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Characteristics of Nanopositioning Electroelastic Digital-to-Analog Converter for Communication Systems

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ABSTRACT

The characteristics of the nanopositioning electroelastic digital-to-analog converter for communication systems are examined. In the static and dynamic regimes this characteristics are received. The static strain and control characteristics of the nanopositioning electroelastic digital-to-analog converter are obtained. The transfer function of the nanopositioning electroelastic digital-to-analog converter is received.

Keywords: Nanopositioning electroelastic digital-to-analog converter; Static and dynamic characteristics; Deformation; Piezoconverter; Strain and control characteristics; Transfer function.

1 Introduction

The nanopositioning electroelastic converter on the piezoelectric effect or the electrostriction effect solves task of precise adjustment for nanotechnology, adaptive optics, antennas, communication systems [1–8]. The tasks of providing accuracy and speed of the control system using the nanopositioning electroelastic digital-to-analog converter with the coded control are topical. These tasks can be solved by determining the static and dynamic characteristics of the nanopositioning electroelastic converter and its static strain and control characteristics [7, 8]. The application of this actuator with the multilayer sectional electroelastic converter using the coded control makes it possible to efficiently use the electromechanical digital-to-analog conversion for the nanodisplacement.

The nanopositioning electroelastic digital-to-analog converter converter for communication systems is used in the form a piezoelectric or electrostriction converter. In the scanning probe microscopy and the gene manipulator the multilayer piezoconverter is applied for the scanner and the manipulator [4–8]. The strain and control characteristics of the electroelastic digital-to-analog converter for communication systems are obtained.

2 Static characteristics

Let us consider the characteristics of the nanopositioning electroelastic digital-to-analog converter for communication systems at the transverse, shear, longitudinal piezoeffects. The piezolayers in the nanopositioning electroelastic digital-to-analog converter are connected in parallel in each section of the converter, and the control voltage is supplied to each section via the multiplexer. The number of piezolayers in the section is equal to the power of 2. To calculate the deformation of the nanopositioning electroelastic digital-to-analog converter, considering the specific features of its strain and control

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characteristics is necessary [4-15]. The electroelastic digital-to-analog converter consists of *N* sections with all *n* layers.

For the electroelastic digital-to-analog converter at the transverse piezoeffect the equation of the electroelasticity [11–34] has the form

$$S_1 = d_{31}E_3 + s_{11}^E T_1, \tag{1}$$

where S_1, d_{31}, E_3, s_{11}^E, T_1 are the relative deformation along the axis 1, the transverse piezomodule, the electric field strength along the axis 3, the elastic compliance with $E = \text{const}$, the mechanical tension along the axis 1.

The displacement of first section [11, 14] on Figure 1 the electroelastic digital-to-analog converter at the transverse piezoeffect has the form

$$\Delta l_1 = (d_{31}l_1/\delta)U, \tag{2}$$

where l_1 is length 1 section δ is the thickness

From (2) the displacement of *k* section the electroelastic digital-to-analog converter for transverse piezoeffect at $F = 0$ has the following form

$$\Delta l_k = (d_{31}l_1/\delta)2^{k-1}U = 2^{k-1}\Delta l_1 = (d_{31}l_k/\delta)U. \tag{3}$$

At $F = 0$ from (3) the displacement of the electroelastic digital-to-analog converter for transverse piezoeffect is obtained in the form

$$\Delta l = (d_{31}l_1/\delta)\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U = \Delta l_1\left(\sum_{k=1}^{N} a_k 2^{k-1}\right), \tag{4}$$

where a_k is the binary code for *k* section on Figure 1.

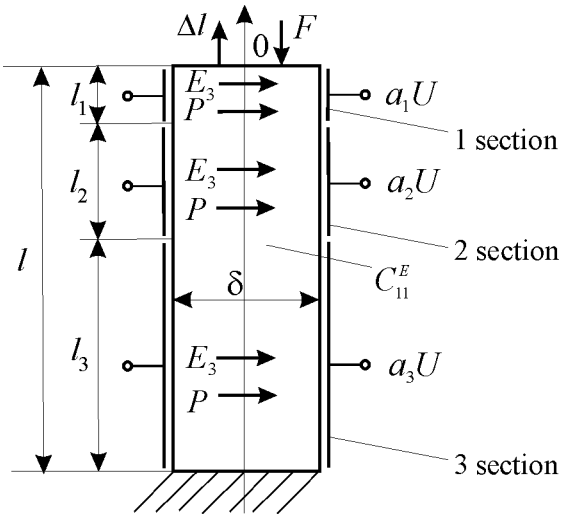


Figure 1. Nanopositioning electroelastic digital-to-analog converter at transverse piezoeffect

The strain characteristic of the electroelastic digital-to-analog converter has the form

$$\Delta l(F) = \Delta l(U, a_k, F)\big|_{U = \text{const}, a_k = \text{const}}. \tag{5}$$

After transformations the strain characteristic of the electroelastic digital-to-analog converter has the following form

$$\Delta l = \Delta l_{\max}\left(1 - F/F_{\max}\right) , \tag{6}$$

where $\Delta l_{\max}$, $F_{\max}$ are maximum the displacement at $F = 0$ and are maximum the force at $\Delta l = 0$.

The strain characteristic of the electroelastic digital-to-analog converter for transverse piezoeffect has the following form

$$\Delta l = \left(d_{31}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U - s_{11}^{E} F l/S_0 , \tag{7}$$

therefore,

$$\Delta l = \left(d_{31}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U - F/C_{11}^{E} , \tag{8}$$

where $C_{11}^{E} = S_0/\left(s_{11}^{E} l\right)$ is the rigidity of the electroelastic digital-to-analog converter for transverse piezoeffect

For the strain characteristic (6) of the electroelastic digital-to-analog converter at transverse piezoeffect the maximum displacement and the maximum force have the form

$$\Delta l_{\max} = \left(d_{31}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U = \Delta l_1 \left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right), \tag{9}$$

$$F_{\max} = \left(d_{31}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)\left(S_0/s_{11}^{E} l\right)U , \tag{10}$$

therefore,

$$F_{\max} = \left(d_{31}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)C_{11}^{E} U . \tag{11}$$

For the electroelastic digital-to-analog converter from ceramic PZT at d_{31} = 2.5·10^{-10} m/V, l_1/δ = 1, U = 60 V the displacement of first section is obtained Δl_1 = 15 nm.

Control characteristic of the electroelastic digital-to-analog converter at transverse piezoeffect and elastic load has the form

$$\Delta l = \frac{\left(d_{31} l_1/\delta\right)}{\left(1 + C_e/C_{11}^{E}\right)}\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U = \Delta l_1 \left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right), \tag{12}$$

therefore,

$$\Delta l_1 = \frac{\left(d_{31} l_1/\delta\right)}{\left(1 + C_e/C_{11}^{E}\right)} U , \tag{13}$$

where C_e is the rigidity of the load.

For the electroelastic digital-to-analog converter at the shear piezoeffect the equation of the electroelasticity [11–34] has the form

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$$S_5 = d_{15}E_1 + s_{55}^E T_5 , \tag{14}$$

where $S_{5`}$, d_{15}, E_1, s_{55}^E, T_5 are the relative deformation along the axis 5, the shear piezomodule, the electric field strength along the axis 1, the elastic compliance with $E = \text{const}$, the mechanical tension along the axis 5. The strain characteristic (6) of electroelastic digital-to-analog converter at shear piezoeffect has the following form

$$\Delta l_{\max} = \left(d_{15}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U = \Delta l_1 \left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right), \tag{15}$$

$$F_{\max} = \left(d_{15}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)\left(S_0/s_{55}^E l\right)U , \tag{16}$$

therefore,

$$F_{\max} = \left(d_{15}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)C_{55}^E U , \tag{17}$$

$$\Delta l_1 = \left(d_{15}\, l_1/\delta\right)U , \tag{18}$$

where $C_{55}^E = S_0/\left(s_{55}^E l\right)$ is the rigidity of electroelastic digital-to-analog converter for shear piezoeffect. For electroelastic digital-to-analog converter from ceramic PZT at d_{15} = 5·10^{-10} m/V, l_1/δ = 1, U = 60 V the displacement of first section is received Δl_1 = 30 nm.

The control characteristic of the electroelastic digital-to-analog converter at shear piezoeffect and elastic load has the form

$$\Delta l = \frac{\left(d_{15} l_1/\delta\right)}{\left(1 + C_e/C_{55}^E\right)}\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U = \Delta l_1 \left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right), \tag{19}$$

$$\Delta l_1 = \frac{\left(d_{15} l_1/\delta\right)}{\left(1 + C_e/C_{55}^E\right)}U . \tag{20}$$

For the electroelastic digital-to-analog converter at the longitudinal piezoeffect the equation of the electroelasticity [11–34] has the form

$$S_3 = d_{33}E_3 + s_{33}^E T_3 , \tag{21}$$

where $S_{3`}$, d_{31}, E_3, s_{33}^E, T_3 are the relative deformation along the axis 3, the longitudinal piezomodule, the electric field strength along the axis 3, the elastic compliance with $E = \text{const}$, the mechanical tension along the axis 3.

For the strain characteristic (6) of the electroelastic digital-to-analog converter at longitudinal piezoeffect the maximum displacement and the maximum force are obtained in the form

$$\Delta l_{\max} = \left(d_{33}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U = \Delta l_1 \left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right), \tag{22}$$

$$F_{\max} = \left(d_{33}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)\left(S_0/s_{33}^E l\right)U\,, \tag{23}$$

therefore,

$$F_{\max} = \left(d_{33}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)C_{33}^E U\,, \tag{24}$$

$$\Delta l_1 = \left(d_{33}\, l_1/\delta\right)U\,, \tag{25}$$

where $C_{33}^E = S_0/\left(s_{33}^E l\right)$ is the rigidity of the electroelastic digital-to-analog converter for longitudinal piezoeffect. For electroelastic digital-to-analog converter from ceramic PZT at d_{33} = 4·10^{-10} m/V, l_1/δ = 1, U = 60 V the displacement of first section is received Δl_1 = 24 nm.

The control characteristic of the electroelastic digital-to-analog converter at longitudinal piezoeffect and elastic load has the form

$$\Delta l = \frac{\left(d_{33} l_1/\delta\right)}{\left(1 + C_e/C_{33}^E\right)}\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U = \Delta l_1\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right), \tag{26}$$

$$\Delta l_1 = \frac{\left(d_{33} l_1/\delta\right)}{\left(1 + C_e/C_{33}^E\right)}U\,, \tag{27}$$

where $C_{33}^E = S_0/\left(s_{33}^E l\right)$ is the rigidity of the digital-to-analog converter for longitudinal piezoeffect.

For the electroelastic digital-to-analog converter the equation in general of the electroelasticity [11–34] has the form

$$S_i = d_{mi} E_m + s_{ij}^E T_j\,, \tag{28}$$

where S_i, d_{mi}, E_m, s_{ij}^E, T_j are the relative deformation, the coefficient of electro elasticity, the electric field strength, the elastic compliance with $E = \text{const}$, the mechanical tension, and the indexes i, j, m. For the strain characteristic (6) of the electroelastic digital-to-analog converter the maximum displacement and the maximum force are received in the form

$$\Delta l_{\max} = \left(d_{mi} l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U\,, \tag{29}$$

$$F_{\max} = \left(d_{mi} l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)U\left(S_0/\left(s_{ij}^E l\right)\right), \tag{30}$$

therefore,

$$F_{\max} = \left(d_{mi}\, l_1/\delta\right)\left(\sum_{k=1}^{N} a_k\, 2^{k-1}\right)C_{ij}^E U\,, \tag{31}$$

$$\Delta l_1 = \left(d_{mi}\, l_1/\delta\right)U\,, \tag{32}$$

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where $C_{ij}^{E}= S_0/\left(s_{ij}^{E} l\right)$ is the rigidity of the electroelastic digital-to-analog converter.

At elastic load in the static regime from (28) the control characteristic of the electroelastic digital-to-analog converter with *N* sections is obtained in the following form

$$\Delta l = k_a U = \frac{\left(d_{mi} l_1/\delta\right)}{\left(1+C_e/C_{ij}^{E}\right)}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right)U = \Delta l_1 c \tag{33}$$

$$k_a = \frac{\left(d_{mi} l_1/\delta\right)}{\left(1+C_e/C_{ij}^{E}\right)}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right), \quad \Delta l_1 = \frac{\left(d_{mi} l_1/\delta\right)U}{\left(1+C_e/C_{ij}^{E}\right)}, \tag{34}$$

$$c = \sum_{k=1}^{N} a_k 2^{k-1}, \quad \Delta l = \Delta l_1\left(\sum_{k=1}^{N} a_k 2^{k-1}\right), \tag{35}$$

where k_a is the transfer coefficient of the digital-to-analog converter, Δl_1 is the deformation of the first section of the converter, c is the decimal code. In the work the static strain and control characteristics of the nanopositioning electroelastic digital-to-analog converter are obtained.

3 Dynamic characteristics

The transfer function [14, 32] of the nanopositioning electroelastic digital-to-analog converter is obtained. At elastic-inertial load at $m << M$ on Figure 2 the transfer function $W(p)$ for the lumped parameters of the nanopositioning electroelastic digital-to-analog converter has the form

$$W(p) = \frac{\Xi(p)}{U(p)} = \frac{k_a}{T_{ij}^2 p^2 + 2T_{ij}\xi_{ij} p + 1}, \tag{36}$$

$$k_a = \frac{\left(d_{mi} l_1/\delta\right)}{\left(1+C_e/C_{ij}^{E}\right)}\left(\sum_{k=1}^{N} a_k 2^{k-1}\right), \tag{37}$$

$$T_{ij} = \sqrt{M/\left(C_e + C_{ij}^{E}\right)}, \quad \xi_{ij} = \alpha l^2 C_{ij}^{E}\Big/\left(3c^{E}\sqrt{M\left(C_e + C_{ij}^{E}\right)}\right), \tag{38}$$

where m, M are the masses of the actuator and the load, $\Xi(p)$, $U(p)$ are the Laplace transforms of the displacement and the voltage, p is the operator, k_a, T_{ij}, ξ_{ij} are the transfer coefficient, the time constant, the coefficient attenuation of the electroelastic digital-to-analog converter.

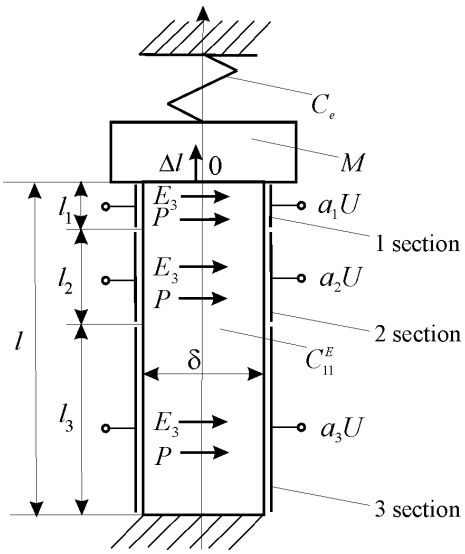


Figure 2. Nanopositioning electroelastic digital-to-analog converter at transverse piezoeffect and elastic-inertial load

At elastic-inertial load in the dynamic regime from (36) the transient response $\xi(t)$ of the displacement the nanopositioning electroelastic digital-to-analog converter is obtained in the form

$$\xi(t)=\xi_0 h(t)=\xi_0\left(1-\left(\sin\left(\beta_{ij}t+\varphi_{ij}\right)\Big/\sqrt{1-\xi_{ij}^2}\right)e^{-\frac{\xi_{ij}t}{T_{ij}}}\right), \tag{39}$$

$$h(t)=1-\left(\sin\left(\beta_{ij}t+\varphi_{ij}\right)\Big/\sqrt{1-\xi_{ij}^2}\right)e^{-\frac{\xi_{ij}t}{T_{ij}}}, \tag{40}$$

$$\xi_0=k_a U_0,\quad \beta_{ij}=\sqrt{1-\xi_{ij}^2}\,\Big/T_{ij},\quad \varphi_{ij}=\operatorname{arctg}\left(\sqrt{1-\xi_{ij}^2}\,\Big/\xi_{ij}\right),$$

where t is the time, ξ_0, U_0 are the amplitudes of the displacement and the voltage.

The transfer function and the transient response of the nanopositioning electroelastic digital-to-analog converter at elastic-inertial load are received for the communications systems.

4 Conclusion

The characteristics in general of the nanopositioning electroelastic digital-to-analog converter for the static and dynamic regimes are obtained. The strain and control characteristics in general of the electroelastic digital-to-analog converter for the communications systems are determined.

The transfer function and the transient response of the nanopositioning electroelastic digital-to-analog converter are received for the communications systems. The strain and control characteristics of the electroelastic digital-to-analog converter for the transverse, shift, longitudinal piezoelectric effects are determined.

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