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Modular Design of Micro/Nanosatellites

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1 Criteria of spacecraft classification

The problems solved by spacecraft (S) determine: choice of orbit, of the on-board equipment, the method of orientation and stabilization principles of communication with ground stations, etc. Currently, the most common types(S) are spacecraft remote sensing (RSE) Earth, navigation Systems (GLONASS, GPS, Galileo), communication systems (Iridium, Globalstar, etc.), automatic scientific spacecraft (Foton / Bion), the orbital station (International Space Station), manned and interplanetary (S). Principles of construction of this manifold (S) is different. One way to reduce economic and cost, schedule, create and run (S) is their unification, which is carried out in relation to a particular class of devices. In connection with this important task is to identify the most important distinguishing characteristics (S) and are categorized by these criteria. It should be noted that at present none of the possible classifications can not be considered complete, final and complete.

The spacecraft will vary according to the following criteria: purpose, design features, by weight, the presence of the crew, the type of control, etc.

In addition, the possible classification:

- mind due to a ground station: no connection, one-way communication (receive commands from a ground station or data to a ground station), two-way communication;
- the possibility of returning to Earth: non-refundable, returned
- the presence of orientation and stabilization: the orientable or nonorientable;

Let see in detail the classification of the SC on the most important distinctive features.

1.1 Spacecraft Classification by Purpose

SC can be divided into automatic and manned. By appointment automated spacecraft can be divided into connected, navigation, (RSE), and scientific, technological, transport, monitoring, near-Earth space, interplanetary manned spacecraft, and so can be divided into transportation, space stations and interplanetary.

Note that the same spacecraft may have multiple appointments at once, which is determined by the composition of the hardware and software of its flight.

Classification of the spacecraft to destination is shown in Fig. 1.1.

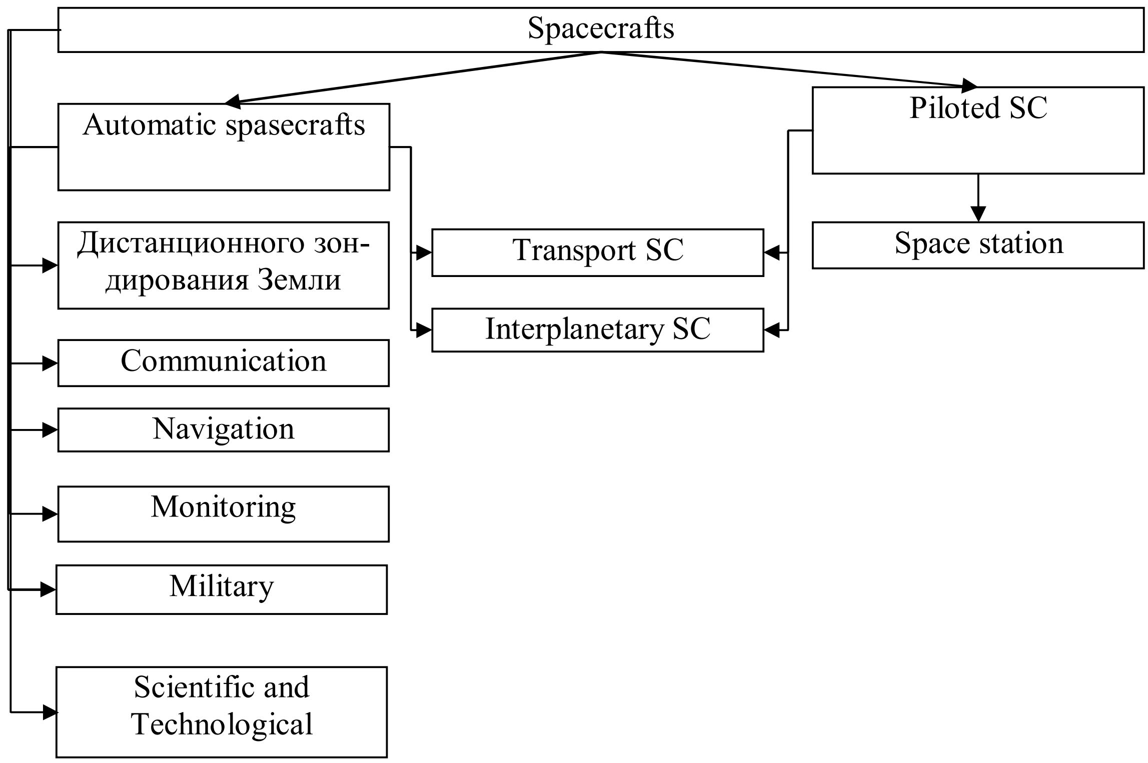

Figure 1.1 – Spacecraft Classification by Purpose

1.2 Spacecraft Classification by Mass

Mass of spacecraft is one of the most important features of the SC, as determines how often and start time of its existence. Spacecraft with a large mass, usually put into orbit by a single run. SC with malyuyu mass can be grouped and displayed on a single orbit of the booster (a cluster running).

On the total mass of the spacecraft can be classified as large, small, mini, micro, nano, pico. Are small spacecraft mass not exceeding 1,000 kg, average weight are between 1,000 and 1,500 pounds and greater - weight of which more than 1,500 kg. In turn, according to the weight of small satellites are divided into mini-(100 ... 500 kg), micro (10 .. 100 kg), nano-(1 ... 10 kg), peak (0.1. .. 1 kg) and femtosputniki (0.1 kg). Ultra SC apparatus will be called with a mass less than 100 kg [1,2].

Classification of the spacecraft mass is shown in Fig. 1.2

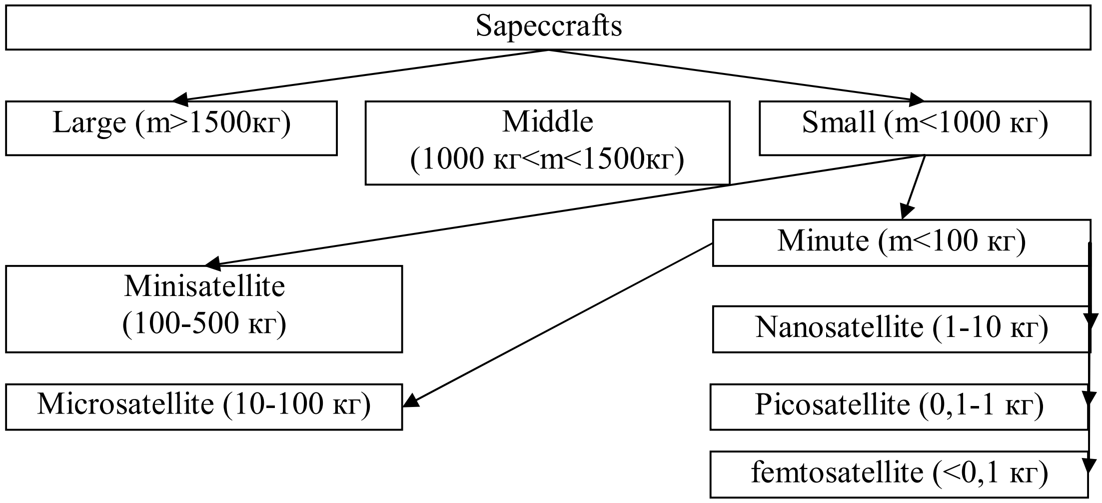

Figure 1.2 – Spacecraft Classification by Mass

1.3 Spacecraft Classification by Design Features

Structurally-power design of spacecraft can be accomplished by the following schemes [3]:

- gooseneck;
- cantilever;
- mixed.

Close-coupled circuit is the implementation of the SC in the form of candy bar consisting of sealed and unsealed sections. The advantage of one-piece scheme - the possibility of a large volume of chambers for the location of the equipment. Drawback - a large mass structures, cables and accessories, the need to seal compartments difficulty unification of several satellites in a single design concept, the complexity in the location of the outside of spacecraft solar arrays, antennas and feeders.

Cantilever scheme executed in the form of power structures, which are attached to equipment and installations to ensure flight and landing equipment. The advantages of this scheme - an opportunity, if necessary perekomponovok board and the target database a large amount of hardware improvements. Drawback - the lack of pressurized compartment.

Mixed scheme represents a compromise between the cantilever and one-piece circuits: monoblock in the form of pressurized compartment for providing equipment and cantilever design to accommodate the target hardware. This scheme is heavily than gooseneck allows the unification of the spacecraft.

By type of performance can be distinguished sealed and unsealed spacecraft.

Consider their differences, advantages and disadvantages of each type of performance.

Hermetically sealed housing enables operation of the satellite payloads on orbit in the same climatic conditions in which it was worked out on Earth. Temperature conditions within the body provides a more reliable means - due to convection of a gas inside the shell. Moving the gas as a coolant made by a fan. However, significantly increase the resource satellite, in the emerging space technology in the past two decades, was a major problem for satellites in an airtight performance: a resource for fans, rubber sealing, etc. are not allowed to significantly increase the term of active existence of the spacecraft. Usually sealed compartments are pressure from 0.13 to 0.9 MPa. Earlier sections dominated by nitrogen, but it worsens the frictional properties of graphite brushes of electric motors (the moisture evaporates, and flakes of graphite are abrasive). When filling the pressurized compartment is necessary supplement of 3 to 4% oxygen and humidity corresponding to the dew point of minus 20 to minus 10 ° C. Temperature compartments is usually chosen in the range of 0 to 40 ° C, and negative temperatures are not desirable. Large pressure losses (leaks) to 30% is undesirable because it may disrupt the normal operation temperature control system. For sealing of joints commonly used white rubber vacuum (almost pure rubber), which allows compression. Technology hatches and manholes single or multiple actions can be sealed with rubber gaskets. Instead of rubber as a seal can be used teflon, but after each disassembly PTFE joint ring should be changed, as the Teflon-elastic material. For flat covers can use the V-clamps, which in turn compresses the joint. For sealing the hatches braces can be used, as in aviation, air hoses. In the hose is fed compressed air under pressure. However, with the hose to provide a high degree of integrity is difficult. For sealing joints operating at high temperatures, the application of metal rings and gaskets made of soft metals. Large-diameter pipelines can be sealed by flanges. For sealing pipes of small diameter is used volumetric deformation seals (rings of rubber, Teflon, aluminum, etc.).

The test sections for leaks in pressure chambers is larger, which are usually made on the outlines of the test object (a form of the nose fairing of the launch vehicle). The cell is simulated flight conditions - the air is evacuated to a pressure of 10-2 to 10-4 Pa.

Simulated solar radiation to heat (infra-red mercury lamps), cooling is carried out by special panels termobarokamery. The object is kept in the chamber for several hours or days. In this measured pressure drop inside the object that determines the degree of tightness. To determine where the leak is charged with helium, an object with an overpressure of 0.2 MPa and with the leak detector scan all the joints, pipes, etc. germorazemy pressure chamber, usually combined with thermal cameras.

Vented satellites may have the following designs:

- Enclosure type (the main power is the central element of the farm or a cylindrical tank remote control);
- open-frame construction;

- Framework scheme (housing units are made as metal frames that are attached with pins to two metal plates milled, located at both ends of the package, recruited from the framework constituting the frame power satellite).

Aerodynamic configuration is important for low-orbit spacecraft, since in these orbits aerodynamic moments are significant. In this case, the SC can be divided into two groups according to position relative to the Earth's surface [3]:

- with a horizontal scheme;
- with a vertical scheme;

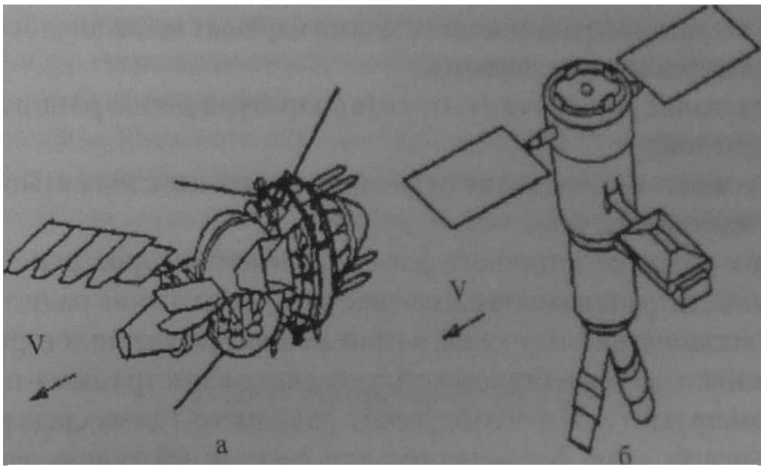

Figure 1.3 – The Aerodynamic configuration
a - with a horizontal scheme; б - with a vertical scheme

In the horizontal scheme of the longitudinal axis of the spacecraft is the velocity vector. The advantage of this scheme is: a small section of the midsection of spacecraft and, therefore, the minimum expenditure of fuel to maintain orbit and convenient location of the target apparatus to study the Earth's surface. Drawback - the complexity of placing long-focus optical devices.

In the vertical scheme of the longitudinal axis of the spacecraft during flight focused on the local vertical. The advantage of this scheme is the convenience of placing the spacecraft on long-focus optical devices, solar batteries, antenna devices on satellites - repeaters. Deficiency - long middle section, which leads to an increase in disturbing the aerodynamic moments about the center of mass.

2 The Main Stages and Steps of Microsatellite Design

The process of creating new products by high levels of time and resources with the involvement of human, industrial and energy resources. As a result, the design of new products creates a design documentation for the manufacture of products, which is defined depending on the destination set of documents that contain the data needed to design, manufacture, inspection, acceptance, delivery, maintenance and repair products. The purpose of the design - to ensure the production of products with the desired properties with the least complexity of manufacturing.

To ensure high quality in design, manufacture and operation of new products, including space technology, as well as to minimize the costs of creating new technology set uniform rules for execution of works in the form of standards [4], which establish the basic stages and steps of creating new products .The main stages of the design, development, manufacture and operation of new equipment are:

- Scientific research(SR)
- design stage, including development work
- manufacture;
- maintenance products.

Scientific research is carried out to create products based on new principles of work for implementation of which will require further study to obtain new or refine existing features analogues. The need to perform this step defines the customer as agreed with разработчиком

Scientific research involves the following steps:

- preplanning patent search;
- development and coordination with the customer specification for Scientific research, state registration;
- preparatory stage (development of areas of research, development and coordination of private customer specification);
- main stage (theoretical and experimental research);
- final stage (the generalization of results and performance assessment Scientific research)
- acceptance scientific research;

Development work includes the following steps:

- technical proposal
- conceptual design
- technical Project
- working design documentation of the prototype (experimental batch) products.

Develop a technical proposal for the implementation of the most important and complex OCD, if provided for TK, to identify additional or revised requirements for the product that can not be established in the TOR.

The purpose of preliminary design (EP) is to establish the fundamental (design, circuit design, etc.) solutions, which give an overview of the principle of operation and construction products. Stage VC will occur if it is provided TK.

Technical project develop, if required by the TOR in order to identify the final design and technological solutions that provide a complete picture of design and technology products, when it advisable to do to develop documentation. For example, in the development of space technology, this stage is not envisaged.

The aim of the development stage of design documentation is to create a set of design (CD) and technological documentation, necessary and sufficient for the production of prototype or experimental batch of the product. This phase is mandatory to create any products.

Stages of the ROC in various stages will be discussed below, depending on complexity of design, skill of performers, the availability of prototypes in consultation with the customer can join or exclusion of individual stages and phases of OCD. This is reflected by VTZ.

2.1 Technical Requirements. Purpose, content and structure

The result of the rationale for the creation (modernization) of the microsatellite have Terms of Reference (TOR) for the microsatellite and its component parts. Typically, these documents are developing on the basis of conducted research, in some cases, the TOR are developed after the preparation of technical proposals (TP).

Terms of Reference is a basic reference document for the development of a microsatellite, which defines the purpose of development, purpose, a set of technical, feasibility, and other special requirements, stages, milestones and deadlines.

In general, the TOR should contain the following sections:

- name, and code base for development;
- developer, manufacturer and collaborators;
- implementation of the development objective and its purpose;
- of the microsatellite;
- technical requirements;
- technical and economic requirements;
- Material Requirements (requirements for finished products and materials used);
- requirements for preservation and packaging, depending on the conditions of storage and transportation, as well as labeling (location, content and method of marking);
- requirements for training aids;
- special requirements (additional special requirements);
- requirements developed by the documentation (of the design, engineering, technological and operational documentation);
- stages of creation (the name of the stages, the timing of their implementation, maintenance work at each stage and the performers).

Materials to be submitted at the end of stages (of documentation, the number of prototypes) and order acceptance.

The most informative is the section of TR "technical requirements", which contains specifications and parameters that define the purpose, operating conditions and applications. This section defines the following performance requirements:

- purpose (specifications, quantities, performance, probabilistic-time and other characteristics of the microsatellite and its component parts);
- robustness (performance reliability, durability, and failure criteria for ultimate limit states, methods and reliability);
- design (basic design requirements, mounting and overall dimensions, fastening methods, methods of control and adjustment, the type of performance, mass properties);
- manufacturability (requirements for production, operation, control and verification of adaptability);
- resistance to external factors (climatic, mechanical, chemical and other factors, to the effect that the product must be persistent at all stages of life cycle);
- harmonization and standardization;
- operation, ease of maintenance and repair (operating conditions, methods of operational control of the control and test equipment);
- Compatibility (range, allowed the quantitative values of parameters of electromagnetic radio-electronic means and methods of measurement of these parameters);
- transport and storage (modes of transportation, transportation options, the climatic conditions of transportation, storage conditions).

The order of development microsatellite (stages and steps) is defined in the TOR for micro-or TR into its component parts. The work performed on the stages and phases are defined in the documents-through planning. Such documents are:

- schedule a microsatellite (schedules create micro components);
- schedule for the development of TP (pilot project), and preliminary design;
- schedule for development, mining and manufacturing micro components;
- work plans for the program to ensure reliability and safety that are developed and refined at various stages.

Schedule a microsatellite is the basis for the development of documents, organizing and coordinating work that is supposed to perform.

Schedule a microsatellite or its components should include:

- consolidated list of works on creation of the stages (including parts);
- turnaround time;
- list of artists works (of the major artists).

Schedule a microsatellite developed during TA (tentative) and refined at the stage of preliminary design (EE).

Program reliability and security software designed for microsatellite and if necessary, into its component parts. Programs should include requirements for content and order of execution of works at all stages of product life cycle (design, manufacture, testing of ground, transportation, use as directed). Previously, these programs are developed in the preparation of TAs and refined in subsequent phases.

Development (modernization), manufacture and operation of micro-and their components, systems, assemblies (devices) that are created by TK is usually carried out on the next steps and stages:

- specification;
- technical proposal (preliminary design);
- conceptual design;-development documentation;
- prototyping, ground testing (standalone and integrated) and the adjustment of working documents;
- operation (an experiment in space).

Reduced order design, manufacture and operation of the microsatellite in justified cases may vary due to association or exclusion of certain stages.

2.2 Technical proposal

The process of designing a micro, as a rule, begins development of the technical proposals. The purpose of the work at this stage is to establish the scientific, economic and institutional indicators, and ways to search for technical solutions to create a microsatellite with specified in the TOR and performance indicators that are not defined at the design stage of TK.

Technical proposals should include materials that substantiate the possibility of creating micro, in particular:

- basic characteristics and preliminary evaluation of the effectiveness of microsatellite (its components), preliminary data on the tests;
- technical description (briefly) with the features of the operation and maintenance, the functioning of the microsatellite in different modes for basic and operational characteristics;
- possible variants of a microsatellite, to assess energy, mass and dimensional characteristics of the microsatellite and its components;
- optimal layout of a microsatellite and its component parts, materials used, fuel components, taking into account the possibilities of experimental and production facilities and technical-economic indicators;
- study for the safety operation of the microsatellite and its components;
- complete analysis (opportunities) run TOR to assess the feasibility of the project microsatellite, as well as proposals for adjustment or development of micro-TK;
- analysis of the technological level of the microsatellite and its component parts and comparing it with the best achievements of national and international science and technology;

- analysis used elektroradioizdely (ERI), completing elements and materials, taking into account the capabilities of industry and providing them to the stages of production and experienced flight models;
- list of experimental studies;
- reliability program, which contains the attainable level of reliability of the work to conduct necessary for its achievement and confirmation as well as methods and ways of working out the software, computing facilities and personnel equipment;
- Techno-economic indicators mikrosptunika, cost estimation for technological support;
- schedule a microsatellite and a list of subcontractors;
- list of theoretical and experimental work to be performed in subsequent stages of the microsatellite;
- information about the production and pilot (test) equipment.

The stage ends with the technical proposals preparation and approval of the following documents: a technical proposal, reliability program, the schedule of a microsatellite. If necessary, the same documents are being developed for its constituents.

2.3 Sketch Purpose and Content

Major work on the creation of a microsatellite are performed on the stage of conceptual design. The purpose of the work on this phase is complex (theoretical and experimental), substantiating the basic characteristics, technical and technological solutions to create a microsatellite and its components, as well as to substantiate the technical and economic indicators.

Draft project on micro-and its components should include:

- results of theoretical, experimental and other work carried out to substantiate the performance specified in the TOR the main characteristics of the microsatellite and its constituent parts;
- link in the complex scheme microsatellite its constituent parts;
- technical description of the microsatellite and its components, the rationale for the design of the materials, coatings, and the selected propellant (working fluid);
- work out the details of operation and exploitation of the microsatellite;
- assessment of microsatellite stability and its components to the effects of space factors;
- safety program operation, including environmental security;
- assess the reliability of the microsatellite and its components based on the results of theoretical and (or) experimental studies;
- Techno-economic performance microsatellite and its component parts, the costs of technological support;

- study schedule (schedules) for the development and to the development and manufacture of micro and its constituent parts;
- the integration of micro components;
- list of emergency situations, indicating microsatellite components, their possible failures and ways out of emergency situations and assess their criticality;
- results of study of the design process microsatellite and its components;
- Results of development of mathematical, computer and information support for automated flight control systems (a list of program modules, memory resources, algorithms, function, operation algorithms, a set of tests, etc.);
- ballistic characteristics (parameters of the orbit, the landing areas of re-entry vehicles);
- list of methods of testing and evaluation methods of their results, including methods of verification given characteristics;
- work on testing and control of microsatellite and its components during the acceptance by the manufacturer, and in preparation for launch at Baikonur;
- drawings of the general form, theory and dimensional drawings, diagrams to describe them to the microsatellite and its key features;
- conformity assessment requirements of the micro characteristics of TK.

At this stage, a program to ensure reliability, which contains a list of works in this and subsequent phases of creation, in order to ensure and prove compliance with the requirements of TOR in terms of reliability.

At the stage of conceptual design microsatellite usually available the following documentation: Explanatory Note conceptual design; albums drawings and diagrams, reliability program, the schedule of a microsatellite. If necessary, such as documents developed into its component parts. In addition, on-demand can be developed and other documents, such as complex test program, security software, programs and methods of testing, etc. If necessary, the same documents are being developed for micro parts.

2.4 Engineering Documentation Developing

The purpose of the work on the stage of working documents (RD) is to develop:

- set of design documentation (CD) for the manufacture and testing of a microsatellite and its constituent parts, including a comprehensive program (integrated software) experimental development (KPEO);
- technical documentation (TD) for the manufacture of prototypes;
- operational documentation (ED);
- software.

The design documentation includes an explanatory note, specifications, drawings album (assembly, overall, assembly, etc.), design (electrical, pneumohydraulic, etc.), program and test procedures, statements, etc.

Process documentation includes: routing processes of manufacturing, assembly, testing, operational processes, etc.

Operational documentation includes: a technical description, operating instructions, forms, passports, instructions, statements, operational documents, etc.

In developing the CD using circuit-design and technological solutions that ensure compliance with the requirements of TK; analyze the possible failures that lead to emergency situations and justify their actions by countering and prevention, considering issues of ground tests.

The design documentation is developed in strict accordance with the existing legal framework [5].

The structure of the CD is sure to KPEO. In some cases it can be developed earlier - at the stage VC.

Experimental development includes consideration of autonomous and complex tests, types of tests, as well as methods and tools for testing software.

Complex test program must include:

- and a list of elements, systems and components microsatellite, which are autonomous and complex tests:
- aims and objectives of testing, the sequence of their implementation;
- types of tests, the number of prototypes or models (for each type of test);
- requirements to simulate real operating conditions in accordance with the TOR;
- order and the amount (duration and quantity) of microsatellite testing and its components with the simultaneous simulation of different influencing factors on the electrical and other mock-ups;
- order of confirmation of the basic performance requirements for safety and security;
- order and the amount of mining software, including onboard computers and automated systems;
- list of programs (PI) and techniques (MI), implementation and evaluation of test results.

List the main types of tests and their content generally includes:

- static tests (linear and cyclic loads, internal pressure, etc.);
- vibrodinamicheskie tests (vibration and dynamic loads);
- environmental tests (external factors);
- thermal and vacuum tests (the impact of the PCF);
- leak tests;
- tested for radiation resistance;
- test for resistance, strength and stability (experimental confirmation of the test object properties to perform its functions during exposure to certain environmental factors, or after it).

2.5 Microsatellite Prototype Manufacturing and Ground Testing

Prototyping microsatellite and its component parts is on previously developed the CD and TD. Prior to the manufacturing necessary to elaborate a CD and analysis for manufacturability, design necessary to manufacture and AP tests; produce materiel for the design and engineering castings, prepare the necessary production and testing equipment, develop guidelines and procedures necessary for the manufacture and testing.

The manufacturing process is accompanied by supervision of the developer.

Confirmation of the requirements specification for the development of a microsatellite and its components is carried out under their experimental testing. Ground tests conducted in stages:

- stand-alone and integrated testing of a microsatellite and its constituent parts, in accordance with KPEO;
- comprehensive testing microsatellite.
- Challenges of autonomous tests are as follows:
- check the functioning of the components in a simulation of external influences at all stages of operation factors and loads;
- identification and elimination of unreliable elements and unacceptable modes of operation;
- determination of the boundaries of efficiency, performance assessment of compliance requirements TK;
- test (adjusted, if necessary) CD and ED.

In general, testing each part of the microsatellite is carried out in the following sequence:

- research trials to test the functionality and compliance with the requirements of item parameters TK (CD design);
- developmental testing (development of PD);
- special tests (resource, etc.) in accordance with KPEO;
- acceptance (test) test.

All newly created micro components are autonomous ground testing in accordance with KPEO. Sufficiency of working out is confirmed positive test results.

Stand-alone tests are conducted at least one or two samples, which can subsequently be subjected to various tests. Is allowed in the combination of the load during the test or some combination of several components into a single unit.

According to the results of the successful stand-alone mining report is prepared, which is the basis for comprehensive testing.

Ground testing of integrated micro battery is carried out after working out parts for prototypes fabricated in accordance with our DD.

Challenges of complex tests are as follows:

- check the functioning of the mutual components in a simulation of external factors and pressures at various (including limits) modes of operation;

- testing of software and algorithms for on-board systems, ground-based control;
- identifying and addressing design and manufacturing defects at the junction of related systems and components;
- checking of components in simulated emergency situations;
- preliminary assessment of compliance with the requirements of TK, including requirements for reliability and a given resource;
- testing of ED;
- definition of technical readiness for flight testing or manual (space experiments).

Sufficiency is determined by working out the positive results of tests carried out in accordance with KPEO, programs and techniques of complex tests. Comprehensive tests are conducted on one or two samples.

Upon completion of experimental testing ground preparing a report ready for flight testing (conducting space experiments).

This report must contain:

- summarized the results of the work of the program to ensure safety and security program microsatellite;
- values of the basic technical and operational characteristics on the results of experimental testing and evaluation of their compliance with the requirements of TK;
- assess the adequacy of the software on-board systems and ground control;
- assess the requirements for reliability of the results of all tests;
- assessment of the adequacy of ED;
- conclusions about the readiness for flight testing (conducting space experiments).

After completing the ground processing and launch a micro phase begins operation (space experiment).

If you intend to manufacture several microsatellites, we further conducted flight tests of one of the vehicles. After successful flight tests are made and runs the entire series of microsatellites.

Outlined in this section the main stages and the stage of creating a micro, the problems solved by each of them, as well as the composition of the documentation presented in Fig. 2.1.

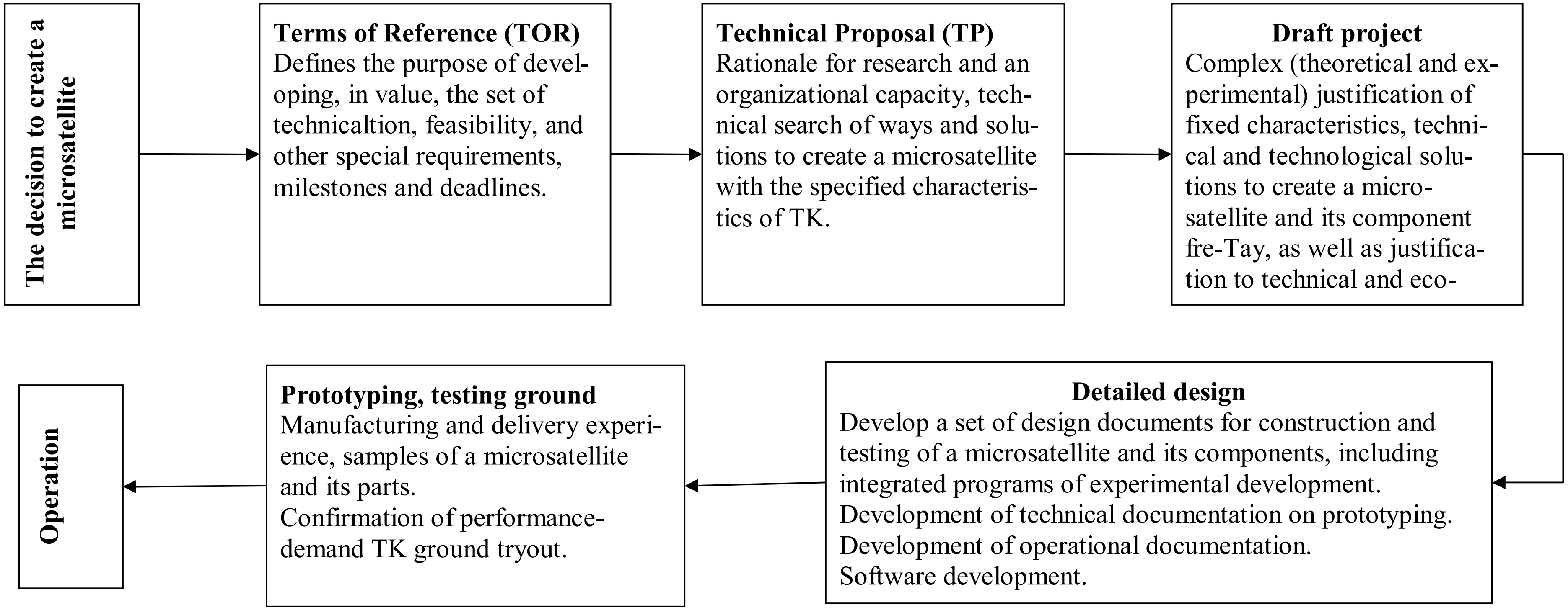

Figure 2.1 – The main stages and the stage of a microsatellite

3- Microsatellites On-Board Systems

The main purpose of onboard systems - ensure the functioning of the microsatellite, which begins from the moment of its separation from the launcher. The composition of the systems on board depends on its purpose. Consider the appointment and composition of the most frequently used service systems.

3.1 On-Board System Purpose and Structure

The microsatellite is a set of functionally related systems: power supply, control, orientation and stabilization, telemetry control, ensuring thermal regime, radio, scientific data collection, movement, and others. Depending on the type of microsatellite individual systems can be combined, and vice versa establish additional (radiation and thermal protection, etc.).

To supply the entire instrumentation system is a micro power supply (EPS). Permanent sources of power can not provide the micro-power for a long time. Therefore, the microsatellite should include sources of revenue for electricity. The greatest development among them have photovoltaic cells (solar cells) that convert solar energy into electricity. Combining them into a single structure called solar batteries (SB).

Tasks SPS are quite complex, as are imposed on the micro-weight and size restrictions that limit the power leads to the Security Council and hence EPS. For the operation of the spacecraft for a long time should be carried out energy balance, the essence of which lies in the fact that the average power of energy consumers must not exceed the average power sources of electricity. Moreover, short-term excess consumption may be a single load of energy balance, but within days he should be reinstated. In case of default of the energy balance EPAs must be disconnected from any load electricity, including those such as the onboard digital computer (onboard computer), which often leads to abnormal situations, ie, microsatellite malfunction.

In addition, consumers of energy demand stabilized voltage power supply of different denomination. To this end, EPA should ensure the transformation of supply voltage and its stability.

Given the limited dimensions and weights microsatellite another task is the maximum energy output SES unit area Sat Energy efficiency depends on the illumination SC and structure photovoltaic (silicon, galievyei etc.) with different efficiency. To maximize energy efficiency at the expense of some light microsatellites attitude control system supplied by Sun Sat. However, when designing such systems should take into account that the positive effect of winning at the expense of lighting has not been offset by the additional consumption of electric power system, the orientation of the Security Council, reduced the reliability microsatellite, loss of mass-dimensional characteristics of the microsatellite as a whole and its appreciation.

Given that when you start Sat are in the folded position, you must install them in working condition after separation from the launcher or microsatellite from the base unit. The solution to this problem is solved by the control system, a central element of which is the onboard computer. As with any management system, it includes sensors and actuators. In this case, the signal on the control system deployment Sat receives from the device separation microsatellite. Typically, the installation of the Security Council in the working position begins with a time delay after the separation of waste for the microsatellite at a certain distance to avoid collision with a booster or a base unit, which is separated from the microsatellite.

Operation of the microsatellite, as a rule, it requires a certain orientation in space. Therefore, the next task is to control the orientation and stabilization of the spacecraft. Orientation is required to install a certain plane microsatellite or parts of it to the specified landmark. As a reference for microsatellite can be Earth, the Sun, planets, stars, etc. The objective is to maintain stability microsatellite microsatellite in position with precision. Given the fact that the angular orientation and stabilization of microsatellite runs the same hardware, these two systems are often combined into one, which is called the orientation and stabilization system (OSS). As the sensor can be used magnetometers (in the orientation of Earth's magnetic field), infrared vertical line (in the orientation of the thermal field of the Earth), solar sensor (with the orientation of the sun), a star sensor (with the orientation of the stars), as well as inertial sensors (gyroscopes) determining the deviation of the microsatellite with respect to the inertial coordinate system.

As the actuators are used for microsatellites OSS magnets (magnetic stabilization), elektroflywheel-type drive engines (changing the kinetic moments).

Some microsatellites in the quality and the sensor and the executive body may be used telescopic rod with a weight at the end, which serves as a gravitational stabilizer. The principle of gravitational stabilization based on the difference between the forces of attraction and micro load at different distances from the center of the Earth. Such a system does not consume energy and is related to passive systems. However, the accuracy of stabilization of the system is low, which limits its scope.

OSS is characterized by precision targeting and stabilization of the angle and angular velocity. The accuracy of orientation and stabilization depends primarily on the accuracy of sensors, the value of control torque and control algorithms (deviation of the micro, not only in the corner, but the angular velocity). The most accurate measurement sensors have a star, but at the same time they are also the most expensive of the number of sensors.

The composition of OSS microsatellite determined with reference to ensure the accuracy of orientation and stabilization energy capacity microsatellite of lifetime and cost microsatellite.

It should also be borne in mind that the stellar and solar sensors determine the angular position relative to the stars or microsatellite Sun. For the angular orientation relative to the Earth to the microsatellite in addition to determine the position of the microsatellite in orbit.

To solve the problem of determining the coordinates (spatial position) microsatellite, and the positioning of objects (including mobile) in the world (the problem of navigation) on microsatellite installed navigation equipment of the consumer (NEC), which, together with control motors may include a motion control system center of mass (MCSCM). However, the NAP can be installed on microsatellite and in the absence of MCSCM. As the NAP is most frequently used satellite radionavigation receivers operate on the signals of GLONASS and GPS.

To ensure the conditions of the equipment on board a microsatellite with the outside temperature changes in space and on the lighted unlit areas at a considerable range of the onboard systems can include thermal control system. The main objective of this system is to reduce the range of temperature changes on-board equipment.

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An important task is the operation of the microsatellite information on the status of onboard systems and APN, the passage of control commands and refine these teams microsatellite equipment. This task is entrusted to a system of telemetry control (STC). STC collects telemetry data, creates a special telemetry frame in a digital code, each digit of which carries information on the status of a particular instrument, apparatus or electrical circuit element (electric signal). The structure of the telemetry frame may be different for each microsatellite or systematized to a certain group of microsatellites.

To transmit telemetry data to ground stations using telemetry radio link that transmits the information "downlink". The volume of telemetry data is usually much greater than that of the command information. Therefore, the data transmission speed of radio telemetry is higher than the command.

Sometimes the command and telemetry radio link radio link combined into one, called the combined command and telemetry radio (SKTRL).

With long-term operation of the micro to store information for transmission to a ground station during short conversations. For this purpose, APS includes a memory block. Sometimes the microsatellites to unify interfaces reception and transmission of information introduced a unified bloc, which called the system of scientific data collection (SSNI). Introduction of the unified SSNI support systems can greatly simplify the approval procedure with the APN board systems microsatellite.

Housing micro-board systems, often called a platform. Creating a unified platform, which can set a different APN, can significantly reduce development time and cost microsatellite.

3.2 On-Board Control System

The main objectives of on-board control system (OCS) [2, 6]:

- receiving information from sensors (magnetometers, sun sensor, star sensor, inertial sensors, etc.);
- receiving information from the navigation equipment of the consumer:
- receiving commands from ground stations of the radio command;
- Motion Control microsatellite around its center of mass (angular position and velocity);
- traffic control center of mass of the microsatellite (used in cases of change of orbital parameters or micro micro slip out of orbit);
- management of micro-satellite onboard equipment using on-board algorithms and team information, to make from Earth;
- control the proper functioning of onboard equipment microsatellite formation of status and functioning of the equipment, carrying as necessary reconfiguration of hardware and software microsatellite array formation telemetry data and transfer it via a telemetry radio link to Earth;
- service tasks, including: the organization of the computational process, synchronization of information exchange between the blocks and micro-board computer, the formation of control commands to units and systems in accordance with the work sequence diagram.

OCS provides:

- installation of the Security Council in the working position after the separation of microsatellite launch vehicle or spacecraft base (if necessary);
- extension of the gravitational stabilizer (for microsatellites using a gravitational stabilization system);
- quenching of the angular velocities derived microsatellite in his office;
- build and maintain three-axis orientation of the microsatellite in the orbital coordinate system (USC) with the required accuracy during the required time;
- reorientation of the micro or individual parts in the direct solution of the target;
- microsatellite withdrawal from orbit after completion of active existence or transfer of a microsatellite in parking orbit (Earth's radiation belts).

Depending on the task and determined the structure of OCS. Sophisticated control algorithms determine the use of an essential element in OCS - on-board computer. Job board computer based on information that is read with appropriate sensors and converted into control commands for the algorithms used in the software. The sensors are sensitive organs of OCS. To control the microsatellite used executive bodies. Composition of sensors and actuators with on-board computer determines the structure and management systems microsatellite, its characteristics, cost and functionality.

The main structural elements of the OCS:

- onboard digital computer;
- orientation and stabilization system;
- collecting telemetry unit;
- command radio link (Earth-to-side);
- telemetry radio link (downlink);
- thermal control system;
- navigational equipment of the consumer.
- In addition, depending on the tasks of the SC may include:
- system control center of mass of the microsatellite (if necessary, change the parameters of the orbit);
- system for collecting information from the payload equipment (to receive and store a large flow of information to the NPA);
- Information radio link (with the High-speed large volume of information during communication sessions).

Important characteristics are the OCS weight equipment, its cost, power consumption, lifetime warranty, the probability of failure-free operation, etc.

3.3 Orientation and Stabilization System

3.3.1 System Classification

Angular stabilization is movement around the center of mass of the microsatellite in those parts of the trajectory, where the flight takes place with significant acceleration: the correction of the orbit, passing from one orbit to another, the transition to the descent trajectory, etc. or in cases where microsatellite carries uncontrollable flight, and to target solutions to temporarily stabilize. Angular stabilization systems require a significant amount of energy because they operate at relatively large perturbing forces and moments.

Angular stabilization of the microsatellite is not an independent task, and has support for traffic management purposes at the center of mass microsatellite.

Orientation is called a micro control the angular motion microsatellite at the site of free flight, ie, microsatellite orientation - is giving its position relative to the axes of certain specified directions.

The need for orientation microsatellite occurs:

- in obtaining energy from solar panels work;
- with navigational measurements;
- for scientific research (direct solution of the target);
- when transmitting information to Earth with the help of beam antenna;
- before turning on the engine braking or accelerating to change the trajectory of the microsatellite.

Orientation microsatellite requires maintaining the set position either permanently or briefly. In contrast to the stabilization of the orientation does not affect the position of center of mass of the microsatellite.

Orientation and stabilization system are often carried out in view of their close collaboration and use the same sensors. According to the number of axes oriented micro distinguish uniaxial orientation at which to maintain a certain angular position of one of its axes relative to a given direction, and a complete orientation, when a certain angular position of being attached to all three axes microsatellite [7].

While the stabilization system used as an exceptionally active, the attitude control system - both active and passive.

The passive attitude control system are: the gravitational, inertial, aerodynamic and others, that such that for their work do not require the expenditure of energy stored on board the microsatellite. They feature high efficiency. However, their application is limited.

For systems that require for their work some of the energy stored on board a microsatellite, or mass, ie active systems are: the orientation of jet engines, inertial flywheel, electromagnetic devices, etc.

The advantage of active systems is their flexibility, ability to provide turn microsatellite in the right direction with the desired angular velocity.

In automated systems, the orientation of management is carried out by commands from Earth, or on-board control systems.

Microsatellite attitude control system receives from the sensors, sensor information about the position of the microsatellite with respect to axes of orientation and the nature of its angular motion.

The most frequently used electro-optical sensors, using as reference landmarks heavenly bodies - Sun, Earth, Moon, stars. Optical devices for visible light or infrared radiation at a deviation from the direction of the axes of sensors to produce a landmark reference electrical signal.

Infrared radiation is an object, such as Earth, it's best to register as day and night sides in this case are equivalent.

As an instrument which registers the angular position of the microsatellite can be used ion probe.

They are also used magnetic sensitive elements to determine the position of the microsatellite with respect to Earth's magnetic field.

Gyroscopic sensors use a rapidly spinning top to keep the property the same direction in space.

Electrical signals from the sensors come in conversion device, which provides:

- gain, matching, and signal transduction in the control signals for switching agencies;
- logical operations necessary for the proper functioning of the orientation system.

Options for orientation and stabilization system shown in Pic. 3.1.

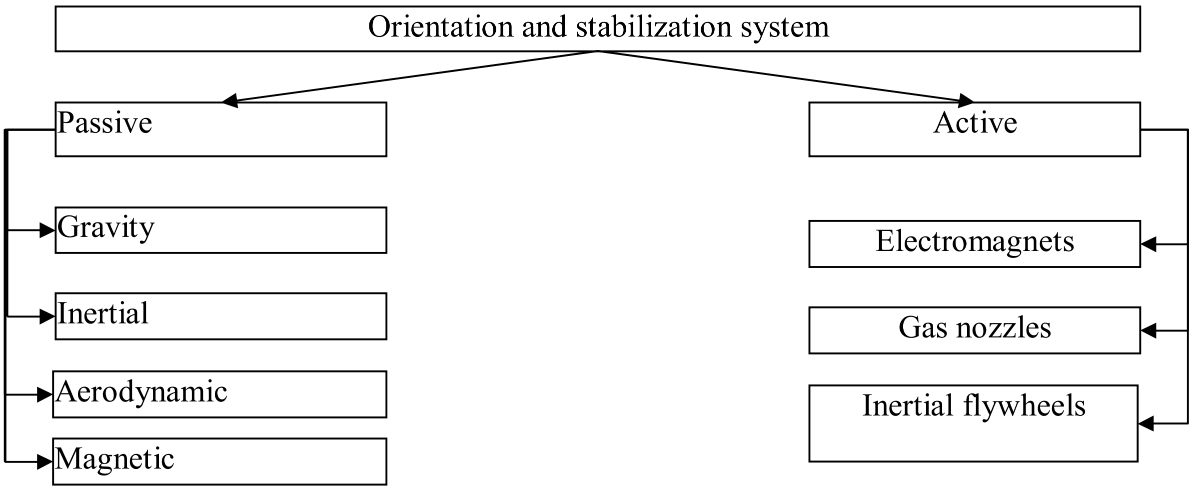


Figure 3.1 – Options for attitude control and stabilization

Since the rotating micro-will operate outside the disturbing moments (gravity, magnetic, aerodynamic) on the control of steering engines, there is a precession.

The angular velocity of precession in this case (Fig. 3.2):

$$\Omega_{ПР} = \frac{\mathbf{M}_{возм}}{\mathbf{H}_{кин} \sin \alpha_{ПР}}$$

where $\mathbf{M}_{возм}$ – external disturbing moment;

$\mathbf{H}_{кин}=J_z\omega_z$ – the angular momentum of microsatellite;

J_z – moment of inertia of microsatellite;

$\alpha_{пр}$ – precession angle relative to the microsatellite z (the axis around which carried twist).

Table 3.1 Comparative analysis of different systems of orientation

systems orientation	rotation	With jet nozzles	Gravity; Wind, solar pressure	magnetic and electromagnetic
accuracy	not less than 1 °	1 '	5° (до 1° с демпфированием)???	до 0,5°
Scope			- gravitational 200 км<H<2000 км - aerodynamic 200 км <H<400 км - solar pressure H>2500 км	600 км <H<6000 км

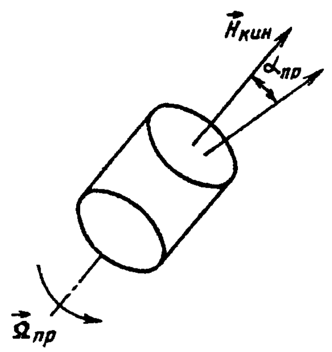


Figure 3.2 – The precession of the micro-satellite, after a preliminary twist when separated from its carrier

The orientation of the rotation ensures the accuracy of not less than 1 °. Comparative analysis of different systems of orientation is shown in Table. 3.1.

The possibility of using a particular system depends on the orientation of the orbital altitude operation microsatellite, such as the system used, the values of the disturbing moments and the moments of stabilization.

3.3.2 The gravitational system of orientation

Gravitational attitude control system is a passive system and therefore does not require for its operation costs of energy or mass, stored on board a microsatellite [2,6,8]. Its functioning is based on gravitational moment, which occurs when the micro is designed so that the moment of inertia about the axis of orientation is much less important than the moment of inertia about the other axes.

This effect can be achieved through a special arrangement in the distribution of mass microsatellite, for example, in the form of an elongated cylinder or dumbbells. Similarly, we obtain the gravitational moment, if the special bars to make beyond the micro loads. If the rod is carried out through a flexible connection with the microsatellite, it is possible damping of oscillations around the stable position.

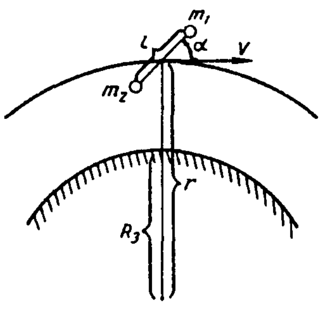


Figure 3.3 – Illustration of a gravitational moment

Such a system is effective for micro committing an orbital flight around the Earth at an altitude orbits lying within 200 km <H <2000 km.

At altitudes lower than indicated in the range of application affects the disturbing influence of the atmosphere. At high altitudes and during flights in the interplanetary space system is ineffective because of the weakened gravity gradient field of the earth and under the gradient of the gravitational field of the Sun.

Consider Fig. 3.3. If there is no separated masses associated with the microsatellite, the total force acting on the microsatellite is

$$F = f\frac{mM}{(R+H)^2} - \frac{mV^2}{(R+H)} = 0$$

With a flexible or rigid bond separated masses m1 and m2 and goods moving at the same speed, but at the heights that differ by some small value, the height of the movement of each staggered mass is different from the height of the movement of their common center of mass at $\pm l \sin\frac{a}{2}$. At the same time on the top load force arises

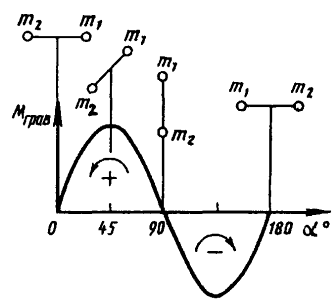


Figure 3.4 – The profile of the gravitational moment

$$\delta f = \frac{m_1}{(R+H)^2}\left(2f\frac{M}{R+H} - V^2\right)\delta H,$$

and the lower cargo

$$\delta f = \frac{m_1}{(R+H)^2}\left(-2f\frac{M}{R+H} + V^2\right)\delta H,$$

or in the general case

$$\delta f = \pm\frac{m_1}{(R+H)^2}\left(2f\frac{M}{R+H} - V^2\right)\delta H, \quad \delta H = \pm\frac{l}{2}\sin\alpha.$$

Gravitational time is of the

$$\delta M_{грав} = \delta F l \cos\alpha$$

or

$$M_{грав} = \frac{ml}{4(R+H)}\left(V^2 - 2f\frac{M}{R+H}\right)\sin 2\alpha.$$

Gravity and time in $\alpha = 0$ and $\alpha = \frac{\pi}{2}$ is zero and the maximum at $\alpha = \frac{\pi}{4}$ (Fig. 3.4). Consequently, for $\alpha = 0$ and $\alpha = \frac{\pi}{4}$ we have two points of balance, but the point $\alpha = 0$ is a point of unstable equilibrium: if the angle a (a microsatellite variations always occur) gravitational moment increases. At the point $\alpha = \frac{\pi}{2}$ position is stable, and a small deviation in the angle α in one direction or another microsatellite will return to this stable position.

The presence of flexible rods or other devices damps vibrations about the equilibrium position $\alpha = \frac{\pi}{2}$ of the microsatellite at. In the absence of damping microsatellite oscillates in pitch and roll with a frequency

$$f_{KA} = \omega \sqrt{\frac{3(J_i - J_z)}{J_z}},$$

where $\omega = \frac{V}{R+H}$ - mean angular velocity of the microsatellite of the earth;

$J_i = J_x$; $J_i = J_y$ - Moments of inertia about axes perpendicular to the longitudinal axis z;

J_z - The moments of inertia about the longitudinal axis z

3.3.3 Aerodynamic orientation system

When driving at low microsatellite orbits can be oriented along the velocity vector of the microsatellite using the atmosphere (Pic. 3.5) [2,6,8]. It is known that the force of air resistance depends on the density of the atmosphere ρ

$$X = \rho \frac{V^2}{2} c_{x_0} S_M .$$

If the values f ρ and V we can not control, then by adjusting the coefficient of aerodynamic drag c_{x_0} and the maximum cross-sectional area S_M of the micro-satellite or a special plane (spherical cylinder, cone, etc.), located at some distance from the micro to the bar or with a flexible connection , can be a wind orientation (see Fig. 3.5).

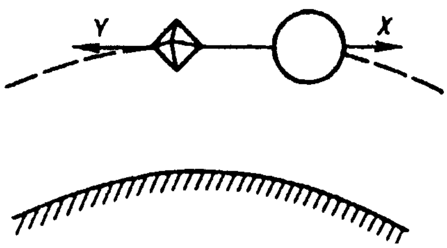


Figure 3.5 – Scheme of aerodynamic stabilization

When you reject an axis α micro oriented along the velocity vector at an angle from the direction of the velocity occurs aerodynamic stabilizing moment

$$M = \rho \frac{V^2}{2} c_{x_0} S_M l \sin \alpha,$$

where l-the distance from the center of mass (or point of attachment in the case of a flexible connection) to the center of pressure.

Due to rotation of the atmosphere with the Earth orientation error of yaw in the orbital frame of reference

$$\Delta\phi_{\max} = \frac{V_{атм}}{V_з},$$

where $V_{атм}$ - the velocity of the atmosphere;

V $_з$ - Angular velocity of the Earth.

Since the motion of spacecraft in a circular polar orbit at an altitude H = 200 km $\Delta\phi_{\max} = 3{,}5°$.

Wind orientation system is effective at altitudes of 200 ... 400 km.

Starting from an altitude of 2500 km is possible to use the effect of the pressure of sunlight to create a system similar to the wind direction.

In this case, the solar pressure can be calculated by the formula

$$F_c = (1+\zeta)\frac{F_0 S}{c}\sin^2\alpha,$$

where - the reflectivity of the screen;
ζ - The solar constant;
S - area of the screen;
c - the speed of light;
α - Angle of attack.

Stabilizing moment at the same amount, which is the projection of a stabilizing force in a direction perpendicular to the shoulder.

3.3.4 Electromagnetic orientation system

Electromagnetic orientation system can be either passive or active. If the microsatellite set of permanent magnets, they will interact with Earth's magnetic field and properly oriented in space microsatellite (Fig. 3.6) [9].

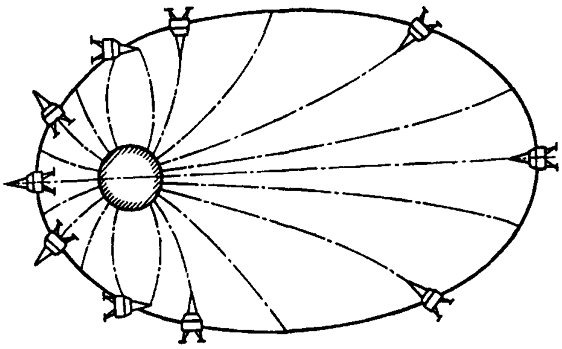


Figure 3.6 – Status of magneto-oriented satellite relative to Earth's magnetic field

Installation of solenoids or electromagnets can actively influence the process of interaction between the electromagnetic field of spacecraft with Earth's magnetic field. Elements of the orientation of the electromagnetic system can be used for vibration damping microsatellite, where other systems of orientation

The system can be used for microsatellites, which flies at altitudes ranging from 600 to 6,000 km.

A passive orientation (orientation using permanent magnets), the stabilizing moment is calculated as [2,9]

$$L_{nacc} = -H_E \mu \sin\sigma$$

Where H_E - Earth's magnetic field;
μ - Magnetic dipole moment;
σ - The angle between the magnetic rod and the magnetic field vector of the Earth.

In turn, the magnetic dipole moment $\mu = VB$ depends on the magnetic core V and the induction of the magnetic field B.

A passive magnetic orientation for the period of microsatellite makes two turns around an axis perpendicular to the orbital plane.

Moment of interaction of an electric circuit with the geomagnetic field (the active orientation) can be calculated by the formula

$$L_{акт} = -\mu_0 nFH_E \sin\sigma ,$$

where μ_0 - permeability;
n - number of revolutions of the electric circuit;
F - area of the circuit.

3.3.5 Orientation and Stabilization with the Use of Gas Nozzle

Orientation and stabilization system with gas nozzle applies to active systems. This system allows you to create large control moments due to greenhouse gas and therefore has found wide application. However, it has a certain drawback - the limited resource of natural gas, which does not use it for long periods of time.

As a rule, this system is used in the initial phase angle of stabilization after the separation of microsatellite launch vehicle or base unit, and compensation of large initial perturbation in the form of the initial angular velocity, obtained after separation of microsatellite, or a large initial misalignment angle (close to 180 °).

Gas nozzles are jet engine that throws the compressed gas under high pressure. The principle of operation of jet engines is based on the law of conservation of momentum. When disposing of the mass of matter (gas) at a certain speed the expiration of microsatellite gets the same amount of traffic (and speed) in the opposite direction.

As with all jet engines, gas engines are characterized by the thrust and specific thrust. The value of thrust produced by the gas jets can reach tens of N.

Управляющий момент, возникающий при использовании сопл, будет

Control torque that can occur with the nozzle, will be

$$M = Ap_k F_{kp} l \cos\alpha$$

α – угол между направлением газового потока и перпендикуляром к плечу.

where A - coefficient depending on the adiabatic exponent;
p_k - Pressure in the chambers of the nozzles;
F_{kp} - The area of nozzle throat;
l - length of moment arm;
α - The angle between the direction of gas flow and perpendicular to the shoulder.

The required fuel for the flight-oriented depends on the accuracy of the angular velocity and accuracy on the corner:

$$m_{opt} = \frac{J(\Delta\omega)^2}{P_{уд} l \Delta\omega} t ,$$

where J - moment of inertia of the microsatellite;
$P_{уд}$ - Specific impulse;
l - shoulder;
t - time of flight-oriented.

3.3.6 The Orientation System with the Use of Inertial Flywheels

At the core orientation systems using inertial flywheel is the property of conservation of angular momentum microsatellite, which consists in the fact that when giving the motor-flywheel on board a microsatellite of the angular velocity in one direction, the micro receives the angular velocity in the opposite direction, which can be described by the equation:

$$J_{X1}\Delta\omega_1 = -J_{X2}\Delta\omega_2, \qquad (3.1)$$

where J_{X1}, J_{X2} - the moments of inertia about the X axis, respectively, micro motor and the flywheel;

$\Delta\omega_1, \Delta\omega_2$ - Increase the angular velocity relative to the X-axis, respectively, and microsatellite-engine flywheel.

As seen from (3.1), changing the angular speed of the motor-flywheel can make a turn or microsatellite, or compensate for existing micro angular velocity.

A distinctive feature of the OSS, using an engine-flywheel is the lack of a working body. The main source of energy such motors is the electrical energy that is renewable for microsatellite with, for example, solar panels. According to the life of an OSS. usually not less than the time of active life microsatellite.

For better manageability point of control from the engine flywheel, it is desirable to get as much as possible. This can be achieved in two ways: either an increase in moment of inertia of the flywheel, or increase the increment of angular velocity. The increase in moment of inertia of the flywheel due to the increase of its dimensions, in cases of microsatellite is undesirable. This method can be applied only to relatively large spacecraft.

The second way is to increase the angular velocity of the motor-flywheel. In modern engines, flywheel speed reaches 36 thousand rpm, and maximum power consumption up to 15W. However, the maximum estimated value for speed is the speed of up to 10 thousand revolutions per minute to provide resource and indicators of reliability.

When the engine-flywheel may be cases when the angular velocity approaches the maximum. In this case, the engine-flywheel must be discharged. To unload the engine can be used by other motor-flywheel axis of rotation coincides with the main motor-flywheel. To unload the engine flywheel, can be used, and other executive agencies (eg, magnets).

To make the executive bodies of more opportunities and, consequently, more complex and precise control algorithms, engines, flywheels can be mounted in a gimbal suspension.

3.4 Power Supply System

The system power supply is designed to provide electricity to onboard equipment microsatellite in orbital flight for a specified period of operation, as well as its ground tests [2,6,8].

The permanent power source (batteries) for microsatellites most widely used chemical batteries (CB), producing electricity on the basis of chemical processes.

Consumption of electricity equipment and support systems of the payload leads to the category of CB. Therefore, to ensure that the PSS in the long term use should be provided for sources of revenue for electricity, providing charge CB. As these energy sources can be used by solar cells, nuclear installations, etc. They are often referred to as a primary source of electricity.

Apparatus microsatellite usually requires a different supply voltage and nominal power supply separately. Therefore, in the PSS includes converters and surge protectors, or, as they are often called secondary sources of energy.

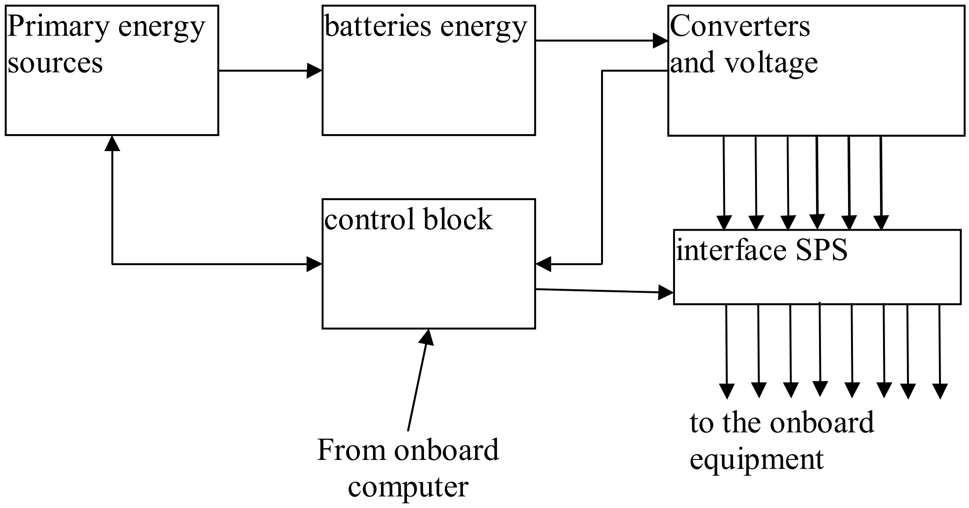


Figure 3.7 – Generalized block diagram of the SPS

To ensure the management of SPS, maintenance and control of operating modes, power on and off at various on-board equipment, etc., of the SPS include a control unit and interface. Generalized block diagram of the SPS is shown in Fig. 3.7.

Microsatellites, operating in near space and conducting research fellow planets in the solar system, most commonly as a primary energy use photovoltaic cells (solar cells), which are combined in panels called solar batteries (SB). Solar panel converts solar radiation into direct current. Compound solar cells is carried out so as to provide the necessary voltage (series connection) and the necessary power (parallel connection). Most often, Sat serve as cellular structures that allow, with the necessary rigidity to ensure minimum specific mass characteristics (mass per square meter SB). Example designs for mobile Sat-based is shown in Figure 3.8.

For efficient operation of solar system may be used solar orientation (SOSB), which should provide an orientation to the sun Sat own with minimal power consumption during the period of active operation of spacecraft. For orientation to the sun using sun sensors. As practice shows, SOSB ineffective for microsatellites because they do not provide the positive effect of increasing the capacity by an additional energy consumption itself SOSB. In addition, it leads to a complication of the design and reduce the reliability.

Theoretically, one meter square solar cells can be removed Sat to 1000 watts of power. However, existing solar cells based on silicon allows to obtain the specific power of 150 to 170 W/m2, and gallium arsenide from 180 to 210 W/m2. The use of multijunction solar cells based on gallium arsenide can increase the power density of 300 W/m2. It should be noted that the PEC based on gallium arsenide is much more expensive than silicon-based.

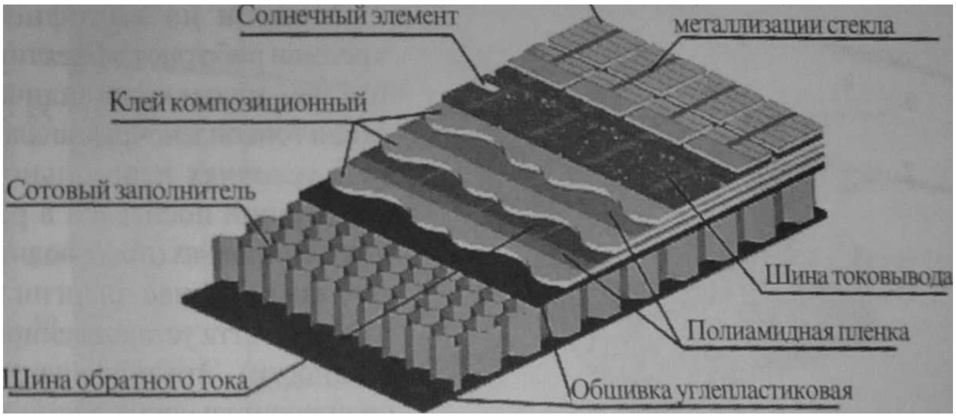
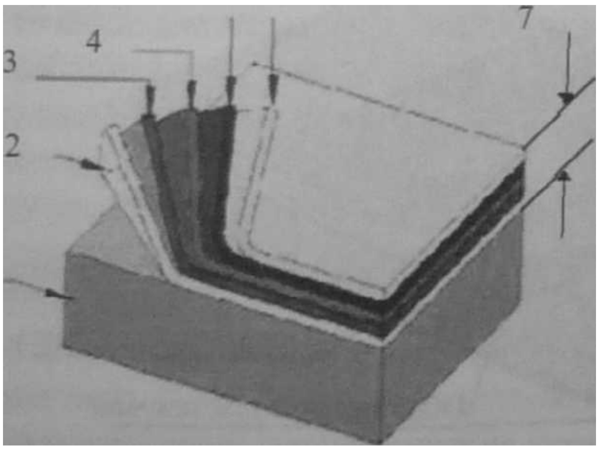


Рисунок 3.8 – Структура солнечных батарей на сотопластовой основе
Picture 3.8 - Structure of the solar cells on the basis of cellular

Part of the light energy that solar cells can convert into electrical energy, called the efficiency solar cells.

Recently found widespread thin-film flexible solar cells based on amorphous silicon (Pic. 3.9).



Picture 3.9 - Structure of the solar cells based on amorphous silicon:
1 - flexible stainless steel substrate, 2-layer film backscatter, 3 - layer sensitive to red ny area solar spectrum, the 4 - layer sensitive to green region of the solar spectrum;
5 - layer sensitive to blue region of the solar spectrum, 6 - transparent electro ¬ conductive film-coated, 7 - total thickness of the multilayer structure (≤ 1 mm)

Solar cell of amorphous silicon is a structurally completed device comprising a multilayer package of films from amorphous silicon alloys, which is applied to the stainless steel substrate and covered with a special protective coating. The thickness of the film package with less than 1 micron.

Amorphous silicon modules work better than other crystalline and thin-film counterparts in non-ideal orientation of carriers in the real world (made more watt-hours of energy from each watt of installed capacity). This increase in productivity, which reaches 20% or more due to higher sensitivity in low light or diffused light, and the best thermal performance. Specific power modules Vt/dm2 -10. It should be borne in mind that the cost of thin-film flexible solar cells is higher than conventional solar cells based on silicon. Flexible solar cells have another advantage - they can be placed on the surface of almost any profile. In this way you can install on a large area micro-photovoltaic cells and thus gain greater power output of the SPS.

The real power, the power taken from the Security Council, much less by finding panels Sat angle to the sun, as well as on the unlit parts of the trajectory.

As the battery power used by BH, which have a nominal voltage, capacity, rated current of the discharge and charge-life and self-discharge current.

Rated voltage - average value of the voltage current source at work in the given names as the mode of charging and discharging.

Rated capacitance (CL) - the product of the number of amps, issued by the load, the number of hours during which maintained a nominal discharge current and rated voltage at 20 ° C.

The service life of energy sources - the time interval during which the source of electrical energy retains its characteristics. For primary energy sources, this time determined by the total length of time of storage and use, and the battery - the amount of charge-discharge cycles, which can provide a current source to reduce its discharge capacity is not below the regulated level. Typically, border performance is set at 0.6 Gh. Battery life depends on many factors: the depth of discharge, charge mode, the period between charge and discharge, temperature and other factors.

Self-discharge - a process that leads to partial loss of capacity in the absence of the discharge current (load off) due to internal chemical processes in the battery itself, but also due to the appearance of the discharge current on the outer surface of contaminated battery. Self-discharge is characterized microcurrents leakage and loss of capacity is estimated as a percentage. A measure of capacity loss (in percentage) during storage is the value of t:

$$S=100(C_0-C_t)/C_0,$$

where C0 - capacity given up by primary or secondary source of the charged current at the initial time of operation;

Ct, - the capacity of the current source at time t /

For CB, intended for use in outer space must meet the requirements:

- high specific weight and dimensions and electrical characteristics;
- wide operating temperature range;

- the ability to charge small currents;
- low self-discharge currents.

As an energy storage in power systems with micro-resource use, the more nickel-cadmium (NiCd) and nickel-hydrogen (NiHa) batteries with energy density of 25 to 35 and from 45 to 55 Wh / kg, respectively. In recent years, microsatellites are used lithium-ion batteries, which have a lower specific weight parameters and lower self-discharge current.

When designing the SPS must take into account the heat in the battery due to the chemical processes occurring in the battery during its charge.

When choosing the BH has to consider many different factors, the main ones are:

- power requirement;
- nature of the load (current, resistance, capacity);
- mode the energy source (continuous, intermittent, pulse);
- structural characteristics (overall weight and dimensions parameters, configuration, type inference);
- electrical characteristics (the maximum stress at the beginning of the discharge, the voltage stability at constant load, the final discharge voltage, resistance characteristics under changing load conditions);
- environmental conditions (temperature range and humidity);
- life;
- value.

In addition to this we have to consider a number of other requirements such as reliability, durability under mechanical load, fire and explosion safety, maintenance and the ability to install safety devices, charging mode, etc.

Most cheap power supplies are tight manganese-zinc cells (MC), but their energy potential is strongly dependent on the rate of discharge. Alkaline batteries have stable voltage. Lithium cells have a high energy performance compared with the alkaline elements, functional in a wide temperature range from -30 to +50 ° C, and in some cases, from -70 to +150 ° C, a more stable discharge voltage, high energy density, low self-discharge (less than 1% per year), long-term storage (up to 12 years) [2].

Lead-acid batteries in comparison with alkali are high operating voltage, a lower cost Ah, but at the same time, they have low specific energy characteristics.

Mercury-zinc batteries as compared with MC have a higher cost, high specific characteristics and stability of the discharge voltage. Silver-zinc cells have in comparison with the MC high specific energy characteristics, the stability of the discharge characteristics, high voltage, long shelf life, less sensitive to an increase in load current.

High capacity lithium power sources in combination with 10-year shelf life makes them indispensable in cases where the consumer is required to ensure the constant readiness of the pulse energy is large enough capacity. Lithium cells producing company: «SAFT» (elements of the series LO, LSH, LO, LM); «VARTA» (Series CR); «PANASONIC» (Series BR); «SONNENSCHEIN» (series SL); of "Energy" (a series of Bleek).

Modern sealed lead-acid batteries have high specific energy characteristics (up to 40 Wh / kg), are efficient in standby at normal temperature for more than 10 years, kept a few hundred cycles. Much of this power source - battery high capacity (up to thousands of ampere-hours). Sealed lead-acid batteries manufactured by: «SONNENSCHEIN» (Germany, A400 and A500 series with capacities from 1.2 to 3,000 Ah), "Cove" (Japan, the HP and HV); «YUASA" (Japan, NP Series , NPH, NPC and NPL capacity from 0.8 to 65 Ah); «PAN ASONIC» (Japan, the series LC with a capacity ranging from 1.3 to 100 Ah); «TOPIN» (Hong Kong, a series of TP with a capacity of 0.8 1000 Ah), «EUROPOWEREP» (Taiwan, a series of EP in capacities ranging from 1.2 to 40A-h); «FIAMM» (Italy, the series fiamm-gs capacity from 1.2 to 8,000 Ah); «CSB "(Taiwan, the battery capacity from 1.3 to 3,000 Ah).

Lithium-ion batteries came on the market less than 10 years ago. They are one of the most promising power sources of autonomous objects of any capacity with high capacity with small dimensions. These batteries have been selected by NASA for use on spacecraft launched to Mars [2]

Converters and surge protectors are designed to produce a regulated voltage of different nominal applied to the micro-board equipment, including office systems and payloads. Typically, on-board equipment uses 5-V power supply circuits for electronic equipment (REE). Fairly common denominations of stress are tension, 12 and 15 V.

In addition to increasing the reliability of power supply used back channels, and separation is one nominal voltage for different customers. Due to this, at a failure of a given nominal channel on-board equipment can be transferred to the backup channel power. In the event of failure of a particular device (eg a short circuit or line break) this device may be disconnected from the power supply, and the remaining equipment will perform its functions, ie, the failure of one device does not lead to loss of all the microsatellite.

Power converters provide conversion from unregulated supply voltage of the batteries in a grid of different denomination. To convert DC battery voltage (typically 24 to 34 V) make the conversion DC to AC and then AC to convert a nominal AC voltage of another denomination. After that convert alternating current into constant and stabilized. Typically, voltage regulators include elements of short-circuit protection equipment in excess of the permissible use of maximum current (eg, 1.5). This protection helps to avoid emergency situations that could lead to a complete failure of the SPS microsatellite.

В последнее время широкое распространение получают преобразователи и стабилизаторы напряжений, выполняемые на интегральных схемах с КПД до 0,8.

Recently, widely spread and voltage converters that are performed on an integrated circuit with an efficiency of 0.8.

The inclusion of interfaces that provide control of channel and power control channels connecting power to the onboard equipment allows to create unified blocks for a wide range of onboard equipment.

The basis of the control unit SPS, usually a microprocessor that can perform various tasks, including the orientation of the Security Council on the solar sensor in space, providing maximum power from photovoltaic cells removal.

An important characteristic of SPS is its own energy consumption. The main consumers are the control unit, the orientation system of solar batteries (if any), protection and control (very often in the form of separate devices), as well as transformers and voltage regulators. The lower per capita consumption of its own power in relation to the electrical power supplied to the on-board equipment, the better job EPAs.

3.5 Thermal Regulation System

Thermal regulation system (the system of thermoregulation) microsatellite designed to provide the necessary thermal conditions on board a microsatellite with a view to the proper functioning of service systems and APN [2,6,8]. Thermoregulatory system usually consists of a passive thermal control and temperature control systems, ie passive and active elements, the correct choice of parameters and which provide maximum thermal control system. This selection is achieved by means of mathematical modeling of thermal processes microsatellite in orbit. It is based on the heat balance equation for a single item, which establishes the thermal connection between adjacent elements and the surrounding space. This equation can be written for the i-th element in the form [2]:

$$m_i c_i \frac{dT}{dt} = S_i \sum_{j=1}^{2} A_i Q_{ji} + \varepsilon_i S_i Q_3 + Q_B + Q_{CЭ} - \varepsilon_i \sigma F_i T_i^4$$

where m_i, c_i, T_i - respectively the mass, heat and temperature of the element;

$Q_i (i = \overline{1,3})$ - Respectively the heat fluxes of direct solar radiation, solar radiation reflected from the Earth, and Earth's own radiation incident on the element;

S_i - Surface area of the element;

$Q_{CЭ}$ - Energy dissipated in the element;

A_i, ε_i -Heat, let down from the adjacent elements;

Respectively the absorption coefficient and the emissivity of the surface element;

σ - Stefan-Boltzmann constant.

At the simulation stage is pre-selected parameters of the system of thermoregulation, but they finally determined after the experimental testing.

Passive thermal control systems are effective when there is a constant heat flux. In fact, the heat flows are constantly changing, so these systems provide the specified temperature range, defined by the boundaries of changes of heat fluxes from different sources, the coefficient of absorption of solar radiation and the relative emissivity of the body.

For active systems include thermal regulation systems that provide forced heat exchange elements microsatellite with the environment. The temperature regime can be implemented through:

- orientation of the microsatellite (the orientation of the microsatellite can change the amount received and radiated heat through the different values of the absorption of solar radiation and relative emissivity for different parts of the surface micro);
- internal thermal resistance;
- thermal resistance between the compartment with the instruments and outside the outer surface (changing the thermal resistance between the devices and the design of housing micro);
- emissivity of the surface with a micro blinds.

Active thermal control system applied by the need for accurate temperature control (for example, with an accuracy of ± 2 ° C). In this case, the circulating gas instrument module removes the heat flow to the body or a special heater. With a large flux of fluid is used. Binding element is a fan to circulate the gas and forced convection. As controls apply chokes flow, working on commands from the temperature sensors.

Forced heat exchange with a micro environment can be provided:

- electrical and radioisotope heater;
- internal and external heat sinks with forced coolant flow between them.

Regulation of the heat capacity of the active thermoregulatory system can be implemented through:

- mechanical changes in the area of radiators (by automatic doors or screens, shading elements are passive systems on the external heat flow, or reversal of the microsatellite in a certain position);
- changes in water flow;
- by-pass of the coolant through the bypass line;
- Periodic inclusion of water flow;
- change the orientation of the microsatellite with respect to external heat sources.

Active cooling system on the basis of helium consists of a gas compressor, two refrigerators, a series of heat exchangers, automation and control equipment.

3.6 Telemetry Control System

System telemetry control (STC) are designed to obtain information on the status of onboard systems: modes of their operation, the power supply voltage, temperature and atmospheric pressure in the compartments, etc. In addition, telemetry data may contain data from satellite navigation and on-board time. Data telemetry monitoring necessary to control onboard systems and trajectory calculations. Information is received pay-off, located on the microsatellite. They can be divided into two types;

- discrete sensors, which are the basic building block NO or NC electric contacts ("dry contact"); they reflect controlled processes (raskrytiesolnechnyh batteries or on-board antennas to enable or disable engine braking);
- analog sensors that measure physical quantities by converting them into electrical signals.

The number of controlled parameters on the operation of the microsatellite can be several tens or even hundreds, therefore, to transfer all information from the gauges (sensors) can be carried out sealing of information (coding). This information is transmitted by radio telemetry to a ground point. On the receiving side of the radio signal is released from each sensor (decoding).

There are various ways to transmit telemetry information. Information on the status of onboard equipment can be transmitted continuously or discretely in fixed intervals. In the second case, the pause between successive readings can be filled with signals from other sensors.

When you send information to radio, problems arise presence of noise. The same problem exists in both analog and discrete hook method of transmitting information. To separate signal from noise using different methods.

Conversations with microsatellite limited time interval. With a large amount of telemetry data, the following methods of receiving and processing telemetry data:

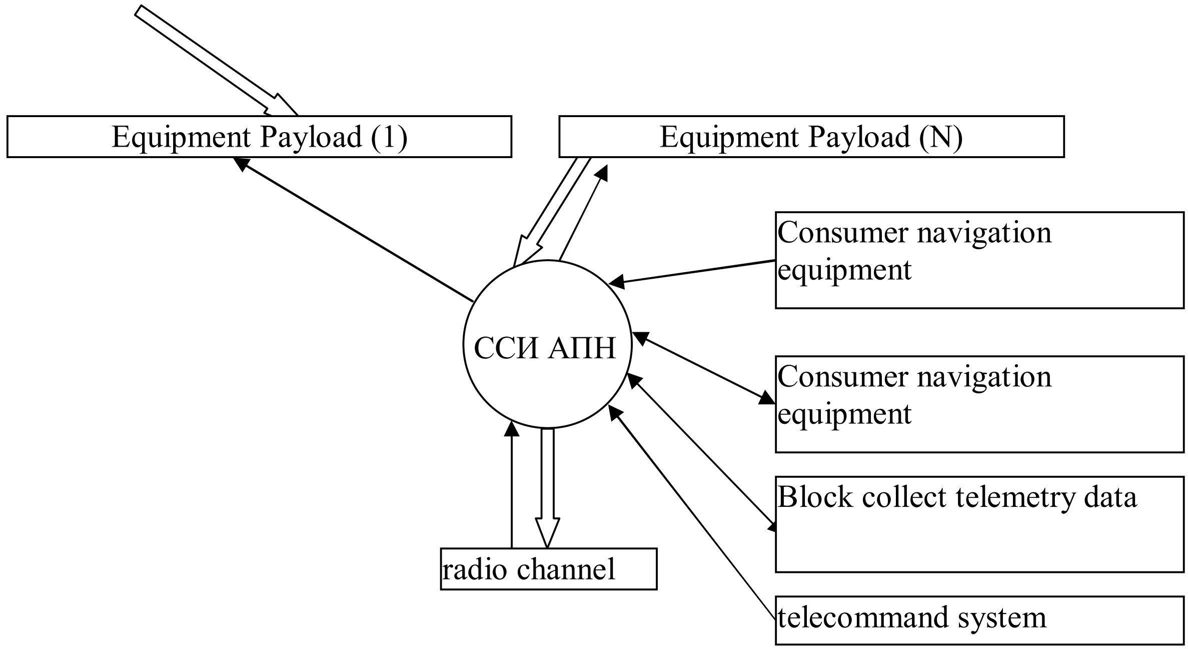
- Pretreatment of airborne telemetry systems (measurement, accumulation and transformation);
- at higher speeds and data transmission on the channel;
- increase in ground stations receiving the information.

Telemetry equipment at these locations consists of radios, equipment and decoding of signal recording, analyzing and displaying information.

Depending on the type of microsatellite can be different variants of telemetry system. Typically, telemetry control system by means of a micro-board computer and a power collecting telemetry data included in the control system.

3.7 The System of Collecting Information from the Payload Equipment

The composition of the microsatellite, but the service systems is a complex payload equipment (APS), designed for space exploration, the measurement of its parameters, conduct technological experiments and other tasks. With large amounts of information, as well as devices APN is necessary to store, transform and transmit this information to the communications, and control these devices. For these sheets introduce a system for collecting information from the payload equipment (SSI APN).



Picture 3.10-information model of information-gathering system with machine-ry of the payload

Consider the functions assigned to the USMS APN, and the structure of information flows in the system. Fig. 3.10 shows the information model of on-board data collection system. SSNI must have a sufficient number of channels to equip the information that comes from scientific instruments (Hill and other spacecraft systems. Data collection should be in accordance with previously recorded programs experiments. In the course of the experiments USMS administers the work of the APN APN: power on / off, switching modes of operation, start / stop measurement. Also must be able to synchronize the measurements for the total group of devices.

Data that is received in SSI on APN scientific instruments, can bind to an astronomical time and, if necessary, to the current position microsatellite. Some of the APN can also bind data to time and coordinate their own transfer to the DIU APN already generated data packets. In such cases, the FID APN must transmit information about the current time and position in the APS. PRS APN is processing data from scientific instruments and records them in memory, the amount which should be enough to save measurement data between communication sessions. One function of the FID APN - data compression (eliminating redundancy) and its preparation for transmission over the air. In addition to individual devices can be used by their specific processing algorithms. USMS APN provides data transmission over the air (NA) on teams and in accordance with the program of the experiment.

The rate of the output stream is determined by capabilities USMS APN radio communication equipment. Delivery of data in the radio channel is carried out with memory (the memory) or directly in real time from scientific instruments. Apart from the main channel of scientific information in the FID APN possible to transmit data at a slower rate and therefore a smaller volume through channel management microsatellite.

The operation of the FID APN by using the commands that can come from a ground station via a radio channel, a control system (CS) system for telecommand (TC) microsatellite By TC arrives, usually a small number of basic commands, such as power on / off USMS APN, switching to a backup set, the choice of basic modes of operation and programs of the experiments. Management of the FID APN via radio or via the control system microsatellite. Through these channels control the FID APN must be provided the ability to adjust or write new programs of experiments, the changes of system and application software

Information about the internal state of health and SSI APN issued in collecting telemetry unit (BSTI). Temperature is measured at the control points, supply voltage and current consumption. The signals from these sensors is directly displayed in the BSTI in analog form. USMS APN issues in BSTI as discrete signals on the current mode of operation, as well as diagnostic test results. In addition to information on the status of SSI APN, it can translate into BSTI telemetry data from the NPA if such data come from them. Self-control data from the FID APN and APN also transmitted together with scientific data via radio.

4 Unification of onboard systems of the microsatellite as means of expense decrease

4.1 General approach to the problem of unification of the microsatellite

The task of designing a micro view of unification with the service systems belongs to a class of search problems extremum with constraints, whose solution can be obtained by reducing it to the problem of finding the extremum of the new features without restrictions. In this new feature is based on the old with the addition of terms containing the restriction. In this case there are additional unknown - Lagrange multipliers, whose number is determined by the number of functions describing constraints [6].

The decision in this case reduces to finding the extremum unimodal functions, which can be carried out by known methods of numerical optimization.

In the particular case to solve a problem you can do without applying the method of Lagrange multipliers. This situation can occur when restricted to the parameters, or when the solution lies on the boundary.

In the process of solving a particular problem for the given numerical values of the source data must be analyzed size range of the desired function and the nature of her conduct.

4.2 Mathematical Problem Statement

Definitions and assumptions. During the preliminary microsatellite, as well as the preparation of the technical requirements for such apparatus there is a need to identify the best of its characteristics. At the same time seek to achieve significant savings: human, financial and material, while reducing development time machine.

This option appears when considering a new research direction in the design of technical systems: Unification, the theoretical foundations of which were developed by a group of authors [10]. It is believed that if 30% of the SC elements redesigned, it is new [11].

Parameter uniformity. In considering the approach to the formulation of project objectives with the Unification view of a need to introduce a parameter or parameters in general uniformity, ie in the selection or determination of such parameters, which would be "sensitive" and the quality of the microsatellite, and costs, and, if possible, at design time. In other words, we need to find a quantitative measure of uniformity. Thus, the parameter unification should be such that to him were "sensitive" the criteria by which to judge the level of the Unification expedient. Given that the mass element is decisive for the microsatellite with the fact that the mass of the satellite depends on the mass of the target hardware ceteris paribus, and the time of active life, and given the fact that many of the criteria of quality and costs in some way dependent on the mass, Unification parameter is proposed that the relative mass unifitsiruemyh elements

Criteria for Standardization. When deciding on the design of the microsatellite based unification should consider three criteria: the quality of the microsatellite, costs, design time.

The quality of the microsatellite. Much can be said about the quality of the microsatellite, but we can define this quality as achievable (if consideration the level of technology) the relative value of the payload. It is clear that compared microsatellites should be the same type and meet the same requirements on the nature of the task, the height of the orbit. And the same type of comparison involves microsatellites with the same intended purpose. It is clear that one machine that has a relative weight of the payload (ie the ratio of payload mass to initial mass microsatellite) more will have a smaller initial mass and, consequently, lower consumption of materials of both the microsatellite and its service units: transport , start, technology

How did unification affect this indicator of quality? Negative, ie The higher level of unification (we are not talking about the quantity of its terms), more than used the "old" elements, the worse it will be this figure. We can say that in terms of quality will be the best micro in which all elements are developed anew, at the present level of technology, using new materials and high-level design, and the worst - one in which all the elements (or the maximum number) are borrowed. If this criterion was the only one that would not be subject of study. However, there are other factors, the impact of unification which is different from its effect on quality. Consider these criteria.

Development costs. It is known that the cost of the development of advanced micro-tens of millions of rubles. Produced cost - is the cost of R & D, mass production because of the complexity of their calculation, using mass as the main parameter. In other words, the cost in mass production are directly related to mass. Therefore, when we consider that the other side, since the mass of unified elements than non-standardized, the costs will be higher. This duality property costs suggests that there must be some optimal level of unification a cost that meets minimum cost

The cost of removal of the microsatellite in the working orbit. The cost of removal of the microsatellite in the working orbit depend on the cost of services. If the solution of the problem and its analysis to consider not only development costs but the costs of removing micro into the working orbit, the character of the cost of unification can be changed in the sense that the best solution may be in the range considered parameter unification. This fact may complicate the solution of the problem.

The cost of services increases the weight of the microsatellite, but this dependence in the general case has a discrete character, but with a fair derivation is a smoothly increasing dependence on the mass of the cost of a microsatellite [6]. For example, the unit cost of removing the payload through existing vehicles at a fair derivation of 6000-11000 USD / kg [6].

The cost of removal at a fair derivation in the working orbit can be determined by the approximate formula:

$$C_{вывед} = C_{вывед}^{попут} m$$

where m - mass of the microsatellite.

Development time. This is an important criterion, and the extent to which it is - which determines the probability of the project, determines the complexity of the formulation of the problem. Analysis of the literature indicates that more or less practical model that links design time parameters microsatellite, no. It is easy to imagine that the refusal of the development of new elements can significantly reduce the time a satellite. That is why designers tend to use intuition all the past experience in new developments. Here's why projects that contain many new elements unnecessarily, often found themselves stranded.

In connection with the foregoing, the development of microsatellite problem arises of determining the optimal or efficient level of the Unification

4.3 Unification Problem Statement Options

If we have the necessary mathematical module development cost micro and mass production, as well as the removal of a microsatellite in the working orbit, we can put the following tasks (Fig 4.1 and 4.2).

The first task of unification: the minimization of development costs for a given satellite capacity. Find the optimal level $K_{ун}^{opt}$ of standardization, minimizing development costs and mass production C_Σ for the index is not less than the specified quality, ie find

$$C_\Sigma = \min_{\{K_{ун}\}} C_\Sigma$$

при

At

$$\mu_{ПН} = \frac{m_{ПН}}{m0} \geq \mu_{ПН}^{доп}$$

where $\mu_{ПН}$ - Quality microsatellite;

$m_{ПН}$- Relative weight of the payload;

$\mu_{ПН}^{доп}$- The minimum permissible value of the quality index microsatellite.

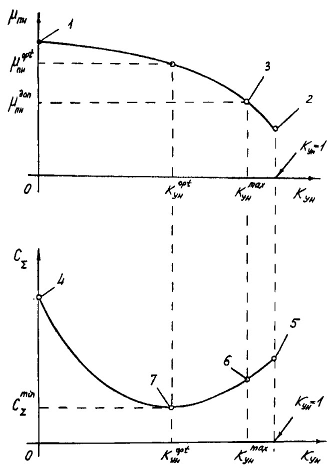


Figure 4.1 – Illustration to the first problem, unification

The graph in Fig. 4.1 illustrates the dependence of the quality level $\mu_{ПН}$ of the Unification of the microsatellite. This is a qualitative graph, and shows that with increasing degree of harmonization of the quality falls.

The point I gives the maximum value $\mu_{ПН}$, provided that all the elements of a microsatellite developed new ($K_{ун} = 0$), ie this "ideal" version of the microsatellite. In this case we have a maximum attainable value of the quality of the microsatellite ceteris paribus. Point 2 shows the importance of quality at the maximum level of the Unification ($K_{ун} = 1$). Although in general, the highest level of the Unification $K_{ун} = 1$ is unlikely, as there is doubt about the possibility of such an answer given by microsatellite specifications. The introduction of restrictions $K_{ун}$, $K_{ун}^{\max}$, ie task $\mu_{ПН}^{доп}$ - the minimum value of the quality index limits the degree of unification of its top value $K_{ун}^{\max}$ (point 3). Thus, the horizontal line limits the possible solutions to the upper half-plane.

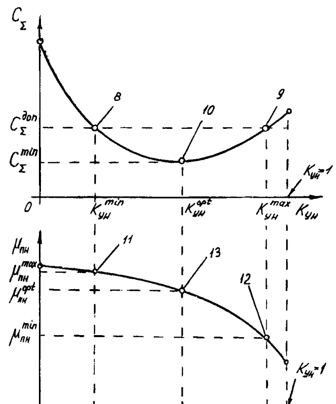


Figure 4.2 – Illustration of the second problem unification

Pic. 4.2 shows the qualitative dependence of the cost of developing and commercializing micro and into orbit C_Σ as a function of rate harmonization $K_{ун}$. As can be seen from the graph, the total cost with increasing degree of unification in the early fall and then rise, which causes weight gain due to the microsatellite, and therefore increase the cost in mass production and in breeding.

Point 4 on the chart with the maximum cost of development and mass production and launch of a fundamentally new microsatellite ($K_{ун}=0$); point 5 - the costs of development and mass production and removal of all or nearly uniform microsatellite.

The introduction of restrictions on narrowing $\mu_{ПН}$ the search area, as shown in point 6, corresponding to the maximum value $K_{ун}^{\max}$ from the previous schedule. Point 7 shows the minimum cost required to find variations by $K_{ун}$. With increasing $K_{ун}$, moving from point 4 will be a reduction in costs by reducing the amount of design work and experimental testing. However, a further increase in $K_{ун}$, beginning with some value, the rise of costs, which is associated with an increase in component costs - namely, the cost of mass production and excretion, which are directly dependent on the mass of the elements of the microsatellite and in general for the microsatellite of the increase in mass of each single unified element. Using previously obtained the boundary value $K_{ун}^{\max}$ from the previous graph, we build the border and thus find a point 6 and the range of possible solutions, which lies to the left of the border. In the graphs (see Pic. 4.1 and 4.2) also shows the optimum value $K_{ун}^{opt}$ that provides the minimum value C_{Σ} and the corresponding optimal value $\mu_{ПН}^{opt}$. It is possible that the optimal solution will lie on the boundary. It depends on the specific conditions and values $\mu_{ПН}^{доп}$. In the analysis of specific projects is established by trial calculations using the computer.

The second unification problem: maximization of quality for a given microsatellite development costs. Find the optimal level $K_{ун}^{opt}$ of standardization, which maximizes the quality of the microsatellite $\mu_{ун}$, with the costs of development and mass production and breeding, not to exceed specified $C_{\Sigma}^{доп}$, ie find

$$\hat{\mu}_{ПН} = \max_{\{K_{ун}\}} \mu_{ПН}$$

at

$$C_{\Sigma} \le C_{\Sigma}^{доп}.$$

This problem is the inverse of the first task of unification, discussed earlier. We return to the cost depending on the level of the Unification (see fig. 4.2). For a given (allowed) the level of costs $C_{\Sigma}^{доп}$ there are two points: the intersection of 8 and 9 graphics with a horizontal line corresponding to this level: the point 8, which gives the minimum acceptable level of unification $K_{ун}^{\min}$, which costs do not exceed specified. Below this level, you can not go down. This value is actually dictates the image of the base or initial version of the microsatellite, which lays the family subsequently upgraded and modified micro-ie beginning of the transition from one project to another while maintaining the most successful design and layout and design and technology solutions.

When we move from high-quality graphics to specific mathematical models and input data corresponding to the particular type of microsatellite, you will see that there is always a minimum level of harmonization is not equal to zero, ie even for the base case there is a certain level of unification. In other words, the "ideal" version of the micro, ie option premium also contains elements borrowed.

Point 9 corresponds to the maximum allowable level of unification $K_{ун}^{\max}$, from which further increases the degree of unification leads to increased costs. Thus, the optimal solution lies in the range $K_{ун}^{\min}$ from to $K_{ун}^{\max}$. This study, conducted in advance, you can limit the number of possible solutions, as well as faster and easier to find the optimal variant.

Turning to the graphics quality, we find two points: point 11 corresponds to the maximum allowable quality, and the point 12 - the minimum for a given level of costs.

As in the case of the previous problem, perhaps the best solution to the border.

Although in general, the solution, as is evident from the graph in Fig. 4.2 (point 10) lies between $K_{ун}^{\min}$ the before $K_{ун}^{\max}$.

Turning to Pic. 4.2, we find the point 13 - the optimum value of the quality of the microsatellite.

If in the investigator in addition to the two models of communication there is also a model describing the dependence of development time on the level of unification, we can formulate three challenges.

Third unification problem: minimize the cost of development as defined by the microsatellite and the timing of development. Find the optimal level of standardization $K_{ун}^{opt}$, minimizing development costs and mass production and excretion C_{Σ}, as in not less than the microsatellites $\mu_{ПН}^{доп}$ and timing of development does not exceed the permissible $T^{доп}$, ie, find

$$\hat{C}_{\Sigma} = \max_{\{K_{ун}\}} C_{\Sigma}$$

$$T \le T^{доп}$$

at

$$\mu_{ПН} = \frac{m_{ПН}}{m_0} \ge \mu_{ПН}^{доп}.$$

Additional restrictions narrowed the range of possible solutions and simplify the procedure for finding the optimal solution.

Fourth unification problem: maximizing the quality of the microsatellite for a given cost and development time. Find the optimal level of unification $K_{ун}^{opt}$, which maximizes the quality of the microsatellite at a cost to the development and mass production and excretion $\mu_{ПН}$, not exceeding the specified date $C_{\Sigma}^{доп}$ and do not exceed the permissible development $T^{доп}$, ie find

$$\hat{\mu}_{ПН} = \overset{\max}{\sup_{\{K_{ун}\}}} \mu_{ПН}$$

at

$$C_{\Sigma} \le C_{\Sigma}^{доп}, \quad T \le T^{доп}.$$

Fifth unification problem: minimize development time for a given microsatellite cost and quality. Find the optimal level of standardization $K_{ун}^{opt}$, minimizing development time T at a cost to the development and mass production and excretion not exceeding specified $C_\Sigma^{доп}$, and not as a micro-satellite below $\mu_{ПН}^{доп}$, ie find

$$\hat{T} = \max_{\{K_{ун}\}} T$$

at

$$C_\Sigma \le C_\Sigma^{доп} \text{ и } \mu_{ПН} = \frac{m_{ПН}}{m_0} \ge \mu_{ПН}^{доп}.$$

If the minimum value $K_{ун}^{\min} = K_{ун1}$ corresponds to the base case, practically corresponds $K_{ун}^{\min} = K_{ун2}$ to the last modernized version, after which the transition to an entirely new version, and the development of microsatellite repeats on $K_{ун}^{\min}$ to $K_{ун}^{\max}$, but on a qualitatively new level, and perhaps with new value $K_{ун}^{\min}$ and $K_{ун}^{\max}$

4.4 Application of the Lagrange Multipliers Method

The design process is necessary microsatellite in the mathematical formulation of the problem of optimization of its design parameters when there are several criteria that characterize the multilateral aspects of its design and operation. At the same time one of the criteria, such as the cost of development and mass production, is chosen as the core C_Σ, and other criteria, such as operational reliability, quality ($\mu_{ПН}$), informative (I), considered as a constraint. Then the problem of optimizing the design parameters can be formulated as follows.

Search

$$\hat{C}_\Sigma = \max_{\{a_i\}} C_\Sigma$$

at, $P \ge P^{доп}$, $\mu_{ПН} \ge \mu_{ПН}^{доп}$, $I \ge I^{доп}$

where a_i - the basic design parameters of the microsatellite.

The optimization problem mathematically microsatellite is a problem with constraints. LaGrange suggested that the problem with the restrictions be reduced to a problem without constraints by introducing additional unknowns - undetermined multipliers determined in the process of finding the optimal design parameters. For this purpose we introduce a new function

$$W = C_\Sigma + \lambda_1\left(P - P^{доп}\right) + \lambda_2\left(\mu_{ПН} - \mu_{ПН}^{доп}\right) + \lambda_3\left(I - I^{доп}\right).$$

When the extreme limits of the function C_Σ coincides with a saddle point.

Then the solution of the problem reduces to solving a system

$$\begin{cases} \dfrac{dW}{da_i} = \dfrac{dC_\Sigma}{da_i} + \lambda_1 \dfrac{dP}{da_i} + \lambda_2 \dfrac{d\mu_{ПН}}{da_i} + \lambda_3 \dfrac{dI}{da_i} = 0 \\ \dfrac{dW}{d\lambda_1} = P - P^{доп} = 0 \\ \dfrac{dW}{d\lambda_2} = \mu_{ПН} - \mu_{ПН}^{доп} = 0 \\ \dfrac{dW}{d\lambda_3} = I - I^{доп} = 0 \end{cases}$$

This technique allows to obtain optimal solutions to be optimized for different performance criteria for the microsatellite.

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