

Analysis of the requirements for microaccelerations and the design appearance of a small spacecraft for technological purposes

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Abstract. The article analyzes the possibility of implementing gravity-sensitive technological processes on board a small technological spacecraft. The requirements for microaccelerations imposed by the physical features of the flow of gravitation-sensitive processes are presented. The advantages and disadvantages of using small spacecraft for space technologies are analyzed. The design image of a small spacecraft for technological purposes is presented. Keywords: small spacecraft for technological purposes; microaccelerations; gravity sensitive processes.

1 Introduction

Carrying out gravity-sensitive processes on board of small spacecraft provides a number of undeniable advantages. Many researchers [1-5] note a significant reduction in the cost and timing of space projects when using a small spacecraft. This makes conducting space experiments widely accessible and allows for full-scale research programs with the possibility prompt response to new data that opens up in the course of research. An important advantage of using a small spacecraft for carrying out technological processes is the possibility of creating on it specifically for the implementation of a specific process with maximum consideration of all its features. This possibility cannot be realized with the help of spacecraft of other classes due to their multitasking. Similar conclusions can be found in the works. The idea of using a base station for the reusable implementation of gravity-sensitive processes, which was proposed and patented at the beginning of this century, will undoubtedly enhance the advantages of a small spacecraft in the field of space technology. On the one side, the problem of delivering results to Earth will be solved in the absence of the possibility of using a descent capsule on a small spacecraft due to its small weight and size parameters. On the other hand, expensive and sometimes unique technological equipment can be reused and even, if necessary, improved during the maintenance of a small spacecraft at the base station.

However, in addition to the undoubted advantages of using a small spacecraft, there are also serious problems, without solving which the effective use of a small spacecraft in the

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field of implementing gravitational-sensitive processes is impossible. One of these problems is to meet the requirements for microaccelerations on board a small spacecraft. The present work will be devoted to the analysis of this problem.

2 **Analysis of micro-acceleration requirements**

Requirements for microaccelerations for the successful implementation of gravity-sensitive processes are becoming more stringent as new processes are developed. For example, we can cite the requirements for some specific processes (Table 1. [6, 7]) and graphs of the desired and achievable values of microaccelerations (Figures 1-3), which are available in the literature [8-18].

Table 1. Required and achievable levels of microaccelerations

Process	Required level of microaccelerations, $\mu\text{m/s}^2$	spacecraft	Launch date	Achievable level of microacceleration s, $\mu\text{m/s}^2$
Obtaining ultrapure germanium	100–1000	skylab	1974	$10^3\text{--}10^5$
Growing single crystals	10–500	MIR	1986	$10^3\text{--}10^4$
Getting foam metal	10–500	ISS Columbus	1998	$10^2\text{--}10^3$
High resolution photography	10–100	NIKA-T	project	10–20
Growing protein structures	10–500	Tiangong-1	2011	$10^2\text{--}10^3$
Creation of drugs and medicines	10–100	Bion-M №1 Foton-M №4 SJ-10	2013 2014 2016	100–500
Directional crystallization	0.1–1	Microgravity platform MAIS: Tiangong-2 Tiangong OKA-T Vozvrat-MKA	2016 2021 project project	1–10
Fluid Physics Experiments	0.01–0.1	Microgravity platform on OKA-T	project	0.1–1 (in the protected area of the platform)

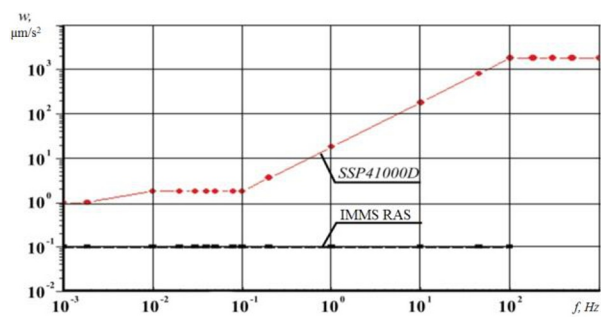


Fig. 1. Requirements for micro-accelerations: upper curve is document SSP41000D [11] on carrying out gravity-sensitive experiments and processes on the ISS; the lower curve is the requirements of IMMS im. Baikov RAS (quoted from [8])

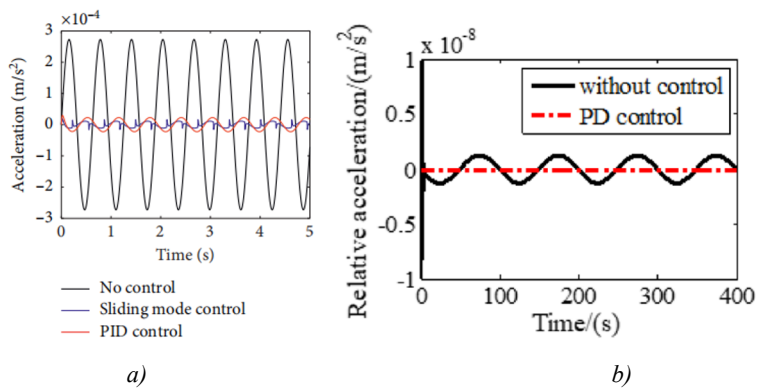
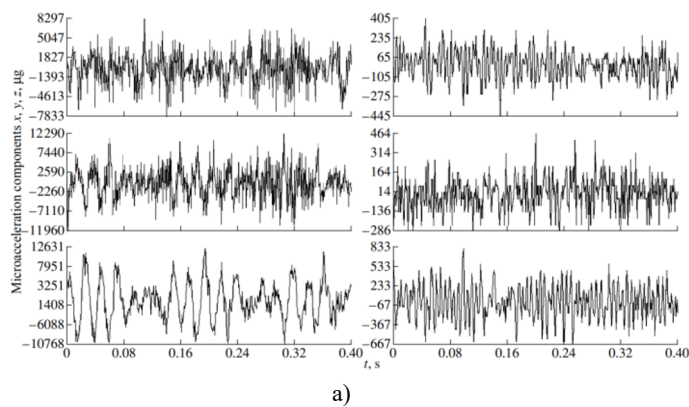


Fig. 2. Level of microaccelerations (model): a) on the Noncontact 6-DOF Lorentz Platform (cited in [12]); b) on the Maglev Vibration Isolation System platform (cited from [9])



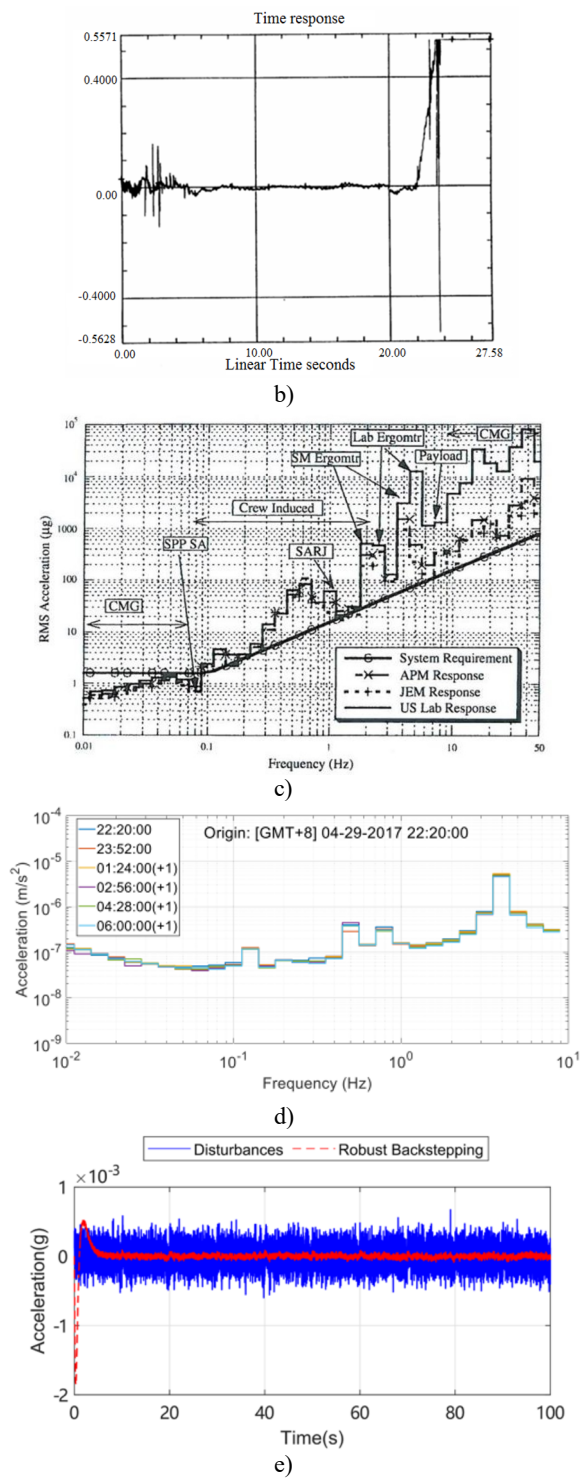


Fig. 3 Level of microaccelerations (experiment): a) VZP-1K on the MIR space station (VM-09 accelerometers on the space station body (left) and inside the VZP-1K protected area (right) [13]; b)

MGIM on the MIR space station [14]; c) at ISS [15]; d) MAIS on Tiangong-2 [16]; e) MAIS on Tiangong [17]

Numerous studies (for example, [1, 3, 9, 13, 14, 19-22]) show that during directed crystallization, the field of microaccelerations of the internal environment of the spacecraft creates the motion of convective type. They contribute to the capture of non-metallic impurities in melts and the formation of several crystallization centers. As a result, the size of a single crystal can be significantly reduced. Experiments on directional crystallization were carried out in space, starting from long-term orbital stations of the Salut [11, 14, 23] and Skylab [14, 24, 25] series (Figure 4). Figure 5 shows the Krater-VM facility, which was used to grow a zinc oxide single crystal weighing about 130 g on the MIR space station in 1997. The entire single crystal growth process at the Krater-VM plant was designed for 130 hours of continuous operation and allowed growing single crystals with a diameter of up to 50 mm.

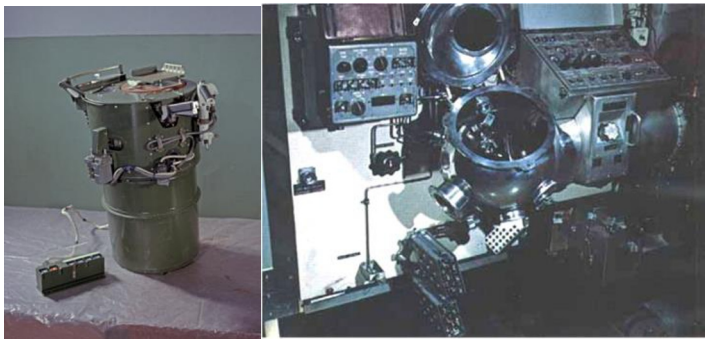


Fig. 4 Equipment for space technology experiments: a) Installation "Vulkan"("Souz-6", 1969); b) Growth installation ("Skylab", 1973)



Fig. 5 Furnace "Krater-VM" for growing single crystals *crucibleless zone melting method*

The influence of microaccelerations on the intensity of convective type movements allowed Russian scientists to conduct research and create a convection sensor DACON [26, 27], which was used to evaluate microaccelerations on the MIR space station (Figure 6).

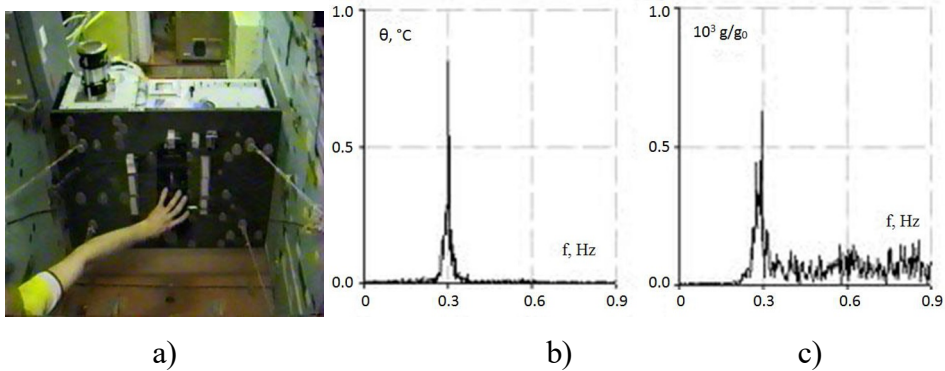


Fig. 6 DACON convection sensor: a) the appearance of the sensor; b) evaluation of microaccelerations using DACON; c) evaluation of microaccelerations using Alice-2 (quoted from [26])

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Currently, additive 3D printing technologies are actively developing. They penetrate deeper and deeper into the aerospace industry, becoming practically indispensable [19, 21, 28]. Indeed, when repairing equipment in orbit, when the delivery of components is very difficult, additive technologies can bring significant benefits in the manufacture of the necessary parts directly on board long-term orbital stations. Figure 7 shows the first test piece made by cosmonaut S.V. Prokofiev on November 28, 2022 on a Russian 3D printer at ISS.



Fig. 7 Test print using a 3D printer on ISS

However, 3D printing in the field of microaccelerations makes adjustments to the implementation of additive technologies in space [19, 21]. Therefore, 3D printing experiments are currently being carried out at the International Space Station. A number of specialists (for example, [19, 21]) note that in the future it will be possible to 3D print large structures in space. Therefore, it is necessary to create conditions for efficient 3D printing, taking into account the requirements for microaccelerations.

Thus, at present, most of the gravity-sensitive processes are performed on specialized laboratory modules of long-term orbital stations (International Space Station and Tiangong). Some of the experiments are carried out on specialized space vehicles (Foton, last launched in 2014; Bion, last launched in 2013, planned for 2025; SJ-10, launched in

2016; TZ-1, launched in 2016). There are no implemented projects of a small spacecraft for technological purposes at the time of writing the dissertation work (the author did not find any materials in the open press). An analysis of the requirements for microaccelerations shows the need to improve the methods and means of creating favorable conditions for the implementation of gravitation-sensitive processes in space in order to successfully develop space technologies.

3 Analysis of the design appearance of a small technological spacecraft

A small spacecraft for technological purposes must meet a number of requirements, the most important of which are the requirements for micro-accelerations, power-to-weight ratio and the layout of the target equipment.

Requirements for microaccelerations were discussed in the previous section. From the point of view of the formation of the design image of a small spacecraft for technological purposes, these requirements are transformed into the need to place a microgravity platform in the internal environment of a small spacecraft with the installation of target equipment on this platform and to ensure effective control of this platform in order to fulfill the restrictions on microaccelerations imposed by the gravity-sensitive process being implemented. . In this work, it is assumed that a single process is performed on a small technological spacecraft. This means that a small technological spacecraft was specially designed for a well-defined gravitational-sensitive process, taking into account the specifics of its implementation and the only target task of a small technological spacecraft is to perform this process.

As a rule, gravity-sensitive processes are energy intensive [2, 4, 8, 14, 15, 28-30]. This, for example, led to the fact that the design and layout diagrams of technological spacecraft of the Foton series for the first spacecraft of the series were devoid of solar panels and used only battery power [3, 5, 31, 32]. However, later upgraded structural layout schemes ("Foton-M" No. 4) included solar panels [5, 31, 33] (Figure 8) in view of the need to increase the power consumption of the target and supporting equipment of the spacecraft.

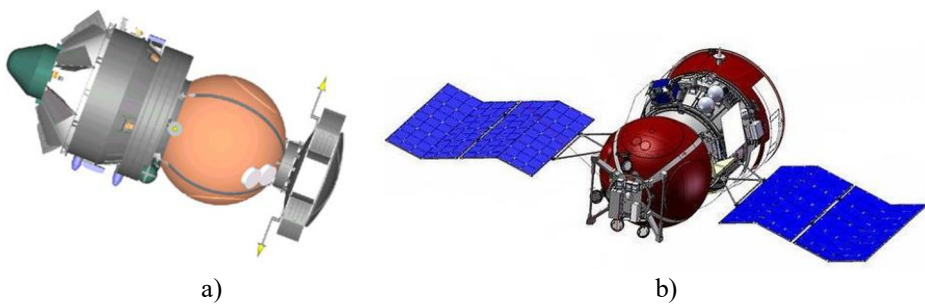


Fig. 8 General view of technological spacecraft: a) "Foton-M" No. 3; b) "Foton-M" No. 4

Despite the fact that a single process is performed on a small technological spacecraft, it is necessary that its structural layout contains solar panels. Only in this way it is possible to achieve the generation of the required amount of electricity for the normal operation of the target and supporting equipment of a small spacecraft for technological purposes. For example, the technological equipment "Growth Installation" [28, 34] has a power consumption in the normal mode of about 165 W and a maximum of 235 W. While the flight and prototype small spacecraft "Aist" (Figure 9 a) without solar panels can provide

only 15 W [35]. Equipped with solar panels, the small spacecraft Aist-2D (Figure 9 b) generates more than 285 W [36].

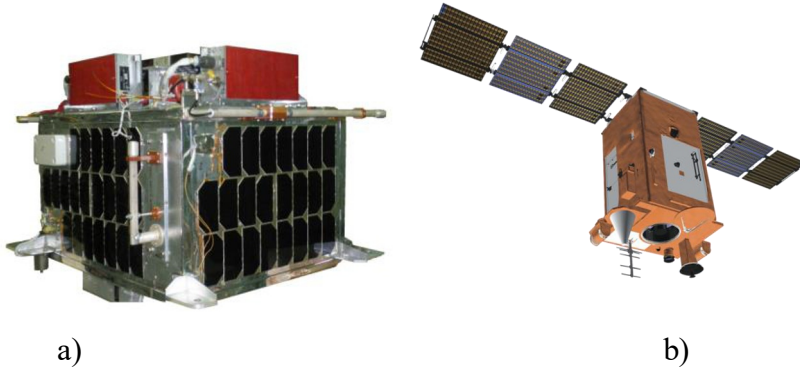


Fig. 9 General view of a small spacecraft: a) flight and prototypes of the small spacecraft "Aist" [35]; b) "Aist-2D" [36]

Thus, it can be stated that the requirements for the power-to-weight ratio determine the presence of large elastic elements in the form of solar panels in the design layout of the design of a small spacecraft for technological purposes.

The requirements for the layout of the target equipment, including the microgravity platform, require the maximum use of all possible design methods to reduce microaccelerations. These methods are described in [2, 5, 34, 37] and can be reduced to the following recommendations:

- optimal location of technological equipment inside a small spacecraft, for example, assuming its placement near the center of mass of a small spacecraft to reduce microaccelerations from rotational motion;
- minimization of the number and size of large elastic elements, taking into account the requirements for power-to-weight ratio, which implies a decrease in the overall influence of the relative movement of the elastic part of a small spacecraft relative to its body;
- optimization of the number and parameters of the executive bodies of the small spacecraft motion control system, involving the choice of its elements while simultaneously taking into account the requirements for the orientation of the small spacecraft and microaccelerations;
- the use of damping devices in the attachment points of solar panels to the body of a small spacecraft, which implies a decrease in the influence of their own oscillations on the field of microaccelerations of the internal environment of a small spacecraft.

4 Conclusion

An analysis of the design image of a small spacecraft for technological purposes makes it possible to construct a model of the apparatus, consisting of a central solid body with elastic elements rigidly attached to it.

5 Acknowledgments

The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation (theme No. FSSS-2023-0007).

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