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THERMOELECTRIC GENERATOR USING TEMPERATURE DIFFERENCES IN LUNAR SOIL

The paper investigates the possibilities of creating a thermoelectric generator on the Moon. The temperature and thermal conditions in the lunar soil are analyzed. The specific power, weight and cost of such a generator are calculated. A thermoelectric generator and solar batteries are compared under the conditions of their use on the Moon.

Key words: thermoelectric ground generator, Moon, design.

Introduction

General characterization of the problem. The progress of mankind is related to constant search and improvement of technologies that provide it with new opportunities both on Earth and in the exploration of the surrounding outer space. Scientists' views have long been aimed at colonizing the nearest planets of the solar system. The first step for this is an attempt to create a space base on the surface of the nearest satellite of the Earth – the Moon.

Ensuring the operation of the lunar base is connected with the needs of its power supply with electrical energy. The main sources of energy currently known to mankind are divided into renewable - energy of the Sun, wind, hydropower of rivers, internal heat of the Earth, and non-renewable - fossil mineral fuel and nuclear energy. For obvious reasons, not all of these sources can be used on the surface of the Moon.

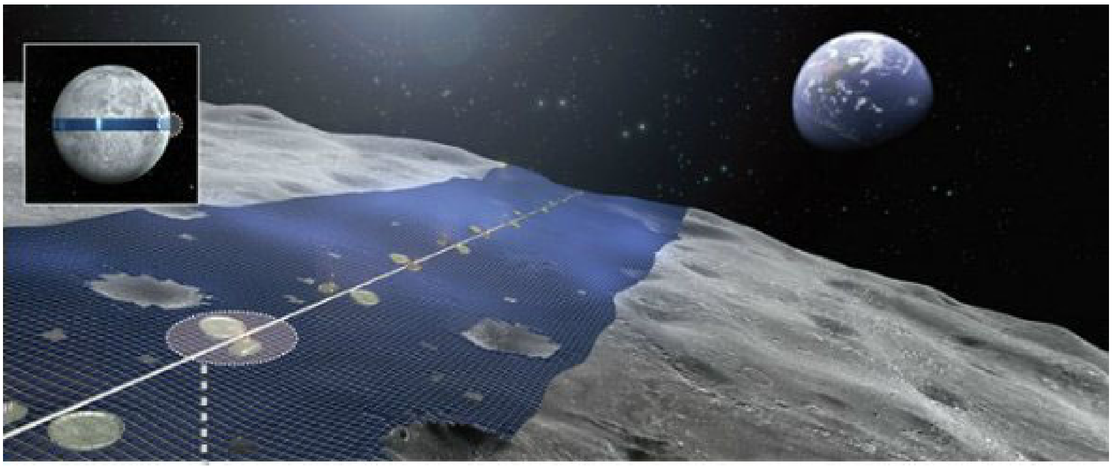

Fig. 1. A variant of a solar power plant on the surface of the Moon, proposed by the Shimizu Corporation of Japan [1].

One of the most interesting sources in this context is the energy of the Sun. For its conversion, solar batteries are used, which with a conversion factor of 10 – 30 % provide good opportunities for generating electrical energy (Fig. 1). However, they also have a number of disadvantages. This is, in particular, a relatively short service life, especially in conditions of harsh cosmic radiation, dependence on the presence of solar radiation (lunar "day" and "night"), as well as relatively large mass and size indicators, which significantly increases the cost of implementing such a project.

An alternative method of energy conversion is the use of temperature differences in the lunar soil, which arise as a result of the thermal action of solar radiation, through thermoelectric energy conversion [2]. Such generators have already been developed and operate in the Earth conditions [3 – 5]. They have a long service life (about 30 years), low weight and dimensions, and are also resistant to mechanical loads and cosmic radiation, which is especially important in the conditions of this task. The characteristics of such thermoelectric converters largely depend on the magnitude of the temperature difference in the soil. Under the conditions of the Moon, the temperature difference in the meter-long near-surface layer of the soil is about 164 K (surface temperature + 127 °C, temperature at a depth of 1 m – 37 °C) for the lunar "day" and 136 K (surface temperature – 173 °C, temperature at a depth of 1 m – 37 °C) for the lunar "night". These are much more favourable indicators for thermoelectricity than for similar generators on Earth (near-surface temperature differences in the Earth's soil range from several to ten degrees).

Therefore, the purpose of this work is to study the possibilities of creating a thermoelectric generator that uses differences in the lunar soil.

Generators using temperature differences in the Earth

The Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine has developed a series of ground-based thermoelectric generators (GTEG), which have been successfully operating for decades and provide power to various low-power devices, including special-purpose equipment, protective and security systems, electronic devices of autonomous weather stations, etc. (Fig. 2). The specific power of such thermogenerators is about 5 W/m^2 at a temperature difference of < 10 K.

The physical model and diagram of the operating principle of a thermoelectric generator using soil thermal energy are shown in Fig. 3.

Fig. 2. Appearance of GTEG Altec-8027.

The thermoelectric generator located in the soil consists of a heat-receiving collector 1, a heat pipe 2, a highly efficient multi-element battery 3, a heat sink 4, a radiator 5, a body 6 and thermal insulation 7. The operating principle of the thermogenerator is as follows: the heat flow q, present in the soil, falls on the heat-receiving pad 1, is led to the hot junctions of the thermopile 3 by the heat pipe 2, is led to the radiator 5 by the heat pipe 4 and dissipates into the lower layers of the soil. To reduce heat loss, the body 6 of the thermogenerator is filled with heat-insulating material. As heat passes through the thermopile, a temperature gradient is created thereupon, which leads to the generation of electric power W. It should be noted that during the day, the direction of heat flow may change to the opposite. This allows you to use such a converter not only during the day, but also at night, when there is no direct flow of solar radiation to the Earth's surface.

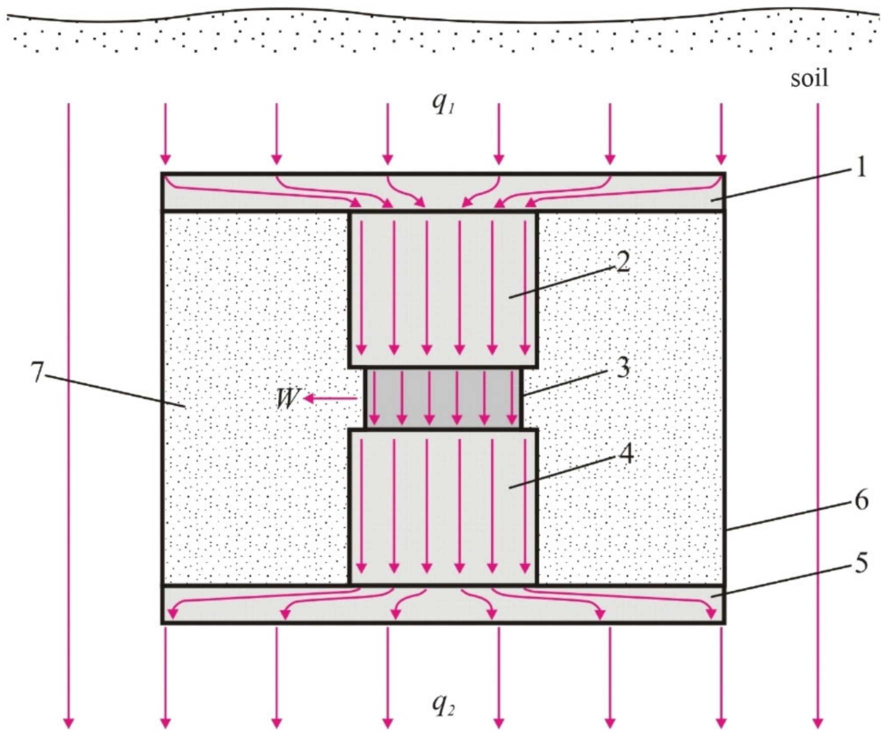

Fig. 3. Physical model of a thermal generator located in soil.

The specified physical model, with regard to some differences, can be used to describe a thermoelectric generator on the Moon.

Using the idea of a ground generator on the Moon

As mentioned above, the temperature conditions in the meter-long near-surface layer of the lunar soil are as follows:

- for a lunar "day"

surface temperature + 127 °C;

temperature at a depth of 1 m – 37 °C;

- for a lunar "night"

surface temperature – 173 °C;

temperature at a depth of 1 m – 37 °C.

Such a temperature difference is favorable for thermoelectric conversion of energy, therefore, during the design of the generator, the conditions of equality of thermal resistances of GTEG and the specified layer of the lunar soil were ensured.

Fig. 4 shows a physical model of a thermoelectric generator on the surface of the Moon.

The source of heat for the generator is the flow of solar radiation q_1, which hits the surface of aluminum foil 1 with a special selective coating that provides the best absorption of thermal energy. The aluminum foil serves as a heat energy concentrator to the legs of thermoelectric material based on bismuth telluride (*BiTe*) *n*-2 and *p*-3 type of conductivity. The aluminum concentrator 4 serves to divert the thermal energy q_2 from the thermoelectric material to the lunar soil. The gap between the aluminum plates is filled with a vacuum, and heat flux q_{loss} takes place in it by radiation. To reduce it, a thin mirror plate 5 was introduced into the generator design. The figure shows an elementary section of such a generator for one pair of thermoelectric material legs.

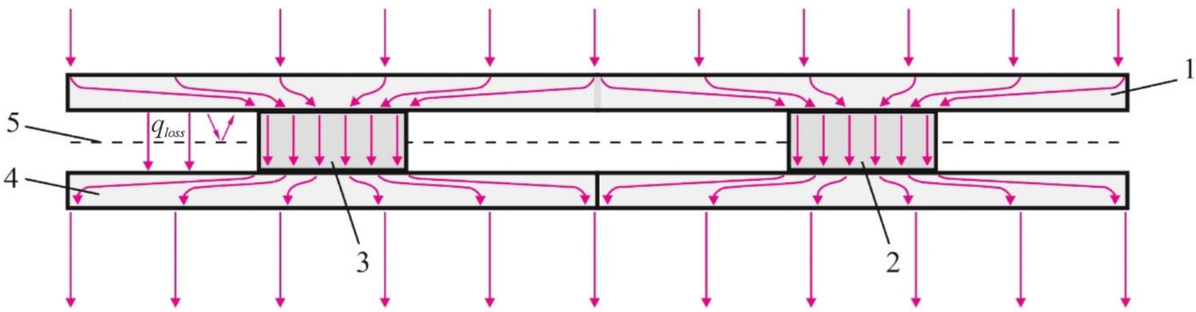

Fig. 4. Physical model of a thermal generator located in lunar soil.

According to the proposed physical model, the design of the generator was calculated, as well as its specific indicators. Calculations were performed using computer simulation methods using the Comsol Multiphysics application program package.

The dimensions of the heat concentrator were determined from the conditions of ensuring the uniformity of the heat flow at the minimum possible thickness. Therefore, the calculated thickness of the heat concentrator is 50 μm.

In addition, an evaluation of heat losses in the gaps between heat concentrators by radiation was carried out. They make up ~ 16 % of the amount of useful heat flow and lead to a decrease in the efficiency of energy conversion. To reduce them, a thin mirror plate (5 in Fig. 4) was introduced into the generator design, which allows to reduce losses to 7 %, and the introduction of two similar plates reduces heat losses to 5 %.

Thus, the final design of the GTEG based on 1 m^2 of the Moon's area is as follows:

- number of thermoelectric material legs – 3124;
- height of legs – 2 mm;
- cross section of legs – 1 x 1 mm;
- thickness of heat concentrators – 50 μm.

In this case, under the conditions of a lunar "day", the electric power generated by GTEG is W_e = 96 W/m^2 (for comparison, the solar generator version produces electric power W_e = 100 W/m^2).

The specific power of the generator in relation to its mass is W_p = 230 W/kg (for comparison, the solar photovoltaic generator has a specific power of W_p = 21 W/kg).

Consequently, in terms of energy indicator, GTEG is on the same level as photovoltaic solar, but has a 6-fold lower specific gravity, which is important given the significant costs of delivering cargo to the Moon. In addition, the operating life of the GTEG is up to 30 years, which significantly exceeds the capabilities of a solar generator, whose resource is 5 – 10 years.

In addition, unlike a photovoltaic solar generator, GTEG can be used in the conditions of the lunar "night", while the electric power generated by it will be $W_e \approx$ 10 W/m^2).

Peculiarities of using the ground generator at the poles of the Moon

An important factor in the use of a thermoelectric generator on the Moon is the geographical location of the lunar base.

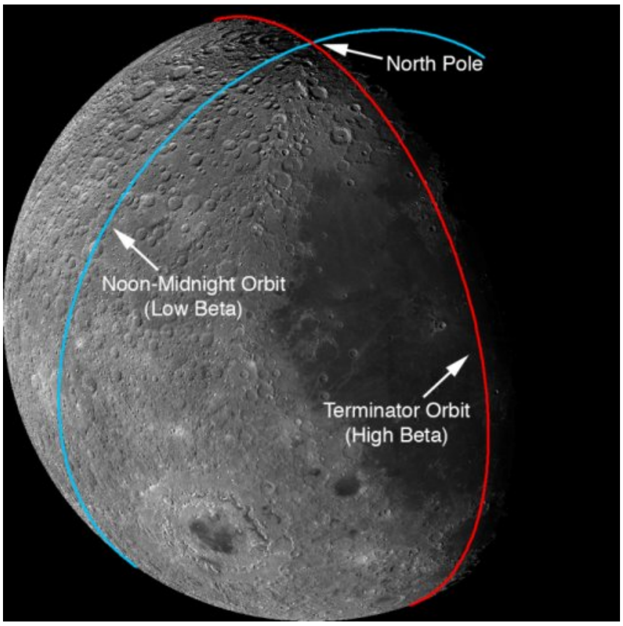

Fig. 5. Photo of the Moon [6].

In the case of the location of the lunar base at the poles, there are some peculiarities related to the angle of incidence of solar radiation on the surface of the Moon. The solar rays at the poles fall tangentially to the surface, which significantly changes the temperature and thermal conditions in the thickness of the lunar soil. On the other hand, lighting conditions at the poles of the Moon are more stable than in the equatorial zone.

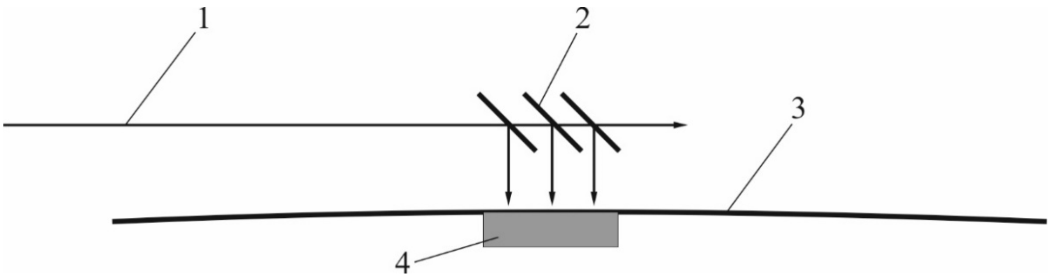

Fig. 6. Location of a thermoelectric generator at the pole of the Moon: 1 – solar rays, 2 – guiding elements, 3 – the surface of the Moon, 4 – thermoelectric generator.

Under such conditions, the use of the thermoelectric generator design proposed above is impossible. The way out of this situation is to use guiding elements in the GTEG design that provide the necessary conditions for the functioning of the generator. Fig. 6 shows a schematic representation of the guiding plates located on the surface of the Moon in the pole area.

Conclusions

1. The possibility of creating a thermoelectric generator using the temperature difference in the lunar soil has been confirmed.
2. It has been calculated that under the conditions of a lunar "day" the electric power generated by the GTEG is $W_e = 96$ W/m^2.
3. It has been determined that the specific power of the generator in relation to its mass is $W_p = 230$ W/kg.
4. It has been established that a thermoelectric generator under lunar night conditions can develop a power of up to $W_e \approx 10$ W/m^2.

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ТЕРМОЕЛЕКТРИЧНИЙ ГЕНЕРАТОР, ЩО ВИКОРИСТОВУЄ ПЕРЕПАДИ ТЕМПЕРАТУР У МІСЯЧНОМУ ГРУНТІ

У роботі виконано дослідження можливостей створення термоелектричного генератора на Місяці. Проаналізовано температурні і теплові умови у місячному ґрунті. Розраховані питомі потужність, вагу і вартість такого генератора. Здійснено порівняння термоелектричного генератора і сонячних батарей в умовах їх використання на Місяці.
Ключові слова: термоелектричний ґрунтовий генератор, Місяць, проектування.

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