Research Article

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Electro Elastic Drive for Nanoscience

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Abstract

For nanoscience research the parameters and the characteristics of the electro elastic drive are obtained. The transfer function and the transfer coefficient on the voltage of the piezo drive are determined. The mechanical characteristic of the piezo drive is received.

Keywords: Electro elastic drive, Piezo drive, Deformation, Transfer coefficient, Characteristic, Nanoscience

Introduction

The electro elastic drive for piezoelectric or electrostrictive effect is applied in nanoscience research (Uchino, 1997; Afonin, 2006; Schultz et al., 2017; Afonin, 2005; Afonin, 2008; Afonin, 2006). The energy transformation is clearly for the electro elastic drive (Schultz et al., 2017; Afonin, 2005; Afonin, 2008; Afonin, 2006; Cady, 1946; Mason, 1964; Yang & Tang, 2009; Zwillinger, 1989; Afonin, 2006; Afonin, 2006; Afonin, 2016; Afonin, 2015; Afonin, 2017; Afonin, 2018; Afonin, 2012; Afonin, 2007; Afonin, 2014; Afonin, 2017, Afonin, 2019; Afonin, 2021). The piezo drive is promising for nano materials science research, adaptive optics and tunel microscopy.

Differential equation for deformation

For the electro elastic drive the equations (Afonin, 2005; Afonin, 2008; Afonin, 2006; Cady, 1946; Mason, 1964; Yang & Tang, 2009; Zwillinger, 1989; Afonin, 2006; Afonin, 2006; Afonin, 2016; Afonin, 2015; Afonin, 2017; Afonin, 2018; Afonin, 2012; Afonin, 2007; Afonin, 2014; Afonin, 2017, Afonin, 2019; Afonin, 2021; Afonin, 2021; Afonin, 2016; Afonin, 2018; Afonin, 2019; Afonin, 2016; Afonin, 2010; Afonin, 2018; Afonin, 2018; Afonin, 2018; Afonin, 2019; Afonin, 2020; Afonin, 2020; Afonin, 2020; Afonin, 2021; Afonin, 2020; Afonin, 2018; Afonin, 2018; Afonin, 2019; Afonin, 2019; Afonin, 2019; Afonin, 2020; Afonin, 2020; Afonin, 2019; Afonin, 2020; Afonin, 2021; Afonin, 2021, Afonin, 2020; Afonin, 2021; Bhushan, 2004; Nalwa, 2004) have form

$$(D)=(d)(T)+(\varepsilon^T)(E)$$
$$(S)=(s^E)(T)+(d)^t(E)$$

where (D), (d), (T), (ε^T), (E), (s^E), $(d)^t$ are matrixes for electric induction, piezo coefficient, mechanical field strength, dielectric constant, electric field strength, relative displacement, elastic compliance, transposed piezo coefficient. For PZT drive this matrixes are determined as

$$(d)=\begin{pmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{15} & 0 & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 \end{pmatrix}$$

$$(\varepsilon^T)=\begin{pmatrix} \varepsilon_{11}^T & 0 & 0 \\ 0 & \varepsilon_{22}^T & 0 \\ 0 & 0 & \varepsilon_{33}^T \end{pmatrix}$$

$$(s^E)=\begin{pmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 \\ s_{12}^E & s_{11}^E & s_{13}^E & 0 & 0 & 0 \\ s_{13}^E & s_{13}^E & s_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{55}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & 2\left(s_{11}^E-s_{12}^E\right) \end{pmatrix}$$

The second-order differential equation [4-52] for the deformation of the drive is written as

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

where $\Xi(x,s)$, x, s, γ, α, c^E are the Laplace transform of the deforation drive, the coordinate, the operator, the wave propagation and attenuation coefficients, the speed at E = const.

The solution the differential equation for the deformation of the drive has the form

$$\Xi(x,s)=Ce^{-x\gamma}+Be^{x\gamma}$$

The boundary conditions for the deformation of the transverse piezo drive have the form

$\Xi(0,s)=\Xi_1(s)$ at $x=0$

$\Xi(h,s)=\Xi_2(s)$ at $x=h$

The solution the differential equation for the deformation of the transverse piezo drive has the form

$$\Xi(x,s)=\frac{\Xi_1(s)\operatorname{sh}((h-x)\gamma)+\Xi_2(s)\operatorname{sh}(x\gamma)}{\operatorname{sh}(h\gamma)}$$

At fixed face of the transverse piezo drive for $x = 0$, $\Xi_1(s)=\Xi(0,s)=0$ the equation of the deformation has the form

$$\Xi(x,s)=\frac{\Xi_2(s)\operatorname{sh}(x\gamma)}{\operatorname{sh}(h\gamma)}$$

By using the equation of the electro elasticity of the transverse piezo drive for elastic-inertial load the Laplace transform of the relative deformation at $x=h$ is written in the form

$$\left.\frac{d\Xi(x,s)}{dx}\right|_{x=h}=d_{31}E_3(s)-\frac{s_{11}^E M p^2\Xi_2(s)}{S_0}-\frac{s_{11}^E C_e\Xi_2(s)}{S_0}$$

This expression is converted to the following form

$$\frac{\Xi_2(s)\gamma}{\operatorname{th}(h\gamma)}+\frac{\Xi_2(s)s_{11}^E M s^2}{S_0}+\frac{\Xi_2(s)s_{11}^E C_l}{S_0}=d_{31}E_3(p)$$

Let us consider the transfer functions with distributed parameters of the transverse piezo drive at the elastic-inertial load. The transfer function on the electric field strength of the transverse piezo drive has the form

$$W_E(s)=\frac{\Xi_2(s)}{E_3(s)}=\frac{d_{31}h}{Ms^2/C_{11}^E+h\gamma\operatorname{cth}(h\gamma)+C_l/C_{11}^E}$$

Where $\Xi_2(s)$, $E_3(s)$, C_l, C_{11}^E are the Laplace transforms of the deformation and the electric field strength, the stiffness of the load and the transverse piezo drive.

The transfer function on the voltage of the transverse piezo drive has the form

$$W_U(s)=\frac{\Xi_2(s)}{U(s)}=\frac{d_{31}h/\delta}{Mp^2/C_{11}^E+h\gamma\operatorname{cth}(h\gamma)+C_l/C_{11}^E}$$

Characteristics of drive

For the transverse piezo drive with the lumped parameters at elastic-inertial load $M >> m$, where M, m the masses of load and drive, the transfer function on the voltage are written in the form

$$W(s)=\frac{\Xi_2(s)}{U(s)}=\frac{k_{U31}}{T_t^2s^2+2T_t\xi_{ut}s+1}$$

where $k_{U31}=d_{31}(h/\delta)/\left(1+C_l/C_{11}^E\right)$ is the transverse transfer coefficient, $T_t=\sqrt{M/\left(C_l+C_{11}^E\right)}$ is the time constant, $\xi_t=\alpha l^2C_{11}^E/\left(3c^E\sqrt{M\left(C_l+C_{11}^E\right)}\right)$ is the attenuation coefficient, $\omega_t=1/T_t$ is the conjugate frequency of the drive.

At $M = 1$ kg, $C_l = 0.1\cdot10^7$ N/m, $C_{11}^E = 1\cdot10^7$ N/m the parameters of the transverse PZT drive are obtained $T_i = 0.3\cdot10^{-3}$ s and $\omega_t = 3.3\cdot10^3$ s^{-1} with the error 10%.

The steady-state movement of the transverse piezo drive at elastic-inertial load is determined

$$\Delta h=\frac{d_{31}(h/\delta)U}{1+C_l/C_{11}^E}=k_{U31}U$$

At $h/\delta = 20$, $C_l/C^E_{11} = 0.1$, $d_{31} = 2.3\cdot10^{-10}$ m/V for the transverse PZT drive is received the coefficient $k_{u31} = 4.2$ nm/V with the error 10%.

For the longitudinal piezo drive the relative displacement [8-18] has form

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

where d_{33} is the longitudinal piezo module, E_3 is the electric field strength on axis 3, s_{33}^E is the elastic compliance, T_3 is the mechanical field of strength on axis 3.

The mechanical characteristic of the longitudinal piezo drive has the form

$$\Delta\delta=\Delta\delta_{\max}\left(1-F/F_{\max}\right)$$

The maximums values of displacement $\Delta\delta_{\max}$ and force F_{max} are determined

$$\Delta\delta_{\max}=d_{33}\delta E_3=d_{33}U$$

$$F_{\max}=d_{33}S_0E_3/s_{33}^E$$

For $E_3 = 0.8\cdot10^5$ V/m, $S_0 = 1.5\cdot10^{-4}$ m^2, $\delta = 2.5\cdot10^{-3}$ m, $d_{33} = 4\cdot10^{-10}$ m/V, $s_{33}^E = 15\cdot10^{-12}$ m^2/N for the longitudinal PZT drive are received $\Delta\delta_{\max} = 80$ nm, $F_{\max} = 320$ N on Figure 1 with the error 10%.

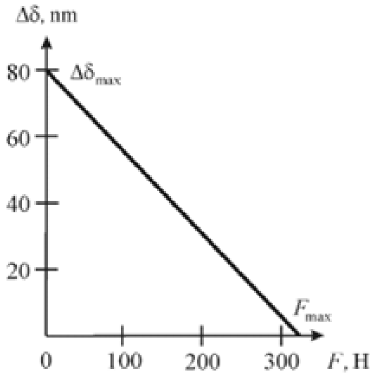

Figure 1: Mechanical characteristic of longitudinal piezo drive for nanoscience.

The maximums values of parameters of the mechanical characteristic for the transverse piezo drive are obtained in the form

$$\Delta h_{\max}=d_{31}hE_3=d_{31}(h/\delta)U$$

$$F_{\max} = d_{31} S_0 E_3 / s_{11}^E$$

The characteristics of the piezo drive are obtained for nanoscience.

Conclusions

The equations of the deformation the electro elastic drive are received. The parameters and the characteristics of the electro elastic drive are obtained. The transfer functions of the piezo drive are obtained for nanoscience research. The characteristics of the piezo drive is determined.

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