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Experince in creating nanosatellites of the "cubesat" "PolyITAN" standard in Igor Sikorsky Kyiv Polytechnic Institute: mission, development and exploitation results

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Abstract. ***This article gives general information about the goals, requirements of missions and describe show these requirements are expressed in the development of nanosatellites (NS) of the PolyITAN series of CubeSat standard. The report also discusses the integration of electronics with the design and payload, provides information on the applied manufacturing methods and tests of NS of various modifications for performing tasks in orbit. The analysis of the results of flight tests of the NS (PolyITAN-1 and PolyITAN-2) and potential capabilities of the developed NS "PolyITAN-3" (assessment of the quality of shooting when sensing the Earth from an altitude of 400 ... 350 km) and "PolyITAN-4" (features of simulating the environment and plant growth under microgravity and cosmic radiation).***

Keywords: frame, honeycomb panel, Igor Sikorsky KPI, launch, nanosatellite (NS), nanosatellite testing, orientation, power budget, thermal vacuum tests.)

I. INTRODUCTION (HEADING 1)

Leading universities of the world are now actively encouraging students to create nano-satellites - small spacecraft, the so-called international standard "CubeSat" (U1 format (single unit) corresponds to a mass of about 1 kg and dimensions of 10×10×10 cm). In addition to solving purely educational purposes, such spacecraft in the future may be used in the implementation of a number of scientific, technical and social projects for different purposes. Standard "CubeSat" makes it possible to create miniature satellites weighing 1-10 kg in a short period of time (1-3 years) and with relatively small means. Such work is carried out in dozens of scientific centers around the world. The rapid development of the element base gives hope for the commercial application of these spacecraft. The establishment of such satellites allows the space research at relatively low financial cost and it is actual for Ukrainian conditions with its high potential in the field of designing and developing of space technology [1-4]. Ease of Use

II. DEVELOPMENT, MANUFACTURE AND LAUNCH OF POLYITAN NANOSATELLITES

A thorough analysis of many options for real and design studies of microsatellites has shown the possibilities of implementation and the feasibility of creating nanosatellites of the CubeSat format for various purposes in higher technical educational institutions. Such spacecraft, of course, have undergone and are undergoing structural changes in comparison with spacecraft produced in the conditions of real aerospace technologies by large corporations. The main distinguishing features of university nanosatellites of the CubeSat format are:

a) less stringent requirements for the payload and other onboard equipment;

b) the possibility of using experimental samples of equipment not certified for work in space;

c) support for radio communication with a CubeSat nano-satellite in radio amateur bands (for example, 144-435 MHz), which, in turn, does not require a special and expensive permit to operate these radio frequencies;

d) the use of commercial (non-specialized) hardware in the payload and spacecraft subsystems;

e) significantly lower financial costs for the production of nanosatellites;

f) the possibility of launching in the form of a passing cargo by agreement with the provider of launch services.

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Such spacecraft are most often used by universities either for testing their own experiments or for practical training of students in educational programs of special disciplines.

III. NANOSATELLITE POLYITAN-1

The PolyITAN-1 satellite was created by a group of young scientists and engineers of the thermal power and radio engineering faculties, the Faculty of Electronics, as well as the Institute of Telecommunication Systems NTUU "Igor Sikorsky Kyiv Polytechnic Institute" under the guidance Prof. Boris Rassamakin. The main goals of the PolyITAN-1 satellite launch were:

a) development of technological flight modes;
b) creation and research of solar sensors for small spacecraft;
c) checking the energy of the solar power sources developed at the university;
d) adaptation to space conditions and improvement for future flights of digital channels for transmitting information from the satellite to the Earth and commands to control it;
e) study of the influence of outer space on the operation of satellite electronic subsystems;
f) study of the functioning of GPS systems of the original design.

To track the flight of the spacecraft and carry out the planned research, the university has created a center with the necessary test equipment.

The first nanosatellite NTUU "Igor Sikorsky Kyiv Polytechnic Institute" - PolyITAN-1 - was launched on June 19, 2014 to work out technological flight modes and study the elements of the apparatus structure with the aim of their further improvement. It transmits telemetry signals to the university's flight control center (active as of 09/23/2021).

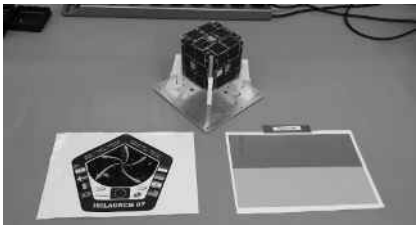

Figure 1. Flight model of the PolyITAN-1 nanosatellite

The results obtained during the flight are used, among other things, in the design of new structures of small satellites, the creation of which is stipulated by the agreements concluded by the NTUU "Igor Sikorsky Kyiv Polytechnic Institute" with other universities. This first launch was carried out through international cooperation NTUU "Igor Sikorsky Kyiv Polytechnic Institute" with Shenyang University (PRC). It should be noted that after the presentation of the nanosatellite model (Figure 1.) at the Institute. Karman (Belgium) Kiev polytechnics were invited to participate in the QB50 International Project, in which several dozen universities have already taken part.

The first nanosatellite NTUU "Igor Sikorsky Kyiv Polytechnic Institute"- PolyITAN-1 - was launched into orbit using the Dnepr launch vehicle, created as part of the conversion on the basis of RS-20 (15A18) ICBMs (NATO classification - SS-18 Satan) and produced on Dnepropetrovsk enterprise "Yuzhmash". The rocket was launched from the Yasny launch base (Orenburg region, Russia) on June 19, 2014 at 11:00 pm local time. In 16 minutes after the launch, all spacecraft successfully departed from the third stage and entered the specified orbits.

IV. MODEL OF "POLYITAN-2-SAU NANOSATELLITE"

At present, the PolyITAN-2-SAU launched into the near-Earth orbit is part of the scientific space network of the QB50 project intended for studying the thermosphere. The main task of the QB50 project is to study the Earth's climate change. The NS carries a payload on board an experimental sensor for analyzing the oncoming gas flow FIPEX, capable of distinguishing and measuring the characteristics of atomic and molecular oxygen, which is the main element at altitudes of 90-420 km from the earth's surface. This is important for the assessment of thermosphere models.

V. OBJECT OF STUDY

Structurally, NS "PolyITAN-2-SAU" is the successor of the previous model (NS "PolyITAN-1") designed at NTUU "KPI" and launched into Earth orbit in 2017 (finished mission in 2019 when was burned in the Earth's atmosphere). The results of the first run and participation in QB50 mission allowed significant changes in the NS design. Thus, "PolyITAN-2-SAU"is a 2U (2-Unit) format, with a payload, which is a thermosphere composition analyzer FIPEX. This is the main difference compared to the first model (PolyITAN-1 is a 1U), which is caused by a special range of tasks to be carried out of the NS.

The key to finding innovative solutions is the need to comply with the requirements of the NS QB50 project, under which the payload is ready to be installed on the projected satellite. Thus these are size, layout, set of subsystems, which should provide integration, and the ability to manage the already developed FIPEX (Figure 2).

Payload is FIPEX (Flux-Probe-Experiment) – parser of the thermosphere composition, developed at Dresden Technical University, which is able to distinguish and

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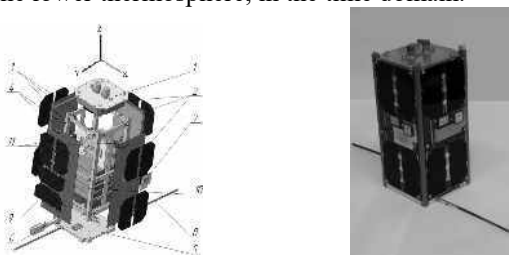
measure the behavior of atomic oxygen, as a key element in the lower thermosphere, in the time domain.



a) *b)*

Figure 2. Engineered (a) and real (b) view of "PolyITAN-2-SAU":
1 – payload (FIPEX); 2 – solar battery;3 – satellite case; 4 – honeycomb panel; 5 – aerial module; 6 – magnetometer with deployment mechanism;7 – GPS/GLONASS aerial; 8 – radio aerial; 9 – flywheel; 10 – electronic platform; 11 – Sun direction sensor.

VI. THERMAL VACUUM TESTING

Thermal vacuum testing, during which was simulated the effect of space factors on the NS and its parts, is one of the important stages in the development of "PolyITAN-2-SAU". Significant factors of space for the thermal vacuum test are: low temperature, vacuum, space blackness, Sunlight and reflected radiation from the Earth [5].

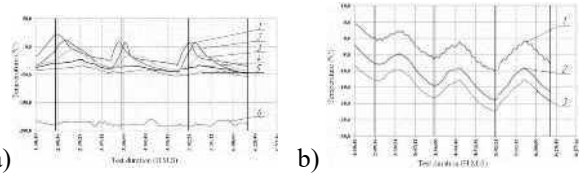
During its orbital motion, NS continuously falls under various influences – Sun radiation, Earth radiation etc., which significantly affect the thermal state and thermal mode of the NS systems, and thus the reliability and efficiency of the NS elements in flight.

At various intervals, the impact of these factors will vary: depending on the NS position in orbit and on the functioning conditions of its systems the carcasses surfaces will be exposed to variable heat flows of different intensity, which will determine the thermal state of subsystems and elements of NS, including its electronic equipment [5].

One of the main characteristics that determine the readiness of the NS PolyITAN-2-SAU to start is conformity of the temperature conditions of the electronic platform and equipment of the NS to their operating temperature range. Thus the result of thermal vacuum test should conclude that during the imitation of external and internal heat evolution, temperatures of NS elements do not exceed their permissible limits. Also during the test there was made the checkup of the functional ability of the satellite subsystems to perform their tasks at the orbit, and confirmation of the correct thermal regulation of NS systems. Also, tests are needed to fulfill international QB50 project requirements. This includes checking performance and capability to control the payload under the impact of space factors.

To carry out the necessary tests simulating thermal vacuum chamber TVC-0.12 [5] was used, which is the single set of tools and equipment that provides the necessary space conditions simulation. This camera is designed specifically for the NS research, elements of space technology and small-sized spacecraft. This camera is located in the NTUU "KPI".

As a result of the test, rotation of NS around the Earth was simulated and the temperature dependence of its components, on which temperature sensors were placed, was received. The Figure 3,a shows the temperature dependence of the inner sides of honeycombed structure which serves as frame, i.e. the temperature distribution on its planes.



a) b)

Figure 3, a. Distribution of temperatures on the inner sides of the NS honeycombs: 1 – side Z+; 2 – side Y–; 3 – side X–; 4 – side X+; 5 – side Y+; 6 – cryo shields.

Figure 3, b. Distribution of temperature on the electronics boards of NS: 1 – radio channel board; 2 – CPU board; 3 – FIPEX board.

Figure 3,b is a graph showing changes in temperature values on the control board of the payload, on the radio board and the CPU board. As can be seen from the chart, board temperature does not significantly dependent on external factors and changed slightly from the Sun to the shadow mode (2…3o). The maximum temperature is presented on radio board (+3…–10°), then the CPU board (–5…–20°) and the control board of payload (–10…–23°). Based on the data it can be stated that the electronic system of NS is within acceptable temperature limits.

Also worth noting the practical independence of temperature between the NS of orbital position, and fluctuations in the radio card, which can be observed in the course of the experiment — those are the results of the performance of this NS element. As a result, thermal vacuum tests:- studied the temperature distribution on the modules, assemblies and construction elements of the NS, electronic board surfaces, depending on the external radiant heat fluxes corresponding to movement of NS by the proposed orbit;- revealed the limits of temperature fluctuations of the NS elements caused by modeling of changes in its orbital position; - confirmed the performance of the NS equipment under conditions consistent with the orbital.

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According to test results, it can be concluded that the engineering model of the NS sustains thermal loads and can operate in space in normal mode.

VII. THE FEATURE OF THE "POLYITAN-3" MISSION

The mission of the project "PolyITAN-3"(for Earth sensing) is creation of 3U CubeSat nanosatellite by developing, modeling and researching effective service subsystems to provide a payload an optoelectronic scanner with a capability of shooting in the range of up to 30 m when operating in orbit at altitudes up to 700 km.

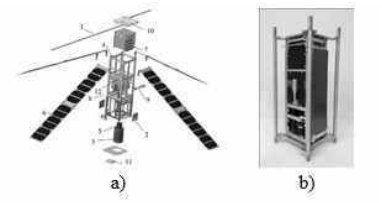

Figure 5. "PolyITAN-3"engineering model (a): 1 – antenna 144/435 MHz,2 – solar sensor,3 – camera lens,4 – frame,5 – camera,6 – solar panels,7 – electronic platform,8 – flywheel,9 – magnetometer,10 – antenna module,11 – high-speed antenna,12 – electromagnet board; and real photo (b).

"PolyITAN-3" (Figure 5) is 3U CubeSat satellite with camera for remote sensing. This feature is associated with new challenges in the thermal control system and the power supply of the satellite. Solar panels have the form of 4 wings, each wing consists of two modules of six elements. The modules are connected in the wing by the mechanism of opening and connected in series. In addition, a high-speed radio link module is used. It has the following properties: 5.7 GHz 800 kB, 2 W; and will be used for transfer of images to the earth station.

All previous work has been carried out, such as selection and development of equipment, electric and thermal calculations, etc. A thermal model of the nanosatellite was created, and a numerical calculation was also carried out in the ESATAN-TMS program. Now the satellite is being assembled, and scheduled to produce thermal-vacuum test.

VIII. THE FEATURE OF THE "POLYITAN-4-BIO" MISSION.

The feature of the PolyITAN-4-BIO mission is current impossibility to give a positive forecast for the stability of higher plants in the conditions of space flight during long flights; since almost all vegetable objects that have been grown on space platforms are annual plants with a short life cycle, and the duration of most of the experiments aboard the ISS did not exceed 30 days. Plants are considered as a source of food and oxygen in bioregenerative life support systems of long space missions.

Such an experiment can be carried out on the platform of a small satellite CubeSat, using the technology created and successfully tested in space conditions created by National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"and microcosm technology growing plants in a closed gas environment, which was developed in the National Botanical Garden. M.M. Grishka NAS of Ukraine. In a unique experiment at this institution, the plants show the ability to grow in a closed gas environment for a long time (currently the duration of the experiment is 12 years).

Carrying out the experiment and promoting it in the media has a powerful image component and will promote the promotion of cosmonautics and the attraction of young people to pre-scientific space exploration.

The technology of the developed unit for long-term cultivation of plants in microgravity can be applied for the implementation of space experiments in the future, as well as being a tested basis for the creation of new cultivation chambers for growing plants aboard spacecraft. With plant life support system (temperature and lighting) from on-board telemetry and model experiments on plant growing is created in a stationary unit under stationary conditions with observation of the condition of plants growing in a stationary unit. Creating such a system will allow for various biological experiments on the CubeSat platform. The proposed space experiment is unparalleled and will be the first attempt at long-term exposure of several species of plants in space flight in a power unit. Information on the resilience of such an artificial ecosystem to the long-term impact of microgravity is a prerequisite for the creation of bioregenerative life support systems and the implementation of their long-term space missions. Plants are considered as a source of food and oxygen in bioregenerative life support systems of long space missions. The satellite design includes a hermoblock with a system for maintaining the viability of plants: fibrous substrate, grating for a substrate, NIR-camera for shooting (observing the state of plants), fan with protection, LED lighting, system for monitoring the environment inside.

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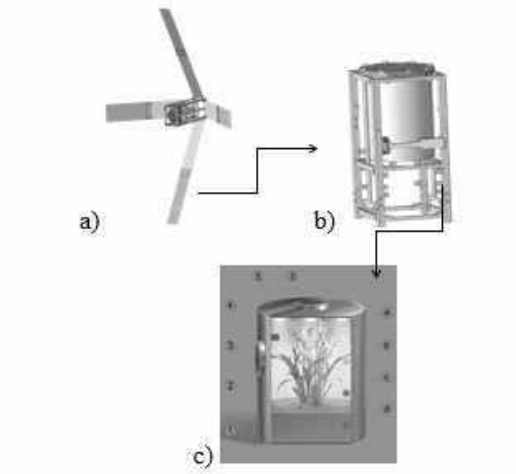

Figure 6. General view "PolyITAN-4-BIO" (a); Placing of hermoblock in the case of "PolyITAN-4-BIO" (b); Herm block composition (c) include plant's life support systems:1 – fibrous substrate, 2 – holding mesh for the substrate, 3 – NIR-camera (to monitor the state of the plant) 4 – fan with protection, 5 – LED light; and the environmental monitoring system inside the unit: a – light sensor, b – CO2 sensor, c – temperature sensor, d – substrate humidity sensor.

Expected results: selection the optimal plant composition with the best growth characteristics and the value of the minimum-sufficient level of water with the mineral component for plant nutrition.

IX. Summary and Conclusions

Aerospace technology and manufacturing techniques were used in the design and manufacturing of nanosatellites series "PolyITAN". Architecture of"PolyITAN" nanosatellite allowed to avoid problems that occur with a reduction in scale structures of satellite systems for their use in small and nanosatellites. This was made possible thanks to realization of the key differences between large satellites and satellites CubeSat, the development of new sub-systems and systems specially designed for use in CubeSat format nanosatellites.

"PolyITAN" nanosatellites provides high-performance electronic platform for testing new materials in space, carrying out scientific experiments and testing of technologies.

Benefits of "PolyITAN" Platform:

a) High precision positioning using GPS + GLONASS (Galileo optional).

b) The cost of mass production is lower by 40-60% than in the US and European counterparts.

c) The presence of a complete set of satellite system at University (satellite into orbit and ground station).

d) Start services, support and maintenance.

e) The possibility of supply of separate components and subsystems.

f) Scalable platform in accordance with the Cubesat standard.

g) Using for a wide range of applications (radio communication, Earth sensing, scientific experiments, etc.).

h) Use of carbon fiber honeycombs for heat control and radiation protection.

i) The full nanosatellite development cycle

Analysis of the functional characteristics of "PolyITAN-1" subsystems and test of the impact of external damaging factors are still going on in the orbit. However, all tests up to this day have been successful and the results are compared with the design.

The PolyITAN-1 nanosatellite is active in the Earth's orbit at a height of 602 ... 607 km to the present time (site: https://www.n2yo.com/?s=40042).

Acknowledgment

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