Piezoelectric Actuator for Micro Robot Used in Nanosatellite

R Bansevicius[1], S Navickaite[2], V Jurenas[3] and A Bubulis[4]
Mechatronics Centre for Research, Studies & Information Kaunas University of Technology, Kaunas, Lithuania

E-mail: sigita.navickaite@ktu.lt

Abstract. Nanosatellites give ideal and cheap ability for space missions focusing on atmosphere research, GPS, scientific activities and other. Seeking to reach the aims of missions there is used special equipment in nanosatellite. One of such devices is piezoelectric robot that is usually responsible for manipulation of functional objects, such as cameras, laser sources, mirrors and other. Piezoelectric bending actuators are widely used for many different applications. One of such applications is precision positioning systems. Precision positioning of the manipulated object is important task for robots used in nanosatellites as well. In this paper authors present new design robot with the piezoelectric actuators for nanosatellites. Investigations are presented and they prove ability to improve the accuracy of the movement for the robotic hand in nanosatellite by using novel piezoelectric actuators that consists of two bending bimorphs.

1. Introduction

Nano-satellites are miniaturised satellites used in space research and such applications as earth observation with high resolution camera's or transmitting high bandwidth data, space science, astronomy and verification of new technologies in orbit. Nanosatellites in generally are measured in dimensions of 10cm x 10cm x 10cm and their mass is less than 1kg. Seeking to reach aims of missions there are used special equipment in nanosatellites. One of such equipment is piezoelectric robot that is usually responsible for manipulated objects, such as cameras, lasers, mirrors, optical elements and other.

Piezoelectric bending actuators are widely investigated. They are used for many different applications, such as precision movement mechatronic systems, optical devices, medicine equipment, space technologies and other [1-3]. Precision positioning of the manipulated object is important task for robots used in nanosatellites.

Piezoelectric effect generates small deformations of piezoelectric bimorph and that is the reason why deflection angle of actuator reaches only 0.01-0.5° [4]. Seeking to enhance such deflections there are new design actuators created [5, 6].

In this paper authors present new construction piezoelectric robot for nanosatellites. Piezoelectric robot consists of piezoelectric cylinder, ferromagnetic sphere, two cantilever piezoelectric bending actuators [7, 8] and manipulated objet (camera, laser source or other). Combination of two bending actuators improves movement of small robotic hand used to manipulate some object. These investigations prove ability to improve the accuracy of the movement for robotic hand in nanosatellite by using novel piezoelectric actuator that consists of two bending bimorphs. Such piezoelectric bending actuator can be characterized as low price and simple construction device.

2. Design of piezoelectric robot for nanosatellites

The configuration of the piezoelectric cylinder electrodes (Figure 1b) lets generate traveling or standing wave. Because of this reason passive ferromagnetic sphere, that is contacting with piezoelectric cylinder in three contact areas, starts to generate the rotational movement around axis x, y or z (Figure 1a). The system, of two piezoelectric cantilever bending actuators bonded together in series, is fixed on sphere surface to enhance the positioning accuracy of the manipulated object. First

---

[2] Corresponding author

piezoelectric cantilever bimorph 5 creates bending movement around axis *y*' and second piezoelectric bimorph 6 around axis *x*" (Figure 1). Here in Figure 2a: l_1 – length of first bimorph (50mm), l_2 – length of second bimorph (40mm), w_1 – width of first bimorph (7.8mm), w_2 – width of second bimorph (2mm), t_1 – thickness of first bimorph (1.8mm), t_2 – thickness of second bimorph (0.8mm).

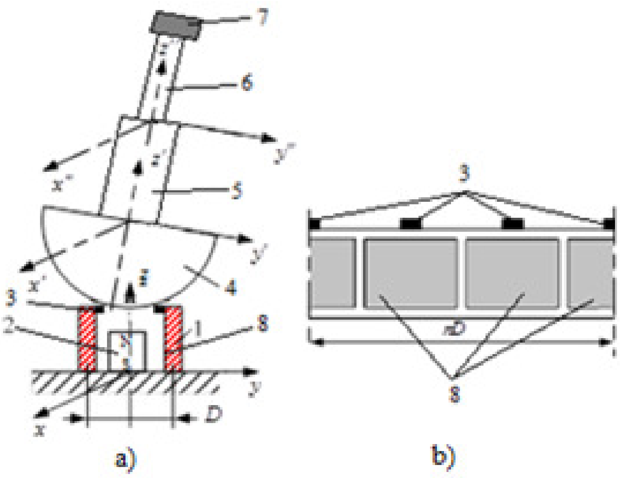


Figure 1. Piezoelectric robot:
a) scheme of the robot,
b) piezoelectric cylinder electrodes configuration.
Here:
1 – piezoelectric cylinder,
2 – permanent magnet,
3 – contact areas,
4 –ferromagnetic sphere-rotor,
5 – first piezoelectric bimorph,
6 - second piezoelectric bimorph,
7 – manipulated object,
8 – configuration of the piezoelectric cylinder electrodes.

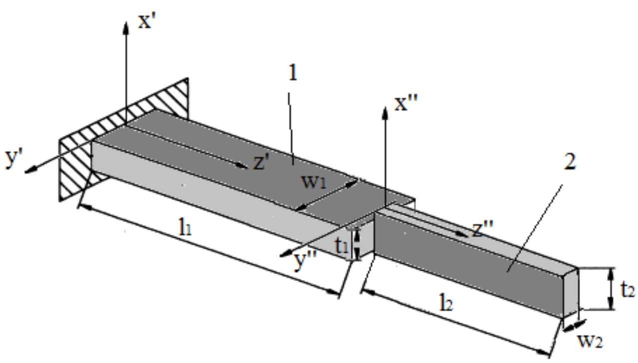


Figure 2. Investigated piezoelectric actuator.
Here:
1 – first piezoelectric bimorph,
2 – second piezoelectric bimorph,
l_1 – length of first bimorph,
l_2 – length of second bimorph,
w_1 – width of first bimorph,
w_2 – width of second bimorph,
t_1 – thickness of first bimorph,
t_2 – thickness of second bimorph.

3. Theoretical analysis

Generally bimorph cantilevered beam is subjected to an electrical excitation V (Figure 3). The beam is characterized by its length l_2, its width w_2, and its half thickness h ($h = t_2 / 2$). In the absence of external force, there is a theoretically linear relation between displacement of the tip δ_2 and applied voltage V.

Where s_{11}^E is the compliance coefficient along the beam, ε_{33}^S and d_{31} are dielectric and piezoelectric material coefficients.

$$\delta_2 = -\frac{3d_{31}}{1 + \dfrac{d_{31}^2}{4 s_{11}^E \varepsilon_{33}^S}} \cdot \frac{l_2^2}{h^2} V \tag{1}$$

In general resonant frequency f of cantilever beam should therefore be as high as possible [11]. For rectangular cantilevers, *f* is given by formula

$$f \approx 0.16 \cdot \sqrt{\frac{E}{\rho} \cdot \frac{t}{l^2}} \tag{2}$$

where ρ is the density of the cantilever material, E – Young modulus, t – thickness of the beam, l – length of the bimorph. High sensitivity and at the same time low noise can be achieved by using small cantilevers.

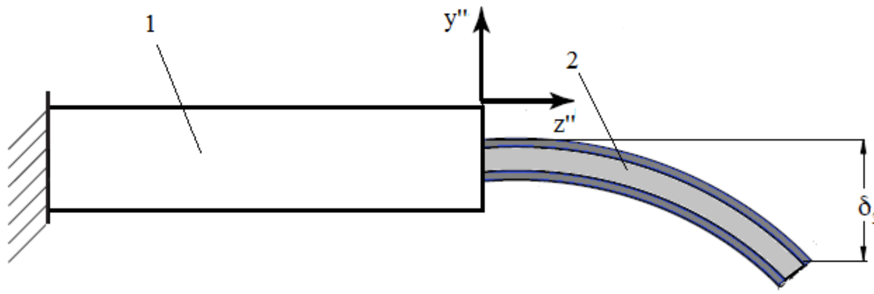


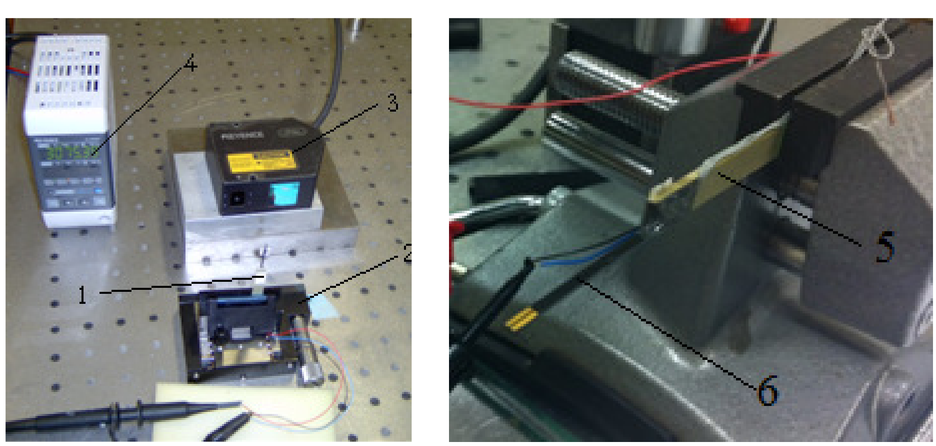
Figure 3. Calculating schemes of investigated actuator.

4. Experimental investigations

Prototype novel actuator (Figure 4b) was made for experimental investigation of its dynamic characteristics. Experimental set up is presented in Figure 4a. During experiments there were investigated three different characteristics of piezoelectric actuators: amplitude-frequency responses, impact response signal measured up with bump test and hysteresis of displacement. Measurements were made on the tip of second piezoelectric bimorph, when voltage of 12Vpp of harmonic signal is applied. The aim of these experiments was to investigate dynamics of precision positioning of the manipulated object for nanosatellites.

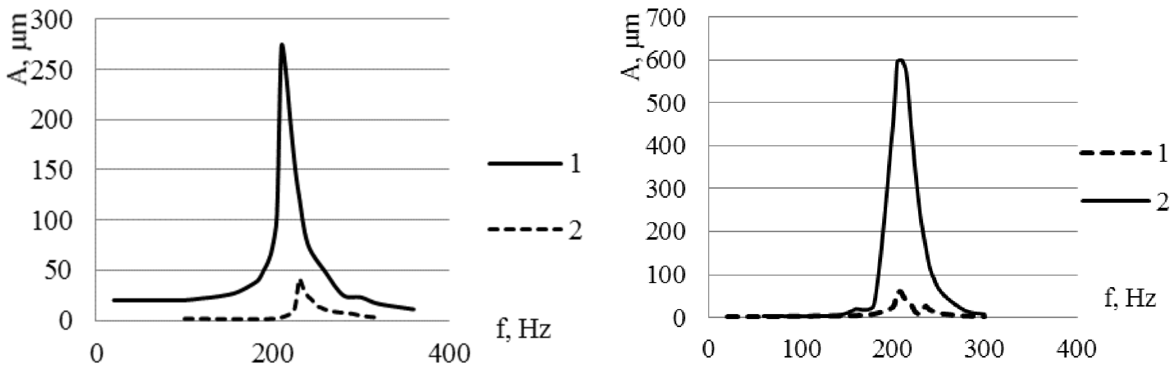
Experimental set up is shown in Figure 3. It consists of: 1 – precision positioning piezoelectric actuators system, 2 – holder of piezoelectric bender, 3 – laser displacement sensor LK-G82, 4 – laser sensor controller LK-G3001PV, 5 – first piezoelectric cantilever, 6 - second piezoelectric cantilever.

As result of experiments we have amplitude-frequency responses that are shown in Figure 5. From amplitude-frequency curves it can be seen that investigated actuator reaches its resonance at frequency 210Hz (amplitude – 275µm), when second bimorph is exited (Figure 4a). In this case movement of the tip is generated in y direction. During vibrating process of first bender, second bimorph gets movement as well. When first bender gets vibrations, the tip of second bender resonates at frequency of 230Hz and reaches amplitudes of 600µm in x direction. So operating frequency range of investigated actuator for precision positioning in y direction is 0-70Hz, and in x direction 0-80Hz.



a) b)

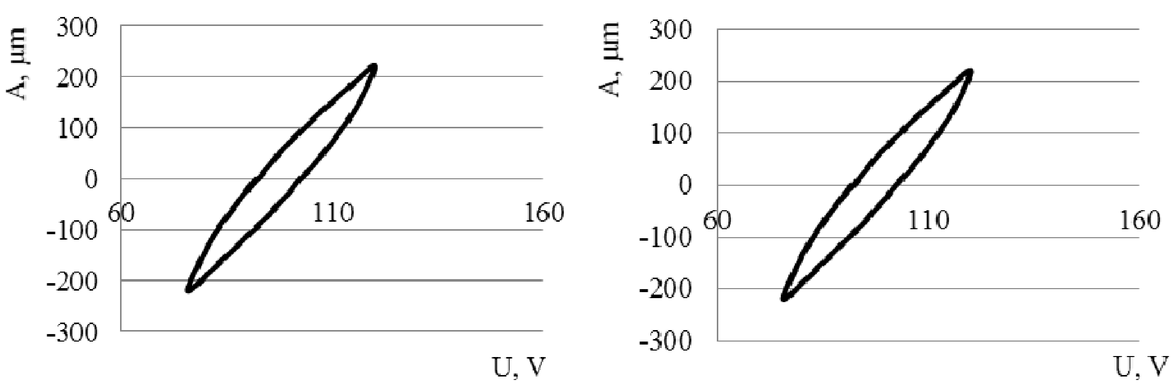
Figure 4. Experimental investigation a) setup and b) piezoelectric actuator used in experiments.



a) b)

Figure 5. Experimental results: a) amplitude-frequency responses of actuators, when 1 – amplitude-frequency response of first actuator, 2 – amplitude-frequency response of second actuator, when first one is vibrating, b) amplitude-frequency responses of actuators, when 1 – amplitude-frequency response of second actuator, when second bender vibrates, 2 – amplitude-frequency response of second actuator.

During experimental investigations of generated displacements the hysteresis of approximately 25% for the tip of piezoelectric actuator in *xy*-plane is measured (20Hz). Thus the control system with feedback for precision positioning of manipulated object must be applied.



b) b)

Figure 6. Experimental results: a) hysteresis of first bimorph, b) hysteresis of second bimorph.

5. Conclusions

A novel piezoelectric-driven 2D scanning actuator using two piezoelectric bimorph cantilevers bonded in series and placed in perpendicular direction has successfully been designed, fabricated and tested. Two bending modes of scanning operation have been investigated. By applying 12Vpp, the tip of actuator can achieve horizontal and vertical resonant vibrational amplitudes of 275µm and 600µm in the bending mode. During experimental investigation there was the hysteresis of approximately 25% for the piezoelectric actuator in *xy*-plane measured. For precision poisoning of manipulated object control system with feedback must be applied.

Acknowledgments

Postdoctoral fellowship is being funded by European Union Structural Funds project "Postdoctoral Fellowship Implementation in Lithuania" within the framework of the Measure for Enhancing Mobility of Scholars and Other Researchers and the Promotion of Student Research

(VP1-3.1-ŠMM-01) of the Program of Human Resources Development Action Plan.

References

[1] Shaffer J J and Fried D L 1970 Bender-bimorph scanner analysis *Appl. Opt.* **9(4)** 933–7
[2] Muralt P, Pohl D W and Denk W 1986 Wide-range, low-operating-voltage, bimorph STM: applications as potentiometer *IBM J. Res. Develop.* **30(5)** 443–50
[3] Lanyi S and Ozvold M 1992 Improved wide-range bimorph scanners *Ultramicroscopy* 1664–7
[4] Kelly Lee J 1979 Piezoelectric bimorph optical beam scanners: analysis and construction *Appl. Opt.* **18(4)** 454–9
[5] Ohtuka Y, Nishikawa H, Koumura T and Hattori T 1995 2-Dimensional optical scanner applying a torsional resonator with 2 degree of freedom *Proceedings of the IEEE Micro Electro Mechanical Systems (MEMS)* Amsterdam Netherlands 306–9
[6] Ikeda M, Totani H, Akiba A, Goto H, Matsumoto M and Yada T 1999 PZT thin film actuator driven micro optical scanning sensor by 3D integration of optical and mechanical devices *Proceedings of the IEEE Micro Electro Mechanical Systems (MEMS)* Orlando USA 435–40
[7] Yorinaga M, Makino D, Kawaguchi K and Naito M 1985 A piezoelectric fan using PZT ceramics *Jpn. J. Appl. Phys.* **24** 203–5
[8] Yoo J H, Hong J I and Cao W 2000 Piezoelectric ceramic bimorph coupled to thin film metal plate as cooling fan for electronic devices *Sens. Actuators A* **79** 8–12