Mechatronic Systems and Materials VI

Part 2

Edited by
Algirdas V. Valiulis, Olegas Černašėjus
and Vadim Mokšin

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Selected, peer reviewed papers from the
9th International Conference on
Mechatronic Systems and Materials
(MSM 2013),
July 1-3, 2013, Vilnius, Lithuania

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Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland
http://www.ttp.net

Volumes 220-221 of
Solid State Phenomena *2-part-set*
ISSN print 1012-0394
ISSN cd 1662-9787
ISSN web 1662-9779

(Pt. B of Diffusion and Defect Data - Solid State Data (ISSN 0377-6883))

Full text available online at *http://www.scientific.net*

***Distributed** worldwide by*

Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
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Fax: +41 (44) 922 10 33
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and in the Americas by

Trans Tech Publications Inc.
PO Box 699, May Street
Enfield, NH 03748
USA

Phone: +1 (603) 632-7377
Fax: +1 (603) 632-5611
e-mail: sales-usa@ttp.net

printed in Germany

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Preface

Selected papers of the 9th International Conference "Mechatronic Systems and Materials – MSM 2013", which was held in Vilnius, Lithuania, from 1 to 3 July 2013 are presented in two volumes. Conference was organized by Vilnius Gediminas Technical University in collaboration with Kaunas University of Technology (Lithuania), Opole University of Technology (Poland), Bialystok Technical University (Poland), Lithuanian Academy of Sciences, IFToMM National Committee of Lithuania.

The aim of the conference was to provide an opportunity for the scientists to share information and facilitate co-operation in mechatronics, new materials and engineering technologies and dissemination of current research results in this multi-disciplinary field. The task of the Conference was not only to acquaint participants with the works of scientists from different countries, but to expand their collaboration in the future.

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Solid State Phenomena Vols. 220-221 (2015) pp 561-564

doi:10.4028/www.scientific.net/SSP.220-221.561

Development of a Novel Device for Attitude Control over Small Satellites

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Keywords: nano-satellite, attitude control, reaction-sphere, momentum of inertia, piezoelectric actuator.

Abstract. Recent years have faced a very modern trend for space exploration activities – constructing, launching and operating nano-satellites have become very popular. One of the major problems of implementing and taking control over the nano-satellite is ensuring accurate but simple and small dimension equipment for attitude control. Most of the equipment implemented for the introduced task was large and bulky in the past and could be hardly used on extremely small satellites. The paper describes equipment under development for attitude control over satellites. Equipment relies on the implementation of piezoelectric transducers for the rotation of a spherical body, i.e. reaction sphere, thus ensuring precise three-axis attitude control over the satellite by means of a single device. Further, the article focuses on the device under development with some calculations and examples of implementing such instruments.

Introduction

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

Attitude control is one of the fundamental problems of operating small satellites. Despite exhaustive researches on satellites attitude control systems done in the past, all of them were intended for use on large satellites and could be hardly implemented in case of small satellites due to its bulkiness and large weight.

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

The task of the piezo reaction wheel onboard of the satellite could be precise attitude control over any of the tasks such as measurements, imaging, communication, etc. The task of the reaction sphere would be precise positioning of the satellite along three axes at any determined moment of the experiment, while coarse positioning could be accomplished using standard active magneto-torque and positioning the satellite in the Earth’s magnetic field. Since the reaction sphere will have the saturation of momentum in a certain time frame (same as any reaction equipment), active magneto-torque can also be used for the desaturation of it [4, 5].

Piezoelectric Actuator

The principle of piezoelectric actuators with several degrees-of-freedom have been implemented for quite a long time; the main advantages include small dimensions and an extreme simplicity of a mechanical part of the device combined with a high resolution of movement (both angular and liner) [6]. Due to provided reasons, it was decided to test the implementation of piezoelectric actuators with several degrees-of-freedom for reaction equipment [7].

The principal examples of implementing the possible constructions of the reaction sphere are shown in Figures 1 and 2. As displayed in Figure 1, ferromagnetic reaction sphere 1 is in contact with cylindrical piezoelectric element 3 via intermediate element 2. The sphere is held in a position using constant magnet 4. The electrodes of piezo-ceramic cylinder 3 are divided into three symmetrical sections by connecting which to the electric signal source rotation is realized.

A passive sphere makes contact with a piezoelectric cylinder or hemisphere in 3 contact areas; an axial travelling wave of the cylinder results in the controllable rotation of the sphere around the vertical axis; rotation around two perpendicular axes are generated by exciting asymmetrical oscillations of the cylinder and by connecting signal generators to three electrodes [7, 8].

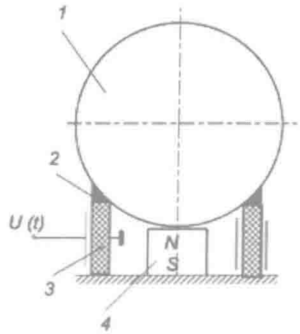

Fig. 1. A possible construction of equipment with a piezoelectric cylinder

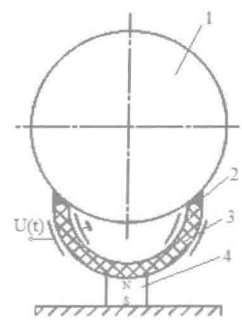

Fig. 2. The construction of equipment with piezoelectric hemisphere

Another application of piezo-ceramics for rotating the reaction sphere is shown in Figure 2. In this case, piezo-ceramics are manufactured in a form of hemisphere. The advantages of the layout of such hemisphere piezo-ceramics are as follows:

- 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 in dimensions in case of the implementation of hemisphere (compared to the shape of cylindrical piezo-ceramics).

The simple realization of the layout of hemisphere piezo-ceramics is shown in Figure 3. In this case, one of higher oscillation forms is excited by connecting a signal generator to electrode 1. Thus, by connecting the signal generator to electrode 2, the direction of movement can be changed.

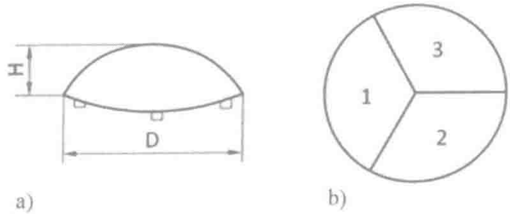

Fig. 3. Sectioned electrodes of the hemispheric piezo-ceramic transducer

The construction shown in Figures 1 and 2 (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 that are unavoidable in case of applying mechanical force onto the sphere to hold it in position. Additionally, the influence of a high strength magnet on the orientation equipment of the satellite (like magnetometers) should be further researched.

Prototypes of a Device for Attitude Control

As a case of design displayed in Figures 4 and 5, the ferromagnetic sphere is hold in place implementing a permanent magnet. Figure 4 shows a construction of a device for piezoelectric attitude control. Then, the reaction sphere is attached to the cylindrical piezoelectric actuator. Figure 5 presents how the reaction sphere is placed on the hemispheric transducer.

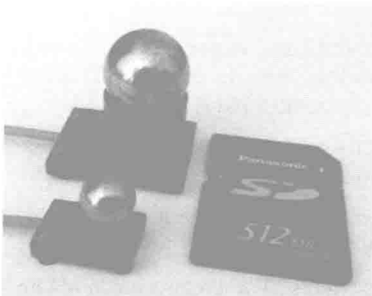

Fig. 4. Test examples of the reaction sphere with a cylinder piezoelectric transducer

Fig. 5. Test example of the sphere with a hemispheric piezoelectric transducer

It is considered that for attitude control over satellite torque capable of compensating the rotation of 8 deg/s, the satellite is fully sufficient [9]. Having in mind the dimensions of standard nano-satellites (10×10×10 cm) and their mass (1 kg), the total momentum of inertia is in the range of $1.67\cdot10^{-3}$, which would require the torque of $2.33\cdot10^{-4}$N·m. Such torque could be produced by the acceleration of 25 mm steel sphere up to 500 min^{-1} (8,3 s^{-1}). Such angular speed of rotation has already been reached under laboratory conditions. Therefore, to ensure precise attitude control over a standard nano-satellite, 25 mm stainless steel sphere is required.

Conclusions

The applications of multi-degree-of-freedom piezoelectric motors for attitude control over small satellites have been proposed thus ensuring accurate orientation, small dimensions and high reliability at an extremely low price. Due to an unexplored nature of implementing piezoelectric actuators with several degrees-of-freedom in space environment, further research must be performed with the aim to determine the suitability of implementing piezoelectric devices described above.

Acknowledgement

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