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Міністерство освіти і науки України
Шосткинський інститут Сумського державного університету (ШІ СумДУ)
41100, м. Шостка, Сумська обл., вул. Гагаріна, 1
тел. (05449)4-28-28, факс (05449)4-01-76, E-mail: info@ishostka.sumdu.edu.ua

«ЗАТВЕРДЖУЮ»
Директорка інституту, к.ф.н.

_____________ Наталія ТУГАЙ

ЗВІТ
З НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Створення демонстраційного макету для моделювання на ньому принципу роботи космічної сонячної енергостанції

ПРОЕКТ КОСМІЧНОЇ СОНЯЧНОЇ ЕНЕРГОСТАНЦІЇ З ТЕПЛОВОЮ СИСТЕМОЮ ПЕРЕТВОРЕННЯ
(проміжний)

Наукові керівники
кан. пед. наук, доцент Ю. М. Мар'їнських

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РЕФЕРАТ

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Об'єкт дослідження — об'єктом дослідження є розробка та створення проекту КСЕС з надпровідним генератором, теплової системи перетворення.

Мета — Створення проекту космічної сонячної енергостанції нового класу з високим значенням коефіцієнту корисної дії в якості альтернативи існуючим проектам перетворення сонячної енергії в механічну і електричну.

Методи дослідження — теоретичне дослідження джерел на предмет створення моделей проектів космічних сонячних електростанцій теплової системи перетворення повного спектру сонячного випромінювання в корисну роботу . Використання статистичного методу, графічного та аналітичного.

У роботі розглянуто наукова і практична значимість розроблених проектів космічних сонячних енергосистем гіроскопічного і циклічного функціонування що представлені в контексті короткого знайомства з раніше розробленими фірмами «Боїнг», «Рокуелл Інт» за програмою НАСА. З'ясована основна проблема в розробці проектів космічних сонячних електростанцій (КСЕС).

З'ясована складність розрахування вартістості виробництва необхідної кількості фотоперетворюющого матеріалу і робочих елементів з нього. Показана відсутність однозначності у вартості одного кіловата електроенергії, виробленої орбітальної КСЕС з урахуванням ресурсу фотоелементів в умовах космосу. Ці фактори, а також проблеми реалізації проектів теплових КСЕС, дають підстави знову переглянути традиційні методи перетворення теплової сонячної енергії в КСЕС.

Розглянута модель конструкції електростанції що передбачає створення і розміщення на ній високотехнологічного виробництва з регульованою гравітацією, що дозволяє не використовувати двигуни і газотурбінні установки, систему наведення, а також холодильник-випромінювач, маса якого становіть близько половини всієї маси КСЕС. Їх

роль виконують теплоперетворюючі робочі модулі, які рухаються в круговій тунельній порожнині «теплової пастки», що має прозору поверхню з низько емісійним покриттям. Доводиться аргументоване пояснення назви Гіроскопічної космічній сонячній енергостанції а також високотемпературних надпровідників і жароміцних і легких конструкційних матеріалів з вуглець композитів що значно покращують її енергетичні та масогабаритні показники.

ЗМІСТ

INTRODUCTION

Nowadays the projects of solar power satellites (SPSs) are much discussed. One of the key issues in the development of these projects is to choose the right solar energy conversion system, which allows producing the necessary amount of power. All solar thermal conversion systems of SPSs known by the present day and based on closed-cycle gas turbines and steam turbines work on Brayton and Rankine cycles faced by such companies as Boeing and Rockwell International [1].

1 GAS TURBINE CONVERTERS, THEIR ADVANTAGES AND DISADVANTAGES IN SPACE ENERGY

Gas turbines have lower internal efficiency than steam turbines, but the advantage of steam turbines is that the non-aggressive working fluid in them is single-phase. Thus, the projects of solar thermal conversion systems with gas turbines [2], which can generate 10 GW of power on an Earth-based receiving rectenna, include 40 modules of approximately 500 MW output capacity each. As a result of the changes [3,4],the number of these modules has been reduced to 4 and one more solar tracking system has been added to trap the reflected solar radiation at the entrance of the receiver. This system cannot solve the task of solar tracking, as near resonant mechanical vibration will appear while SPS's working, which will negate the desirable effect. The mechanical vibration will be transmitted through the conversion system of SPS that will probably cause the collapse of some big and massive parts of the system. This paper does not deal with this issue. Furthermore, the weight of the cooling system, which is 61729 thousand tonnes, comprises 30% of the total weight of the solar energy conversion system. Sometime later the4-module project of SPS was modified: the number of energy modules was increased to 16, a parabolic faceted concentrator [5], the dimensions of which in the plan view was 2057x 2910 m, was added. On each of the cylindrical heat receivers, 4 gas turbines with electric generators were adjusted.

2 A VARIANT OF THE ELECTROCHEMICAL METHOD FOR DIRECT CONVERSION OF HEAT INTO ELECTRICITY

Another project of SPS with liquid metal steam turbines was developed by Rockwell International Company [1]. The advantage of this project is the lower requirement for preciseness of reflection from the solar collector. In the article [6], an additional scheme to the well-known method of thermodynamic conversion of solar energy into electrical energy is considered in the framework of the thermal cycle “high temperature electrolytic steam decomposition on the components (H2 and O2) + electrochemical generation by the way of the water recombination from H2 and 02 in the low temperature fuel cell". It greatly complicates the design of the power plant, increases its mass and dimensional characteristics and its concentrator, and increases the likelihood of an explosion. Although the new version [7] of the electrochemical method for the direct heat conversion into electric power in the «concentrator – thermal cycle» block. Performed the calculation of the efficiency of the new electrochemical cycle modification at t1 = 1000oC with the steam electrolysis under reduced pressure (0.1 atm) and electrochemical generation under increased pressure (10 atm).In the comparative analysis of studies [8] on the conversion of solar energy SPS shows the prospects of thermodynamic method over photovoltaic. It provides for the use of modern materials and advanced technologies in the design of the SPS project, take into account the useful world experience [9, 10] of the development and operation of solar thermal power plants under terrestrial conditions. Global trends for the future of solar energy indicate the need to create renewable energy projects. [11, 12]

3 THE UNIQUE FEATURES OF THE GYROSCOPIC SPS WITH NEW TCS AND SUPERCONDUCTIVE GENERATOR, AND ITS

GSPS with the new TCS and superconductive generator (here and elsewhere GSPS) consists of two functional parts: the first one, which is the heat conversion part that collects the energy of solar radiation and converts it to mechanical energy with the help of a heat converter (module), and the second one, which converts the mechanical energy into the electricity with the help of a superconductive generator.

Among the properties of the GSPS, one of its distinctive features is low costs of its creation due to relatively cheap constituents compared to the photoconverting SPS, for which the heterostructure (multilayer) CIGS flexible solar batteries based on Cu (InGa)Se2 are considered to be suitable. It is not possible to save the large-area surfaces of such expensive photoconverters from the destructive impact caused by electrons, protons and meteor showers. The concept of reducing the area of the photoconverters along with increasing the concentration of solar radiation with the pointing accuracy of ± 1.5 °Cin [14] does not solve the problems of the heat sink and the control of gigantic concentrators in contrast to the gyroscopic SPS, where there is no need in a separate pointing system and the external housing of the heat receiver chamber protects the cylinder from radiation fluxes.

4 PRINCIPAL DESIGN FEATURE

The main unique feature of the GSPS project, considered in this paper, is its belonging to a new class of GSPSs, which will be able to convert the solar radiation into mechanical work and the work into electricity in the necessary proportions. The project of the GSPS includes the possibility to place and create a high-technology production on it with controllable artificial gravity.

The distinctive feature of construction makes it possible not to use steam turbines and gas turbines, as well as a radiator, the weight of which is about a half of the total weight of SPS with the solar thermal conversion system [1-2]. Their function is performed by the heat conversion surfaces of modules housings with load-bearing members, resisting a slowly fluctuating load. The modules move inside a round tunnel cavity of a “thermal trap”, which has a transparent surface with low-emissivity covering. Through this surface, an intense concentrated flux of solar radiation enters the thermal trap. Less intense infrared radiation, emitted by the heated module housing with the load-bearing members and the working fluid in the chamber, all situated in the thermal trap, leaves it through the transparent surface with low-emissivity covering [15]. It is possible to use metal vapour, steam or gas as the working fluid.

The high efficiency of the GSPS, its low weight and small dimensions are reached due to the use of widely produced second-generation high-temperature superconductors (HTS), the phenomenon of superconductivity, as well as the lightweight heat-resistant construction materials based on carbonaceous composites [16,17,18,19]. The combination of a high-temperature receiver with low-temperature superconducting circuits of the generator, situated behind the thermal shield, gives an opportunity to set in space conditions the necessary temperature regime for them during their whole lifecycle. All the thin-walled cylindrical bars, assemblies and joints of the load-bearing frames of the generator superconducting circuits, as well as those parts of the power plant, which are not shaded from the thermal radiation, are covered with a light-reflecting material. This removes the temperature anisotropy of the construction elements, causing their heat expansion and contraction.

5 THE MAIN PARTS OF THE GSPS WITH THE NEW TCS SUPERCONDUCTIVE GENERATOR

The power plant consists of 4 parts. The first is a heat conversion part. It consists of the active volume modules with the working fluid, situated one by one in a circle in the cavity of the tunnel thermal trap and rigidly connected with each other by plane elements (Fig. 2). While rotating, this part moves in the tunnel thermal trap, fixed with respect to the sun. The trap, which is the heat receiver, is situated in the focal region, which is in its turn situated around the circumference above the concentrators. The part of the circle, which remains free, and therefore the number of modules (from one to three), not situated above the concentrators outside the thermal trap (i.e. in the heat radiation zone), is calculated taking into account the power plant weight, dimensions and capacity.

The second part comprises the superconducting generator, which is a synchronous electric machine. The allowable current density in the high-temperature superconductor windings can tens of times exceed the current density in the windings of hysteresis machines. That is why the great current in the excitation winding of the superconductor generator shall make it possible to generate magnetic fields of about several teslas. In this case, the dimensions are being reduced significantly, since they are inversely proportional to the product of the allowable current density by the magnetic field induction. As a result, the material consumption is decreasing, which shall decrease the weight-and-dimensional parameters and determine the structure compactness of the superconductor generator with a low-capacity cry system, because its structure will be in the shading area with already low temperature along the perimeter or in the centre of GSPS. The high magnetic field induction in the spacing between the rotor winding and the stator winding shall make it possible to reduce the current density in the stator winding, in order to create the same shaft torque value that leads to reduction of the electric loss and to increasing of the efficiency factor.

The last part of the power plant is a hermetic room with the working, engineering and utility services area, situated above the load-bearing frame of the GSPS in addition to technological equipment, this area may contain special devices and radiating equipment necessary to increase the charge density in the plasma of the nearby space and then affect it with alternating pulse electric field for the orientation and partial relocation of the power plant, which is a sun-oriented gyroscopic system(Fig.2).

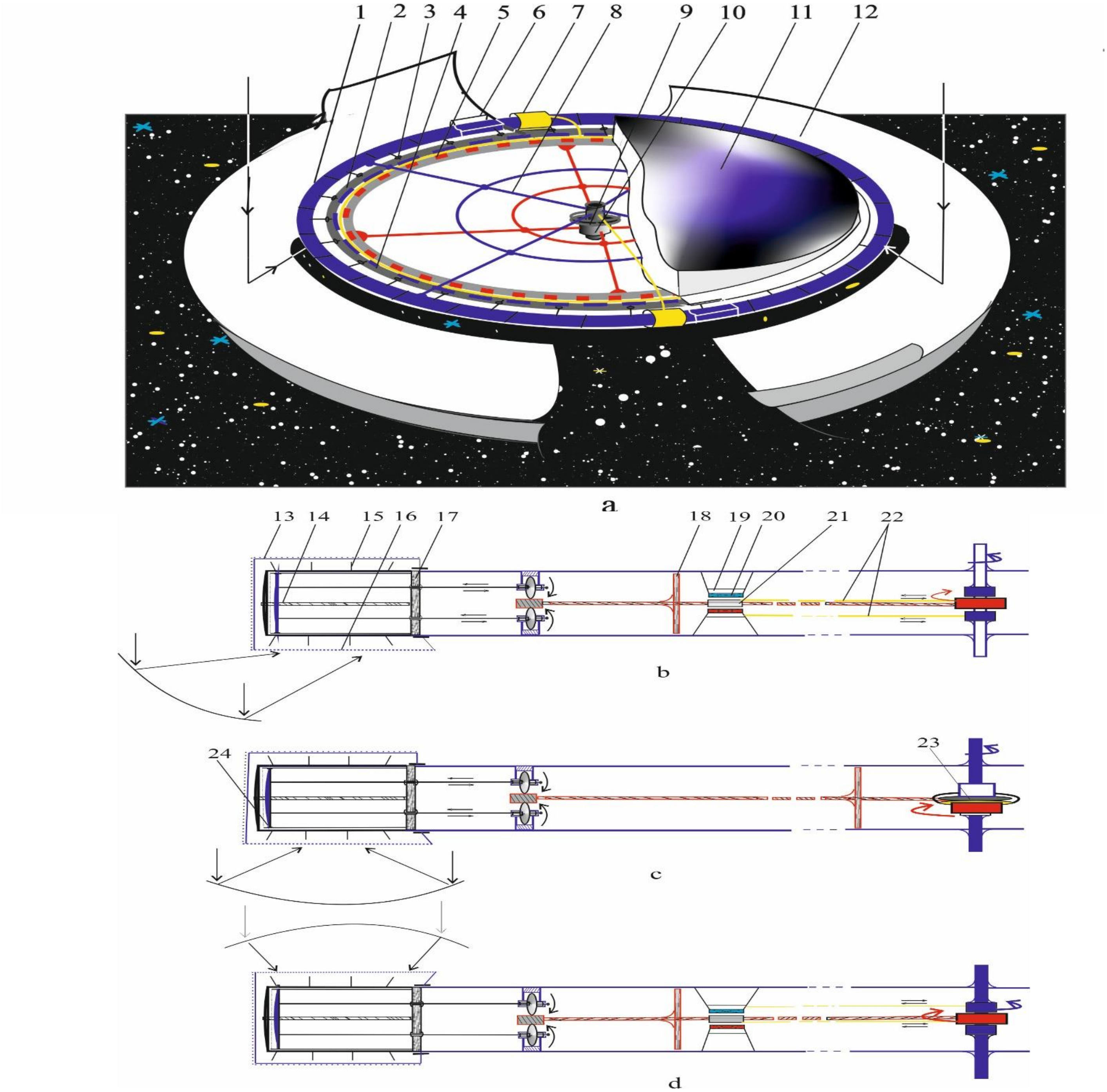

Fig.2. The schemes of the GSPS with concentrators: a and b – on the periphery of the heat receiver, c – under the heat receiver (in this case the diameter of the engineering area is made smaller to increase the area of solar radiation incident on the concentrator; this decision allows to get some additional symmetric solar radiation flux from the two sides of the concentrator onto the heat receiver), d – above the heat receiver in the form of an inflatable lens.

1 – load-bearing frame with the heat conversion modules, rotating anti-clockwise; 2 – load-bearing frame of the superconducting rotor; 3 – the docking mechanism of the kinematic constraint between the module rod and the guide, made of carbon composite. The docking mechanism converts the translatory motion of the rod into contra-rotation of 1 and 2. Taking into account the fact that the rod stroke has the same duration as the cycle, in order to get the needed number of working cycles per turn, it is necessary to alter the contours' moments of in ertia; 4 – the superconducting loops of the rotor circuit, between these loops there is a cavity, through which the refrigerant circulates; 5 – the superconducting winding on the load-bearing frame of the stator circuit or the winding made of a cryogenic conductor, between which the rotor circuit is situated; 6 – the rigid tunnel cavity of the thermal trap with the return mechanism, fixed in front of it, necessary to return the rod, which has completely extended from the module, to its initial position, and thus to return the working fluid to its initial state; 7 – the cylindrical housing assembly of the cooler, in the lateral cavity of which the refrigerant circulates. The lateral surface of the housing assembly fully covers the module, moving at the end of the heat radiation zone, except for the distance, necessary for the rod stroke. It cools the working fluid down to the steam condensate temperature or to a similar gas condensate temperature. As a result, minimal work is done to return the working fluid to its initial state; 8 – the stator load-bearing frame, one part of which is rigidly connected to each module housing and the opposite part is connected to the shaft in the power plant centre with the help of a sleeve; 9 – the cryostat, providing the refrigerant circulation through the cavity of the superconducting generator circuits 4, 5 and through the cooler housing assembly 7; 10 – the superconducting generator instead of 4 and 5, this variant of the GSPS design provides low superconducting material consumption as well as simple production and layout of the superconducting generator, that has already been assembled on Earth, in its centre. This variant, depending on the type of the conductor, may allow going without the cryogenic system; 11 –the technologic housing surface, consisting of film solar cells, serves as a direct-

current power source in the circuit of magnetization of the rotor superconducting loops; 12 – the solar concentrator; 13 –heat reflective surface of the thermal trap; 14 – plane connecting elements of the modules; 15 – thin carbon composite ribs; 16 –low-emissivity transparent covering, deposited by magnetron sputtering on the film; 17 – thermal shield; 18 – heat reflective foil; 19 – the cavity for refrigerant circulation, situated above the stator windings; 20 – stator winding; 21 – rotor winding with the cavities for refrigerant circulation; 22 – circulation cavity of the refrigerant; 23 – cryostat; 24 – piston.

This variant of the power plant (Fig. 3) is the most effective, compact and less resource-consuming. This variant implements the idea of converting the whole incident flux of the solar radiation onto the concentrator, considering the fact that it has “windows”, through which the heat from the modules, moving over them without the thermal trap in the so called heat-radiating zone, is being “relieved”. Upon completion of the motion, the working fluid in it and in the cryostat is transferred to the initial state.

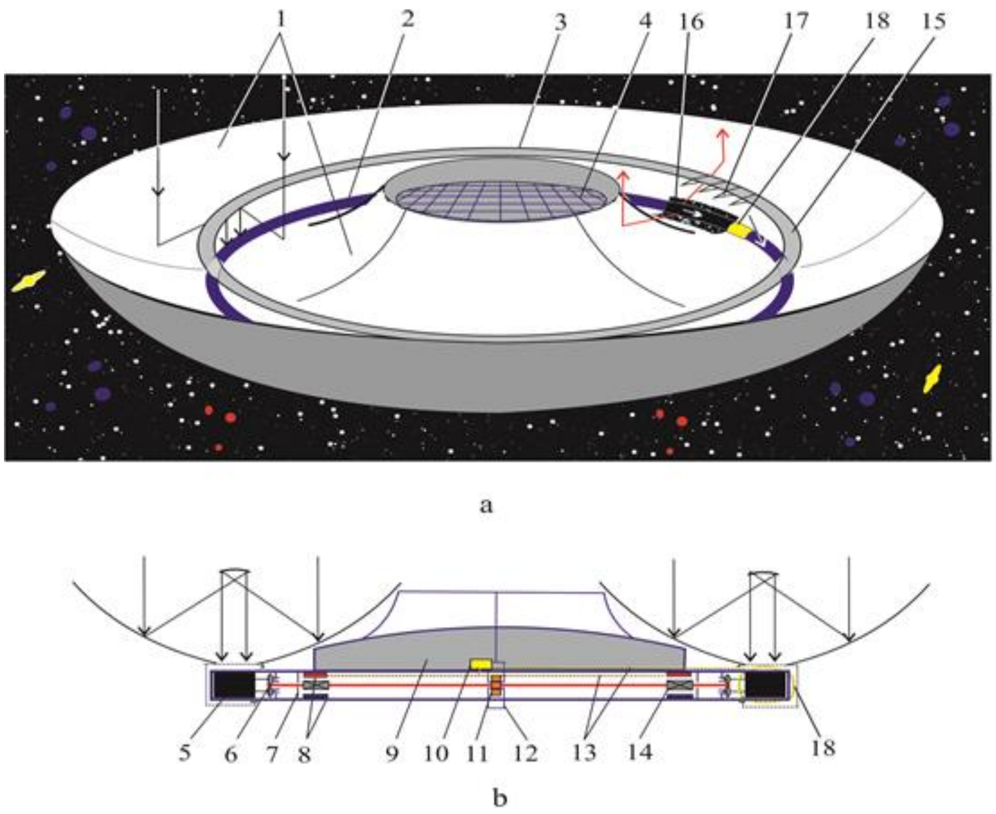

Fig.3. The GSPS and the compound film concentrator of solar radiation above the heat receiver (a), the power plant cross-sectional view (b).

1 – parabolic concentrator; 2 – heat conversion modules contour; 3 – parabolic concentrated solar radiation reflector; 4 – solar cells; 5 – heat conversion module; 6 – docking mechanism of the kinematic constraint; 7 – protecting thermal shield, made of foil; 8 – stator winding; 9 – engineering area; 10 – cryostat; 11,12 – the shaft of the stator and rotor load-bearing frame; 13 – refrigerant circulation circuit; 14 – superconducting rotor coils; 15 –counter-reflector; 16 – modules moving in the heat-radiating zone (depending on the size of the power plant there may be several such zones with a re-radiation system); 17 - reflecting system for concentrated solar radiation falling onto the surface of the thermal trap behind the cryostat 18, where after the working fluid with the piston in the module are transferred to the initial state.

CONCLUSION

Two basic designs GSPS include placement of production facilities in the center of a special purpose equipment and transmission to Earth. The prospect of heat conversion system substantiated using high-tech materials of construction and the superconductor technology functioning in space, uniformity constituting safe to micrometeor flow and radiation of which GSPS necessary power is formed, and also the possibility of manufacturing and testing of the experimental sample in the vacuum chamber with cryogenic technology and in space. By changing the shape of the hub, it is realized the possibility GSPS placing on the moon

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