A Compound Piezo Drive for Nanotechnology and Nanochemistry Research

*Afonin Sergey Mikhailovich**

National Research University of Electronic Technology, MIET, Moscow, Russia

*Corresponding author:

Afonin Sergey Mikhailovich

National Research University of Electronic Technology, MIET, 124498, Moscow, Russia, E-mail: learner01@mail.ru

Received: July 18, 2024
Published: October 21, 2024

ABSTRACT

For nanotechnology and nanochemistry research a compound piezo drive is applied in nanomechatronics systems. A compound piezo drive for nanotechnology and nanochemistry is used in scanning microscopy, adaptive optics amd interferometry. The model and scheme of a compound piezo drive is determined. Its functions and matrix deformations are founded. The schemes and parameters of the compound piezo drive at the voltage control are determined under various boundary conditions its operation in the different application. The parameters of the compound longitudinal PZT drive at the voltage control are obtained.

Keywords: Compound Piezo Drive, Model, Scheme, Voltage Control, Nanotechnology and Nanochemistry Research

INTRODUCTION

A compound piezo drive is applied for nanotechnology and nanochemistry research [1-17]. This drive based on the piezoelectric effect [18-40]. A compound piezo drive is used in scanning microscopy, adaptive optics, interferometry, nanostabilization [41-53]. The deformations of a compound piezo drive are written by using its model and scheme. The model, scheme and functions are obtained by applied the method of mathematical physics. The compound piezo drive is widely used in practice at the voltage control. Therefore, in the article considers the structural schemes of the composite piezo drive under various boundary conditions its operation.

MODEL AND SCHEMES

The model and schemes of a compound piezo drive are determined using the equation inverse piezo effect.

The equation inverse piezo effect has the form [6-52]

at the voltage control

Citation: Afonin SM. (2024). A Compound Piezo Drive for Nanotechnology and Nanochemistry Research. Catalysis Research. 4(1):18.

DOI: https://doi.org/10.35702/catalres.10018

$$S_i = d_{mi}E_m + s_{ij}^E T_j$$

At current the control

$$S_i = g_{mi}D_m + s_{ij}^D T_j$$

here T_j, S_i, E_m, D_m, d_{mi}, g_{mi}, s_{ij}^E, s_{ij}^D are the strength of mechanic field, the relative deformation, the strength of electric field, the electric induction, the piezo module, the piezo constant, the elastic compliances at $E = \text{const}$ and at $D = \text{const}$, i, j, m are the indexes.

In general, the equation of inverse piezo effect is written

$$S_i = \nu_{mi}\Psi_m + s_{ij}^\Psi T_j$$

here $\Psi_m = E_m, D_m$ is control parameter at the control of voltage or current.

A compound drive consists from the piezo layers connected in series mechanically and parallel electrically [6 – 44]. For *T-form* quadripole of *k* piezo layer the system of equations is determined

$$F_{k\,\text{inp}}(s) = -(Z_1 + Z_2)\Xi_k(s) + Z_2\Xi_{k+1}(s)$$
$$-F_{k\,\text{out}}(s) = -Z_2\Xi_k(s) + (Z_1 + Z_2)\Xi_{k+1}(s)$$

$$Z_1 = \frac{S_0\gamma\,\text{th}(\delta\gamma)}{s_{ij}^\Psi},\; Z_2 = \frac{S_0\gamma}{s_{ij}^\Psi\,\text{sh}(\delta\gamma)}$$

here Z_1, Z_2, s, δ, γ, $F_{k\,\text{inp}}(s)$, $F_{k\,\text{out}}(s)$, $\Xi_k(s)$, $\Xi_{k+1}(s)$ are the resistances of quadripole, the parameter, the thickness, the coefficient propagation wave, the Laplace transform of the forces at the input and output ends, the transforms of the displacements at input and output ends.

Therefore, the system of the equations for k piezo layer is obtained

$$-F_{k\,\text{inp}}(s) = \left(1 + \frac{Z_1}{Z_2}\right)F_{k_{out}}(s) + Z_1\left(2 + \frac{Z_1}{Z_2}\right)\Xi_{k+1}(s)$$

$$\Xi_k(s) = \frac{1}{Z_1}F_{k\,\text{out}}(s) + \left(1 + \frac{Z_1}{Z_2}\right)\Xi_{k+1}(s)$$

This system is founded in the matrix form

$$\begin{bmatrix} -F_{k\,\text{inp}}(s) \\ \Xi_k(s) \end{bmatrix} = [M]\begin{bmatrix} F_{k\,\text{out}}(s) \\ \Xi_{k+1}(s) \end{bmatrix}$$

$$[M] = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} = \begin{bmatrix} 1 + \dfrac{Z_1}{Z_2} & Z_1\left(2 + \dfrac{Z_1}{Z_1}\right) \\ \dfrac{1}{Z_2} & 1 + \dfrac{Z_1}{Z_2} \end{bmatrix}$$

$$m_{11} = m_{22} = 1 + \frac{Z_1}{Z_2} = \text{ch}(\delta\gamma),\; m_{12} = Z_1\left(2 + \frac{Z_1}{Z_1}\right) = Z_0\text{sh}(\delta\gamma)$$

$$m_{21} = \frac{1}{Z_2} = \frac{\text{sh}(\delta\gamma)}{Z_0},\; Z_0 = \frac{S_0\gamma}{s_{ij}^\Psi}$$

At the boundary between two layers the equation of forces is determined

$$F_{k\,\text{out}}(s) = -F_{k+1\,\text{inp}}(s)$$

For a compound drive with layers and length its system has the matrix form

$$\begin{bmatrix} -F_{1\,\text{inp}}(s) \\ \Xi_1(s) \end{bmatrix} = [M]^n\begin{bmatrix} F_{n\,\text{out}}(s) \\ \Xi_{n+1}(s) \end{bmatrix}$$

$$[M]^n = \begin{bmatrix} \text{ch}(l\gamma) & Z_0\text{sh}(l\gamma) \\ \dfrac{\text{sh}(l\gamma)}{Z_0} & \text{ch}(l\gamma) \end{bmatrix}$$

The equations of end forces for a compound drive are obtained

at $x = 0$, $T_j(0,s)S_0 = F_1(s) + M_1 s^2\Xi_1(s)$

at $x = l$, $T_j(l,s)S_0 = -F_2(s) - M_2 s^2\Xi_2(s)$

From the general equation of inverse piezo effect, the Laplace transform of force causes deformation is determined

$$F(s) = \frac{\nu_{mi}S_0\Psi_m(s)}{s_{ij}^\Psi}$$

Then the reverse coefficient for widely used in practice at the voltage control with $U(s) = E_m(s)\delta$ is determined in the form

$$k_r = \frac{F(s)}{U(s)} = \frac{d_{mi}S_0}{\delta s_{ij}^E}$$

This coefficient is used for the calculations of the compound

DOI: https://doi.org/10.35702/catalres.10018

piezo drive at the voltage control.

In general, the model and scheme of a compound piezo drive are founded on Figure 1

$$\Xi_1(s)=\left(1/\left(M_1 s^2\right)\right)\left\{-F_1(s)+\left(1/\chi_{ij}^{\Psi}\right)\left[\begin{matrix}\nu_{mi}\Psi_m(s)-(\gamma/\mathrm{sh}(l\gamma))\times\\ \times\left(\mathrm{ch}(l\gamma)\Xi_1(s)-\Xi_2(s)\right)\end{matrix}\right]\right\}$$

$$\Xi_2(s)=\left(1/\left(M_2 s^2\right)\right)\left\{-F_2(s)+\left(1/\chi_{ij}^{\Psi}\right)\left[\begin{matrix}\nu_{mi}\Psi_m(s)-(\gamma/\mathrm{sh}(l\gamma))\times\\ \times\left(\mathrm{ch}(l\gamma)\Xi_2(s)-\Xi_1(s)\right)\end{matrix}\right]\right\}$$

here $\nu_{mi}=\begin{cases}d_{33},d_{31},d_{15}\\ g_{33},g_{31},g_{15}\end{cases}$, $\Psi_m=\begin{cases}E_3,E_1\\ D_3,D_1\end{cases}$, $s_{ij}^{\Psi}=\begin{cases}s_{33}^{E},s_{11}^{E},s_{55}^{E}\\ s_{33}^{D},s_{11}^{D},s_{55}^{D}\end{cases}$, $c^{\Psi}=\begin{cases}c^{E}\\ c^{D}\end{cases}$, $\gamma=\begin{cases}\gamma^{E}\\ \gamma^{E}\end{cases}$, $\chi_{ij}^{\Psi}=s_{ij}^{\Psi}/S_0$.

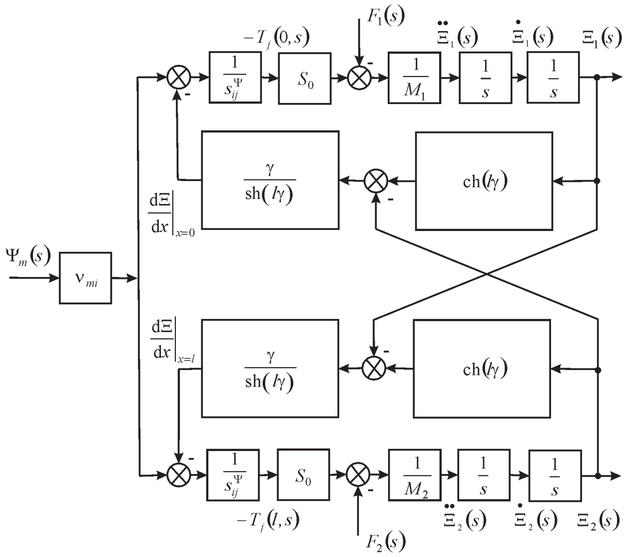

Figure 1. In general scheme compound piezo drive.

Its matrix equation is obtained

$$\begin{bmatrix}\Xi_1(s)\\ \Xi_2(s)\end{bmatrix}=\left[W(s)\right]\begin{bmatrix}\Psi_m(s)\\ F_1(s)\\ F_2(s)\end{bmatrix}$$

$$\left[W(s)\right]=\begin{bmatrix}W_{11}(s) & W_{12}(s) & W_{13}(s)\\ W_{21}(s) & W_{22}(s) & W_{23}(s)\end{bmatrix}$$

This functions are founded

$$W_{11}(s)=\Xi_1(s)/\Psi_m(s)=\nu_{mi}\left[M_2\chi_{ij}^{\Psi}s^2+\gamma\mathrm{th}(l\gamma/2)\right]/A_{ij}$$

$$A_{ij}=M_1M_2\left(\chi_{ij}^{\Psi}\right)^2 s^4+\left\{(M_1+M_2)\chi_{ij}^{\Psi}/\left[c^{\Psi}\mathrm{th}(l\gamma)\right]\right\}s^3+$$
$$+\left[(M_1+M_2)\chi_{ij}^{\Psi}\alpha/\mathrm{th}(l\gamma)+1/\left(c^{\Psi}\right)^2\right]s^2+2\alpha s/c^{\Psi}+\alpha^2$$

$$W_{21}(s)=\Xi_2(s)/\Psi_m(s)=\nu_{ij}\left[M_1\chi_{ij}^{\Psi}s^2+\gamma\mathrm{th}(l\gamma/2)\right]/A_{ij}$$

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

$$W_{13}(s)=\Xi_1(s)/F_2(s)=$$
$$=W_{22}(s)=\Xi_2(s)/F_1(s)=\left[\chi_{ij}^{\Psi}\gamma/\mathrm{sh}(l\gamma)\right]/A_{ij}$$

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

The equation of direct piezo effect is written [6-52]

$$D_m=d_{mi}T_i+\varepsilon_{mk}^{T}E_k$$

here k is the index, ε_{mk}^{T} is the dielectric constants. Then for the compound piezo drive at the voltage control we have its direct and reverse coefficients in the form

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

The Laplace transform of the negative feedback voltage on Figure 2 at the voltage control is obtained in the form

$$U_d(s)=\frac{d_{mi}S_0R}{\delta s_{ij}^{E}}\dot{\Xi}_e(s)=k_dR\dot{\Xi}_e(s),\ e=1,2$$

here e, R, C_n are the ends number, the resistance, the compound capacity. The sheme with negative feedbacks on Figure 2 and parameters of the compound piezo drive at the voltage control are determined.

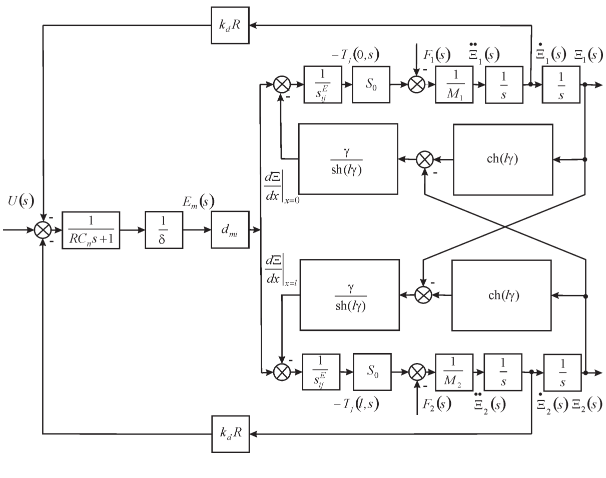

Figure 2. Scheme compound drive at voltage control.

For the compound drive at the voltage control with first fixed and elastic-inertial load the scheme is obtained on Figure 3

DOI: https://doi.org/10.35702/catalres.10018

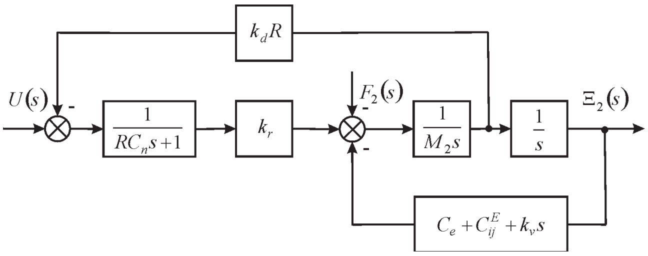

Figure 3. Scheme compound drive at voltage control with first fixed end and elastic-inertial load.

For the compound longitudinal piezo drive at the voltage control with first fixed end and the elastic-inertial load for $R = 0$ its function is determined in the form

$$W(s) = \frac{\Xi_2(s)}{U(s)} = \frac{d_{33}n}{\left(1 + C_e/C_{33}^E\right)\left(T_t^2 s^2 + 2T_t \xi_t s + 1\right)}$$

$$T_t = \sqrt{M_2/\left(C_e + C_{33}^E\right)},\ \xi_t = \alpha l^2 C_{33}^E \Big/ \left[3c^E \sqrt{M_2\left(C_e + C_{33}^E\right)}\right]$$

$$C_{33}^E = S_0/\left(s_{33}^E l\right)$$

Its transient response is obtained

$$\xi(t) = \xi_m \left(1 - \frac{e^{-\frac{\xi_t t}{T_t}}}{\sqrt{1-\xi_t^2}} \sin(\omega_t t + \varphi_t)\right)$$

$$\xi_m = \frac{d_{33}nU}{1 + C_e/C_{33}^E},\ \omega_t = \sqrt{1-\xi_t^2}\Big/T_t,\ \varphi_t = \mathrm{arctg}\left(\sqrt{1-\xi_t^2}\Big/\xi_t\right)$$

For the compound longitudinal PZT drive at the voltage control U =120 V, $d_{33} = 4{\cdot}10^{-10}$ m/V, n = 8, M = 2 kg, C_{33}^E = 5.8·10^{7} N/m, C_e = 0.6·10^{7} N/m its parameters ξ_m = 348 nm and T_t = 1.77·10^{-4} s are obtained with error 10%.

The schemes and parameters of the compound piezo drive at the voltage control are determined.

DISCUSSION

The compound piezo drive at the voltage control is used for research in nanotechnology and nanochemistry due to its large ranges of movement and force. The model and scheme of a compound drive are founded by applied of mathematical physics method. By using the equations of quadripoles and forces its model, scheme, functions are obtained. For a compound piezo drive its system is determined in the matrix form. The scheme of the compound piezo drive at the voltage control is obtained.

CONCLUSION

A compound piezo drive for nanotechnology and nanochemistry research is applied in scanning microscopy, adaptive optics, interferometry, nanostabilization. Its model, scheme, functions are determined by applied the method of mathematical physics.

The schemes and parameters of the compound piezo drive at the voltage control are determined under various boundary conditions its operation. The parameters of the compound longitudinal PZT drive at the voltage control with first fixed end and elastic-inertial load are obtained.

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