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Structural Scheme of an Engine for Nanomedicine and Nanotechnology

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Abstract

The structural model of an engine is determined for nanomedicine and nanotechnology. The structural scheme of an engine for nanodisplacement is obtained. The matrix equation is constructed for an engine for nanomedicine and nanotechnology.

Keywords: Electro Magneto Elastic Engine; Piezo Engine; Structural Scheme; Parameter; Nanomedicine and Nanotechnology

Introduction

A nanoengine is used for scanning microscopy for nanomedicine, nanotechnology and adaptive optics. The piezo engine is applied to penetrate the cell and manipulate genes [1-25]. The application of an electro magneto elastic engine in the form the piezoelectric, electrostriction or magnetostriction engine is promising for aligning the mirrors of laser optics and scanning in the atomic-force microscope [19-58].

Structural Model of an Engine

The electro magneto elasticity expression [1-8] is used

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

here S_i is the relative deformation on axis *i*, E_m is the electric field strength on axis *m*, H_m is the magnetic field strength on axis *m*, $s_{ij}^{E,H}$ is the elastic compliance for $E = \text{const}$, $H = \text{const}$, T_j is the mechanical stress on the axis j, d_{mi}^{H} is the piezo module, d_{mi}^{E} is the magnetostriction coefficient.

The expression of the reverse piezo effect [1-8] has the form

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

here S_i, d_{mi}, E_m, s_{ij}^{E}, T_j are the relative displacement, piezo module, strength electric field, elastic compliance, strength mechanical field.

The expression of the longitudinal inverse piezo effect [1-8] has the form

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

The differential equation of an engine is used [4-56]

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

here $\Xi(x,s)$, s, x, γ are the transformation Laplace for displacement, the parameter, the coordinate, the coefficient of propagation. For the longitudinal piezo engine we have at $x = 0$ the deformation $\Xi(0,s) = \Xi_1(s)$ and at $x = \delta$ $\Xi(\delta,s) = \Xi_2(s)$. The decision is calculated

$$\Xi(x,s)=\left\{\Xi_1(s)\,\mathrm{sh}\left[(\delta-x)\gamma\right]+\Xi_2(s)\,\mathrm{sh}(x\gamma)\right\}\Big/\mathrm{sh}(\delta\gamma)$$

The set of equations for boundary conditions is determined [4,5,12-32]

$$T_3(0,s)=\frac{1}{s_{33}^E}\frac{d\Xi(x,s)}{dx}\bigg|_{x=0}-\frac{d_{33}}{s_{33}^E}E_3(s)$$

$$T_3(\delta,s)=\frac{1}{s_{33}^E}\frac{d\Xi(x,s)}{dx}\bigg|_{x=\delta}-\frac{d_{33}}{s_{33}^E}E_3(s)$$

Its structural model is written in the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{33}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{33}E_3(s)-\left[\gamma/\mathrm{sh}(\delta\gamma)\right]\\ \times\left[\mathrm{ch}(\delta\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{33}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{33}E_3(s)-\left[\gamma/\mathrm{sh}(\delta\gamma)\right]\\ \times\left[\mathrm{ch}(\delta\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{33}^E=s_{33}^E/S_0$$

here $\Xi_1(s)$, $\Xi_2(s)$ are the transforms of the displacements, S_0 is the area.

The expression of the longitudinal magnetostriction [1-8] has the form

$$S_3=d_{33}H_3+s_{33}^HT_3$$

The structural model of the longitudinal magnetostriction engine is transformed in the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{33}^H\right)^{-1}\\ \times\left[\begin{array}{l}d_{33}H_3(s)-\left[\gamma/\mathrm{sh}(\delta\gamma)\right]\\ \times\left[\mathrm{ch}(\delta\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{33}^H\right)^{-1}\\ \times\left[\begin{array}{l}d_{33}H_3(s)-\left[\gamma/\mathrm{sh}(\delta\gamma)\right]\\ \times\left[\mathrm{ch}(\delta\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{33}^H=s_{33}^H/S_0$$

The expression of the transverse inverse piezo effect [1-8] has the form

$$S_1=d_{31}E_3+s_{11}^ET_1$$

The decision of the differential equation is written

$$\Xi(x,s)=\left\{\Xi_1(s)\,\mathrm{sh}\left[(h-x)\gamma\right]+\Xi_2(s)\,\mathrm{sh}(x\gamma)\right\}\Big/\mathrm{sh}(h\gamma)$$

The set of equations is obtained

$$T_1(0,s)=\frac{1}{s_{11}^E}\frac{d\Xi(x,s)}{dx}\bigg|_{x=0}-\frac{d_{31}}{s_{11}^E}E_3(s)$$

$$T_1(h,s)=\frac{1}{s_{11}^E}\frac{d\Xi(x,s)}{dx}\bigg|_{x=h}-\frac{d_{31}}{s_{11}^E}E_3(s)$$

The structural model of the transverse piezo engine is written

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{11}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{31}E_3(s)-\left[\gamma/\mathrm{sh}(h\gamma)\right]\\ \times\left[\mathrm{ch}(h\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{11}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{31}E_3(s)-\left[\gamma/\mathrm{sh}(h\gamma)\right]\\ \times\left[\mathrm{ch}(h\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{11}^E=s_{11}^E/S_0$$

The expression of the transverse magnetostriction [1-8] has the form

$$S_1=d_{31}H_3+s_{11}^HT_1$$

The structural model is determined in the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{11}^H\right)^{-1}\\ \times\left[\begin{array}{l}d_{31}H_3(s)-\left[\gamma/\mathrm{sh}(h\gamma)\right]\\ \times\left[\mathrm{ch}(h\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{11}^H\right)^{-1}\\ \times\left[\begin{array}{l}d_{31}H_3(s)-\left[\gamma/\mathrm{sh}(h\gamma)\right]\\ \times\left[\mathrm{ch}(h\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{11}^H=s_{11}^H/S_0$$

The expression of the shift inverse piezo effect [1-8] has the form

$$S_5=d_{15}E_1+s_{55}^E T_5$$

The decision of the differential equation is calculated

$$\Xi(x,s)=\left\{\Xi_1(s)\mathrm{sh}\left[(b-x)\gamma\right]+\Xi_2(s)\mathrm{sh}(x\gamma)\right\}/\mathrm{sh}(b\gamma)$$

The set of equations for the shift piezo engine is written

$$T_5(0,s)=\frac{1}{s_{55}^E}\frac{d\Xi(x,s)}{dx}\bigg|_{x=0}-\frac{d_{15}}{s_{55}^E}E_1(s)$$

$$T_5(b,s)=\frac{1}{s_{55}^E}\frac{d\Xi(x,s)}{dx}\bigg|_{x=b}-\frac{d_{15}}{s_{55}^E}E_1(s)$$

Its structural model has the form

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{55}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{15}E_1(s)-\left[\gamma/\mathrm{sh}(b\gamma)\right]\\ \times\left[\mathrm{ch}(b\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{55}^E\right)^{-1}\\ \times\left[\begin{array}{l}d_{15}E_1(s)-\left[\gamma/\mathrm{sh}(b\gamma)\right]\\ \times\left[\mathrm{ch}(b\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{55}^E=s_{55}^E/S_0$$

The expression of the shift magnetostriction [1-8] has the form

$$S_5=d_{15}H_1+s_{55}^H T_5$$

The structural model of the shift magnetostrictive engine is transformed

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{55}^H\right)^{-1}\\ \times\left[\begin{array}{l}d_{15}H_1(s)-\left[\gamma/\mathrm{sh}(b\gamma)\right]\\ \times\left[\mathrm{ch}(b\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{55}^H\right)^{-1}\\ \times\left[\begin{array}{l}d_{15}H_1(s)-\left[\gamma/\mathrm{sh}(b\gamma)\right]\\ \times\left[\mathrm{ch}(b\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{55}^H=s_{55}^H/S_0$$

At $l=\{\ \delta,h,b$ the decision of the differential equation of an engine in general has the form

$$\Xi(x,s)=\left\{\Xi_1(s)\mathrm{sh}\left[(l-x)\gamma\right]+\Xi_2(s)\mathrm{sh}(x\gamma)\right\}/\mathrm{sh}(l\gamma)$$

The set of equations is determined

$$T_j(0,s)=\frac{1}{s_{ij}^\Psi}\frac{d\Xi(x,s)}{dx}\bigg|_{x=0}-\frac{\nu_{mi}}{s_{ij}^\Psi}\Psi_m(s)$$

$$T_j(l,s)=\frac{1}{s_{ij}^\Psi}\frac{d\Xi(x,s)}{dx}\bigg|_{x=l}-\frac{\nu_{mi}}{s_{ij}^\Psi}\Psi_m(s)$$

The structural model in general of an engine on Figure 1 is calculated

$$\Xi_1(s)=\left(M_1s^2\right)^{-1}\left\{\begin{array}{l}-F_1(s)+\left(\chi_{ij}^\Psi\right)^{-1}\\ \times\left[\begin{array}{l}\nu_{mi}\Psi_m(s)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\\ \times\left[\mathrm{ch}(l\gamma)\Xi_1(s)-\Xi_2(s)\right]\end{array}\right]\end{array}\right\}$$

$$\Xi_2(s)=\left(M_2s^2\right)^{-1}\left\{\begin{array}{l}-F_2(s)+\left(\chi_{ij}^\Psi\right)^{-1}\\ \times\left[\begin{array}{l}\nu_{mi}\Psi_m(s)-\left[\gamma/\mathrm{sh}(l\gamma)\right]\\ \times\left[\mathrm{ch}(l\gamma)\Xi_2(s)-\Xi_1(s)\right]\end{array}\right]\end{array}\right\}$$

$$\chi_{ij}^\Psi=s_{ij}^\Psi/S_0$$

here

$$\nu_{mi}=\begin{cases}d_{33},d_{31},d_{15}\\ g_{33},g_{31},g_{15}\\ d_{33},d_{31},d_{15}\end{cases}$$

$$\Psi_m=\begin{cases}E_3,E_1\\D_3,D_1\\H_3,H_1\end{cases}$$

$$s_{ij}^{\Psi}=\begin{cases}s_{33}^{E},s_{11}^{E},s_{55}^{E}\\s_{33}^{D},s_{11}^{D},s_{55}^{D}\\s_{33}^{H},s_{11}^{H},s_{55}^{H}\end{cases}$$

$$\gamma=\{\gamma^E,\gamma^D,\gamma^H\}$$

$$c^{\Psi}=\{c^E,c^D,c^H\}$$

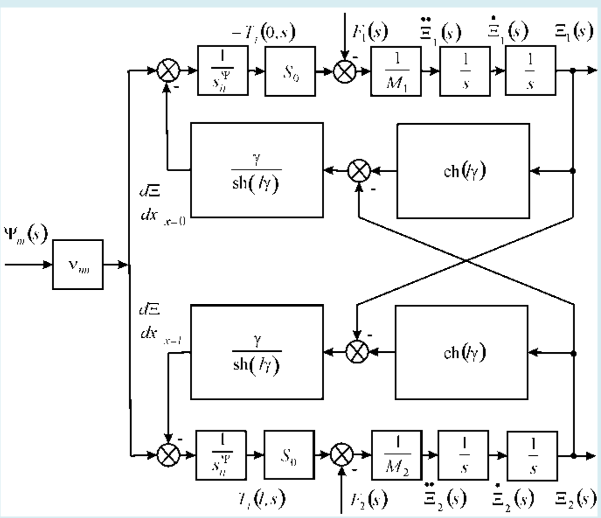

Figure 1: Structural scheme of engine for nanomedicine and nanotechnology.

The matrix of deformations is calculated

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

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

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

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

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

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

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

The static longitudinal deformations are obtained

$$\xi_1=d_{33}UM_2/(M_1+M_2)$$

$$\xi_2=d_{33}UM_1/(M_1+M_2)$$

For $d_{33}=4\cdot10^{-10}$ m/V, U= 25 V, M_1= 1 kg, M_2= 4 kg we have ξ_1 = 8 nm, ξ_2 = 2 nm and $\xi_1+\xi_2$ = 10 nm at error 10%.

The expression of the direct piezo effect [8-16] is used

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

Where D_m, ε_{mk}^{E} are the electric induction and the permittivity,

The direct coefficient at voltage control is written

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

The expression of the transform voltage negative feedback at voltage control on Figure 2 is used

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

The maximum force at voltage control is determined

$$F_{\max}=E_md_{mi}S_0/s_{ij}^{E}$$

$$T_{j\max}=E_md_{mi}/s_{ij}^{E}$$

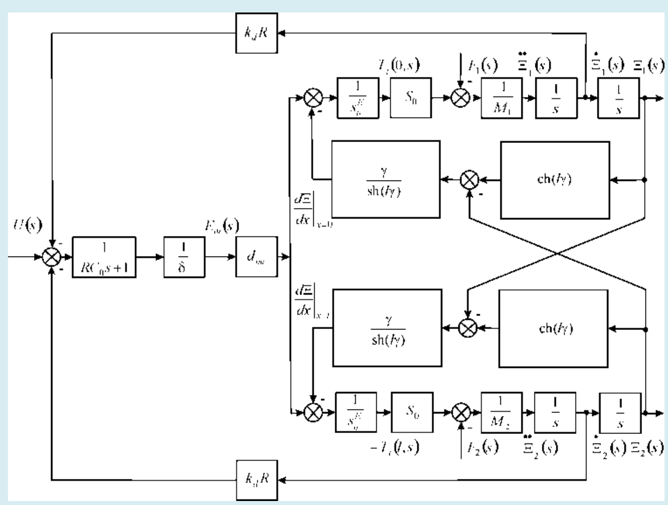

Figure 2: Structural scheme of piezo engine with negative feedback.

The maximum force at current control has the form

$$F_{\max} = \frac{U}{\delta} d_{mi} \frac{S_0}{s_{ij}^E} + \frac{F_{\max}}{S_0} d_{mi} S_c \frac{1}{\varepsilon_{mk}^T S_c / \delta} \frac{1}{\delta} d_{mi} \frac{S_0}{s_{ij}^E}$$

$$\frac{F_{\max}}{S_0}\left(1 - \frac{d_{mi}^2}{\varepsilon_{mk}^T s_{ij}^E}\right) s_{ij}^E = E_m d_{mi}$$

$$T_{j\max}\left(1 - k_{mi}^2\right) s_{ij}^E = E_m d_{mi}$$

$$k_{mi} = d_{mi} \Big/ \sqrt{s_{ij}^E \varepsilon_{mk}^T}$$

here k_{mi} is the coefficient of electromechanical coupling.

The expressions at current control are used

$$F_{\max} = E_m d_{mi} S_0 / s_{ij}^D$$

$$T_{j\max} = E_m d_{mi} / s_{ij}^D$$

$$s_{ij}^D = \left(1 - k_{mi}^2\right) s_{ij}^E$$

The mechanical characteristic [11-26] is determined

$$S_i\left(T_j\right)\Big|_{\Psi = const} = \nu_{mi} \Psi_m \Big|_{\Psi = const} + s_{ij}^{\Psi} T_j$$

The adjustment characteristic [11-26] is obtained

$$S_i\left(\Psi_m\right)\Big|_{T = const} = \nu_{mi} \Psi_m + s_{ij}^{\Psi} T_j \Big|_{T = const}$$

Therefore, the mechanical characteristics of the engine has the form

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

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

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

The expression for the transverse piezo engine is calculated

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

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

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

At d_{31} = 2·10^{-10} m/V, E_3 = 0.25·10^5 V/m, h = 2.5·10^{-2} m, S_0 = 1.5·10^{-5} m^2, s_{11}^E = 15·10^{-12} m^2/N we have $\Delta h_{\max}$ = 125 nm, $F_{\max}$ = 5 N with error 10%

The deformation of an engine at elastic load has the form

$$\frac{\Delta l}{l} = \nu_{mi} \Psi_m - \frac{s_{ij}^{\Psi}}{S_0} F, \quad F = C_e \Delta l$$

The adjustment characteristic is determined

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

The coefficients in general are calculated

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

$$s_{ij} = k_s s_{ij}^E$$

$$\left(1 - k_{mi}^2\right) \le k_s \le 1$$

At one fixed face and elastic-inertial load Figure 2 is transformed to Figure 3.

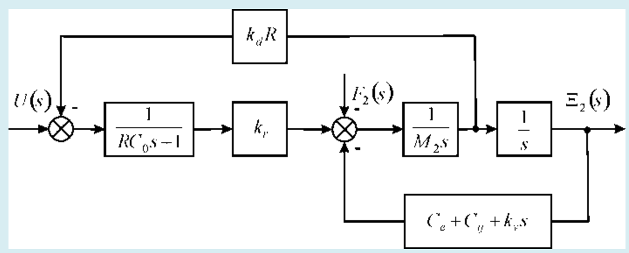

Figure 3: Structural scheme of piezo engine at one fixed face and elastic-inertial load.

Therefore, the function of piezo engine for $R = 0$ has the form

$$W(s) = \frac{\Xi(s)}{U(s)} = \frac{k_{31}^U}{T_t^2 s^2 + 2T_t \xi_t s + 1}$$

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

$$T_t = \sqrt{M \big/ \left(C_l + C_{11}^E\right)}, \quad \omega_t = 1/T_t$$

At M= 1 kg, C_l = 0.1·10^7, C_{11}^E = 1.5·10^7, d_{31} = 2·10^{-10} m/V, h/δ = 20 the parameters of piezo engine are calculated T_t = 0.25·10^{-3} s, ω_t = 4·10^3 s^{-1}, k_{31}^U = 3.75 nm/V with error 10%.

Conclusions

The structural scheme of an engine is calculated for nanomedicine and nanotechnology. The matrix of the deformations of an engine is determined. The parameters of the piezo engine for nanodisplacement are obtained.

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