Design, testing and operation of «AIST» small satellites

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***Abstract*— «AIST» small satellites (SS) were codeveloped by Samara state aerospace university and Samara Space-Rocket Centre "Progress". The article describes the results of development, ground and flight testing of small satellites of scientific and educational purpose, that were placed into the near-earth orbit on the April 19th and December 28th 2013 as additional payload on the Russian Soyuz-2.1b and Soyuz-2.1v launch vehicles. The analysis of telemetry data concerning the support systems performance has been carried out. The telemetry form the scientific equipment has been analyzed as well.**

Keywords—small spacecraft; scientific equipment; testing; small satellite; orbit

I. Introduction

The AIST small satellite was developed for scientific and educational purpose on the initiative from Samara state aerospace university (SSAU) with the financial support from the government of Samara region. The spacecraft was designed by students and young scientists of SSAU and specialists of the JSC "Space-Rocket Centre "Progress" (SRC "Progress"). The main idea of creating the AIST small satellite was to involve the senior SSAU students into real research and development to help them quicker adapt on the enterprise. However, the satellite performance functions definition, mass and dimensions restrictions imposed by the means of the orbit incretion showed the need to address a number of engineering, design and technological challenges, to form new approaches to the experimental development of the product.

II. Design and specification of the AIST small spacecraft

The analysis of the actual problems of scientific research in outer space, the possibility of the launch of small satellite, its mass, energy, and financial capacity of the project, as well as educational objectives carried out by the specialists and researches of SSAU and SRC "Progress" had led to the following definition of the AIST small spacecraft purpose [1]:

– refining of methods of small satellite microacceleration compensation that are essential for perspective spacecraft types like "Bion-M" and "Foton-M".

– determining the fluctuations in the Earth's magnetic field for a long residence time of the spacecraft in the orbit;

– orbital research of the energy composition and the nature of the motion of microparticles;

– solution of a number of technological problems of production of small satellites;

– commissioning of the "Doka-N" ground control unit for small satellites;

– inclusion the process of design, build, operation of the "AIST" spacecraft into the educational process in SSAU.

The AIST small satellite was designed to solve the following tasks:

- Development of a unified compact space platform weighing up to 100kg for long-term (up to 3 years) research, technological experimentation and implementation of modern educational programs;
- creation of an information link in the amateur frequency bands for communication of educational and scientific nature from the universities of Samara region to another Russian and foreign universities;
- monitoring the Earth's magnetic field and study of the problems of microgravity, the implementation of long-term compensation modes of the low-frequency acceleration component on board the spacecraft to a minimum value that does not exceed the range of values from 10^{-5} g_0 to 10^{-7} g_0 ("MAGCOM" scientific equipment);
- study of the behavior of high-speed mechanical particles of natural and artificial origin, interacting with the surface of the ionization sensor and the estimation of their parameters - mass and velocity; periodic measurement of the spatial position of the sun relative to the body axis coordinates of the spacecraft, followed by evaluation of the possible charged particle flows on its surface;
- study of the level of electrification of the spacecraft and the dynamics of change in the surface charge (METEOR scientific equipment);
- experimental space testing of new types of future photovoltaic arrays (BF) of gallium arsenide (GaAs), created using nanotechnology;
- development of the technology of associated launch of a small satellite into a working orbit with a heavy research spacecraft-carrier;
- development of production technologies for small non-hermetic spacecraft with highly complexed onboard equipment.

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Solution of the mentioned above tasks lead the the design of a small spacecraft shown on the figure 1. The onboard systems arrangement is shown on the figure 2.

The main technical characteristics of the AIST small satellite:

- initial orbit parameters: near-circular H = 575км; inclination I = 64,9°;
- mass – 38 kg;
- dimensions: 400×500×600 mm;
- lifetime – up to 3 years;
- the spacecraft commits unoriented flight;
- radio circuit: 2 receivers 145MHz, 2 transmitters 435MHz.

Space platform of the AIST satellite utilizes an onboard control system - command-and-control navigation system (CCNS) Doka-276, developed by NILAKT-ROSTO (Kaluga).

CCNS provides:

- command and control of the satellite onboard systems;
- telemetric control of the satellite onboard equipment;
- the work of the onboard radiocircui in the VHF and UHF wave band;
- power distribution for onboard systems;
- formation of pulse and potential control commands;
- command and control of the piroequipment;
- information exchange channels – CAN, RS-422, RS-232;
- formation and maintenance of the on-board time scale;
- on-board command queue;
- navigational control of the spacecraft orbit parameters;
- power system automatic;
- thermal control system automatic.

AIST satellite is fitted with scientific equipment MAGCOM and METEOR.

MAGCOM scientific equipment («MAGnetic COMpensator») consists of an electronics block, two three-component magnetometers (DM No.1 and DM No.2), electromagnets control unit (BYEM) and three orthogonally arranged solenoids (EM-X,EM-Y,EM-Z). SBC VSX-104 is used as an on-board central computer. CCNS communication module is based on ATmega680 microcontroller.

METEOR comprises 6 multiparameter sensors (MS), each

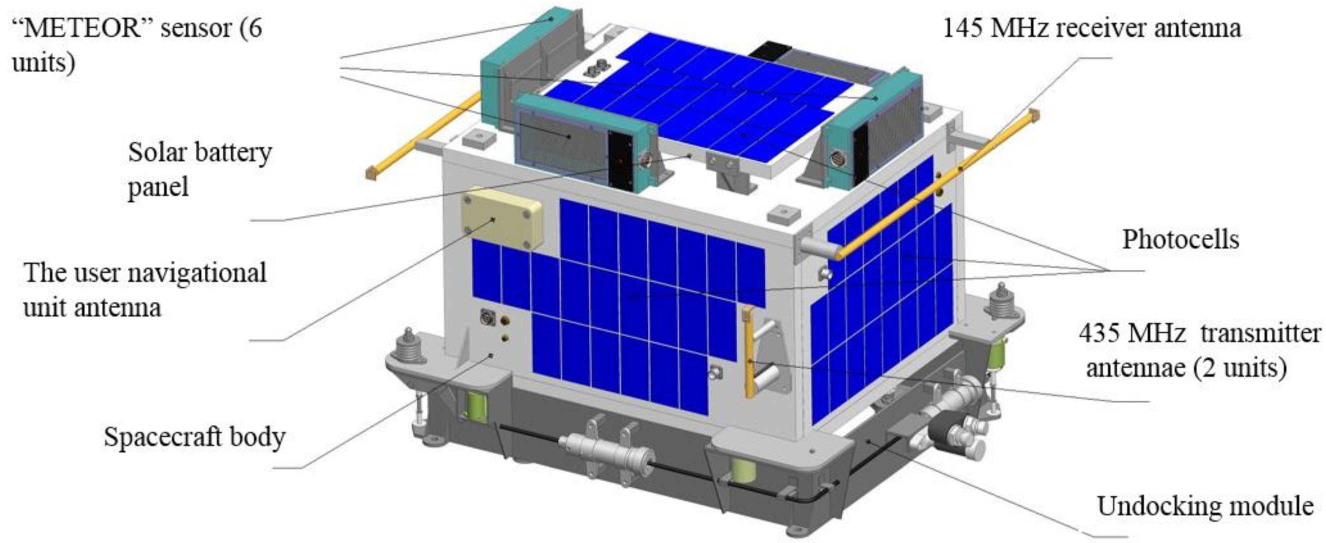

Fig.1. General view of the spacecraft in operational configuration

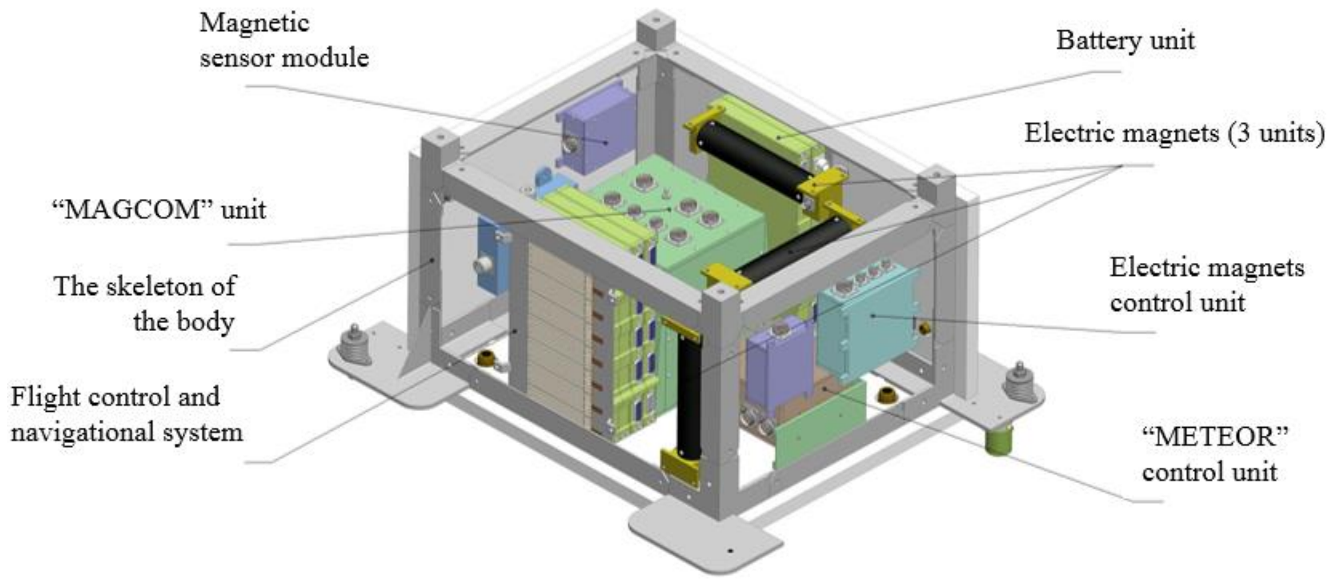

Fig.2. AIST small spacecraft onboard systems arrangement

of which contains a high-speed sensor dust particles, temperature sensor, solar sensor and sensor of electrification. The sensor of high-speed dust particles uses the effect of ionization from collision of matter particles and the target, area of the target is roughly 84 sm^2. The signal from the ions, charged by the collision of the dust particles with the target is received with a charge-sensitive amplifier with the use of a controller, comparator and a memory block to register the collision. The solar sensors are being used to determine the position of the spacecraft in the moment of collision and therefore determine the trajectory of the particle. Temperature sensors are also used to determine whether the spacecraft is in the shade or in the sun. Capacitor type electrifying sensor is used to evaluate currents of charged particles on the surface of the spacecraft and the dynamic of the surface charge [2,3].

III. Ground testing of the spacecraft

For experimental testing of the AIST small satellite a technological development sample unit was created. With sequential retooling, it served as a dynamic experimental model for vibration strength testing, heat experimental model - for thermal vacuum testing and electric experimental model - for complex electric and radio tests.

For the testing of the AIST sattelite separation device (SD) from the spacecraft-carrier («Bion-M» No.1) a dimensions and mass imitator was designed. The feature characteristic of the imitator is a strict (±1 mm) tolerance for the center of mass positioning. The vibration and thermal vacuum testing were concluded with sevenfold release of the lock pins under conditions of vacuum, high and low temperature. A characteristic design feature of the SD is the need to ensure separation of the small satellite from the mounting base plane of the spacecraft-carrier with a twist not exceeding 5° per second. These requirements are imposed both by the seating placement of the satellite and energy capabilities of the MAGCOM scientific equipment to provide the desired dynamics of reducing the speed of rotation of the spacecraft in the orbit. A special stand with a falling carriage to create conditions of weightlessness simulation was developed for the testing of the mass imitator behavior after it separates from the SD (see fig. 3). Separation of the imitator from the SD occurs in freefall to meet the conditions of weightlessness. A characteristic feature of the imitator used in the experiment is the triaxial accelerometer located in the center of its mass. The accelerometer was developed in SSAU. The running time of the accelerometer does not exceed 1,5s.

During testing of the technological sample unit for vibration strength low and high frequency tests were conducted to imitate transporting (aviation and motor transport) and the active phase of the launch (see Fig. 4).

After the end of the vibration strength testing, the thermal vacuum testing was conducted. Testing was conducted on a technological sample unit with the standard design and onboard equipment. The purposes of the thermal vacuum testing were:

- checking thermal calculation and refinement of the thermal regime of the satellite;
- testing of the thermal control system;
- testing of satellite in conditions close to the standard.

The thermal control system of the AIST satellite is based on the means of passive thermal control and electric heaters. The required temperature is established by unregulated ratio of optical coefficients on the surfaces of the structural elements of the small satellite, insulating elements, electric heaters and heat pipes that ensure thermal conditions for scientific equipment and command and control navigation system.

Thermal vacuum testing took into account the non-oriented flight of the satellite in extreme conditions of its normal operation and simulated the external heat flows and internal heating of real onboard equipment in modes "Hypothermia" and "Overheating".

As a result of thermal vacuum testing of the AIST satellite, the thermal balance calculation model of the spacecraft was refined. The thermal control system was worked out and implemented. Initial performance testing of all systems of the satellite was carried out. This made it possible to significantly reduce the time of complex electrical verification of flight and testing units of the AIST satellite.

Based on the analysis of the results of complex tests (Fig. 6) by the management of SRC “Progress” and SSAU it was decided to further use of technological sample unit of the AIST small satellite as a satellite-demonstrator (educational space laboratory) - the first payload for a new carrier rocket "Soyuz 2.1v" with "Volga" insertion block, also developed by SRC “Progress”.

Fig. 3. Ground testing of the separation device

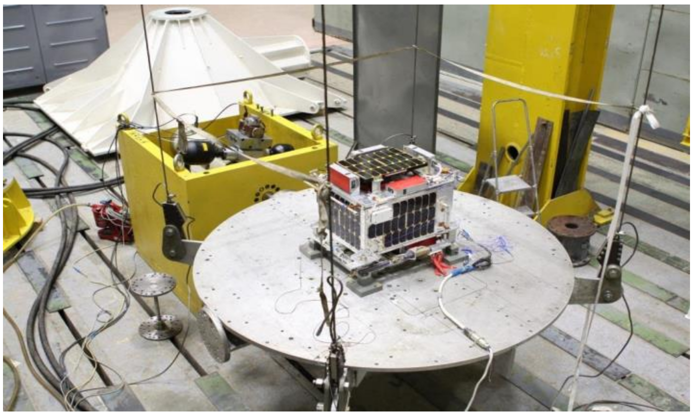

Fig. 4. Vibration strength testing for the flight conditions

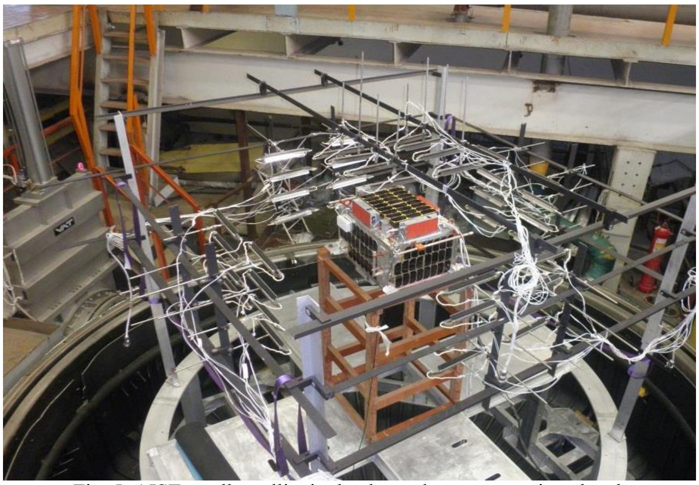
Fig. 5. AIST small satellite in the thermal-vacuum testing chamber

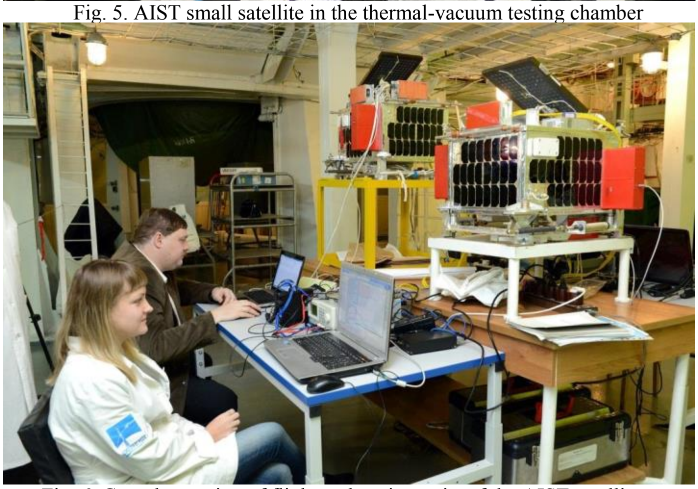
Fig. 6. Complex testing of flight and testing units of the AIST satellite

IV. Flight Testing and Operation of the AIST Spacecraft

On April 19, 2013, at 10:00 UTC the launch vehicle “Soyuz 2.1b” blasted off from the Baikonur cosmodrome, as a way cargo with “Bion-M” №1 satellite, put to orbit a first small satellite created on the AIST platform.

On December 28, 2013, at 12:30 UTC in the course of the debut launch of the new light launcher “Soyuz 2.1v” developed by SRC “Progress”, the second small satellite on the “AIST” platform was put into orbit from the Plesetsk Cosmodrome.

Control of AIST small satellites is being done form the Center for receiving and processing of information "Samara" of "RCC" Progress" employees of the company and students and postgraduates of SSAU.

From 5 to 7 communication sessions are held daily with both spacecrafts. The sessions last from 32s to 640s each. As the result of the sessions the telemetry files (TF) are generated (TF file contains 1440 measurements of 126 parameters). Measurements of the magnetic field of the Earth are conducted with 6s intervals with two 3-component magnetometers. Figure 7 shows the results of the scientific equipment functioning in the field of geomagnetic study. The measurements were made on 16th of May 2013 from 20h 25min 9s to 23h 59min 34s.

The dependence of the angular velocity of the spacecraft from time in the accelerations compensation mode is shown in Figure 8. Figure 9 shows a plot of the magnitude of the magnetic field vector compensation in the accelerations compensation mode. Process of electrification registration using "METEOR" scientific equipment is shown in Figure 10. Magnetic orientation algorithms of the spacecraft are being debugged based on accurate measurements of the magnetic field of the Earth, "METEOR" data is continually evaluated. There are more than 20 registered high-speed collision of microparticles with the AIST.

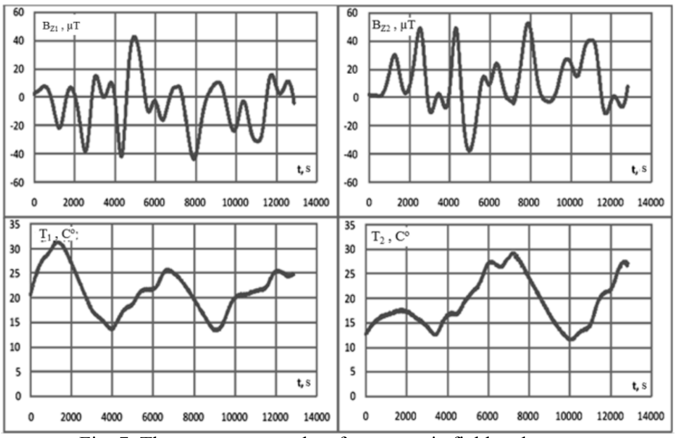

Fig. 7. The measurement data for magnetic field and temperature

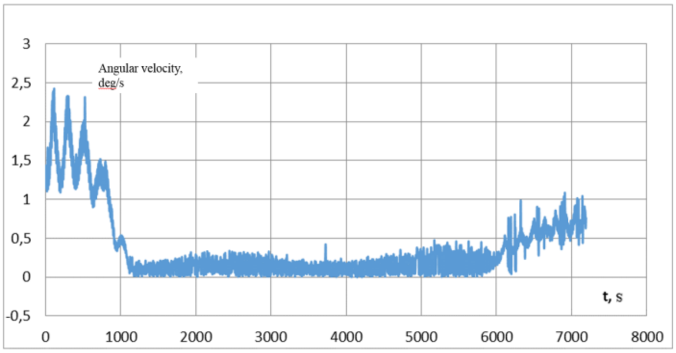

Fig. 8. The dependence of the angular velocity of the small satellite from time in the micreacceleration compensation mode

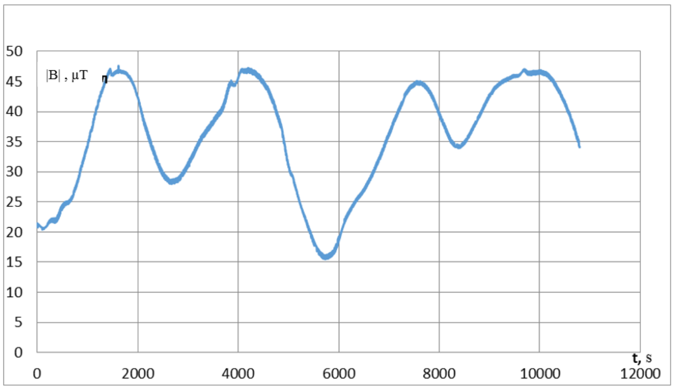

Fig. 9. Modulus of the magnetic field vector in the micreacceleration compensation mode

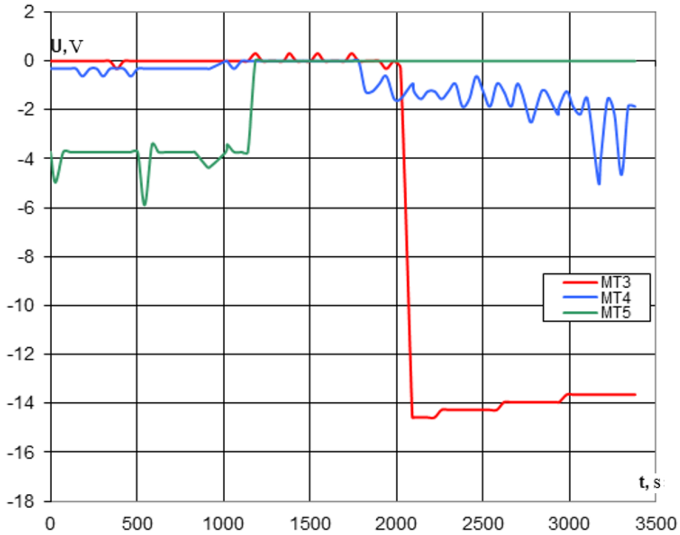

Fig. 10. Registration of the small satellite's "AIST" electrification process

V. Conclusion

Joint development, launch into orbit and operation of two small satellites contributed to the development of technologies in the design, manufacture and testing of small spacecrafts. Flight tests of a space platform weighing up to 20kg, which provides operation for complex scientific-technological equipment designed for space exploration and new technological processes at an altitude of up to 650 km was successfully completed. The ground control was created, allowing to operate the spacecraft and to solve the educational tasks of training of highly qualified specialists. The technology of associated start and the system of small spacecraft unstressed separation from the device carrier were tested.

The experiments made in an orbit show that the equipment "MAGKOM" reduces the angular velocities of the 39kg spacecraft from 3 to 0,2 grad/s in less than 20 minutes, furthermore, this level of angular velocity can be maintained throughout the whole period of spacecraft's active existence.

Scientific equipment "METEOR" is able to detect micrometeoroids in near-Earth space with the registration of direction of their movement. It allows adaptive signal processing from multi-sensors. Accumulation and analysis of telemetry and scientific information coming from both satellites is carried out.

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