Research Article

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Absolute stability of system with nano piezoengine for biomechanics

Abstract

The nano piezoengine is used for biomechanics and nano sciences in dosing device, scanning microscopy, nano manipulator, nano pump. For the nano piezoengine with hysteresis in control system its set of equilibrium positions is the segment of line. The frequency method for studying the stability of system is used. By applying Yakubovich criterion for system with the nano piezoengine the absolute stability of system is calculated for biomechanics. The ratio of the piezomodules of the nano piezoengine with transverse, longitudinal, shear piezoelectric effects is proportional the ratio of its tangents of the angle of inclination to the hysteresis.

Keywords: absolute stability system, nano piezoengine, hysteresis, set equilibrium positions, biomechanics

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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

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Introduction

Many equilibrium positions are found in system with nano piezoengine for biomechanics and nano science. For calculation absolute stability of system with the nano piezoengine is using Yakubovich criterion, which is the development of the Lyapunov and Popov criterions.[1–20] The nano piezoengine is used for biomechanics and nano sciences in dosing device, scanning microscopy, nano manipulator, nano pump.[3–30]

Method

The frequency method for studying the stability of system is used to study the absolute stability of control system with the nano piezoengine.

Result

In this work for discussions stability of system with the nano piezoengine are used three main problems: the set of equilibrium positions, the Yakubovich criterion for the absolute stability of system, the maximum of the tangent the angle of inclination to the hysteresis loop of the nano piezoengine.

For written the hysteresis of the nano piezoengine for biomechanics and nano science the Preisach model is used for its hysteresis deformation. The hysteresis Preisach function of the relative deformation the nano piezoengine on Figure 1 is determined.[3–28]

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

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

In control system the set of equilibrium positions is the set of points M of intersection of the line L with the hysteresis characteristic of nano piezo engine on Figure 1 in the form of the selected line segment.[3] Respectively, the equation of the line L is evaluated

$$E_m + kS_i = 0$$

here k - the transfer coefficient for the linear part of control system.

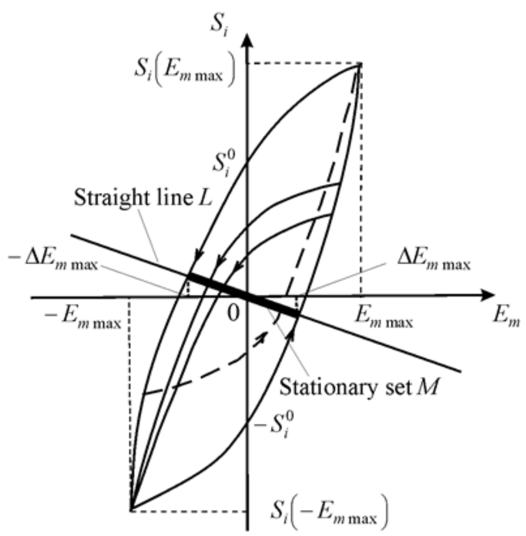

Figure 1 Hysteresis characteristic of nano piezoengine.

The expression for the symmetric main hysteresis loop[28] of the characteristic of nano piezoengine on Figure 1 is determined in the form

$$S_i = d_{mi}E_m - \gamma_{mi}E_{m\,max}\left(1 - \frac{E_m^2}{E_{m\,max}^2}\right)^{n_{mi}} sign\dot{E}_m$$

here d_{mi} - the piezo module, $\gamma_{mi} = S_i^0 / E_{m\,max}$ - the coefficient of hysteresis, S_i^0 - the relative deformation at $E_m = 0$, n_{mi} - the coefficient for the nano piezoengine from PZT $n_{mi} = 1$.

The width of the resting zone at $\Delta E_{m\,max}$ is obtained

$$\Delta E_{m\,max} + kS_i^+\left(\Delta E_{m\,max}\right) = 0$$

here Δ - the relative value of electric field strength; $S_i^+\left(\Delta E_{m\,max}\right)$ - the value of the relative deformation on the ascending branch for $\dot{E}_m > 0$, $S_i^-\left(-\Delta E_{m\,max}\right)$ - the value of the relative deformation on the descending branch for $\dot{E}_m < 0$ on Figure 1.

At the symmetric main hysteresis loop characteristic of the nano piezo engine the equation is evaluated

$$S_i^+\left(\Delta E_{m\,\max}\right) = d_{mi}\Delta E_{m\,\max} - \gamma_{mi}E_{m\,\max}\left(1 - \frac{\left(\Delta E_{m\,\max}\right)^2}{E_{m\,\max}^2}\right)$$

After transformation this expression is determined

$$S_i^+\left(\Delta E_{m\,\max}\right) = d_{mi}\Delta E_{m\,\max} - \gamma_{mi}E_{m\,\max}\left(1-\Delta^2\right)$$

From equation for the width of the resting zone the expression is calculated

$$\Delta E_{m\,\max} + kE_{m\,\max}\left[d_{mi}\Delta - \gamma_{mi}\left(1-\Delta^2\right)\right] = 0$$

Then the equation is determined

$$\Delta + k\left[d_{mi}\Delta - \gamma_{mi}\left(1-\Delta^2\right)\right] = 0$$

The quadratic equation is calculated

$$\Delta^2 + \frac{\left(1+kd_{mi}\right)}{k\gamma_{mi}}\Delta - 1 = 0$$

The relative width of the rest zone of system with the nano piezoengine for biomechanics and nano sciences is obtained from this quadratic equation for the symmetric loop characteristic in the form

$$2\Delta = -\frac{\left(1+kd_{mi}\right)}{k\gamma_{mi}} + \sqrt{\frac{\left(1+kd_{mi}\right)^2}{k^2\gamma_{mi}^2} + 4}$$

and for the asymmetric loop characteristic its relative width of the rest zone of system is evaluated in the form

$$\Delta^+ + \Delta^- = -\frac{\left(1+kd_{mi}\right)}{2k}\left(\frac{1}{\gamma_{mi}^+} + \frac{1}{\gamma_{mi}^-}\right) + \frac{1}{2}\sqrt{\frac{\left(1+kd_{mi}\right)^2}{k^2\left(\gamma_{mi}^+\right)^2} + 4} + \frac{1}{2}\sqrt{\frac{\left(1+kd_{mi}\right)^2}{k^2\left(\gamma_{mi}^-\right)^2} + 4}$$

From the Yakubovich criterion,[1–4] which is the development of the Lyapunov and Popov criterions, the absolute stability of system with the nano piezoengine for biomechanics is obtained. The condition for the absolute stability of system with nano piezoactuator from PZT for biomechanics on Figure 2 is evaluated in the form

$$\mathrm{Re}\,\nu_{mi}W\left(j\omega\right) \geq -1$$

here ω - the frequency, j - the imaginary unit, ν_{mi} - maximum of the tangent the angle of inclination to the hysteresis loop. The amplitude-phase frequency characteristic on Figure 2 shows the frequency transfer function $W(j\omega)$ with boundary vertical line B, passing point -1 on real axis.

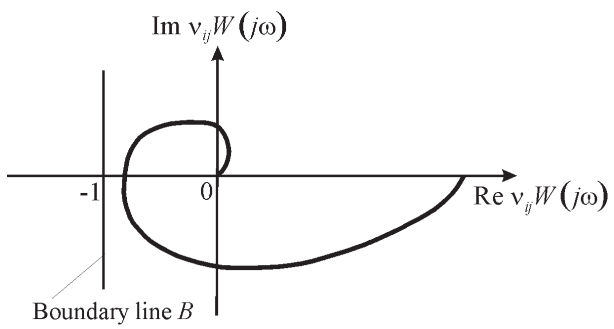

Figure 2 Absolute stability of system with nano piezoengine.

At the maximum strength of electric field in the nano piezoengine the minimum for the tangent the angle of inclination has the form $\min\left[dS_i/dE_m\right] = 0$ and maximum has the form $\max\left[dS_i/dE_m\right] = \nu_{mi}$. For the nano piezoengine from PZT for biomechanics we have its maximum tangents ν_{31} = 0.55 nm/V for transverse piezoeffect, ν_{33} = 1 nm/V for longitudinal piezoeffect, and ν_{15} = 1.25 nm/V for shear piezoeffect at error 10%.

Discussion

Therefore, the ratio of the piezomodules of the nano piezoengine from PZT with transverse, longitudinal, shear piezoelectric effects is proportional the ratio of its tangents of the angle of inclination to the hysteresis in the form:

$$d_{31} : d_{33} : d_{15} = \nu_{31} : \nu_{33} : \nu_{15}$$

Conclusion

For the nano piezoengine with hysteresis in the control system for biomechanics its set of equilibrium positions of the control system is the segment of line. The frequency method for studying the stability of system is used. By using Yakubovich criterion for system with the nano piezoengine the absolute stability of control system is obtained for biomechanics. The ratio of the piezomodules of the nano piezoengine with transverse, longitudinal, shear piezoelectric effects is proportional the ratio of its tangents of the angle of inclination to its hysteresis deformation.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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