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STATE OF THE ART IN THE DEVELOPMENT OF ORBITAL INDUSTRIAL PLATFORMS

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Мета статті – проведення аналізу стану розробки орбітальних промислових платформ та її компонент. В статті запропоновано загальний вигляд базової орбітальної промислової платформи, яка складається з: основних несучих конструкцій, бортових систем, бортового комплексу керування, бортових сервісних пристроїв, приймальних доків, модуля первинної переробки, модуля вторинної переробки, промислового модуля та складального модуля. Проведено аналіз стану розробки основних складових модулів орбітальної промислової платформи. Проведено аналіз технологічних процесів в умовах вакууму та невагомості та визначено, що в умовах космічного простору можливо виробляти нові матеріали та речовини з кращими характеристиками у порівнянні із земними аналогами. Найбільший інтерес щодо розробки технологічних процесів в умовах вакууму та невагомості і необхідного для цього обладнання проявляють США, Росія та країни ЄС. Показано, що на початковому етапі розвитку орбітальних промислових платформ сировина для виробництва унікальних матеріалів може поставлятися с Землі. При подальшому розвитку технологій стане можливим використання космічних ресурсів. Орбітальні промислові платформи є новим класом технічних систем. Для розробки математичної моделі орбітальної платформи та її складових наведено її функціональну схему, на якій показано основні функціональні зв'язки елементів платформи. Проблема розробки орбітальних промислових платформ, будучи комплексною, має широкий спектр різних аспектів вирішення. У зв'язку з необхідністю розробки науково-методичного забезпечення процесу створення орбітальних промислових платформ, виник комплекс наукових і технологічних завдань, породжених особливостями зазначеної проблеми. Цей комплекс включає розробку нових класифікаторів, конструктивних схем, математичних моделей та методів проєктування базової платформи та її складових модулів.

Ключові слова: *індустріалізація космосу, великі космічні конструкції, орбітальна індустріальна платформа, технологічні процеси в космосі.*

The goal of this article is to analyze the state of the art in the development of orbital industrial platforms and their components. The article proposes the general arrangement of a base orbital industrial platform, which consists of main supporting structures, onboard systems, an onboard control system, onboard service devices, receiving docks, a primary processing module, a secondary processing module, an industrial module, and an assembly module. The state of the art in the development of the key component modules of an orbital industrial platform is analyzed, and it is concluded that space conditions make it possible to produce new materials and substances whose characteristics are improved in comparison with their earth counterparts. The most interest in the development of production processes in vacuum and zero gravity conditions is shown by the USA, Russia, and the EU countries. It is shown that at the initial stage of development of orbital industrial platforms raw materials for the production of unique materials can be supplied from the Earth. With further technological development, it will be possible to use space resources. Orbital industrial platforms are a new class of engineering systems. To develop a mathematical model of an orbital platform and components thereof, its functional diagram with the key functional links between the platform components is presented. The problem of orbital industrial platform development is complex, and thus it has a wide range of different aspects of its solution. The need to develop a scientific methodology for the process of orbital industrial platform development has given rise to a package of scientific and technological problems generated by the features of this problem. This package includes the development of new classifiers, construction arrangements, mathematical models, and design methods for a base platform and components thereof.

Keywords: *industrialization of space, large space structures, orbital industrial platform, production processes in space.*

Introduction. The actual level of consumption of land resources in the near future may lead to crises: food, energy, environmental, resource (oxygen, water, wood, soil, etc.), etc. To prevent the critical phase of the crisis, humanity needs to move to a new paradigm of world and national science. The solution to the most important problems, namely, energy and resources, can be found in the large-scale exploration of near space and its resources [1 – 4].

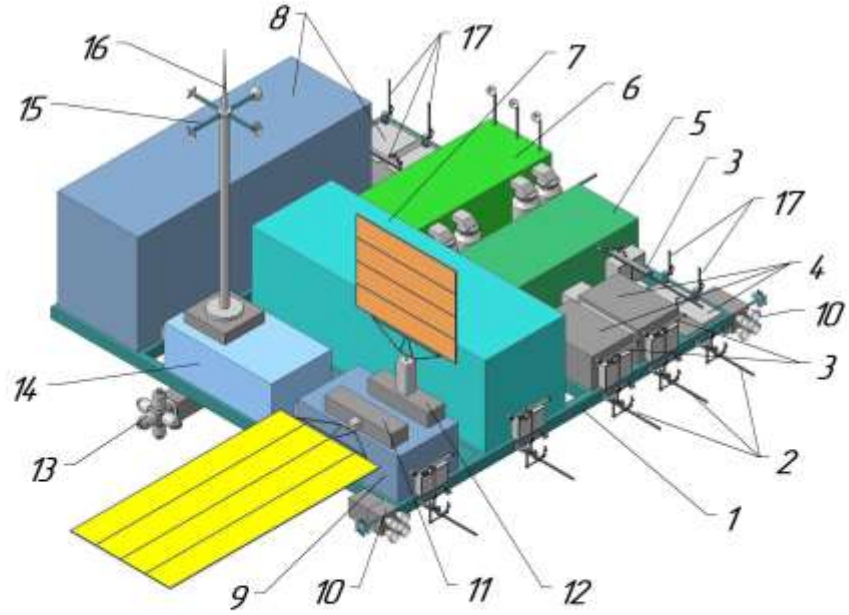
According to analysts at Goldman Sachs Group Inc (GSGI), explored metal reserves (EMR), such as platinum, copper and nickel, remain on Earth for no more than 40 years. This situation forces researchers to look for EMR resources in the currently accessible part of near-Earth space. In [5], GSGI called for the development of platinum mining in space. According to the results of the estimates, it is determined that the space complex will cost $ 26 billion to capture asteroids close to Earth. It is also determined that with the development of one asteroid, the pre-existing company can receive platinum worth $ 50 billion.

Further space exploration is limited by the difficulty of launching large dimensions and masses into orbit. Thus, at the initial stage of near-space industrialization, orbital industrial platforms can be placed in outer space.

1. General scheme of the orbital industrial platform. In general, the orbital industrial platform (OIP) contains:

– main supporting structures;
– onboard systems;
– onboard control complex;
– onboard service devices;
– receiving docks;
– module of primary processing of raw materials;
– module of secondary processing of raw materials;
– industrial module;
– assembly module.

In fig. 1 shows the appearance of the OIP.



1 – main supporting structures; 2 – docking bay of service spacecraft; 3 – remotely controlled cargo manipulator; 4 – receiving dock; 5 – module of primary processing of raw materials; 6 – module of secondary processing of raw materials; 7 – industrial module; 8 – assembly module; 9 – onboard systems; 10 – propulsion system; 11 – power supply system; 12 – thermoregulation system; 13 – manned spacecraft docking system; 14 – onboard control complex; 15 – telemetry control system; 16 – command radio line; 17 – remote-controlled manipulator, cargo crane boom.

Fig. 1

2. The main supporting structures of orbital industrial platforms. In [6] the most important elements of the design and features of the creation and operation of multifunctional expandable space systems, which include OIP, including those that have no analogues and prototypes, and are a necessary element of promising space infrastructure:

– considerable weight and dimensions of a design;
– modular principle of construction, reconfigurability;
– formation of the final form of the system for some time in accordance with a pre–designed strategy;
– maintenance of working capacity and change (expansion) of functionality at the expense of regular service, in particular by replacement of the unified blocks.

An example of implemented systems of this class is orbital stations [7 – 11]. Considering orbital stations as prototypes of space systems of the future, for example, orbital industrial platforms, it is necessary to note the important role of project continuity and the relevance of universal technologies.

Made In Space, Inc. develops the service spacecraft (SS) "Archinaut", which is a robotic 3D printer, and is designed for the manufacture and assembly of large structures in space [12]. SS "Archinaut" is planned to be used in the orbit of the James Webb space telescope. Final ground tests of all service systems are currently underway.

In order to ensure normal conditions for the execution of technological processes, when designing the OIP, it is necessary to determine the external and internal disturbances of the basic supporting structure of the platform.

External perturbations of the OIP are:

– aerodynamic resistance;
– indignation from the power of solar pressure;
– gravitational disturbances.

Internal perturbations of the OIP are perturbations caused by the operation of technological and auxiliary technological equipment.

When developing the design appearance of the main supporting structures of the OIP, it is necessary to solve the following tasks:

– development of a constructive scheme;
– development of a mathematical model of the force interaction of the main elements and modules of the platform structure;
– development of scientific and methodological support for the design of the OIP, which includes models and methods for determining its key parameters.

3. The module for primary processing of raw materials may include a system for identification, sorting and primary defragmentation of raw materials. At this stage of processing of raw materials, the classification and identification of the processed object by chemical composition and size is carried out. Next, primary defragmentation is performed; for these purposes, laser installations, various pneumatic or hydraulic shears, etc. can be used. After identification, classification and sorting, the defragmented object goes to the recycling module.

To design a module for primary processing (MPP) of raw materials, it is necessary to solve the following tasks:

– development of the design diagram of the MPP;
– determination of the overall mass characteristics of the MPP;
– determination of the dynamic characteristics of the technological equipment installed at the MPP;
– determination of the energy characteristics of the technological equipment installed at the MPP.

4. The module for secondary processing of raw materials includes devices for secondary defragmentation to the specified size of the fraction. At the stage of secondary processing, various furnaces for casting blanks can be used, as well as mills for grinding raw materials to the size of fractions necessary for the functioning of 3D printers.

To design a module for secondary processing (MSP) of raw materials, it is necessary to solve the following tasks:

– development of a constructive scheme of the MSP;
– determination of the overall and mass characteristics of the MSP;
– determination of the dynamic characteristics of the technological equipment installed on the MSP;
– determination of the energy characteristics of the technological equipment installed at the MSP.

5. Industrial module. On the industrial module, industrial technological equipment is installed for the manufacture of the corresponding products, on which various technological processes can be implemented, the output of which are structural elements of space technology objects, as well as new substances.

It is possible to single out the main types of technological processes that, under vacuum and zero gravity, will make it possible to obtain products with unique microstructures and technological properties: biomaterials and biological products for various purposes, including pharmaceuticals; structural elements based on additive technologies; unique semiconductor materials and optical fibers; specific products of space metallurgy, synthesis of polymers with special properties, etc.

5.1. Production of biomaterials and bioproducts in space. At present, space biology is being widely developed, and various directions in biotechnology are being developed. There are some areas of research in this area:

– study of the influence of outer space on living organisms and cells, to ensure further long-term space missions;

– creation of unique biomaterials and bioproducts in outer space, which, after the necessary refinement, can be used to create unique medical preparations.

For decades, the International Space Station has experimented in these two directions. To ensure long-term interplanetary missions, experiments are being carried out:

– "Bioemulsion" [13 – 15], the purpose of which is to create probiotic preparations under orbital flight conditions, are more effective for long-term space missions;

– "Magnetic 3D-bioprinter" [16, 17], the purpose of which is to study the possibility of formative three-dimensional biofabrication of tissue constructs, is carried out by the method of self-assembly of living tissues and organs in microgravity using a magnetic field created by permanent magnets;

– “BioFabrication Facility” [18, 19], the purpose of which is to develop the technology of 3D printing of organopodifiable tissues in outer space using a 3D bioprinter from Techshot Inc., which will make it possible to produce entire human organs in space in the future.

Experiments are carried out to create unique medicines:

– "Astrovaccina" [20], the purpose of which is the cultivation in zero gravity of E. coli – the producer of the Caf1 protein, which in the future will make it possible to create new drugs, including those for AIDS and a number of tumor diseases.

– "Antigen" [21], the purpose of which is to formulate the principles of increasing the productivity of producer strains, the stability of their expression and optimization of the production of vaccines against hepatitis B;

– "Aryl" [22], the purpose of which is to ensure the process of creating a drug of genetically engineered alpha-2 interferon, which is used to treat many diseases – hepatitis B and C, herpes, hairy cell leukemia, Kaposi's sarcoma, acute candidaloma, kidney cancer;

– "BIF" [23], the purpose of which is to obtain probiotics with improved biomedical performance and increase the efficiency of their production;

– "Vaccine-K" [24], the purpose of which is to obtain crystals of a candidate protein for vaccines against human immunodeficiency virus (HIV-1) in microgravity in order to determine the atomic structure with high resolution, which will create a more advanced vaccine against AIDS.

5.2. Manufacturing in space using additive technologies. One of the areas of production in space is the use of additive technologies for 3D printing of structural elements.

The Italian space agency ASI has created a portable on-board 3D printer POP3D, which was launched into orbit in 2015 [25]. The compact cube printer measures 25 cm and weighs 5.5 kg. For printing structural elements, biodegradable types of plastic are used, using the method of so-called "fused filaments". It usually takes about half an hour to make one plastic part on a POP3D printer, which was subsequently returned to Earth for detailed testing, including comparison with an identical part printed on the ground.

The Made In Space company, which owns a number of patents devoted to production in outer space, namely, the processing of materials [26, 27], the manufacture of optical films [28, 29], metal casting [30], space additive 3D printing technologies [31 – 35], the processing of space resources [36, 37], proposed to manufacture spacecraft on the ISS using 3D printing technologies [38].

To reduce the cost of obtaining material for production in space, Tether Unlimited Inc (TUI) is developing ways to process polymeric materials such as plastic and metal waste on board the ISS to create feedstock for additive and subtractive manufacturing [38]. In 2018, TUI installed a payload called Refabricator [39] aboard the ISS to demonstrate closed-loop recycling and 3D printing of plastic parts, and the company is currently working to develop metal recycling and manufacturing technologies for NASA's FabLab »For use in orbit with only manufactured critical parts.

From this brief overview, it is clear enough that additive technologies are developing at an accelerating pace.

5.3 Production of semiconductor materials in space. Successful flight tests of the WSF orbital installation [40] in space during the space missions of the Space Shuttle program STS-60, STS-69 and STS-69 proved the economic efficiency of obtaining semiconductor structures in outer space in comparison with ground-based technologies.

In works [41 – 43] by the Institute of Semiconductor Physics named after AV Rzhanov SB RAS proposed a project of an orbital industrial platform for the industrial production of new high-quality semiconductor materials in orbital flight conditions, where it is in principle possible to obtain products (single crystals and heteroepitaxial structures) of a higher quality than in terrestrial conditions.

5.4. Optical fiber production in space. Through years of in-house research and development funded by private sources, Made In Space (MIS) has gained the expertise to successfully manufacture large quantities of high quality optical fiber [44]. MIS is partnering with Thorlabs, an industry leader in ZBLAN optical fiber preforms and terrestrial materials, to rapidly industrialize optical fiber production in space. Optical fiber ZBLAN, which is made with the involvement of the space environment based on fluorine, can reduce signal transmission losses by up to 10-100 times, compared to a similar fiber manufactured under terrestrial conditions.

5.5. Space metallurgy. As you know, the most widespread method of obtaining solid metals and alloys under terrestrial conditions is crystallization from the liquid phase. In the conditions of outer space, it becomes possible to grow crystals from vapors of substances with the help of its inherent vacuum and weightlessness.

5.5.1 Foundry in zero gravity. In [45], the main types of foundry production under zero gravity conditions are given:

– casting of spheres;
– casting of thick-walled hollow balls;
– casting of thin-walled hollow balls;
– adhesive multilayer casting.

One of the promising areas of space metallurgy is the casting of spheres. So in work [45] it is noted that due to the excess of surface tension forces of the force of gravitational attraction, it becomes possible to obtain spheres close to ideal, with a diameter of up to 20 mm. Also in this work [45] it was shown that the process of casting spherical balls can be performed by the pushing method followed by magnetic (or ultrasonic) suspension of the melt.

It is also noted in [45] that, in addition to casting balls of an ideal shape, there are ample opportunities for casting objects of axisymmetric shape, for example, for the manufacture of optical lenses.

The use of the technology of casting thick-walled hollow balls can be used to manufacture high-pressure cylinders in outer space [45].

Casting thin-walled balls in zero gravity allows the bearing balls to be elastically deformed, which will ensure self-regulation of the bearing under load and compensate for deviations in angular and axial dimensions, and, according to various estimates, will extend the service life up to 8 times [45].

With the help of adhesive multilayer casting in outer space, it is possible to carry out sequential pouring into the matrix of materials differing not only in density (there will be no mixing of layers), but also, which is no less important, in the melting point [45].

In [46], the results of ground experiments of vacuum solar metallurgy, solar powder metallurgy of titanium, solar surface treatment of titanium and titanium welding are briefly examined. It is shown that the results obtained can be used to create melting furnaces for use in outer space, namely on the Moon, Mars and the main asteroid belt.

5.5.2 Growing crystals in zero gravity. As is known, the main method for obtaining solid metals and alloys under terrestrial conditions is crystallization from the liquid phase. In the conditions of outer space, because of the inherent vacuum and weightlessness, it becomes possible to grow crystals from vapors of substances.

There are basic methods of growing crystals in outer space [45]:

– method of growing crystals from melt on seed crystals;
– method of directional crystallization;
– crucible–free smelting method;
– growing single crystals from the vapor phase.

The use of space conditions for growing crystals makes it possible to create crystals with a lattice of a more ideal shape, which significantly increases their efficiency.

When developing an industrial module (IM), it is necessary to solve the following tasks:
– to develop a constructive scheme;
– to determine the overall and mass characteristics;
– to develop a technology for assembling technological equipment at the IM;
– to determine the requirements for the on-board control complex to ensure the implementation of technological processes at the IM;
– to determine the composition and requirements for auxiliary technological equipment;
– to develop a technology for storage on board the production facility and delivery of finished products to the consumer.

6. Assembly module. In the assembly module, the corresponding products are assembled from the elements made in the IM. When developing an assembly module for an OIP, it is necessary to solve the following tasks:
– to develop a technology for assembling space objects in vacuum and zero gravity;
– to develop a methodology for setting up and testing computer facilities and equipment of the assembled space object in vacuum and zero gravity;
– to develop a methodology for testing space objects at OIP.

7. Sources of raw materials for orbital industrial platforms. At the initial stage of the development of orbital OPPs, raw materials for the production of unique materials can be supplied from the ground, for example, a silicon charge for growing semiconductors in orbit. With the further development of technologies, it will become possible to use space resources.

The company for the development of space resources – Planetary Resources Inc (PRI) was one of the first to declare that the purpose of its creation is to utilize the resources of near space [47]. PRI is developing small spacecraft of the Arcyd series, which will be equipped with orbital telescopes for observing celestial bodies, in particular, for asteroids close to Earth, which could be potentially suitable for resource development [48] – [51].

Deep Space Industries is also working on the creation of technological equipment for the capture and processing of asteroids [52].

In the United States, under the leadership of the Institute of Space Research named after V. M. Keck is developing a project for the capture, transportation and disposal of a small asteroid [53].

Made In Space Inc. was proposed a method of extraction and processing of space resources in situ, for example, on an asteroid, has been proposed [54]. The method also includes the ability to manufacture elements of a reentry spacecraft using additive technologies from resources recycled on site, for example, a container for returning samples, elements of the spacecraft body, and elements of a heat shield.

At present, according to various estimates, there are about 7000 tons of CO in space orbits [55]. In connection with the above, it makes sense to consider the existing space debris (CM) as one of the types of near space resources [1 – 4]. It is assumed that some of the CM can be stored and processed directly in orbit. The proposed view of CM leads to the need for its utilization for further use.

8. On-board systems include the onboard control complex, power supply system, thermoregulation system, onboard service devices, docking systems.

8.1. The onboard control complex includes an on-board control system, a motion control system, a telemetry control system, and a command radio line.

When designing an on-board control system for the OIP, it is necessary to solve the following tasks:

– determination of system level requirements for platform management modes;
– selection of the type of platform management;
– determination of external and internal platform disturbances;
– selection of the type and parameters of the platform control system;
– development of algorithms for monitoring and controlling the orientation of the platform.

8.2. Power supply system. Carrying out technological operations on OIP in the conditions of vacuum and weightlessness will demand considerable expenses of the electric power. The energy module, by analogy with orbital stations, can be made in the form of solar panels, power management system and battery system, to compensate for electricity in the shadow area of the orbit. In case of insufficient energy, solar space power plants (SSPP) can serve as an additional source of energy. In the long run, these could be nuclear energy sources.

The SSPP concept was first formulated and presented by Dr. Peter Glaser [56]. More than half a century has passed since the concept was put forward until our time. During this time, developed space countries have developed a number of SSPP projects.

Artemis Innovation Management Solutions LLC has developed the "SPS-ALPHA" SSPP project as part of NASA's Innovative Advanced Concepts Program [57]. The Project conducted a cross-cutting systematic analysis of the concept, which was proposed to determine its technical feasibility, determine the architecture of the concept and conduct an initial assessment of the economic viability of the proposed SSPP concept. The SSPP power range for energy delivery to Earth is 100 MW-100 GW. The Project proposed four main SSPP design schemes to provide orbital space infrastructure:

– SSES CommSat, made in the form of two symmetric circular solar concentrators with an area of 300 m^2 each, the mass of the entire system is 3 tons, the power is 8 kW;
– SSES CommSat-ALPHA, made in the form of a flat hexagon, consisting of hexagonal elements, the total area of the solar concentrator is 180 m^2, the mass of the entire system is 3 tons, the power is 8 kW;
– SSES CommSat-ALPHA, made in the form of a flat hexagon, consisting of hexagonal elements, the total area of the solar concentrator is 600 m2, the mass of the entire system is 6 tons, the power is 16 kW;

– SSES CommSat-ALPHA, made in the form of a flat hexagon, consisting of hexagonal elements, the total area of the solar concentrator is 1200 m^2, the mass of the entire system is 12 tons, the power is 32 kW.

In [58], the following SKES layout schemes were proposed the SSES circuit with the panel is formed using unified: 1) hexagonal modules; 2) tetrahedral modules; 3) structures, pneumatically hardened; 4) flexible unfolding photoconverters, based on solar sail technology.

The first and third schemes will have an expected capacity of 170 kW, the second 80 kW, and the fourth 300 kW.

The People's Republic of China plans to launch the SSES prototype into geostationary orbit by 2022 [59]. The research laboratories of Chongqing are engaged in the development of this station. After the technology has been tested on the prototype, commercial production of space electricity is planned by 2050.

When designing an energy module (EM) of an OIP, it is necessary to solve the following tasks:

– determination of requirements for EM;
– selection of the type and parameters of the power source;
– selection of the type and parameters of the energy storage unit;
– determination of requirements for regulation and control of EM;
– development of a method for choosing the parameters of EM of OIP.

8.3. Thermoregulation system. The thermal control system (TCS) of the OIP must provide a temperature regime for the normal functioning of all modules and subsystems of the platform. Thus, when designing this system, it is necessary to solve a number of problems:

– determination of requirements for TCS of OPP;
– development of the structural scheme of TCS;
– development of a mathematical model of the functioning of the TCS;
– assessment of the impact of external and internal sources of thermal radiation of the OIP;
– development of a design method for TCS of OIP.

8.4. On-board service devices include mechanized and robotic means of servicing the orbital platform, for example, remotely controlled manipulators, cargo boom cranes, service spacecraft, etc.

Space Logistics LLC, a subsidiary of Northrop Grumman, for the period 2020-2021. performed a series of successful flight tests of service spacecraft [60]. Service spacecraft MEV-1, the purpose of which is the approach, docking and docking with spacecraft, whose active life is over, for refueling them with rocket fuel, was successfully launched into orbit and docked with the Intelsat IS-901 spacecraft 25 February 2020 [60]. And already on April 15, 2021, another MEV-2 SS was launched into orbit, which was docked with the Intelsat IS-1002 spacecraft [60]. This confirms the technical feasibility of creating service spacecraft for servicing orbital industrial platforms.

For the transport support of the OIP, it is necessary to develop a design appearance of the service spacecraft, intended for its maintenance. When developing the design of the service spacecraft, it will be necessary to solve a number of tasks:

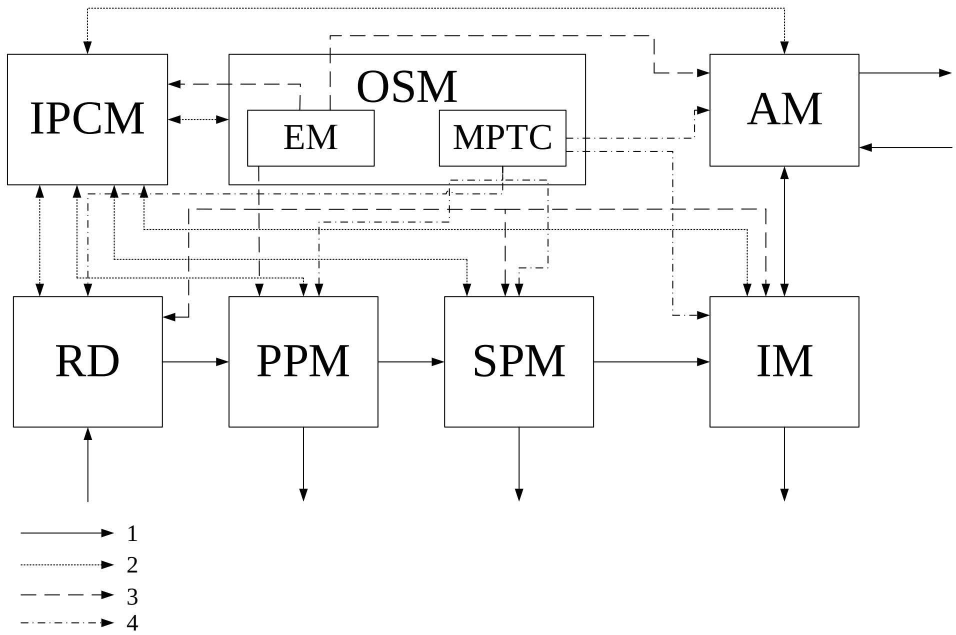
– development of a constructive scheme;
– determination of overall and mass characteristics;

– development of a method and device for mooring to the receiving docks of the platform;
– development of a technology for storing manufactured products at a production facility and delivering it to a consumer;
– development of technology for moving cargo on the platform
– development of a mathematical model of functioning;
– development of a method for selecting design parameters.

The receiving docks should be equipped with systems for docking and docking with service spacecraft. To capture, fix and dock the service spacecraft with the OIP, it is necessary to develop the design appearance of the receiving docks, for this it is necessary to solve the following tasks:
– development of a structural diagram of a device for gripping, fixing and docking service spacecraft with OIP;
– determination of overall and mass characteristics;
– development of a method for selecting design parameters.

9. Functional scheme of the orbital industrial platform. At the initial stage of developing a mathematical model for the functioning of the basic OIP, it is necessary to determine the functional connections of the main elements of the platform.

The functional diagram of the basic OIP is shown in Fig. 2.



1 – cargo traffic; 2 – communication and control channel; 3 – power supply line; 4 – line for ensuring the thermal regime; IPCM – industrial platform control module; OSM – onboard systems module; EM – energy module; MPTC – module for providing thermal conditions; RD – receiving dock; PPM – primary processing module; SPM – secondary processing module; IM – industrial module; AM – an assembly module.

Fig. 2

10. Conclusion. Rocket and space science and technology have come close to the next stage of industrialization of space – mass production in space of various types of products for the needs of the space industry. For the implementation of mass production in space, there is a need for the development and creation of orbital industrial platforms.

When developing a qualitatively new system, development occurs at different stages from an idea, a concept and a phenomenological concept of a future system to the development of an industrial product. OIP is a new class of technical systems. Thus, their design, like the design of any complex system, begins with the definition of one or common goals and restrictions and is aimed at ensuring their implementation at the lowest possible cost. This stage is referred to in the literature as the concept development stage or conceptual design stage.

The problem of developing the OIP, being complex, has a wide range of different aspects of solving this problem. For this reason, in connection with the need to develop scientific and methodological support for the process of creating an OIP, a complex of scientific and technological problems arose, generated by the peculiarities of this problem. These include the following tasks:

– development of a classifier and classification of technological processes in vacuum and zero gravity, existing orbital platforms for various purposes, technological and auxiliary equipment to be placed at the OIP. Determination of their overall mass characteristics, energy characteristics. Formulation of the basic requirements for the installation and operation of this equipment on the platform;

– development of the structural diagram of the OIP body;

– development of a logistics scheme for raw materials and finished products manufactured at the OIP. Development of a structural diagram and a method for designing a service spacecraft for servicing the OIP;

– development of a mathematical model of the force interaction of the main elements and modules of the platform structure;

– development of scientific and methodological support for the design of the OIP, which includes models and methods for determining its key parameters.

– assessment of manufacturing features and assembly of the components of the OIP under ground conditions. Development of options for mounting OIP in orbit;

– development of a methodology for a feasibility study of the process of creating and deploying OIP.

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