International Journal of Mechanical Engineering and Robotics Research Vol. 8, No. 4, July 2019

Measurements Analysis of the Earth's Magnetic Field Data Obtained from the Flight Model of AIST Small Spacecraft

Andry V. Sedelnikov
Department of Space Engineering, Samara National Research University, Samara, Russia
Email: axe_backdraft@inbox.ru

Ekaterina S. Khnyryova
Department of Further Mathematics, Samara National Research University, Samara, Russia
Email: khnyryova@gmail.com

Alexander S. Filippov
Department of Space Engineering, Samara National Research University, Samara, Russia
Email: filippoval89@mail.ru

Tatyana A. Ivashova
Faculty of Electronics and Instrument Engineering, Samara National Research University,
Samara, Russia
Email: itanya970@gmail.com

***Abstract*—It is necessary to estimate the rotational motion parameters of the spacecraft around the center of mass because we should know the conditions of carrying out technological processes. One way to estimate it is to measure the Earth's magnetic field by means of onboard equipment. Measurements were made with the use of MAGKOM scientific equipment onboard AIST small spacecraft series. Measurement data processing of two sensors was performed. First, we can see that statistic investigation confirms the correct operation of measuring equipment. Second, a significant shift in average was established between corresponding channels of various sensors. Third, other devices and scientific equipments operation can significantly affect the measurement data. These results can be used in the design of advanced space technique and the creation of new information measurement system with high accuracy.**

***Index Terms*—small spacecraft, magnetometer, microacceleration, data measurement analysis**

I. INTRODUCTION

The problem of microacceleration minimization is the most important problem of modern space materials science. This problem is the cause of slowing down pace of space technology development. Nowadays, the capabilities of rocket and space technology lag behind the need for successful implementation of gravity-sensitive processes. Despite of the 50-year history of this problem, it has not solved [1]. At the same time, orbital space stations are not suitable for the implementation of breakthrough space technologies because of the complexity of their structure and the need for periodic docking of cargo and manned spacecraft. It is difficult to create favorable conditions for the realization of gravity-sensitive processes on spacecraft of this class, even in special laboratory modules [2]. For example, inside the Columbus European module within the International Space Station (ISS), the level of microacceleration is 10^{-5} g. Directional crystallization experiments require the 10^{-7} g level of microacceleration.

The most promising spacecraft for the development of space technology is medium-class spacecraft. There are two specialized series of such spacecraft in Russia. The BION series is designed for biomedical experiments. Another FOTON series is used for technological experiments. The Chinese spacecraft Shijian (SJ) is the analogue of a Russian series of specialized spacecraft [3]. On such spacecraft the level of microacceleration is 10^{-6} g. With the use of additional means of vibration protection (MGIM, VZP1K microgravity platform), this level can decrease by an order and reach 10^{-7} g.

The main disadvantage of medium-class spacecrafts is the large time intervals between their launches. So, the FOTON M-3 spacecraft was launched in 2007. The next spacecraft of FOTON M-4 series was launched in 2014. This problem can be solved by the rapidly developing small spacecrafts. Their advantages are:

1. Low cost of launches;
2. Possibility of multi-spacecraft launches with one launch vehicle;
3. Possibility of multi-spacecraft launches as a hosted payload module;

Manuscript received April 25, 2018; revised May 1, 2019.

doi: 10.18178/ijmerr.8.4.542-546

4. Well-timed delivery of the experimental results to Earth.

However, the motion of small spacecrafts is insufficiently investigated, unlike medium-class spacecraft and orbital stations [4]. Therefore, the problem of investigating the conditions in the spacecraft internal environment for assessing the capability of implementing gravity-sensitive processes is relevant, important and well-timed.

II. METHODS

To estimate the level of microacceleration in the small spacecraft internal environment, it is necessary to know the parameters of its evolution around the center of mass. One way to estimate these parameters is to measure the Earth's magnetic field by means of onboard magnetometers. Magnetometers are used on a spacecrafts, begin with the first. They are well investigated and are used in the spacecraft's orbital motion control system. In the case of a compact design, the magnetometer sensors are located close to other scientific equipment with a conducting loop and a battery, therefore, before estimating the spacecraft rotational motion, it is necessary to check the operation correctness of the measuring devices. In the paper statistical tests was used to verify the correct operation of magnetometer two sensors onboard AIST small spacecraft.

The AIST small spacecraft flight model (Fig. 1) was placed into orbit on 21 April 2013 as hosted payload module of the BION-M1 spacecraft. The mass of AIST small spacecraft was 39 kg. The height of the near-circular orbit was about 570 km. Orbit inclination was – 64.9^0.

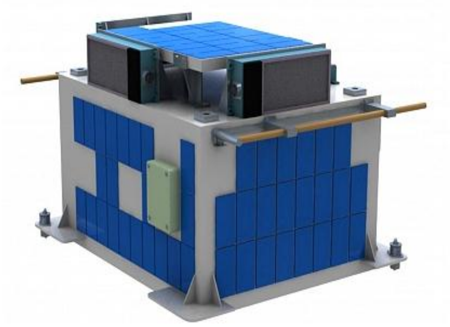


Figure 1. General view of the AIST small spacecraft flight model.

Figure 2. The MAGKOM scientific equipment: a – electronics component; b – electromagnets control component; c – three-component magnetometer; d – electromagnets [5].

Spacecraft fall away occurred normally without giving it a high initial angular velocity. This is the difference between the technological model and flight model of AIST small spacecrafts. From 27 April to 20 May 2013 the MAGKOM scientific equipment carried out a number of Earth's magnetic field measurements. This equipment consisted of two three-component magnetometer sensors (figure 2).

In the normal mode, the magnetic field was measured every 6 seconds. Dependences of the magnetic induction vector components for measurements on 27 April 2013 are shown in Fig. 3.

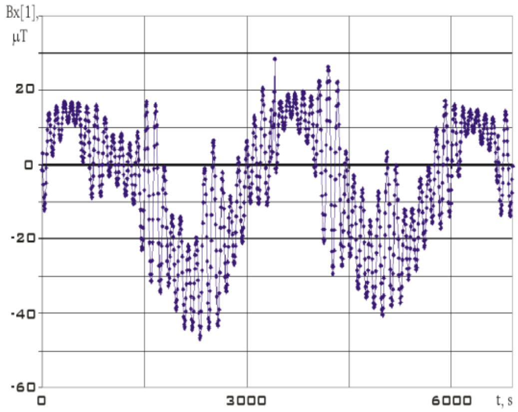


Figure 3a. Measurement data of the magnetometer sensor No. 1 on 27 April 2013 for the channel [X1].

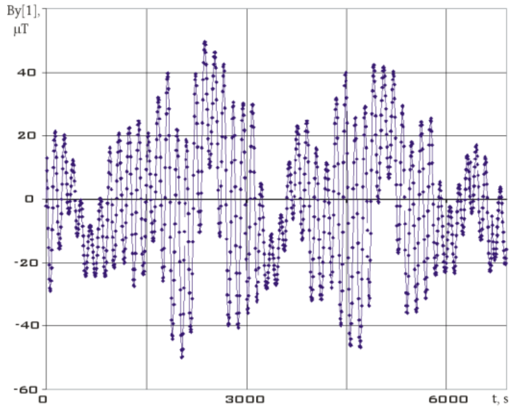


Figure 3b. Measurement data of the magnetometer sensor No. 1 on 27 April 2013 for the channel [Y1].

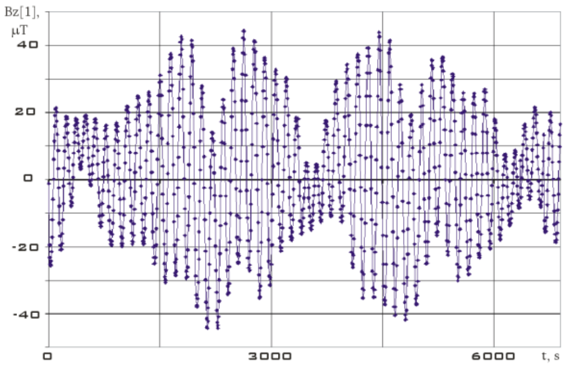


Figure 3c. Measurement data of the magnetometer sensor No. 1 on 27 April 2013 for the channel [Z1].

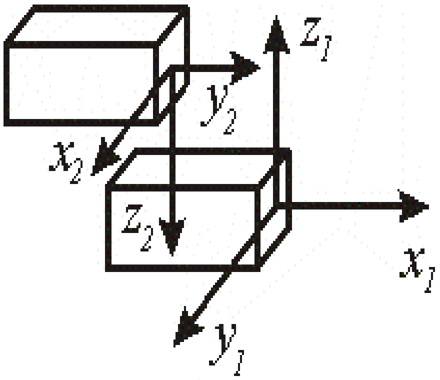


Figure 4. Relative orientation of the magnetometer sensors structural coordinate system.

The aim of the investigation is to verify the measurement data correctness of the Earth's magnetic field induction vector components by onboard equipment of the AIST small spacecraft flight model. To achieve the aim, a number of statistical tests are performed on the data correspondence of two different magnetometer sensors.

When analyzing the data measurement of magnetic field on the AIST small spacecraft technological model, the authors of [6] noted the differences in the measurement channel X1 of the first magnetometer sensor from the other measuring channels. In the AIST small spacecraft flight model such features were not revealed.

The measuring channels conformity of two different magnetometers for all sessions was checked. It confirmed the orientation of the construction line of the sensors according to the AIST small spacecraft layout diagram (Fig. 4).

To analyze the measurement data, 8 sessions were selected. At the analysis first stage the main numerical characteristics of the measurement data were determined. As an example, these characteristics for 27 April 2013 are given in Table I.

TABLE I. THE BASIC STATISTICAL CHARACTERISTICS OF THE MEASUREMENT DATA SOURCE

Parameter, dimension	[X_1]	[Y_2]	[Y_1]	[X_2]	[Z_1]	[Z_2]
Mean value, μT	-4.892	0.079	-1.566	-0.155	1.388	-6.187
Sample variance, μT^2	278.051	368.245	406.700	386.992	382.673	412.102
Maximum value, μT	28.381	35.840	49.626	49.909	44.305	41.140
Minimum value, μT	-46.787	-48.094	-49.924	-47.639	-44.209	-51.548
Left confidence limit, μT	-54.917	-57.490	-62.066	-59.172	-57.299	-54.714
Right confidence limit, μT	45.132	57.648	58.935	58.861	60.074	67.088
Number of outlier	5	3	5	4	1	4

At the analysis the second stage the following statistical hypotheses were tested.

1. The shift hypothesis of the corresponding measurement channels.

Because the value distribution law is unknown, a non-parametric Kenoua criterion was used. Its statistics has the form [7]:

$$|M| = \frac{|m_1 - m_2|}{\sqrt{s_1^2 + s_2^2}} \le u_{\frac{1+\alpha}{2}} \tag{1}$$

$$m = \frac{1}{6}\left(x_{\frac{1}{16}n} + x_{\frac{1}{4}n} + 2x_{\frac{1}{2}n} + x_{\frac{3}{4}n} + x_{\frac{15}{16}n} \right)$$

$$s = \frac{1}{4}\left(x_{\frac{1}{16}n} + \frac{3}{4}x_{\frac{1}{4}n} - \frac{3}{4}x_{\frac{3}{4}n} - x_{\frac{15}{16}n} \right); \tag{2}$$

where $u_{\frac{1+\alpha}{2}}$ is quantile of standard normal distribution; n is sample volume.

2. Hypothesis about the average sample values equality of the corresponding measurement channels.

Two criteria were used to test the hypothesis. The first criterion is the maximum-likelihood criterion. Its statistics has the form [7]:

$$z = \left(\bar{x}_1 - \bar{x}_2\right)\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)^{-0,5} \tag{3}$$

where $\bar{x}$ is average sample value, and σ is root-mean-square deviation.

The second criterion is the paired t-test [7]:

$$t = \frac{\bar{y}}{s_y}\sqrt{n}, \tag{4}$$

where $y_i = x_{1i} - x_{2i}$; $\bar{y}$ and s_y are the mean value and root-mean-square deviation value of y; n is sample volume.

3. Hypothesis about the sample variances equality of the corresponding measurement channels. For testing, the Fisher test was used. Its statistics has the form [7]:

$$F = \frac{\sigma_1^2}{\sigma_2^2}. \tag{5}$$

III. RESULTS

As a result of testing for all measurement sessions, the shift hypothesis was rejected at 1% significance level.

The hypothesis of equality of mean values was rejected at 1% significance level for the channels [X1] and [Y2], [Z1] and [-Z2]. For the channels [Y1] and [X2], the hypothesis on the equality of mean values was adopted at the 5% significance level using the maximum-likelihood criterion for the measurement data of 27 April, 29 April, 10 May and 20 May. For 16 May the hypothesis was adopted at the 1% significance level by the maximum-likelihood criterion. For 02 May, 07 May and 14 May the hypothesis was rejected at both significance levels. The hypothesis of equality of mean values was rejected by the paired t-test at 1% significance level for all relevant measurement channels.

The hypothesis of equality of sample variances for channels [X1] and [Y2] was adopted only for measurements of 02 May. For channels [Y1] and [X2], the hypothesis was adopted at the 5% significance level for all measurements except for 02 May. For the channels [Z1] and [-Z2], the hypothesis was adopted at the 5% significance level for the measurements of 27 April, 29 April, 14 May and 20 May, at 1% significance level for 10 May. For the measurements of 02 May, 07 May and 16 May, the hypothesis on the equality of sample variances was rejected at 1% significance level.

IV. DISCUSSION

When analyzing the data, the following feature was revealed. On 02 May and 07 May the microaccelerations compensatory mode was activated. For this purpose the magnets were used. They created a magnetic field that interacted with the Earth's magnetic field. The interaction result was a decrease in the rotation angular rate of the spacecraft around the center of mass [8]. At the same time, the observed values of the statistical criteria by which the hypotheses were tested, measurement sessions on 02 May and 07 May were significantly different from the values in other measurement sessions. The modulus values of the angular rate vector were calculated from:

$$\omega_{i+1} = \frac{\arccos\left[\left(B_{xi}\cdot B_{xi+1} + B_{yi}\cdot B_{yi+1} + .. + B_{zi}\cdot B_{zi+1}\right)/\left(\left|\vec{B}_i\right|\cdot\left|\vec{B}_{i+1}\right|\right)\right]}{t_{i+1}-t_i} \quad (6)$$

where n is measurements amount; $\vec{B}(B_x, B_y, B_z)$ is magnetic induction vector.

The results of the sensor No. 2 estimating of 27 April 2013 are shown in Fig. 5.

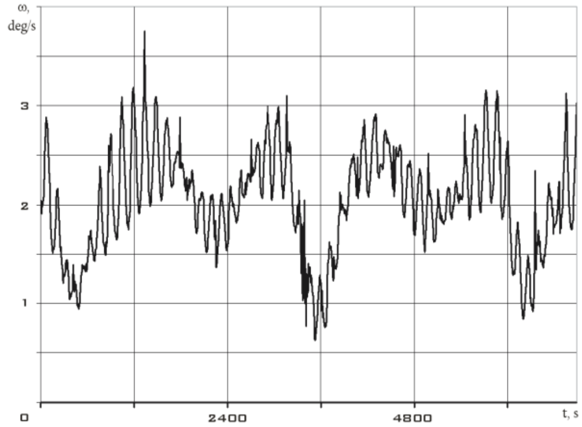


Figure 5. The modulus estimate of the spacecraft evolution angular rate vector around the mass center from magnetometer No. 2 measurements data.

V. CONCLUSIONS

Thus, the following conclusions can be made based on the analysis.

1. Statistic investigation in the paper confirms the correct operation of measuring equipment.
2. Significant shift in mean values was established between measurements of corresponding channels of various sensors of magnetometer. The same effect was observed in the analysis of measurement data on the technological model AIST spacecraft.
3. Operation of other devices and scientific equipment can significantly affect the measurement data.
4. Based on the measurement data of correctly operating magnetometer sensors, it is able to estimate the spacecraft rotation angular rate around the center of mass.

ACKNOWLEDGMENT

The research is done in accordance with the Agreement No. 14.578.21.0229 by 26 September 2017 between Ministry of education and science and Samara University (the unique identifier of the project RFMEFI57817X0229).

REFERENCES

[1] A. V. Sedelnikov and K. I. Potienko, “How to estimate microaccelerations for spacecraft with elliptical orbit,” *Microgravity Sciences and Technology*, vol. 28, no. 1, pp. 41–48, 2016.

[2] A. I. Belousov, A. V. Sedelnikov, and K. I. Potienko, “Study of effective application of electric jet engine as a mean to reduce microacceleration level,” *International Review of Aerospace Engineering*, vol. 8, no. 4, pp. 157–160, 2015.

[3] W. R. Hu, J. F. Zhao, M. Long, X. W. Zhang, Q. S. Liu, M. Y. Hou, Q. Kang, Y. R. Wang, S. H. Xu, W. J. Kong, H. Zhang, S. F. Wang, Y. Q. Sun, H. Y. Hang, Y. P. Huang, W. M. Cai, Y. Zhao, J. W. Dai, H. Q. Zheng, E. K. Duan and J. F. Wang, “Space program SJ-10 of microgravity research,” *Microgravity Sciences and Technology*, vol. 26, no. 3, pp. 159-169, 2014

[4] A. V. Sedelnikov, “Fractal assessment of microaccelerations at weak damping of natural oscillation in spacecraft elastic elements,” *Russian Aeronautics*, vol. 57, no. 2, pp. 111–117, 2007.

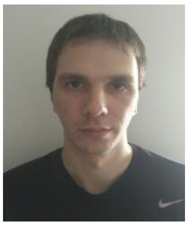
[5] V. I. Abrashkin, K. E. Voronov, A. V. Piyakov, et all., “Definition of rotary motion of the satellite AIST according to onboard measurements of the Earth’s magnetic field,” *Preprint of Keldysh Institute of Applied Mathematics Russian Academy of Sciences*, vol. 17, no. 2, 38 p., 2014.A. V. Sedelnikov. (2018). Rapid analysis of onboard measurements of earth magnetic field for the purpose of estimation of microaccelerations inside the inner environment of AIST small spacecraft during its uncontrolled orbital flight. *International Rewiev of Aerospace Engineering* [Online]. 11(2). Available: https://www.praiseworthyprize.org/jsm/index.php?journal=ireas e&page=article&op=view&path%5B%5D=21268

[6] A. Kobzar, *Applied Mathematical Statistics* Moscow, Russia: Publishing House PHIZMATLIT, 2006, 816 p.

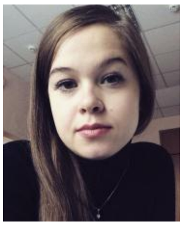
[7] V. I. Abrashkin, K. E. Voronov, A. V. Piyakov, et all., “Uncontrolled rotational motion of the Aist small spacecraft prototype,” *Cosmic Research*, vol. 55, no. 2, pp. 128–141, 2017.

[8] A. V. Sedelnikov, “Fast analysis of onboard measurements of the earth magnetic field for the purpose of microaccelerations decrement on board of the “AIST” small spacecraft during its uncontrolled orbital flight,” *International Review of Aerospace Engineering*, vol. 11, no. 2, pp. 76–83, 2018.

Andry V. Sedelnikov holds PhD in Control and Tests of Spacecraft from Department of Space Engineering in Samara University. Area of specialization includes modeling of a field of microaccelerations of the spacecraft internal environment. Dr. Sedelnikov is a member of an editorial board American Journal of Aerospace Engineering.



Ekaterina S. Khnyryova is Postgraduate Student and Assistant Lecturer in the Further Mathematics Department at Institute of IT, Mathematics and Electronics in Samara University. Her research interests are in the area of measurement data processing.



Alexander S. Filippov graduated from Samara University in 2012. He is a Leading Engineer designer in Joint Stock Company "Rocket and Space Center" Progress" and also Postgraduate Student at Samara University. His area of research is control and testing of spacecraft systems.

Tatyana A. Ivashova is student at Samara University, who studies electronics and nanoelectronics. Her research interests are in the field of data obtained from the small spacecraft AIST. In particular, her research is concerned with the processing of these data.