

Frequency method for determination self-oscillations in control systems with a piezo actuator for astrophysical research

Abstract

For the control system with a piezo actuator in astrophysical research the condition for the existence of self-oscillations is determined. Frequency method for determination self-oscillations in control systems is applied. By using the harmonious linearization of hysteresis and Nyquist stability criterion the condition of the existence of self-oscillations is obtained.

Keywords: frequency method, control system, piezoactuator, hysteresis, self-oscillations, astrophysical research

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Introduction

A piezo actuator is used in astrophysics for image stabilization and scan system.¹⁻¹⁹ Frequency method for determination self-oscillations in scan system is applied.²⁰⁻⁴⁶ for Nyquist stability criterion of self-oscillations at harmonious linearization of hysteresis characteristic of a piezo actuator.

Condition of self-oscillations

The scan system with a piezo actuator is used for astrophysical research in system adaptive optics. Nyquist stability criterion of self-oscillations at harmonious linearization of hysteresis characteristic^{2,20-40} of a piezo actuator has the form

$$W_l(\alpha\Omega)W_g(E_{m \max}) = -1$$

where α is the imaginary unit, Ω - the frequency of self-oscillations, $W_l(\alpha\Omega)$ - the frequency transfer function of the linear part, $W_g(E_{m \max})$ - the transfer function of the hysteresis part, $E_{m \max}$ - amplitude of the electric field strength for m axis.

For the scan system with a piezo actuator for astrophysical research the condition of self-oscillations is written

$$1 + W_l(\alpha\Omega)W_g(E_{m \max}) = 0.$$

The condition of self-oscillations is determined in the form

$$W_l(\alpha\Omega) = -\frac{1}{W_g(E_{m \max})}$$

here the left side of this equation has the form of the amplitude-phase characteristic of the linear part of the system, and the right side of the equation has the form of the inverse amplitude-phase characteristic of the hysteresis link of the piezo actuator with the inverse sign minus.

Preisach hysteresis function a piezo actuator has the form²²⁻⁴⁰

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

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

The symmetric hysteresis the deformation²²⁻⁴⁰ a piezo actuator has the form

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

$$d_{mi} = d_{mi}^0 + a_{mi}E_m^2, \gamma_{mi} = S_i^0 / E_{m \max}$$

here d_{mi} , γ_{mi} , S_i^0 , n - the piezo module, the hysteresis coefficient, the relative deformation for $E_m = 0$, and the power 1, 2, 3, ...

The transfer function of the linear part of the scan system with a piezo actuator for elastic-inertia load^{22,37-46} has the form

$$W_l(p) = \frac{k_l}{T_l^2 p^2 + 2T_l \xi_l p + 1}$$

After transformations we have this condition for the scan system with the PZT actuator at the power $n = 1$ in the form

$$\frac{1}{\frac{1 - T_l^2 \Omega^2}{k_l} + \alpha \frac{2T_l \xi_l \Omega}{k_l}} = \frac{1}{-(d_{mi}^0 + a_{mi}E_{m \max}^2) + \alpha \frac{8\gamma_{mi}}{3\pi}}$$

here

$$\Omega = \frac{4\gamma_{mi}k_l}{3\pi T_l \xi_l}$$

For the scan system with the PZT actuator $k_l = 3.2 \cdot 10^8$ V/m, $d_{33}^0 = 4 \cdot 10^{-10}$ m/V, $\gamma_{33} = 0.8 \cdot 10^{-10}$ m/V, $a_{33} = 3.1 \cdot 10^{-22}$ m³/V³, $T_l = 10^{-3}$ s, $\xi_l = 10^{-2}$ the frequency is determined $\Omega = 1.1 \cdot 10^3$ s⁻¹ with error of 10 %.

The frequency transfer function of the symmetric hysteresis the deformation of a piezo actuator is received in the form

$$W_g(E_{m \max}) = S_i(E_{m \max}) / E_m(E_{m \max})$$

then

$$W_g(E_{m \max}) = q_{mi}(E_{m \max}) + \alpha q'_{mi}(E_{m \max})$$

For $n = 1$

$$q_{mi}(E_{m \max}) = d_{mi} \cdot q'_{mi}(E_{m \max}) = -\frac{4 \cdot 2 \cdot \gamma_{mi}}{\pi \cdot 3} = -\frac{8\gamma_{mi}}{3\pi}$$

For $n = 2$

$$q_{mi}(E_{m \max}) = d_{mi} \cdot q'_{mi}(E_{m \max}) = -\frac{4 \cdot 2 \cdot 4 \cdot \gamma_{mi}}{\pi \cdot 3 \cdot 5} = -\frac{32\gamma_{mi}}{15\pi}$$

For $n = 3$

$$q_{mi}(E_{m \max}) = d_{mi} \cdot q'_{mi}(E_{m \max}) = -\frac{4 \cdot 2 \cdot 4 \cdot 6 \cdot \gamma_{mi}}{\pi \cdot 3 \cdot 5 \cdot 7} = -\frac{192\gamma_{mi}}{105\pi}$$

For n to $n+1$

$$q_{mi}(E_{m \max}) = d_{mi} \cdot q'_{mi(n)}(E_{m \max}) = \frac{2n}{2n+1} q'_{mi(n-1)}(E_{m \max})$$

For $n+1$

$$q_{mi}(E_{m \max}) = d_{mi} \cdot q'_{mi}(E_{m \max}) = -\frac{4 \cdot 2 \cdot 4 \cdot 6 \cdot \dots \cdot 2n \cdot \gamma_{mi}}{\pi \cdot 3 \cdot 5 \cdot 7 \cdot \dots \cdot (2n+1)}$$

The stability criterion and frequency method are used.

Discussion

By using of frequency method the parameters of self-oscillations are obtained in the scan system. Nyquist stability criterion is used for calculation the self-oscillations in the control system with a piezo actuator at harmonious linearization of hysteresis characteristic of a piezo actuator.

Conclusion

For the scan system its condition of self-oscillations is determined. For calculation the self-oscillations frequency method is applied at harmonious linearization of hysteresis characteristic of a piezo actuator.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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