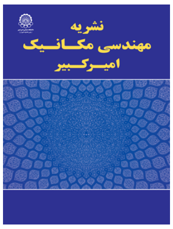

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CubeSat antenna vibration control using piezoelectric bender considering system requirements

E. Maani [1*], E. Zabihian[2]

[1] College of Engineering, University of Tehran, Tehran, Iran
[2] Satellite research institute, Iranian space research center. Tehran, Iran

ABSTRACT: Vibration control of satellite antenna is the main concern to good quality data transmission and reduction of mechanical disturbance in attitude maneuvers. This paper is devoted to mathematical modeling and vibration control of cube-sat antenna. To do this aim, piezoelectric sensor and actuator are utilized and mathematical model of antenna by considering piezoelectric actuator as input parameter and antenna tip deflection as the output parameter. By performing experimental tests, system unknown parameters as damping ratio and natural frequency are obtained based on FFT analysis and the least square method. To control the antenna vibration, its mathematical model is obtained by considering piezoelectric voltage as an input and antenna tip deflection as an output. Herein, due to limitation on the power subsystem, it is not possible to apply continuous voltages and only 100V voltage is available which complicates the control task. Three different control algorithms are proposed for antenna control and compared together. The results show that the proposed control strategies are efficient and can reduce the control time from 10 to about 1 second. The appearing parameters in the selected control algorithm are optimized using genetic algorithm. The presented results in this paper are useful for the design and control of antenna and also for the accurate design of satellite control subsystem.

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1- Introduction

Today, communication satellites play an important role in different technologies and people's daily life. There are different subsystems in the satellite as structure, attitude control, thermal control, onboard computer, and communication [1]. Satellites use different types of antenna to communicate with Ground Station (GS) and the antenna should be pointed to the GS for an accurate transmission of data [2]. Different disturbance torques and forces in the spaces lead to satellite and antenna vibration which reduces the efficiency of data communication [3] that should be controlled for reliable data transmissionn. Piezoelectric actuators have been used in satellites for different aims [4-6].

In this paper, a piezoelectric actuator will be utilized to control the vibration of a satellite antenna. Herein, CubeSat antenna will be modeled as a Clamped-Clamped beam with a piezoelectric sensor and actuator. Although different studies were devoted to controlling the beam using piezoelectric [7,8], they cannot be utilized to satellite antenna control due to the limitation of available voltage levels in satellite. There are several voltage buses in the satellite and the designed controller cannot apply continuous voltage to piezoelectric which adds complexity to the control process. This paper is devoted to the control of satellite antenna by considering above mentioned limitation of control voltage and this is the main novelty of this study.

*Corresponding author's email: e.maani@ut.ac.ir

2- Problem Statement

Fig. 1 shows the antenna of CubeSat.

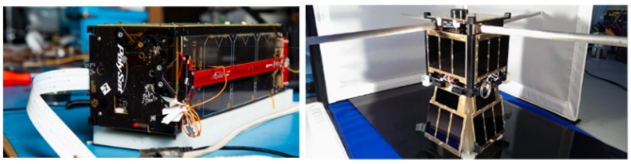

Fig. 1. CubeSat antenna

In this paper, the satellite antenna is modeled as a clamped-clamped beam as shown in Fig. 2.

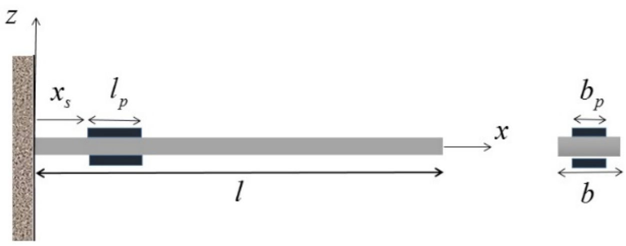

Fig. 2. Clamped-Clamped beam with piezoelectric sensor and actuator

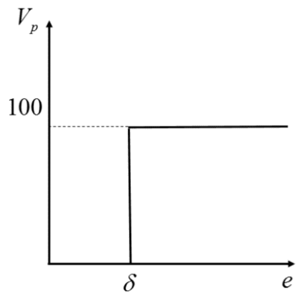

Fig. 3. Control algorithm (method 1)

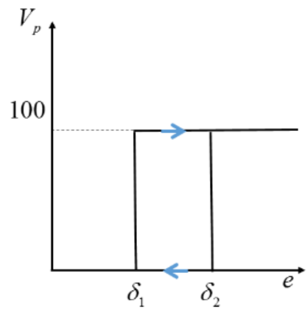

Fig. 4. Control algorithm

The equation of antenna motion can be written as a forth-order partial differential equation which can be converted to an ordinary differential equation using the Galerkin method as Eq. (1).

$$\ddot{u} + 2\zeta\omega_n\dot{u} + \omega_n^2 u = k_p V_p(t) \tag{1}$$

In this equation, ω_n , ζ and k_p depends on antenna geometrical and physical parameters and V_p is the applied voltage to the piezoelectric actuator.

3- Control Algorithm

By applying the PID controller to this system as method 1, it is shown that the antenna vibration is controlled but it is not practical because of the limitation of the applied voltage to ± 100 V. To control the vibration of the antenna following control algorithm is proposed as the method 2:

In this algorithm e is the beam end velocity error and δ is threshold. The last proposed algorithm is as follows:

This control algorithm can be written as following mathematical model:

$$V_p = \begin{cases} -100 & \dot{u} \geq \delta_2 \\ -100 & \delta_1 \leq \dot{u} \leq \delta_2 \ \& \ \ddot{u} \geq 0 \\ 0 & \delta_1 \leq \dot{u} \leq \delta_2 \ \& \ \ddot{u} \leq 0 \\ 0 & |\dot{u}| < \delta_1 \\ 0 & -\delta_2 \leq \dot{u} \leq -\delta_1 \ \& \ \ddot{u} \geq 0 \\ 100 & -\delta_2 \leq \dot{u} \leq -\delta_1 \ \& \ \ddot{u} \leq 0 \\ 100 & \dot{u} \leq -\delta_2 \end{cases} \tag{2}$$

In this algorithm e is the beam end velocity error and δ_1 and δ_2 are two thresholds that should be determined to reach the optimal solution. Because of the importance of energy in satellite mission, the objective function is defined as a linear combination of settling time and total energy consumption as follows:

$$f(\delta_1, \delta_2) = W_1 T_s + W_2 E \tag{3}$$

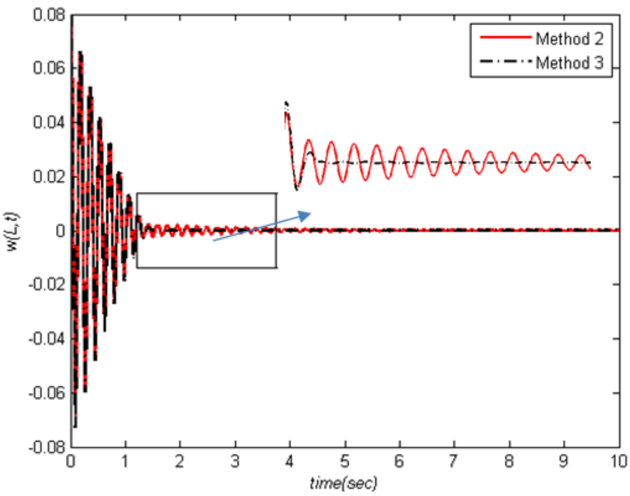

Fig. 5. Antenna vibration based on two proposed method

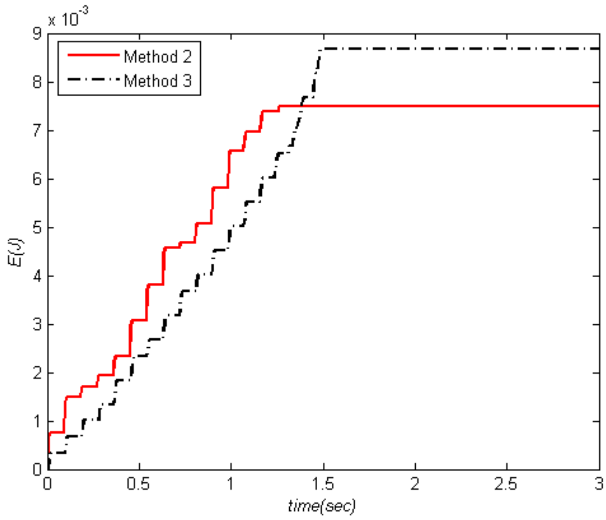

Fig. 6. Energy consumption of two proposed methods

4- 4. Resutls and Discussion

Fig. 5 shows the vibration of the antenna based on two proposed methods. As seen in this figure the efficiency of method 3 is more than method 2.

Fig. 6 compares the energy consumption of two proposed methods.

5- Conclusions

In this paper, control of cube sat antenna by considering the limitation of the applied voltage to the piezoelectric actuator is proposed based on different algorithms and the results are compared. The appearing parameters in control strategies are optimized using genetic algorithm. The results show that the proposed control strategies are efficient and can reduce the control time from 10 to about 1 second. The presented results in this paper are useful for the design and control of antenna and also for the accurate design of satellite control subsystem.

References

[1] L.-L. Fu, A. Cazenave, Satellite altimetry and earth sciences: a handbook of techniques and applications, Elsevier, 2000.

[2] S. Gao, K. Clark, M. Unwin, J. Zackrisson, W. Shiroma, J. Akagi, K. Maynard, P. Garner, L. Boccia, G. Amendola, Antennas for modern small satellites, IEEE Antennas and Propagation Magazine, 51(4) (2009) 40-56.

[3] G.B. Maganti, S.N. Singh, Simplified adaptive control of an orbiting flexible spacecraft, Acta Astronautica, 61(7-8) (2007) 575-589.

[4] S. Kayastha, O. Tekinalp, K. Ozgoren, Quaternion based state dependent ricatti equation control of a satellite camera on piezoelectric actuators, in: AIAA/AAS Astrodynamics Specialist Conference, 2010, pp. 8378.

[5] C. Vasques, J.D. Rodrigues, Active vibration control of smart piezoelectric beams: comparison of classical and optimal feedback control strategies, Computers & structures, 84(22-23) (2006) 1402-1414.

[6] M. Makhtoumi, Active Vibration Control of Launch Vehicle on Satellite Using Piezoelectric Stack Actuator, arXiv preprint arXiv:1903.07396, (2018).

[7] M. Naderi, A. Ariaei, Repair of Free Vibration Behavior of a Cracked Rotating Timoshenko Beam Using a Piezoelectric Patch and Applying Differential Transform Method, Amirkabir Journal of Mechanical Engineering, 51(1) (2019) 97-108.

[8] T. Malzer, H. Rams, M. Schöberl, Energy-Based In-Domain Control of a Piezo-Actuated Euler-Bernoulli Beam, IFAC-PapersOnLine, 52(2) (2019) 144-149.

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