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Absolute Stability of Control System with Electro Magneto Elastic Actuator for Nano Science and Nano Biomedicine Research

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Abstract

The stationary set of the control system of the hysteresis deformation of the electro magneto elastic actuator is the segment of the straight line. The aim of this work is to determine the condition of the absolute stability on the derivative for control system of the deformation of the electro magneto elastic actuator in automatic nanomanipulators for nanoscience and nanobiomedicine research. The frequency methods for Lyapunov stable control system are used to calculate the condition the absolute stability of the control system with electro magneto elastic actuator. In result we obtained the condition of the absolute stability on the derivative for the control system with the electro magneto elastic actuator in automatic nanomanipulators for nanoscience and nanobiomedicine research.

Keywords: Absolute stability, Control system, Electro magneto elastic actuator, Piezoactuator, Hysteresis deformation, Stationary set, Transfer function.

Introduction

The control systems with electro magneto elastic actuator on piezoelectric, electrostrictive and magnetostrictive effects solves problems of the precise matching in the nanotechnology, the compensation of the temperature and gravitational deformations, the atmospheric turbulence by the wave front correction [1-15].

The piezoactuator for Nano science and Nano biomedicine research is used in the scanning tunneling microscope, the scanning force microscope, the atomic force microscope, in the gene manipulator [16-30].

The condition of the absolute stability on the derivative for control system of the deformation of the electro magneto elastic actuator is calculated. The problems of using criteria absolute stability of the control system with electro magneto elastic actuator for Nano science and Nano biomedicine research are discussed. The stationary set of the control system of the deformation of the electro magneto elastic actuator is determined.

Aim

The aim of this work is to calculate the condition of the absolute stability on the derivative for control system of the deformation of the electro magneto elastic actuator in automatic nanomanipulators for nanoscience and nanobiomedicine research.

Method

The frequency methods for Lyapunov stable control system are used to determine the condition of the absolute stability of control system with electro magneto elastic actuator in automatic nanomanipulators for nanoscience and nanobiomedicine research [2,3].

Results

We determined the expression for the sufficient absolute stability condition of the control system with the hysteresis nonlinearity of the electro magneto elastic actuator using the Yakubovich absolute stability criterion with the condition on the derivative, which is the development of the Popov absolute stability criterion [2,3].

For the Lyapunov stable control system and the Yalubovich absolute stability criterion for the systems with the single hysteresis nonlinearity provides the simplest and pictorial representation of results of the investigation of the stability of the strain control system with the electro magneto elastic actuator.

We use the transfer function of the linear part of the system $W_{ij}(p)$ and the hysteresis function of the relative deformation S_j of the electro magneto elastic actuator for description of the system.

We have the description of the hysteresis nonlinearity of the actuator in the form [17]

$$S_j = F\left[\Psi_i\big|_0^t, t, S_j(0), \operatorname{sign}\dot{\Psi}_i\right] \quad (1)$$

Where S_j is the relative displacement of the cross section of the actuator along j axis Ψ_i is the control parameter of the actuator along *i* axis. The hysteresis function S_j at each time instant *t* depends on the behavior of the function $\Psi_i = E_i$ or $\Psi_i = H_i$ where E_i and H_i are the electric field strength and the magnetic field strength on the interval $[0, t]$ the value of *t*, the initial value $S_j(0)$, and the sign of the rate of Ψ_i the field strength variation. We consider the alternating sign hysteresis characteristics deformation of the piezoactuator on **Figure 1**.

The set $L[E_i(0)]$ is the vertical segment $[S_j^0, -S_j^0]$ bounded by the points of intersection of the ordinate axis with the hysteresis loop at the maximum admissible field strength in the piezoactuator.

We receive the stationary set for the deformation of the piezoactuator on Figure 1 for the stable linear part of the control system. Therefore, we draw the straight line L with the equation

$$E_i + W_{ij}(0) S_j = 0 \quad (2)$$

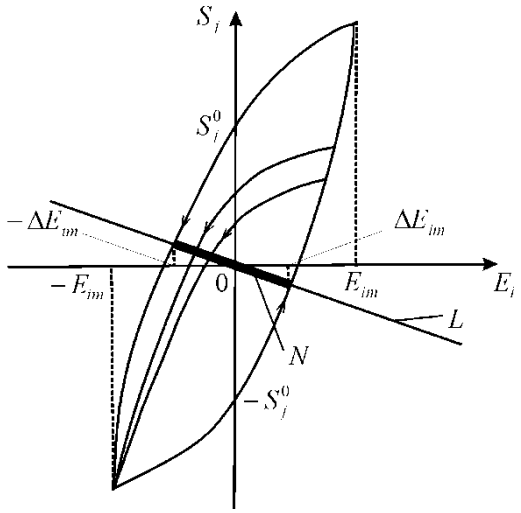

Figure 1: Hysteresis type characteristic deformation of piezoactuator.

We have the value of the transfer function $W_{ij}(0)$ of the linear part of the control system for the deformation of the piezoactuator in static regime. The set of points N for intersection of this straight line L with the hysteresis characteristic represents the segment of the straight line marked on figure 1. At $E_{i0} = E_i(0)$ and $S_{j0} = S_j(0)$ we have the stationary solution to the control system.

For stationary set we have

$$E_{i0} + W_{ij}(0) S_{j0} = 0 \quad (3)$$

The stationary set N of the system is the marked segment of straight line L in figure 1 with the set of pairs (E_{i0}, S_{j0}). Each point of intersection of the hysteresis nonlinearity with the partial loops and the straight line L corresponds to one equilibrium position with the coordinates (E_{i0}, S_{j0}).

Let us consider butterfly type characteristic of the deformation of the electro magneto elastic actuator for Nano science research. For the actuator with the electrostrictive effect the deformation characteristic on butterfly wings is observed for unipolar change of the electric field strength on **Figure 2**.

The particular cycle is the hysteresis loop. For butterfly type characteristic deformation of actuator in the control system the coordinate origin is moved to new zero with top dash on Figure 2. For hysteresis loop on butterfly type characteristic we have stationary set N of the system marked segment of straight line L in Figure 2. For the magnetostrictive actuator the deformation characteristic has the butterfly type.

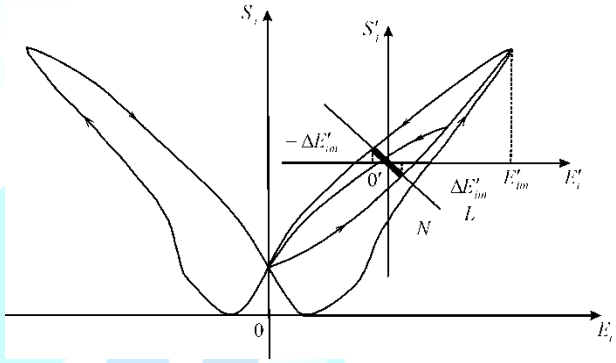

Figure 2: Butterfly type characteristic deformation of actuator with electrostrictive effect.

The function $S_j(E_i)$ of the hysteresis loop of the piezoactuator is continuous. Therefore, we have quantities

$$\nu_{1ij},\ \nu_{2ij} \in \left[0, \nu_{ij}\right], \nu_{ij} = \max\left[\frac{dS_j}{dE_i}\right] \quad (4)$$

Where the quantities ν_{1ij} and ν_{2ij} are calculated using the hysteresis characteristic on figure 1 for the maximum admissible electric field strength in the piezoactuator.

The quantities $\nu_{1ij} = 0$ and $\nu_{2ij} = \nu_{ij}$ are the minimum and the maximum values of the tangent of the inclination angle of the tangent line to the hysteresis nonlinearity of the piezoactuator. Thus, we obtain

$$\nu_{33} : \nu_{31} :\ \nu_{15} = d_{33} : d_{31} :\ d_{15} \quad (5)$$

where the ratios of the tangents of the inclination angle of the tangent line to the hysteresis nonlinearity of the piezoactuator for longitudinal, transverse and shift piezoeffects are proportional to the ratios of the piezomodules. We have the expression for the sufficient absolute stability condition of the system with the hysteresis nonlinearity of the electro magneto elastic actuator using the Yakubovich absolute

stability criterion with the condition on the derivative. The Yalubovich criterion is the development of the Popov absolute stability criterion [2].

For the Lyapunov stabile control system the Yalubovich absolute stability criterion for the system with the single hysteresis nonlinearity provides the simplest and pictorial representation of results of the investigation of the stability control system [2,3]. Therefore, the sufficient absolute stability condition of the control system of the deformation of the electro magneto elastic actuator at $\nu_{1ij}=0$, $\nu_{2ij}=\nu_{ij}$ has the form

$$\mathrm{Re}\,\nu_{ij}W_{ij}(j\omega)\geq -1 \quad (6)$$

Where in brackets j is the imaginary unity and is the frequency.
The amplitude-phase characteristic of the open-loop system $\nu_{ij}W_{ij}(j\omega)$ on **Figure 3** should be situated to the right of the straight line

$$\mathrm{Re}\,\nu_{ij}W_{ij}(j\omega)=-1 \quad (7)$$

For all values of $\omega\geq 0$

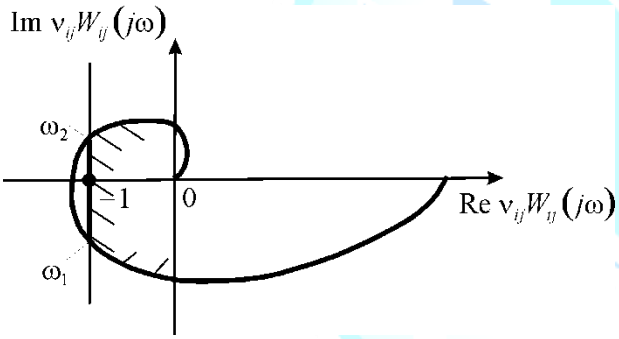

Figure 3: Absolute stability criterion for control system with electro magneto elastic actuator, shaded corrected characteristic.

For the absolute stability criterion for the system with electro magneto elastic actuator on the plane of the logarithmic amplitude frequency characteristic and the phase frequency characteristic we have

$$L(\omega)=Q[\varphi(\omega)], L(\omega)=20\lg|\nu_{ij}W_{ij}(j\omega)| \quad (8)$$

The corrected logarithmic amplitude frequency characteristic is below the boundary curve in the form

$$L(\omega)=20\lg|1/\cos\varphi| \quad (9)$$

For the piezoactuator from PZT the value of the maximum tangent of the inclination angle of the tangent line to hysteresis nonlinearity is about 1 nm/V for longitudinal piezoeffect and about 0.6 nm/V for transverse piezoeffect.

Summary

We used the frequency methods for Lyapunov stable control system to calculate the condition the absolute stability of the control system with electro magneto elastic actuator in automatic nanomanipulators.

Conclusions

We received the stationary set of the control system of the deformation of the electro magneto elastic actuator. We determined condition of the absolute stability on the derivative for the control system with the electro magneto elastic actuator in automatic nanomanipulators for nanoscience and nanobiomedicine research.

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