, converts the electrical signals into the displacement and the force **??**1 ?8]. The piezoactuator for the nanomechanics is provided the displacement from nanometers to tens of micrometers, a force to 1000 N. The piezoactuator is used in the nanomechanics and the nanotechnology for the scanning tunneling microscopes, the scanning force microscopes and the atomic force microscopes **??**14 ?32].

In the present paper the generalized structuralparametric model and the generalized parametric structural schematic diagram of the electromagnetoelastic actuator are constructed by solving the equation of the electromagnetolasticity, the wave equation with the Laplace transform, the boundary conditions on loaded working surfaces of the actuator, the strains along the coordinate axes. The transfer functions and the parametric structural schematic diagrams of the piezoactuator are obtained from the generalized structural-parametric model. In [6,7] was determined the solution of the wave equation of the piezoactuator. In the **??**14 ?16, 30] were obtained the structural-parametric models, the schematic diagrams for simple piezoactuator and this models were transformed to the structural-parametric model of the electromagnetoelastic actuator. The structural-model of the electroelastic actuator was determined in contrast electrical equivalent circuit for calculation of piezoelectric transmitter and receiver **??**9 ?12]. In [8,27] was used the transfer functions of the piezoactuator for the decision problem absolute stability conditions for a system controlling the deformation of the electromagnetoelastic actuator. The elastic compliances and the mechanical and adjusting characteristics of the piezoactuator were found in **??**18, 21 ? 23, 28, 29] for calculation its transfer functions and the structuralparametric models. The structural-parametric model of the multilayer and compound piezoactuator was determined in **??**18?20]. In this paper is solving the problem of building the generalized structural parametric model and the generalized parametric structural schematic diagram of the electromagnetoelastic actuator for using the equation of electromagnetoelasticity.

2 II. Structural-Parametric Model

The general structural-parametric model and the parametric structural schematic diagram of the electromagnetoelastic actuator are obtained. In the electroelastic actuator are presented six stress components 1

T , 2 T , 3 T , 4 T , 5 T , 6 T , the components 1 T ? 3 T are related to extension-compression stresses, 4 T ? 6 T to shear stresses. For the electroelastic actuator its deformation corresponds to stressed state. In piezoceramics

PZT the matrix state equations [12,14] connected the electric and elastic variables have the form two equations, then the first equation describes the direct piezoelectric effect, the second -the inverse piezoelectric effectE ? dT D T + = (1) E d T s S t E + = (2)

where D is the column matrix of electric induction; S is the column matrix of relative deformations; T is the column matrix of mechanical stresses; E is the column matrix of electric field strength; E s is the elastic compliance matrix forconst = E ; T ? is the matrix of dielectric constants for const = T ; t d

is the transposed matrix of the piezoelectric modules.

The piezoactuator (piezoplate) has the following properties: ? is the thickness, h is the height, b is theT Global Journal of Researches in Engineering width, respectively { b h l , , ? =

the length of the piezoactuator for the longitudinal, transverse and shift piezoeffects. The direction of the polarization axis ?, i.e., the direction along which polarization was performed, is usually taken as the direction of axis 3. The equation of the inverse piezoeffect for controlling voltage [6,12] has the form( ) ( ) t , x T s t d S j ij m mi i ? + ? = (3) ( ) x t , x S i ? ? ? = , ( ) ( ) ( ) ? = = ? t U t E t m m

where i S is the relative displacement of the cross section of the piezoactuator along axis i, ( ) for the piezoactuator is respectively, the thickness, the height, the width for the longitudinal, transverse, shift piezoeffects.t

For calculation of actuator is used the wave equation [6,7,12,14] for the wave propagation in a long line with damping but without distortions. After Laplace transform is obtained the linear ordinary second-order differential equation with the parameter p, whereupon the original problem for the partial differential hyperbolic equation of type using the Laplace transform is reduced to the simpler problem [6,13] for the linear ordinary differential equation , ? is the damping coefficient of the wave, ? is the control parameter: E is the electric field strength for the voltage control, D is the electrical induction for the current control, H is the magnet field strength.

From (3), (**??**), the boundary conditions on loaded surfaces, the strains along the axes the system of equations for the generalized structural-parametric model and the generalized parametric structural schematic diagram Figure 1 of the actuator are determined ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? + ? ? ? ? ? ? ? ? ? = ? ? p p l l p d p F p M p m mi ij 2 1 1 2 1 1 ch sh 1 1 (6) ( ) ( ) ( ) ( ) ( ) ( ) ( ) [ ] ? + ? ? ? ? ? ? ? ? ? = ? ? p p l l p d p F p M p m mi ij 1 2

3 III. Matrix Transfer Function

The matrix transfer function of the electromagnetoelastic actuator for the nanomedicine and the nanotechnology is deduced from its structuralparametric model (6) in the following form ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ? = ? ? ? ? ? ? ? ? ? ? p F p F p p W p W p W p W p W p+ ? = ? = ? ? ? ? ? (8) ( ) ( ) ( ) 2 1 1 0 31 0 21 0 0 2 lim M M M hU d p U p pW p + ? = ? = ? ? ? ? ? (9)

For the piezoactuator from PZT under the transverse piezoeffect at1 M m « , 2 M m « , 10 31 10 5 2 ? ? = . d m/V, 20 = ? h , 30 = U V, 2 1 = M kg, 8 2 = M

kg the static displacements of the faces are determined( ) 120 ? 1 = ? nm, ( ) 30 ? 2 = ? nm, ( ) ( ) 150 ? ? 2 1 = ? + ? nm.

For the approximation of the hyperbolic cotangent by two terms of the power series in transfer function (7) the following expressions of the transfer function of the piezoactuator is obtained for the elasticinertial load at? ? 1 M , 2 M m « under the transverse piezoeffect ( )**( ) ( ) ( )**) p T p T (C C h d p U p p W t t t E e 1 2 1 2 2 11 31 2 + ? + + ? = ? =**(10)**

(

) E e t C C M T 11 2 + = , ( ) ? ? ? ? ? ? + ? = ? E e E E t C C M c C h( ) ( ) ? + ? ? ? ? ? ? ? ? = ?

4 IV. Results and Discussions

The structural-parametric model and parametric structural schematic diagrams of the voltage-controlled piezoactuator for the longitudinal, transverse and shift piezoeffects are determined from the generalized structural-parametric model of the electromagnetoelastic actuator with the replacement of the following parameters.{ 1 3 3 E , E , E m = ? , { 15 31 33 d , d , d d mi = , { E E E ij s , s , s s 55 11 33 = ? , { b , h , l ? =

The generalized structural-parametric model, the generalized parametric structural schematic diagram and the matrix transfer function of the electromagnetoelastic actuator are obtained from the solutions of the equation of the electromagnetoelasticity, the Laplace transform and the linear ordinary differential equation of the second order.

From the generalized matrix transfer function of the electromagnetoelastic actuator after algebraic transformations are constructed the matrix transfer function of the piezoactuator for the longitudinal, transverse and shift piezoeffects.

5 V. Conclusions

The generalized structural-parametric model, the generalized parametric structural schematic diagram, the matrix transfer function of the electromagnetoelastic actuator for the nanomechanics are obtained.

The structural-parametric model, the matrix transfer function and the parametric structural schematic diagram of the piezoactuator for the transverse, longitudinal, shift piezoeffects are obtained from the generalized structural-parametric model of the electromagnetoelastic actuator. From the solution of the equation of the electromagnetolasticity, the wave equation with the Laplace transform and the deformations along the axes the generalized structuralparametric model and the generalized parametric structural schematic diagram of the electromagnetoelastic actuator are constructed for the control systems in the nanomechanics. The deformations of the actuator are described by using the matrix transfer function of the electromagnetoelastic actuator. [1]

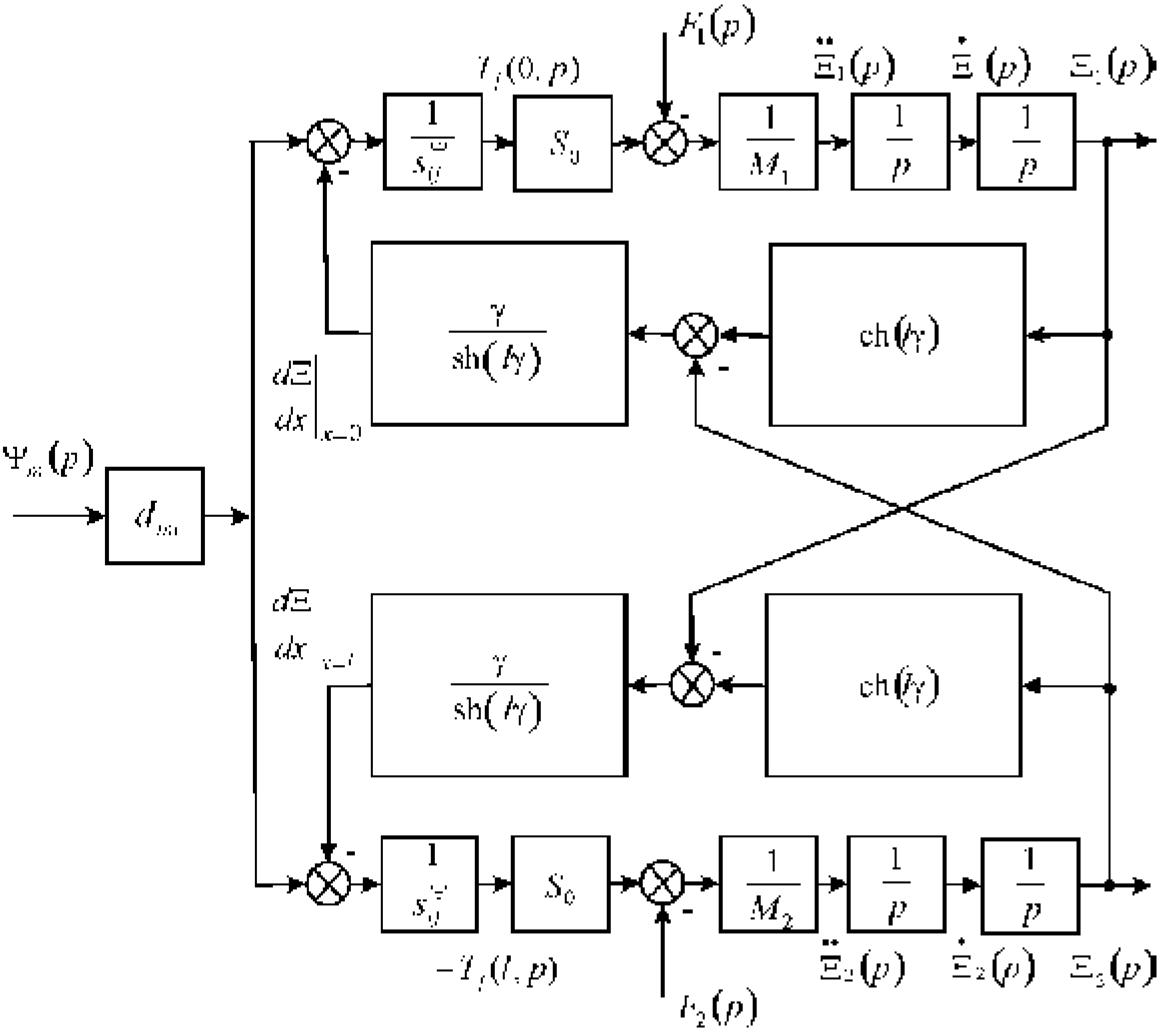

Figure 1:

[IEEE/ASME Transactions on Mechatronics] , 10.1109/TMECH.2009.2034973. doi: 10.1 109/ TMECH.2009.2034973. *IEEE/ASME Transactions on Mechatronics* 15 (5) p. .

[Doklady physics] , doi: 10.1134/ S10 28335808030063. *Doklady physics* 53 (3) p. .

[Nanoscience and Nanotechnology. Ed. by Nalwa HS ()] , *Calif. Global Journal of Researches in Engineering* Nanoscience and Nanotechnology. Ed. by Nalwa HS (ed.) 2004. American Scientific Publishers.

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

[Afonin ()] 'Absolute stability conditions for a system controlling the deformation of an elecromagnetoelastic transduser'. S M Afonin . 10.1134/S106. *Doklady mathematics* 2006. 74 (3) p. 2406060391.

[Afonin ()] 'Block diagrams of a multilayer piezoelectric motor for nanomicrodisplacements based on the transverse piezoeffect'. S M Afonin . doi: 10.113 4/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. .

[Talakokula et al. ()] 'Diagnosis of carbonation induced corrosion initiation and progressionin reinforced concrete structures using piezo-impedance transducers'. V Talakokula , S Bhalla , R J Ball , C R Bowen , G L Pesce , R Kurchania , B Bhattacharjee , A Gupta , K Paine . 10.1016/j.sna.2016.02.033. *Sensors and Actuators A: Physical* 2016. 242 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 of solids* 2007. 42 (1) p. .

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

[Afonin ()] 'Electroelasticity problems for multilayer nano-and micro motors'. S M Afonin . doi: 10.3 103/ S1068798X11090036. *Russian engineering research* 2011. 31 (9) 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 . doi: 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 . 2010.

[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.

[Uchino ()] *Piezoelectric actuator and ultrasonic motors*, K Uchino . 1997. 1997. Boston, MA: Kluwer Academic Publisher. 347.

[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 . doi: 10.11 34/ S1064562406020402. *Doklady mathematics* 2006. 73 (2) p. .

[Afonin ()] 'Stability of strain control systems of nano-and micro displacement piezotransducers'. S M Afonin . doi: 10. 31 03/ S0025654414020095. *Mechanics of solids* 2014. 49 (2) p. .

[Przybylski ()] *Static and dynamic analysis of a flex tensional 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 of solids* 2009. 44 (6) p. .

[Afonin ()] *Structural parametric model of a piezoelectric nanodisplacement transduser*, S M Afonin . 2008.

[Afonin ()] 'Structural-parametric model and transfer functions of electroelastic actuator for nanoand micro displacement'. 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 nano-and micro displacement 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 micro displacement for mechatronic systems'. S M Afonin . 10.11648/j.ijtam.20160202.15. *International Journal of Theoretical and Applied Mathematics* 2016. 2 (2) p. .