Research Article

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Electromagnetoelastic Engine for Nanorobotics and Automation Research

Afonin SM

***Corresponding author**
Afonin Sergey Mikhailovich, National Research University of Electronic Technology, MIET, 124498, Moscow, Russia.

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Abstract
In the work the characteristics of an electromagnetoelastic engine for nanorobotics and automation research are found. The structural diagram of an electromagnetoelastic engine is received. In the visibility of energy conversion, the structural diagram of an electromagnetoelastic engine has a difference from Cady and Mason electrical equivalent circuits of a piezo vibrator. The matrix equation and the matrix transfer function of an electromagnetoelastic engine are derived.

Keywords: Electromagnetoelastic Engine, Piezo Engine, Nanorobotics, Deformation, Characteristics, Structural Schema, Matrix Equation

Introduction
In nanorobotics and automation research an electromagnetoelastic engine in the form of piezo engine or magnetostriction engine is used for nanopositioner, nanomanipulator, laser system, nanopump, scanning microscopy [1-4]. The piezo engine is applied for microsurgical operation, optical-mechanical device, adaptive optics system, fiber-optic system, photolithography, adaptive telescope [5-14].

The electromagnetoelasticity equation and the differential equation of an electromagnetoelastic engine are solved to obtain the structural schema of an engine. In the visibility of energy conversion the structural schema of an electromagnetoelastic engine has a difference for from Cady and Mason electrical equivalent circuits of a piezo vibrator. By applying the methods of electromagnetoelasticity the structural schema of an electromagnetoelastic engine for nanorobotics and automation research is received [4-12].

Characteristics of engine
For nanorobotics and automation research the structural schema of an electromagnetoelastic engine replaces Cady and Mason electrical equivalent circuits [5-8]. The equation electromagnetoelasticity of an electromagnetoelastic engine [1-23] has the form

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

where S_i, d_{mi}, Ψ_m, s_{ij}^{Ψ} and T_j are the relative deformation, the module, the control parameter or the intensity of field, the elastic compliance, and the mechanical intensity.

In static for nanorobotics and automation research the mechanical characteristic [4-40] of an electromagnetoelastic engine has the form

$$S_i\big|_{\Psi=\text{const}} = d_{mi}\Psi_m\big|_{\Psi=\text{const}} + s_{ij}^{\Psi}T_j$$

In static the regulation characteristic [4-39] an electromagnetoelastic engine has the form

$$S_i\big|_{T=\text{const}} = d_{mi}\Psi_m + s_{ij}^{\Psi}T_j\big|_{T=\text{const}}$$

After transforms the mechanical characteristic of an electromagnetoelastic engine has the form

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

where index max is used for the maximum value of the parameter in the form displacement or force

$$\Delta l_{\max} = d_{mi}\Psi_m l$$

$$F_{\max} = T_{j\max}S_0 = d_{mi}\Psi_m S_0 / s_{ij}^{\Psi}$$

For the piezo engine at the transverse piezoelectric effect the maximum values of parameters have the form

$$\Delta h_{\max} = d_{31}E_3 h$$

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

At $d_{31} = 2\cdot10^{-10}$ m/V, $E_3 = 0.6\cdot10^{5}$ V/m, $h = 2.5\cdot10^{-2}$ m, $S_0 = 1.5\cdot10^{-5}$ m^2, $s_{11}^{E} = 15\cdot10^{-12}$ m^2/N the parameters of the transverse piezo engine are received $\Delta h_{max} = 300$ nm and $F_{max} = 12$ N.

The regulation characteristic of an electromagnetoelastic engine for nanorobotics and automation research at elastic load is obtained in the form

$$\frac{\Delta l}{l} = d_{mi}\Psi_m - \frac{s_{ij}^{\Psi} C_e}{S_0}\Delta l$$

$$F = C_e \Delta l$$

In static at elastic load the equation of the displacement of an electromagnetoelastic engine has the form

$$\Delta l = \frac{d_{mi} l \Psi_m}{1 + C_e / C_{ij}^{\Psi}}$$

Therefore, the equation of the displacement at elastic load for the transverse piezo engine for nanorobotics and automation research has the form

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

$$k_{31}^U = (d_{31} h/\delta) / \left(1 + C_e / C_{11}^E\right)$$

where k_{31}^U is the transfer coefficient.

At $d_{31} = 2\cdot10^{-10}$ m/V, $h/\delta = 16$, $C_{11}^E = 2.8\cdot10^7$ N/m, $C_e = 0.4\cdot10^7$ N/m, $U = 300$ V the parameters of the transverse piezo engine are obtained $k_{31}^U = 2.8$ nm/V and $\Delta h = 840$ nm. Theoretical and practical parameters are coincidences with an error of 10%.

The differential equation of an electromagnetoelastic engine for the mechatronics control systems in nanorobotics and automation research has the form [4-35]

$$d^2\Xi(x,p)/dx^2 - \gamma^2 \Xi(x,p) = 0$$

$$\gamma = p/c^{\Psi} + \alpha$$

where $\Xi(x, p)$ is the transform of Laplace for displacement; p, γ, c^{Ψ}, α are the operator of transform, the coefficient of wave propagation, the speed of sound, the coefficient of attenuation .

Therefore, the decision of the differential equation of an electromagnetoelastic engine has the form

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

In this decision the coefficients C, B have the form

$$C = \left(\Xi_1 e^{l\gamma} - \Xi_2\right) / [2\operatorname{sh}(l\gamma)]$$

$$B = \left(\Xi_2 - \Xi_1 e^{-l\gamma}\right) / [2\operatorname{sh}(l\gamma)]$$

where $\Xi_1(p)$, $\Xi_2(p)$ are the transforms Laplace of displacements for faces 1 and 2 for an engine.

The system of the equations for the transforms Laplace of forces on faces of an electromagnetoelastic engine for nanorobotics and automation research is found [10-40]

$$M_1 p^2 \Xi_1(p) + F_1(p) = S_0 T_j(0,p)$$

$$-M_2 p^2 \Xi_2(p) - F_2(p) = S_0 T_j(l,p)$$

where M_1, M_2, $F_1(p)$, $F_2(p)$, $T_j(0,p)$, $T_j(l,p)$, S_0 are the masses of the loads, the transforms Laplace of forces and stress on faces 1 and 2, the area of an engine.

For an electromagnetoelastic engine the system of the equations the transforms Laplace of stresses on faces has the form

$$T_j(0,p) = \frac{1}{s_{ij}^{\Psi}} \frac{d\Xi(0,p)}{dx} - \frac{d_{mi}}{s_{ij}^{\Psi}} \Psi_m(p)$$

$$T_j(l,p) = \frac{1}{s_{ij}^{\Psi}} \frac{d\Xi(l,p)}{dx} - \frac{d_{mi}}{s_{ij}^{\Psi}} \Psi_m(p)$$

Therefore, the system of the equations for the structural schema on Figure 1 and model of an electromagnetoelastic engine for nanorobotics and automation research has the form

$$\Xi_1(p) = \left(M_1 p^2\right)^{-1} \times \left\{ \begin{array}{l} -F_1(p) + \left(1/\chi_{ij}^{\Psi}\right) \\ \times \left[d_{mi}\Psi_m(p) + [\gamma/\operatorname{sh}(l\gamma)] \right. \\ \left. \times [\Xi_2(p) - \operatorname{ch}(l\gamma)\Xi_1(p)] \right] \end{array} \right\}$$

$$\Xi_2(p) = \left(M_2 p^2\right)^{-1} \times \left\{ \begin{array}{l} -F_2(p) + \left(1/\chi_{ij}^{\Psi}\right) \times \\ \times \left[d_{mi}\Psi_m(p) + [\gamma/\operatorname{sh}(l\gamma)] \right. \\ \left. \times [\Xi_1(p) - \operatorname{ch}(l\gamma)\Xi_2(p)] \right] \end{array} \right\}$$

where $\chi_{ij}^{\Psi} = s_{ij}^{\Psi} / S_0$, $d_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ d_{33}, d_{31}, d_{15} \end{cases}$, $\Psi_m = \begin{cases} E_3, E_1 \\ H_3, H_1 \end{cases}$,

$s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^H, s_{11}^H, s_{55}^H \end{cases}$, $\gamma = \begin{cases} \gamma^E \\ \gamma^H \end{cases}$, E and H are the intensity of electric field and the intensity of magnetic field.

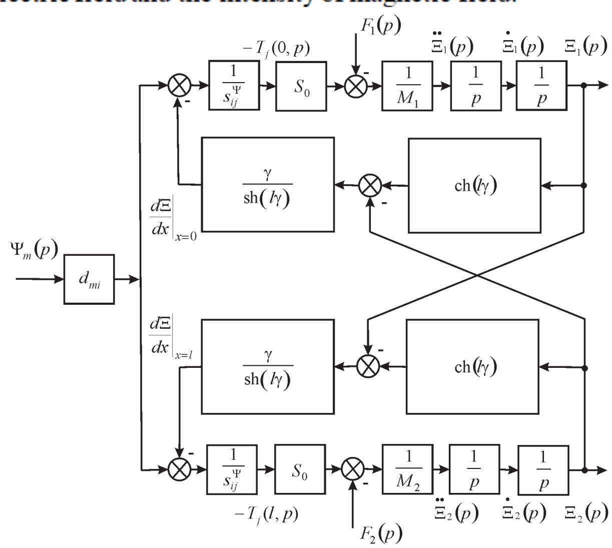

Figure 1: *Structural schema of electromagnetoelastic engine for nanorobotics and automation research.*

Hence the matrix equation of an electromagnetoelastic engine for nanorobotics and automation research with matrix transfer function has the form

$$\begin{pmatrix} \Xi_1(p) \\ \Xi_2(p) \end{pmatrix} = \begin{pmatrix} W_{11}(p) & W_{12}(p) & W_{13}(p) \\ W_{21}(p) & W_{22}(p) & W_{23}(p) \end{pmatrix} \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix}$$

After transforms the matrix equation of an electromagnetoelastic engine at the inertial load the steady-state displacements $\xi_1(\infty)$, $\xi_2(\infty)$ of an electromagnetoelastic engine have the form

$$\xi_1(t)\big|_{t\to\infty} = \xi_1(\infty) = d_{mi}\Psi_m l\, M_2/(M_1+M_2)$$

$$\xi_2(t)\big|_{t\to\infty} = \xi_2(\infty) = d_{mi}\Psi_m l\, M_1/(M_1+M_2)$$

Therefore, the steady-state displacements of the transverse piezo engine at the inertial load have the form

$$\xi_1(\infty) = d_{31}(h/\delta)UM_2/(M_1+M_2)$$

$$\xi_2(\infty) = d_{31}(h/\delta)UM_1/(M_1+M_2)$$

At $d_{31} = 2\cdot 10^{-10}$ m/V, $h/\delta = 20$, $U = 200$ V, $M_1 = 2$ kg and $M_2 = 8$ kg the parameters of the transverse piezo engine are found $\xi_1(\infty) = 640$ nm, $\xi_2(\infty) = 160$ nm, $\xi_1(\infty) + \xi_2(\infty) = 800$ nm.

Conclusions

In the work the characteristics of an electromagnetoelastic engine for nanorobotics and automation research are received. The structural schema of an electromagnetoelastic engine for nanorobotics and automation research is shown. In the visibility of energy conversion the structural schema of an electromagnetoelastic actuator has a difference from Cady and Mason electrical equivalent circuits of a piezo vibrator.

From the equation electromagnetoelasticity and the differential equation of an electromagnetoelastic engine the structural schema of an engine is found. The matrix equation and the matrix transfer function of an electromagnetoelastic engine for nanorobotics and automation research are written.

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