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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

$$W_l(\alpha \grave{U}) W_g(E_{m\,\max}) = -1$$

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

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

The condition of self-oscillations is determined in the form

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

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 form [22 - 40]

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

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

The symmetric hysteresis the deformation [22 - 40] a piezo actuator has the form

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

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

here $d_{\grave{\imath}n}$, $\gamma_{\grave{\imath}n}$, S_i^0, n - the piezo module, the hysteresis coefficient, the relative deformation for $E_m = 0$, 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

$$W_l(p) = \frac{k_l}{T_t^2 p^2 + 2T_t \hat{\imath}_t p + 1}$$

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

$$\frac{1}{\dfrac{1 - T_t^2\Omega^2}{k_l} + \alpha\dfrac{2T_t\xi_t\Omega}{k_l}} = \frac{1}{-\left(d_{\grave{\imath}n}^0 + a_{\grave{\imath}n} E_{m\,\max}^2\right) + \alpha\dfrac{8\gamma_{\grave{\imath}n}}{3\pi}}$$

here

$$\Omega = \frac{4\gamma_{\grave{\imath}n} k_l}{3\pi T_t \xi_t}$$

For the scan system with the PZT actuator $k_l = 3.2\cdot10^8$ V/m, $d_{33}^0 = 4\cdot10^{-10}$ m/V, $\gamma_{33} = 0.8\cdot10^{-10}$ m/V, $a_{33} = 3.1\cdot10^{-22}$ m^3/V^3, $T_t = 10^{-3}$ s, $\xi_t = 10^{-2}$ the frequency is determined $\Omega = 1.1\cdot10^3$ 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

$$W_g(E_{m\,\max}) = q_{\grave{\imath}n}(E_{m\,\max}) + jq'_{\grave{\imath}n}(E_{m\,\max})$$

For $n = 1$

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

For $n=2$

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

For $n=3$

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

For n to $n+1$

$$q_{in}\left(E_{m\max}\right)=d_{in}\ ,\ q'_{in\,(n)}\left(E_{m\max}\right)=\frac{2n}{2n+1}q'_{in\,(n-1)}\left(E_{m\max}\right)$$

For $n+1$

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

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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None.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

1. Uchino K. Piezoelectric actuator and ultrasonic motors. Boston, MA: Kluwer Academic Publisher; 1997. 350 p.
2. Besekersky VA, Popov EP. Theory of automatic control systems. St. Petersburg: Professiya; 2003. 752 p.
3. Afonin SM. Absolute stability conditions for a system controlling the deformation of an elecromagnetoelastic transduser. *Doklady Mathematics*. 2006;74(3):943–948.
4. Bhushan B. Springer Handbook of Nanotechnology. New York: Springer; 2004. 1222 p.
5. Shevtsov SN, Soloviev AN, Parinov IA, et al. Piezoelectric actuators and generators for energy harvesting. Switzerland: Research and Development Springer; 2018. 182 p.
6. Afonin SM. Generalized parametric structural model of a compound elecromagnetoelastic transduser. *Doklady Physics*. 2005;50(2):77–82.
7. Afonin SM. Structural parametric model of a piezoelectric nanodisplacement transducer. *Doklady Physics*. 2008;53(3):137–143.
8. Afonin SM. Solution of the wave equation for the control of an elecromagnetoelastic transduser. *Doklady Mathematics*. 2006;73(2):307–313.
9. Afonin SM. Optimal control of a multilayer electroelastic engine with a longitudinal piezoeffect for nanomechatronics systems. *Applied System Innovation*. 2020;3(4):1–7.
10. Afonin SM. Coded control of a sectional electroelastic engine for nanomechatronics systems. *Applied System Innovation*. 2021;4(3):1–11.
11. Afonin SM. Structural-parametric model of electromagnetoelastic actuator for nanomechanics. *Actuators.* 2018;7(1):1–9.
12. Afonin SM. Structural-parametric model and diagram of a multilayer electromagnetoelastic actuator for nanomechanics. *Actuators.* 2019;8(3):1–14.
13. Cady WG. Piezoelectricity: An introduction to the theory and applications of electromechancial phenomena in crystals. New York, London: McGraw-Hill Book Company; 1946. 806 p.
14. Mason W. Physical acoustics: principles and methods. New York: Academic Press; 1964. 515 p.
15. Liu Y, Zeng A, Zhang S, et al. An experimental investigation on polarization process of a PZT-52 tube actuator with interdigitated electrodes. *Micromachines*. 2022;13(10):1760.
16. Jang Seon-Min, Yang Su Chul. Highly piezoelectric BaTiO3 nanorod bundle arrays using epitaxially grown TiO2 nanomaterials. *Nanotechnology*. 2018;29(23):235602.
17. Afonin SM. Structural-parametric model and transfer functions of electroelastic actuator for nano- and microdisplacement. In: *Piezoelectrics and nanomaterials: fundamentals. developments and applications*. New York: Nova Science; 2015. p. 225–242.
18. Afonin SM. Structural-parametric model electromagnetoelastic actuator nanodisplacement for mechatronics. *International Journal of Physics*. 2017;5(1):9–15.
19. Afonin SM. Structural-parametric model multilayer electromagnetoelastic actuator for nanomechatronics. *International Journal of Physics*. 2019;7(2):50–57.
20. Afonin SM. Condition absolute stability control system of electromagnetoelastic actuator for communication equipment. *Transactions on Networks and Communications*. 2020;8(1):8–15.
21. Afonin SM. Rigidity of a multilayer piezoelectric actuator for the nano and micro range. *Russian Engineering Research*. 2021;41(4):285–288.
22. Afonin SM. Structural scheme of an electromagnetoelastic actuator for nanotechnology research. In: Parinov IA, Chang SH, Putri EP, editors. *Physics and mechanics of new materials and their applications*. PHENMA 2023. Springer Proceedings in Materials. Springer; 2024. p. 486–501.
23. Afonin SM. Electromagnetoelastic actuator for large telescopes. *Aeronautics and Aerospace Open Access Journal*. 2018;2(5): 270–272.
24. Afonin SM. Piezoactuator of nanodisplacement for astrophysics. *Aeronautics and Aerospace Open Access Journal*. 2022;6(4): 155–158.
25. Afonin SM. Condition absolute stability of system with nano piezoactuator for astrophysics research. *Aeronautics and Aerospace Open Access Journal*. 2023;7(3):99–102.
26. Afonin SM. Piezoengine for nanomedicine and applied bionics. *MOJ Applied Bionics and Biomechanics*. 2022;6(1):30-33.
27. Afonin SM. System with nano piezoengine under randomly influences for biomechanics. *MOJ Applied Bionics and Biomechanics*. 2024;8(1):1–3.
28. Afonin SM. DAC electro elastic engine for nanomedicine. *MOJ Applied Bionics and Biomechanics*. 2024;8(1):38-40.
29. Afonin SM. Characteristics of an electroelastic actuator nano- and microdisplacement for nanotechnology. In: Bartul Z, Trenor J, editors. *Advances in Nanotechnology*. New York: Nova Science; 2021. p. 251–266.
30. Afonin SM. Absolute stability of system with nano piezoengine for biomechanics. *MOJ Applied Bionics and Biomechanics*. 2023;7(1):211–213.

31. Afonin SM. Structural model of nano piezoengine for applied biomechanics and biosciencess. *MOJ Applied Bionics and Biomechanics*. 2023;7(1):21–25.
32. Afonin SM. Multilayer piezo engine for nanomedicine research. *MOJ Applied Bionics and Biomechanics*. 2020;4(2):30–31.
33. Afonin SM. Characteristics electroelastic engine for nanobiomechanics. *MOJ Applied Bionics and Biomechanics*. 2020;4(3):51–53.
34. Afonin SM. Piezo actuators for nanomedicine research. *MOJ Applied Bionics and Biomechanics*. 2019;3(2):56–57.
35. Afonin SM. Structural scheme of piezoactuator for astrophysics. *Physics & Astronomy International Journal*. 2024;8(1):32–36.
36. Afonin SM. Nanopiezoactuator for astrophysics equipment. *Physics & Astronomy International Journal*. 2023;7(2):153–155.
37. Afonin SM. Electroelastic actuator of nanomechatronics systems for nanoscience. In: Min HS, editor. *Recent progress in chemical science research*. India, UK, London: BP International; 2023. p. 15–27.
38. Afonin SM. Structural scheme of electroelastic actuator for nanomechatronics. In: Ivan A, Parinov, Shun-Hsyung Chang, Banh Tien Long, editors. *Advanced Materials; Proceedings of the International Conference on "Physics and Mechanics of New Materials and Their Applications*. PHENMA 2019. Switzerland: Springer Nature; 2019. p. 487–502.
39. Afonin SM. Absolute stability of control system for deformation of electromagnetoelastic actuator under random impacts in nanoresearch. In: Parinov IA, Chang SH, Kim YH, editors. *Physics and Mechanics of New Materials and Their Applications*. PHENMA 2020. Springer Proceedings in Materials; Switzerland: Springer; 2021. p. 519–531.
40. Afonin SM. Harmonious linearization of hysteresis characteristic of an electroelastic actuator for nanomechatronics systems. In: Parinov IA, Chang SH, Soloviev AN, editors. *Physics and Mechanics of New Materials and Their Applications*. Proceedings of the International Conference PHENMA 2021-2022. Springer Proceedings in Materials series; Springer; 2023. p. 419–428.
41. Afonin SM. Structural parametric model and diagram of electromagnetoelastic actuator for nanodisplacement in chemistry and biochemistry research. In: Baena OJR, editor. *Current Topics on Chemistry and Biochemistry*. India, UK: B P International; 2023. p. 77–95.
42. Afonin SM. Structural-parametric models of electromagnetoelastic actuators of nano- and microdisplacement for robotics and mechatronics systems. St. Petersburg and Moscow, Russia: Proceedings of the 2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus); 2017. p. 769–773.
43. Afonin SM. Multilayer electromagnetoelastic actuator for robotics systems of nanotechnology. Moscow and St. Petersburg, Russia: Proceedings of the 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus); 2018. p. 1698–1701.
44. Afonin SM. Digital analog electro elastic converter actuator for nanoresearch. St. Petersburg and Moscow, Russia: Proceedings of the 2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus); 2020. p. 2332–2335.
45. Schultz J, Ueda J, Asada H. Cellular actuators. Oxford: Butterworth-Heinemann Publisher; 2017. 382 p.
46. Nalwa HS. Encyclopedia of nanoscience and nanotechnology. Los Angeles: American Scientific Publishers; 2004.