

849. Novel attitude control devices for CubeSat satellites

Domantas Bručas¹, Ramutis Bansevicius², Aurelijus Domeika³,
Vidmantas Tomkus⁴, Vytautas Bakanauskas⁵

¹Space Science and Technology Institute, Vilnius Gediminas Technical University, Lithuania

^{2,3,5}Kaunas University of Technology, Lithuania

⁴Lithuanian Space Association, Lithuania

E-mail: ¹dobr@kmti.lt, ²ramutis.bansevicus@ktu.lt, ³aurelijus.domeika@ktu.edu,

⁴vto@space-lt.eu, ⁵vytautas.bakanauskas@ktu.lt

(Received 15 May 2012; accepted 4 September 2012)

Abstract. In recent years a very modern trend of space exploration activities – constructing, launching and operating nano-satellites, became very popular. One of the main problems in implementation and control of nano-satellite is ensuring accurate yet simple and small-sized attitude control equipment. Most of the equipment implemented for that task in the past was large, bulky and could be hardly used on extremely small CubeSat standard nano-satellites. The equipment under development for attitude control of the satellites is described in this paper. The equipment relies on implementation of piezoelectric transducers for rotation of spherical body – reaction sphere, thus ensuring precise three-axis attitude control of the satellite by means of single device. Description of the device under development with some calculations and examples of implementation of such instrumentation is further described in the paper.

Keywords: nano-satellite, CubeSat, attitude control, reaction-wheel, momentum of inertia.

Introduction

In recent years due to the miniaturization, the instrumentation which used to be large and bulky in the past has decreased its dimensions tenths of times. Recently a brand new trend in science has formed – creation, launching and control of miniature “micro”, “nano” and “pico” satellites. Such small satellites have the weight in the range of 1 ... 10 kg and due to their small price and short life cycle, are often used for purposes of education, technology demonstration, technology testing and science experiment.

Fundamental problem in operation of such small satellites is their attitude control. Despite a lot of research in satellite attitude control systems done in the past, all of them were intended for use on large conventional satellites and can hardly be implemented in small satellites due to bulkiness and large weight. Generally there exist several technical spacecraft attitude control solutions:

1. Implementation of thrusters (of different principles);
2. Magnetic (passive or active);
3. Inertial;
4. Gravitation;
5. Aerodynamic;
6. Solar wind.

The most precise mean of attitude control of spacecraft is implementation of inertial forces. One of such systems - implementation of "reaction wheels" - wheels of high enough mass producing torque opposite to the acceleration of its rotation [1, 2]. In usual systems implemented till this day, the fly wheels were accelerated (and rotated) by means of electric motors, due to that three of reaction wheels were required to control the attitude of satellite in all three axis. The quantity of needed reaction wheels together with complexity of electrical motor itself determined large mass and high price of the precise attitude control system [3, 4].

The instrument described in the paper implementing reaction sphere (instead of reaction wheels) could allow satellite three axis attitude control by means of single instrument (instead of three independent reaction wheels) [5]. Though the idea of implementation of reaction spheres

for satellite attitude control is not new, the gears intended for rotation of the sphere were based on electromagnetic principle (similar to electric motors), therefore they were large, bulky, extremely complex and expensive [6, 7]. Due to that fact such reaction spheres could hardly be implemented in case of small satellites [8, 9].

The idea and instrumentation further described could allow implementation of reaction sphere for three-axis satellite attitude control having minimal weigh, dimensions and low price.

Piezoelectric actuation of reaction sphere

The principle of piezoelectric actuators with several degrees-of-freedom have been implemented for quite a long time, the main advantages being small dimensions and extreme simplicity of mechanical part of the device, combined with high resolution of movement (both angular and liner) [10]. Due to these reasons it was decided to test the implementation of piezoelectric actuators with several degrees-of-freedom for reaction equipment [11].

The example of implementation of possible design of reaction sphere is shown in Fig. 1. The ferromagnetic reaction sphere (usually the stainless steel sphere) 1 is in contact with cylindrical piezoelectric transducer 3 via the intermediate element 2. The sphere is held in a position using permanent magnet 4. The electrodes of piezoceramic cylinder 3 are divided into three symmetrical sections by connecting to them the high frequency electric signal, the rotation is realized.

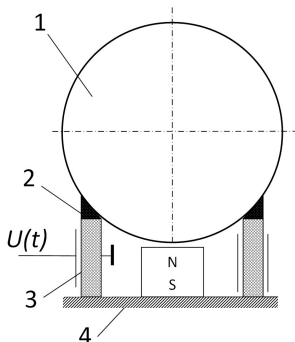


Fig. 1. Possible construction of the equipment



Fig. 2. Examples of piezoceramic hemisphere

Another application of piezoceramics for rotating the reaction sphere is provided in Fig. 2. In this case the piezoceramics are manufactured in a form of hemisphere. The advantages of such hemisphere piezoceramics layout are:

- By choosing the topology of electrodes three dimensional oscillations are generated, the parameters of which can be changed by adjusting the frequency of excitation;
- There is a node of oscillations at which the attaching point can be positioned;
- There is a decrease of dimensions in the case of implementation of hemisphere (compared to the cylindrical piezoceramics shape).

Simple realization of hemispheric piezoceramics layout is shown in Fig. 3. In this case one of the higher oscillation modes is excited by connecting signal generator to electrode 1, thus by connecting signal generator to the electrode 2, the direction of the movement can be changed. The schematics of case when the rotation about the symmetry axis of the piezoceramics is realized, is shown in Fig. 4. That way the rotation of sphere about all three axes can be ensured, thus providing the change of momentum of inertia for full satellite attitude control in single compact device.

In the case of design illustrated in Fig. 5, the ferromagnetic sphere is hold in place implementing permanent magnet. In Fig. 6 a construction of reaction sphere with hemispheres attached from both sides and intended to fix the sphere in its place is shown.

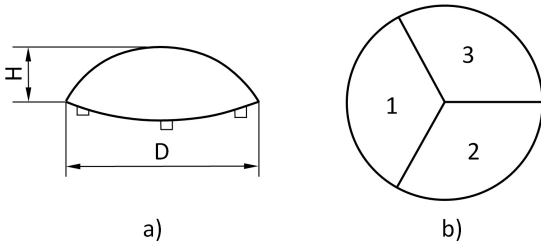


Fig. 3. Sectioned electrodes of hemispheric piezoceramic transducer

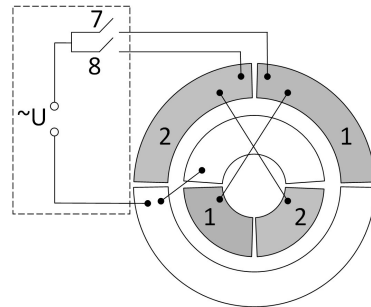


Fig. 4. Connection of electrodes of the transducer to the signal generator



Fig. 5. Laboratory test example of sphere with implementation of permanent magnet for sphere attachment



Fig. 6. Test example of sphere with two hemispheric piezoelectric transducers

The construction shown in Fig. 5 (implementing a constant magnet to hold the sphere in place) is quite promising in space environment since it allows reducing both the mass of the construction and negative forces of friction, which are unavoidable in the case of applying mechanical force onto the sphere to hold it in position. Additionally, influence of high strength magnet on the orientation equipment of the satellite (like magnetometers) should be further researched.

Implementation of piezo reaction sphere on the satellite

As was mentioned before, small satellites activities and market is highly growing in recent years. Therefore it is assumed that the best way of testing the proposed attitude control equipment and its initial implementation could be in CubeSat standard nano-satellites.

The CubeSat nano-satellites are special satellites having the dimensions of 10x10x10 cm and mass of more than 1 kg. Such satellites are mostly constructed by universities or other organizations with the main task of education, fast technology demonstration and in-orbit equipment validation (Fig. 7). Such satellites are launched as auxiliary payload on the rocket together with main payload (large satellite).

The task of piezoelectric “reaction wheel” onboard of the CubeSat satellite could be precise attitude control for any of the performed tasks (such as measurements, imaging, communication

etc.). The task of the reaction sphere would be precise positioning of the satellite along three axes, while coarse positioning could be accomplished using standard active magneto-torques. Since reaction sphere will have the saturation of momentum in the certain time frame (same as any reaction equipment), the active magneto-torques could also be used for its desaturation.

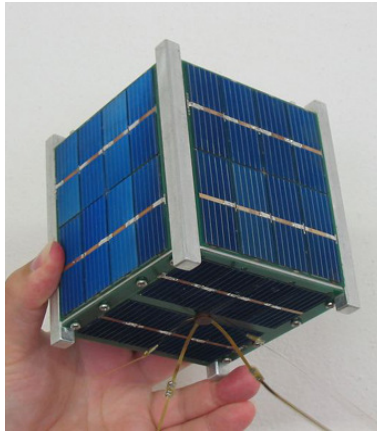


Fig. 7. Example of CubeSat standard nano-satellite [12]

It is considered that for attitude control of the satellite, torque capable of compensating the rotation of 8 deg/s of satellite, is sufficient [3]. Having in mind the dimensions of the CubeSat satellite ($10 \times 10 \times 10$ cm) and its mass (1 kg), the total momentum of inertia is in the range of $1.67 \cdot 10^{-3} \text{ kg} \cdot \text{m}^2$, which would require the torque of $2.33 \cdot 10^{-4} \text{ Nm}$. Such torque could be produced by acceleration of 25 mm diameter steel sphere up to 500 min^{-1} ($8,3 \text{ s}^{-1}$). Such angular speed of rotation has already been reached in laboratory conditions. Therefore, to ensure precise attitude control of CubeSat standard nano-satellite, a 25 mm diameter steel sphere is required.

As an example the project of 1 Unit CubeSat with piezo reaction wheel and the earth observation camera will be further described. Mounting of the camera, suitable for earth observation, was hardly possible in the past due to the need of precise satellite attitude control system. The project layout is shown in Fig. 8 and 9.

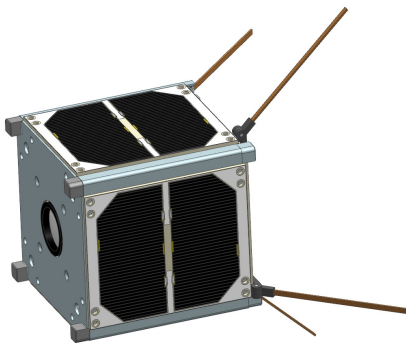


Fig. 8. General view of the proposed satellite

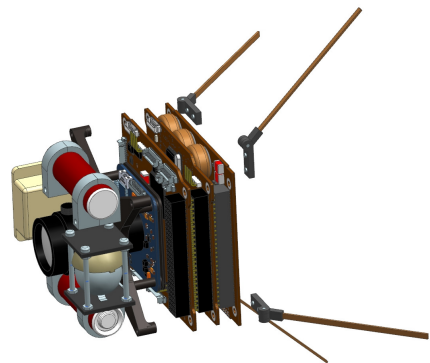


Fig. 9. View of the satellite with body structure and solar panels removed

A detailed exploded view is shown in Fig. 10. All of the details of CubeSat (1U) are fitted inside a standard frame (3, 11) with standard power unit (4), UHV communication unit (5), attitude determination and control unit (ADCS) (6), camera (7), batteries (8), reaction sphere (9),

oscillations generator of reaction sphere (10), with solar cells with integrated magneto-torques (2) and communication antennas attached to the frame. All of the parts used for the satellite except for the piezo reaction sphere and its oscillations generator are standard and commercially available. The equipment installed in the CubeSat is sufficient for full satellite in-orbit operation and communication with earth station.

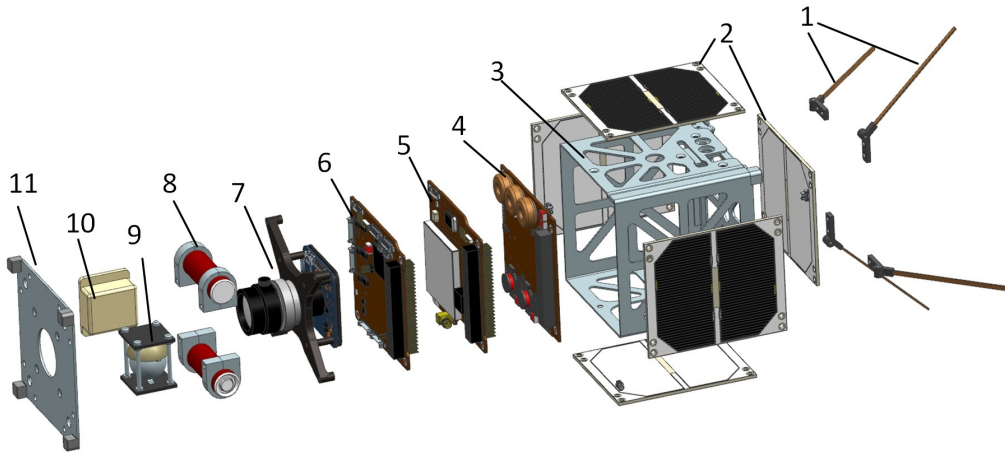


Fig. 10. Construction of CubeSat

As can be seen from Fig. 8, 9 and 10, reaction sphere can be integrated into the CubeSat structure to provide precise attitude control for earth observation. In this case attitude of CubeSat would be determined by means of attitude determination and control unit (ADCS), same unit providing the signals for attitude control equipment. The coarse attitude control could be performed by means of magneto-torques, integrated in solar cells (standard commercially available unit), while precise attitude control could be ensured implementing piezo reaction sphere. The desaturation of momentum of reaction sphere would be accomplished by magneto-torques in the magnetic field of the earth.

In conclusion, it can be stated that despite the obvious advantages of the implementation of piezo reaction sphere for attitude control on the satellites (including nano-satellites) such as:

- Extremely small size of the gear;
 - Lack of mechanical parts ensuring high reliability;
 - Rapid reaction of the gear ensuring rapid attitude control of the satellite;
 - Low price of the reaction equipment,
- piezoelectric attitude control equipment has also some serious implementation drawbacks:
- High energy consumptions (still to be determined);
 - Lack of the feedback on the sphere rotation (control of reaction sphere solely by satellite attitude determination system can sometimes be problematic);
 - Wear of contact areas sphere – contacting elements, fixed to the piezoelectric transducer (which in case of implementation on nano-satellites could be of less importance due to short orbital life cycle of the satellite itself).

Conclusions

The equipment for precise attitude control of small satellites is proposed ensuring accurate orientation at extremely low price, small dimensions and high reliability. Due to unexplored nature of implementation of piezoactuators with several degrees-of-freedom in space

environment, further research must be performed to determine the suitability of implementation of piezoelectric devices, described above.

Acknowledgement

Work has been supported by the Agency for Science, Innovation and Technology (MITA), Project PjezoPoz, Nr. 31V-143.

References

- [1] **Leve F., Tatsch A., Fitz-Coy N.** A scalable control moment gyro design for attitude control of micro-, nano-, and pico-class satellites. *Advances in the Astronautical Sciences*, Vol. 128, 2007, p. 235 – 237.
- [2] **Inamori T. et al.** Attitude stabilization for the nano remote sensing satellite PRISM. *Journal of Aerospace Engineering*, 2011, p. 187 – 191.
- [3] **Anderson A. D., Sellers J. J., Hashida Y.** Attitude determination and control system simulation and analysis for low-cost micro-satellites. *Proceedings of Aerospace Conference*, Volume 5-6, 2004, p. 29 – 35.
- [4] **Santoni F., Bolotti F.** Attitude determination of small spinning spacecraft using three axis magnetometer and solar panel data. *Aerospace Conference Proceedings*, 2000, p. 129-133.
- [5] **Das S., Sinha M., Kumar K. D., Misra A.** Reconfigurable magnetic attitude control of Earthpointing satellites. *Proceedings of the Institution of Mechanical Engineers, Part G, Journal of Aerospace Engineering*, 2010, p. 1309 – 1326.
- [6] **Schropl H.** Attitude stabilization of satellites by means of the free reaction sphere. *NASA Techdocs*, 1965, p. 27.
- [7] **Chetelat O., Onillon E., Perriard Y.** An open-loop control strategy of a reaction sphere for satellite attitude control. *Wiley and Sons Inc.*, 2001, p. 1 – 4.
- [8] **Onillon E., Chételat O., Rossini L., Droz S., Lisowski L., Moerschell J.** Reaction sphere for attitude control. *CSEM Scientific and Technical Report*, 2008, Patent No WO 2007/113666 A2, 2 p.
- [9] **Rossini L., Chetelat O., Onillon E., Perriard Y.** Analytical and experimental investigation on the force and torque of a reaction sphere for satellite attitude control. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 2011, p. 487 – 492.
- [10] **Bansevičius R., Drukteinienė A., Kulvietis G.** Trajectory planning method of rotating mobile piezorobot. *Journal of Vibroengineering*, Vol. 11, Issue 4, 2009, p. 690 – 696.
- [11] **Bansevičius R., Kargaudas V.** Attitude control of micro- and nanosatellite's using multidegree-of-freedom piezoelectric actuators. *Vibration Problems, ICOVP*, 2011, p. 379 – 384.
- [12] HARBOR – High Altitude Reconnaissance Balloon for Outreach and Research, <http://space.weber.edu/harbor/systemScience.shtml>.