УДК 629.783
Doi: 10.31772/2712-8970-2023-24-3-558-568

Для цитирования: Оценка основных параметров телеметрии ReshUCube-1 за период 10 месяцев на орбите / О. Е. Шимова, Д. М. Зуев, Д. Д. Великанов и др. // Сибирский аэрокосмический журнал. 2023. Т. 24, № 3. С. 558–568. Doi: 10.31772/2712-8970-2023-24-3-558-568.

For citation: Shimova O. E., Zuev D. M., Velikanov D. D. et al. [Evaluation of the main parameters of ReshUCube-1 telemetry over a period of 10 months in orbit]. *Siberian Aerospace Journal.* 2023, Vol. 24, No. 3, P. 558–568. Doi: 10.31772/2712-8970-2023-24-3-558-568.

Оценка основных параметров телеметрии ReshUCube-1 за период 10 месяцев на орбите

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С увеличением количества запускаемых космических аппаратов набирает популярность такое направление, как автоматизация процессов управления космическими аппаратами. Одним из важнейших процессов является анализ телеметрических данных при эксплуатации космического аппарата. Научно-образовательный спутник Сибирского государственного университета науки и технологий имени академика М. Ф. Решетнёва ReshUCube-1 успешно эксплуатируется на орбите и выполняет свои научные задачи уже более полугода. В статье рассмотрен перечень основных параметров, анализируемых операторами Центра управления полётами для оценки состояния спутника ReshUCube-1. Описан состав и основные функциональные характеристики оборудования на космическом аппарате. Приведены качественные показатели и количественные пределы для всех описываемых параметров, а также их значимость и влияние на функционирование устройств и всего космического аппарата в целом.

Ключевые слова: ReshUCube-1, Cubesat, спутник, телеметрия, эксплуатация.

Evaluation of the main parameters of ReshUCube-1 telemetry over a period of 10 months in orbit

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With the increase in the number of launched spacecraft, such a direction as automation of spacecraft control processes is gaining popularity. One of these most important processes is the analysis of telemetry data during the operation of a spacecraft. Scientific and educational satellite of the Reshetnev Siberian State University of Science and Technology has been successfully exploitated in orbit and has been performing its scientific tasks for more than six months. The article considers a list of the main parameters analyzed by the operators of the Mission Control Center to assess the state of the ReshUCube-1 satellite. The composition and main functional characteristics of the equipment on the spacecraft are described. Qualitative indicators and quantitative limits for all described parameters are given, as well as their significance and impact on the functioning of devices and the entire spacecraft as a whole.

Keywords: ReshUCube-1, CubeSat, satellite, telemetry, exploitation.

Introduction

With the development of technology, there is a tendency to reduce the size of launched spacecraft. CubeSat nanosatellites [1; 2] are well established in the space segment market. They have many advantages, but mainly the following can be pointed out:

– development time is reduced by times;
– lower cost of a satellite vehicle itself;
– lower cost of launching due to relatively small mass.

From the numerous advantages of launching CubeSat satellites, there is a noticeable increase in the total number of launched spacecraft of this type [3-5]. Therefore there appeared a new direction for research and development in this field - automation of spacecraft control processes [6]. For example, the Reshetnev Siberian State University of Science and Technology plans to control 6 spacecraft by 2024. At the moment the university is working with three space missions:

– ReshUCube-1 satellite at the stage of operation in orbit;
– ReshUCube-2 satellite will be launched on June 26, 2023;
– ReshUCube-3 satellite constellation is planned to be launched in 2024.

The first space mission of the university CubeSat

On April 9, 2022, the ReshUCube-1 scientific and educational satellite was launched into orbit [7; 8]. The spacecraft belongs to the class of nanosatellite cubesats of 3U type format (Fig. 1), has overall dimensions of 10×10×34 cm and mass of 3.397 kg. The goal of the ReshUCube project is to involve schoolchildren in space and research activities as part of the "Planet Duty Officer" program supported by the the Innovation Assistance Fund [9-11]. Additional scientific objectives include:

– Gaining university flight experience in spacecraft control;
– testing of promising domestic element base;
– study of near-Earth space and the Earth's surface.

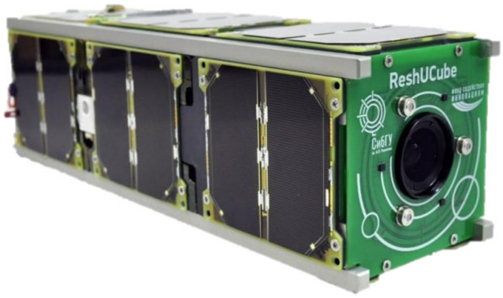

Рис. 1. Фото спутника ReshUCube-1

Fig. 1. Photo of the ReshUCube-1 satellite

Functional composition

Conventionally, a satellite can be divided into two components: the platform and the payload. The payload part includes all those devices that determine the function of the spacecraft and the purpose of its operation. In particular, the ReshUCube-1 satellite was launched to involve schoolchildren in space and science activities. For this purpose, employees of the laboratory "Small spacecraft" of the Reshetnev Siberian State University of Science and Technology decided to develop a payload "Reconfigurable laboratory" [12]. Within the concept of a reconfigurable laboratory, the spacecraft carries a set of different equipment and sensors, using which it is possible to perform various experiments on the following topics:

– technological experiments;
– radiation monitoring;
– study of the Earth's atmosphere and magnetosphere;
– study of orbital motion of spacecraft;
– observation of the Earth's surface.

The ability to load new payload software during the flight allows reconfiguration of the laboratory operation.

A spacecraft platform is a set of all major devices required for successful operation of the spacecraft in orbit. For the ReshUCube-1 satellite, the OrbiCraft-Pro 3U platform of the "Profi" modification (SXC3-GA-ADC) was purchased from Sputnix LLC [13]. All devices of the platform can be divided into subsystems depending on the functions performed:

1. Power Supply System (PSS). This part includes the power supply system board, battery pack of 4 power sources, and solar panels. The main function of this system is to provide power to all devices on board. In addition, the unit performs the task of performing survivability algorithms: current control, hang-up protection, battery recharging, device shutdowns.
2. Radio communication system. This system includes a very high frequency (VHF) antenna and the transceiver unit itself. In addition to the primary function of providing communication between the satellite and the ground control station, the transceiver has a permanent non-volatile memory for storing user command schedules. Thus, it is possible to control the satellite even out of radio visibility.
3. On-Board Control System (OCS). This system includes a motherboard with various devices from other systems and an on-board computing module that acts as a switch for sensors and motherboard configuration.
4. Orientation and Stabilization System (OSS). This system includes many devices: the OSS microcontroller, the flywheel assembly, a set of solar sensors, magnetic coils, an angular velocity sensor, and magnetometers. Obviously, the system is needed for establishing the desired orientation of the spacecraft, damping the angular velocity, as well as determining the spacecraft's own orientation.

Beacon

The science program requires maintaining the viability of the satellite. For this purpose, the operators of the mission control center first of all need to evaluate the service telemetry data received from the satellite [14]. By promptly analyzing the state of the spacecraft, the operator can timely take the necessary actions in case of abnormal situations and prevent their occurrence in advance. The main source of information is a message, called "beacon", which is periodically sent out every 30 seconds. This data packet contains all basic telemetry on the status of the power system and the radio communication system:

– temperature value of the battery, VHF transmitter and amplifier;
– battery charge;
– values of currents and voltages from solar panels;
– values of the restart counter;
– angular velocity values;
– values of currents and status flags of power supply channels;
– flags of critical battery states;
– on-board time.

All telemetry received from the satellite is stored in a special database. If it is necessary to analyze information on the spacecraft status, it is possible to upload data from the very beginning of the operation period, as well as for convenience to make selections, sorting by packages and time periods.

Temperature

One of the problems of spacecraft design and operation is heat transfer.

Therefore, the temperature of devices on board is the first important parameter to pay attention to when working with a spacecraft. There are 16 regular temperature sensors on the satellite platform to monitor the thermal behavior of various devices. The most important is the battery module, as lithium-ion batteries have their own operating temperature limits: from -20 to +50 °C. ReshUCube-1 has its own operating mode on board [15; 16]. Fig. 2 shows the temperature graph of the battery module for April 2023. As can be seen from the graph, the temperature of the battery module varied from -7 to +15 °C. The average value of the battery module temperature is approximately +3 °C, which is comfortable conditions for the operation of lithium-ion batteries.

Fig. 3 shows the temperature graph of the transceiver and the VHF amplifier. Three patterns can be found on the graph.

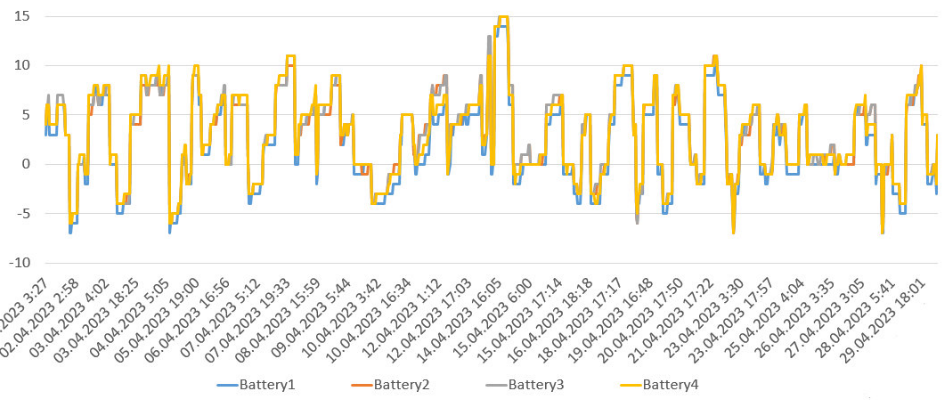

Рис. 2. График температуры модуля АКБ

Fig. 2. Battery module temperature graph

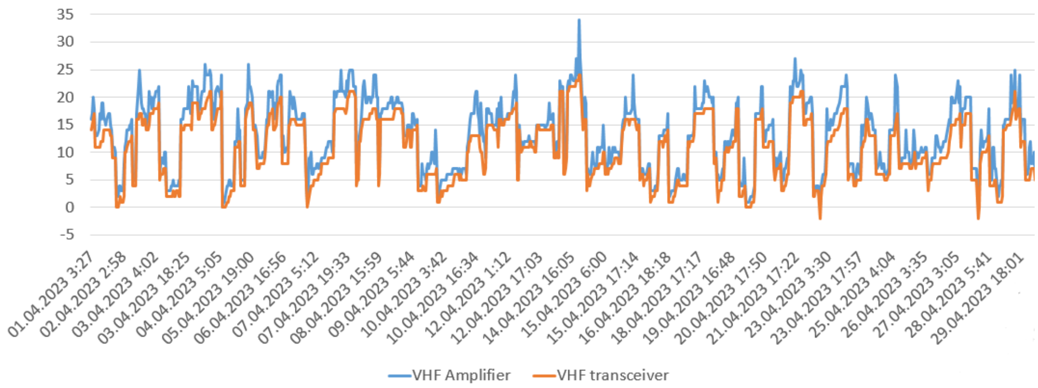

Рис. 3. График температуры трансивера и усилителя УКВ

Fig. 3. Temperature graph of the transceiver and the VHF amplifier

1. The temperature values of these devices fluctuate greatly, but almost never drop to values below zero (except for a few isolated cases of dropping to -2°): from 0 to +34°C for the amplifier and from -2 to +24°C for the transceiver itself. Constantly positive values can be explained by the fact that the devices of the radio subsystem operate constantly, even outside the radio visibility area, and therefore, they are constantly heated.

2. The amplifier temperature follows the same pattern as the transceiver temperature, but the values are always slightly higher. This is due to the way the devices work: the amplifier warms up more when it is in constant operation.

3. If we consider the temperature changes within each session separately, we can notice that the temperature of the radio communication system devices is constantly increasing during the session. This can be explained by the fact that during a session with the satellite the packet exchange is much more intensive, while during the rest of the time the satellite only sends out beacons once every 30 min and listens to the air.

Battery charge

The next important parameter, which control will prevent many problems during operation, is the battery charge. Self-rescue mechanisms are built into the satellite platform by the manufacturer from the very beginning. Table 1 describes the voltage limit values and corresponding actions of automatic charge level control. Despite the fact that the satellite has a discharge protection system, it is undesirable to allow such situations, as they reduce the life of the battery.

Table 1

Limit values of battery voltages

Battery charge level	Battery voltage limit values, mV	Procedure
Normal	6700	Normal operating mode
Minimal	6200	Disabling the battery heaters
Critical	5700	Disabling all power supply channels of devices (except VHF)
Dangerous	5200	VHF muting

Fig. 4 shows the graph of battery voltage variation for April 2023.The values range from 7668 to 7972 mV and the average value is 7881 mV, all these values indicate normal operation. This demonstrates that the PSS is designed well, so that even with the active use of the OSS and other energy consuming elements, the battery charge does not fall below the normal value.

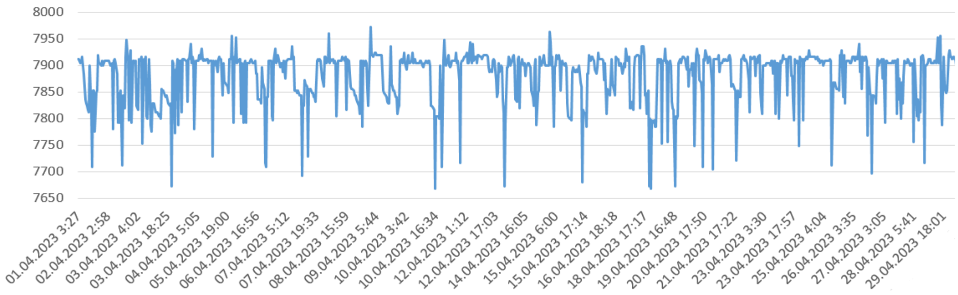

Рис. 4. График величины напряжения АКБ за апрель 2023 г.

Fig. 4. Graph of the battery voltage for April 2023

It should be noted that for convenience of the operator and to save time, special fields of the so-called flags type are provided. If the spacecraft hardware has detected critical changes, a "flag is raised" (checkboxes are checked). An example is shown in Fig. 5.

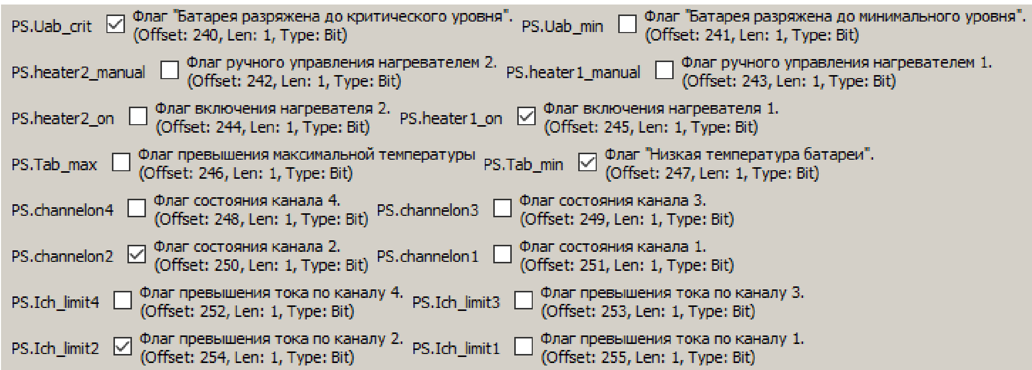

Рис. 5. Примеры флагов в маяке

Fig. 5. Examples of flags in the beacon

Energy from solar panels

Solar panel currents also play an important role in evaluating telemetry information and analyzing the energy balance of the spacecraft. As can be seen from the graph for April 2023 shown in Fig. 6, the values of the solar panel channel currents change greatly and rapidly. The current of channel 1 (Z– side of the spacecraft) is labeled as СП1 current, the current of channel 2 (Y+ and Y– sides) is labeled as СП2, and the current of channel 3 (X+ and X– sides) is labeled as СП3. This is due to rapid changes in the position of the apparatus, in particular, rotation around its axes. The arrangement of the planes (sides) of the spacecraft is shown in Fig. 7.

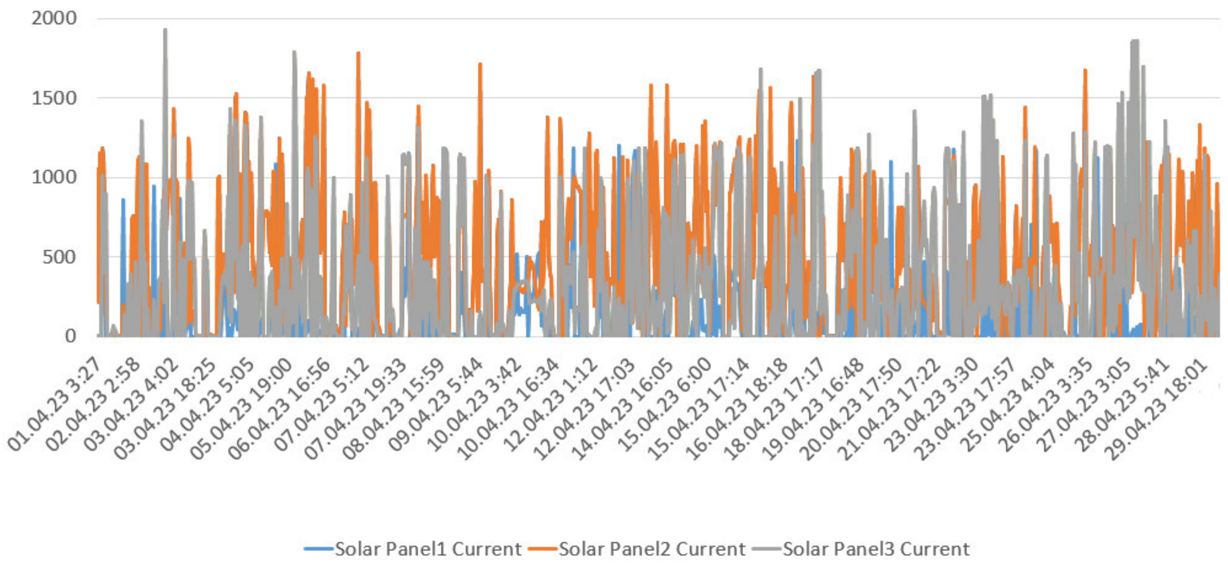

Рис. 6. График токов солнечных панелей за апрель 2023 г.

Fig. 6. Graph of solar panel currents for April 2023

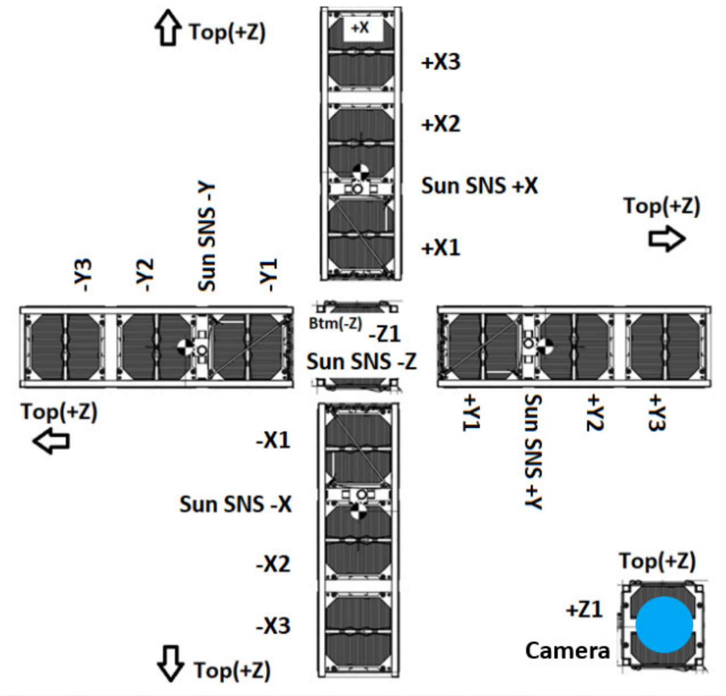

Рис. 7. Расположение плоскостей на КА

Fig. 7. Location of planes on the satellite

One more regularity can be noticed by analyzing a more detailed graph for several days, where one can see the changes of currents during several nearest sessions (Fig. 8). The graph clearly shows periods with zero (or almost zero) values, which means that the satellite was in the shadow zone relative to the position of the Earth and the Sun.

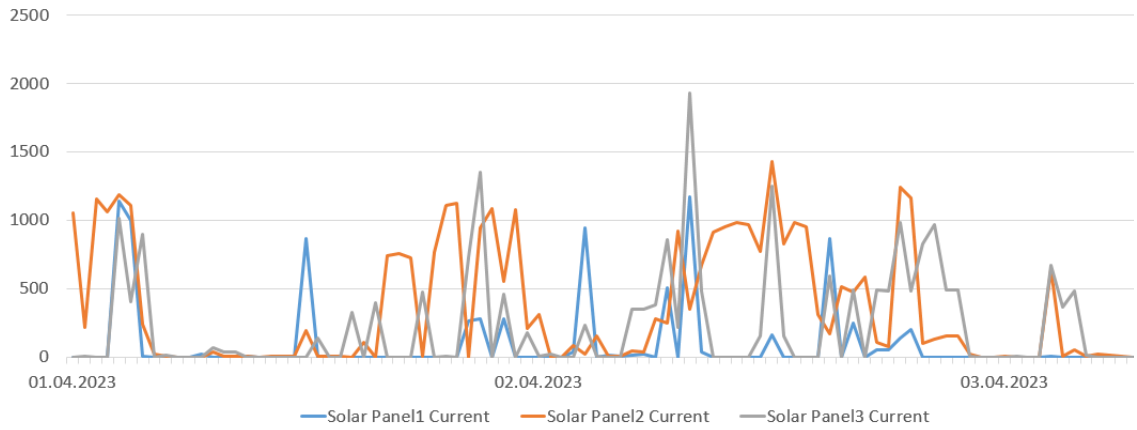

Рис. 8. График токов солнечных панелей за 1–3 апреля 2023 г.

Fig. 8. Graph of solar panel currents for April 1–3, 2023

By analyzing telemetry data on solar panel currents, it is possible to assess their degradation level and subsequently adjust the satellite's energy balance.

Angular velocities and stabilization

Another indispensable parameter in analyzing the spacecraft operation are the values of angular velocities of the satellite. These parameters can change for the worse (increase), which can adversely affect the quality of communication in the "space - Earth" channel, since the position of the antenna pattern will constantly change. Fig. 9 shows the graph of angular velocity changes from May 10 to May 14. During this period, no work was carried out with the orientation and stabilization system: the angular velocities were not damped, the orientation was not set using the flywheel block. The graph shows that even within one day the angular velocities rapidly change not only the modulus of the value, but also the sign, which means that the direction of twisting changes. It can also be seen that the modules of the angular velocity values fluctuate within the range of up to 8°, which is normal. Without the influence of external factors, the ReshUCube-1 satellite has no tendency to twist. The location of the spacecraft axes is shown in Fig. 10.

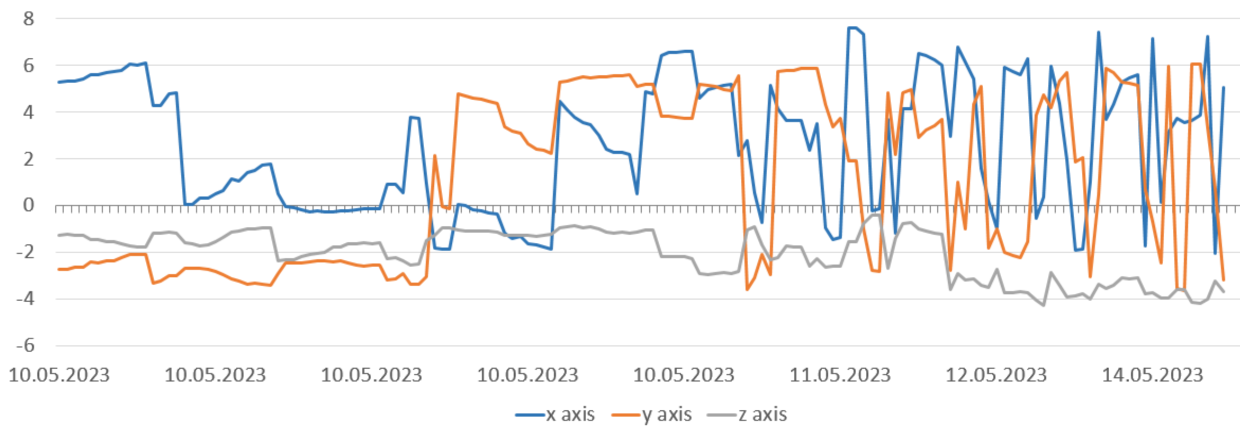

Рис. 9. График значений угловых скоростей за 10–14 мая 2023 г.

Fig. 9. Graph of angular velocity values for May 10–14, 2023

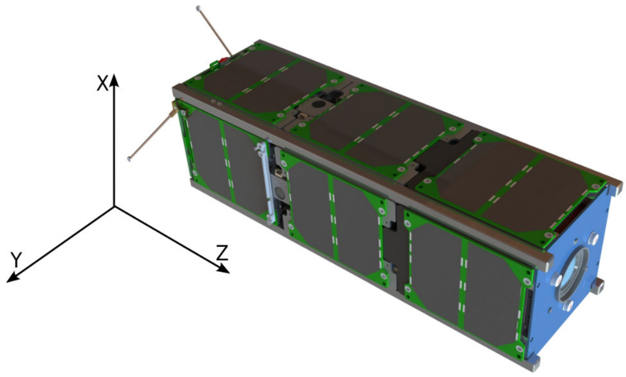

Рис. 10. Расположение осей КА

Fig. 10. Location of the satellite axes

For damping of angular velocities, the spacecraft is equipped with the B-DOT angular velocity damping algorithm. The damping is performed using magnetic coils, since, unlike damping using flywheel motors, this method reduces the angular momentum of the spacecraft impulse itself, rather than using the temporary counteracting momentum of the impulse.

Angular velocities need to be damped at values greater than 7°/s. The reduction rate with magnetic coils is approximately 1°/min according to flight data.

In general, satellite stabilization is disturbed under the influence of various forces: aerodynamic, gravitational, magnetic, and radiation. Earlier it was said that the spacecraft has no tendency to twist. During flight operation it was revealed that in most cases the stabilization of ReshUCube-1 is disturbed when the torque of the flywheel engine block affects the orientation. One of the reasons for this is the fact that with prolonged orientation control the flywheels go into saturation mode (their velocities are not sufficient to compensate for the angular momentum of the spacecraft). In this case, it is necessary to include an additional orientation system to relieve the flywheels, in particular, magnetic coils.

The second reason for the loss of stabilization is that, when the power supply to the flywheel motor unit is cut off, the flywheels themselves continue to spin uncontrollably for some time, spinning the spacecraft. To avoid such situations, commands for damping of angular velocities should be included in the flight cyclogram after orientation cycles.

On-Board Time and TLE

On-board time and TLE data are among the most important functional parameters. Due to some relativistic effects of the theory of relativity, the time on the spacecraft is constantly lagging behind, which causes an error to accumulate (about 1 s per day). It is important to constantly monitor this value and periodically synchronize it with the time at the ground station. Also one of the routine operations with the spacecraft is updating of TLE data describing the spacecraft motion. The satellite, using the onboard time scale and TLE data together, can independently determine its location. But orbital parameters are gradually changing, so the TLE data become irrelevant. It is believed that to accurately determine the location of the satellite it is necessary to update the orbital parameters at least once every 5 days. In this case, the satellite pointing error will be more than 6 km. For some tasks that do not require high accuracy in time, for example, scheduling of communication sessions to plan the time of work of operators, the shelf life of TLE data is 14 days, then the error will be 460 km, such a distance the satellite travels in one minute.

Conclusion

On the basis of flight experience of ReshUCube-1 spacecraft operation, a list of telemetry parameters necessary to assess the state of the satellite and its subsystems has been defined. The given qualitative and quantitative characteristics allow to efficiently build the process of telemetry evaluation by the operators of the Mission Control Center. It becomes possible to shift some responsibilities from operators to machines, in particular, monitoring of vital telemetry parameters. Therefore, the first step on the way to automation of spacecraft operation processes is the definition of boundary indicators. Automation of operation processes will make it possible to increase the number of satellites in operation without losing the quality of work.

Благодарности

Работа выполнена при поддержке Фонда содействия инновациям в рамках программы «Дежурный по планете» (Space Pi) 6-й очереди. Проект «Космическая миссия ReshUCube», договор № 71С2/МОЛ/71271 от 29.11.2021.

Acknowledgment

The work was carried out with the support of the Innovation Assistance Fund within the framework of the “Planet Duty Officer” (Space Pi) program of the 6th stage. The project “ReshUCube Space Mission”, Contract No. 71C2/MOL/71271 dated 11.29.2021.

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