

Research article

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System with nano piezoengine under randomly influences for biomechanics

Abstract

The sufficient condition of absolute stability system with nano piezoengine by using the derivative of the hysteretic piezoengine deformation is determined for the randomly influences. The set of equilibrium positions of the piezoengine in the control system is stable relative to mathematical expectations, when the condition of absolute stability with the maximum piezo module is met. The statistical linearization method is using for the determination condition of absolute stability control system with the nano piezoengine.

Keywords: sufficient condition of absolute stability system, randomly influences, nano piezoengine, hysteresis, biomechanics

Volume 8 Issue I - 2024

Afonin SM

National Research University of Electronic Technology MIET, Russia

Correspondence: Afonin SM. National Research University of Electronic Technology MIET, Moscow, Russia, Email learner01@mail.ru

Received: December 12, 2023 | Published: January 16, 2024

Introduction

The movement nano piezoengine is achieved due to its deformation, when the electrical voltage is applied.^{1–11} The nano piezoengine is used for biomechanics for scanning microscopy, nano manipulator, dosing device, nano pump.^{12–27} In articles^{1,3,18} the absolute stability of control system under deterministic influences is considered. The sets of equilibrium positions of the systems the piezoengines under deterministic influences are obtained in articles.^{18,23} Structural models and transfer functions of the piezoengines are defined in.^{5–22,24,25} In this work the absolute stability of system with the piezoengine under randomly influences is obtained for biomechanics.

Method

The statistical linearization method is using for condition of absolute stability system with the nano piezoengine under the randomly influences for biomechanics.

Results

The application of the criterion of absolute stability of system with the piezoengine²³ is determined for biomechanics. In this work, the Preisach hysteresis model is used.¹⁴ The hysteresis Preisach function of the relative deformation the piezoengine has the form

$$S_i = F\left[E_m\Big|_0^t, t, S_i(0), \operatorname{sign}\dot{E}_m\right]$$

here S_i - the deformation, t - time, $S_i(0)$ - the initial condition for the deformation, E_m - the strength of electric field, $\operatorname{sign} \dot{E}_m$ - the sign for velocity of change strength of electric field.

For the piezoengine the vertices of the basic hysteresis loops lie on the initial curve in the form $S_i = F_1(E_m)$.²³ The initial curve^{3,23} of the hysteresis deformation has the form $F_1(E_m) = d_{mi}^0 E_m + c_{mi} E_m^3 = d_{mi}^{\max} E_m$ the maximum of the piezomodule

$$d_{mi}^{\text{max}}$$
 has the form $d_{mi}^{\text{max}} = d_{mi}^0 + c_{mi} E_m^2$

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where d_{mi}^{0} - the initial piezomodule, c_{mi} - the coefficient, E_{m} - the strength of electric field.

From the Yakubovich criterion²³ the criterion absolute stability of control system for the nano piezoengine is obtained for biomechanics. The condition for the absolute stability of system with nano piezoengine at deterministic influences is estimated in the form $\operatorname{Re} v_{mi} W(j\omega) \ge -1$

here ω - the frequency, *j* - the imaginary unit, v_{mi} - maximum of the tangent the angle of inclination to the hysteresis loop.

For the longitudinal piezoengine at deterministic influences the maximum tangent of the hysteresis deformation $v_{33} = 1 \text{ nm/V}$ has the form for the longitudinal piezoeffect.

The equilibrium positions of the piezoengine in the system for controlling its deformation are stable relative to mathematical expectations, when the condition of absolute stability with the maximum piezomodule as the maximum derivative of the hysteresis characteristic is satisfied.

Let us consider the use of the statistical linearization method to calculate the stability of control system for the piezoengine with normal Gaussian distribution of random influences. For statistical linearization the derivative in general has the form

$$\frac{\partial m_{S_i}}{\partial m_{E_m}} = \frac{1}{2\sigma_{E_m}^2} \int_{-\infty}^{+\infty} \left[S_i^+(E_m) + S_i^-(E_m) \right] \left(E_m - m_{E_m} \right) \frac{1}{\sigma_{E_m} \sqrt{2\pi}} e^{-\frac{\left(E_m - m_{E_m} \right)^2}{2\sigma_{E_m}^2}} dE_m$$

where S_i - the relative deformation, $F_1(E_m) = (S_i^+(E_m) + S_i^-(E_m))/2$ - the initial curve, and indexes + and – are upper indexes for increase and decrease hysteresis deformation.

Then by using the equation of the initial curve, we have statistical linearization the derivative of the nonlinear relative deformation the nano piezoengine at normal Gaussian distribution of the random influences in the form

$$\frac{\partial m_{S_i}}{\partial m_{E_m}} = \frac{1}{\sigma_{E_m}^2} \int_{-\infty}^{+\infty} F_1(E_m) \left(E_m - m_{E_m} \right) \frac{1}{\sigma_{E_m} \sqrt{2\pi}} e^{-\frac{\left(E_m - m_{E_m} \right)^2}{2\sigma_{E_m}^2}} dE_m$$

The derivative for the hysteresis characteristic at the mathematical expectation of the electric field strength equal to zero $m_{E_m} = 0$ has form

$$\frac{\partial m_{S_i}}{\partial m_{E_m}} = \frac{1}{\sigma_{E_m}^2} \int_{-\infty}^{+\infty} d_{mi}^{\max} E_m \left(E_m - m_{E_m} \right) \frac{1}{\sigma_{E_m} \sqrt{2\pi}} e^{-\frac{\left(E_m - m_{E_m} \right)^2}{2\sigma_{E_m}^2}} dE_m = d_{mi}^{\max}$$

Accordingly after statistical linearization the derivative of the hysteresis deformation piezoengine, the condition of absolute stability

MOJ App Bio Biomech. 2024;8(1):1-3.



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of control system with nano piezoengine under randomly influences is written as $\operatorname{Re} d_{mi}^{\max} W(j\omega) \ge -1$ for control system with the hysteresis characteristic at the randomly influences $g(t) = m_g(t) + g_0(t)$, $|m_{g}(t)| \leq R_{g}$

where R_{σ} - the upper bound, and the derivative of the hysteresis characteristic has the form

$$\mathbf{0} < \frac{\partial m_{S_i}\left(m_{E_m}, \sigma_{E_m}\right)}{\partial m_{E_m}} < d_{mi}^{\max}$$

This expression for the derivative of the hysteretic deformation is used to the graphically illustration of the sufficient condition for the absolute stability of the control system with nano piezoengine under the randomly influences on Figure 1.



Boundary line B

Figure I Sufficient condition of absolute stability system.

For the longitudinal piezoengine at the randomly influences the maximum of the piezomodule has the form $d_{33}^{\text{max}} = 1.7 \text{ nm/V}$ for the longitudinal piezoeffect.

Discussion

The equilibrium positions of the piezoengine in the system for controlling its deformation are stable relative to mathematical expectations, when the condition of absolute stability with the maximum piezomodule as the maximum derivative of the hysteresis characteristic is satisfied.

Conclusion

The sufficient condition of absolute stability system on the derivative for the randomly influences is determined by using of the statistical linearization method. The equilibrium positions of the piezoengine in control system are stable relative to mathematical expectations. The condition for the absolute stability of the control system under random influences is obtained, taking into account the maximum piezo module of the piezoengine.

Acknowledgments

None.

Funding

None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Citation: Afonin SM. System with nano piezoengine under randomly influences for biomechanics. MOJ App Bio Biomech. 2024;8(1):1-3. DOI: 10.15406/mojabb.2024.08.00198

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