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Thermoelectric Generators Current Intensifiers

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The materials of the article included the following questions: operation of the FLEXTEG module in the thermoelectric generator mode; effects accompanying the thermoelectric generator and its current-voltage characteristic; the discussion of the results. The energy balance of thermal currents is estimated using the Seebeck and Thomson effects, as well as electric currents in the circuit – Peltier, and Joule-Lenz when changing the direction of their circulation. An isotropic design of a module of heat and power generators installed on an envelope flexible plate with different weights is obtained, which increases before the inflection line and decreases after it; in this case, the properties of semiconductors are independent of their location on the flexible plate. A reduction in the influence of a traveling electromagnetic bending wave on its deformation in a flexible plate has been achieved by distributing the weight of thermoelectric generators on the surface of the plate. The main factors influencing the properties of semiconductor materials and operating parameters of thermo-electric generators are estimated. The current-voltage characteristic of a thermoelectric generator with patterns of change in the intervals of voltage (0-6.0 V), current strength (0-1.4 A), power (0-4.0 W) at various temperature gradients (5, 0-105 °C), while the efficiency of thermoelectric generators was 84.0 %.

Keywords: Semiconductor thermoelement, Thermoelectric generator, Current strength and voltage, Power, Volt-ampere characteristic.

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1. INTRODUCTION

The greatest development in recent years has been the work on thermoelectric, thermionic and magnetohydrodynamic methods of converting thermal energy into electrical energy, and the thermoelectric method is the most developed. At present, thermoelectric generators with a power of several watts to several kilowatts have been developed and are being operated, manufactured and designed. They are designed for "small power" and have such unique qualities as complete autonomy, high reliability, ease of operation, durability, as well as high specific energy and weight characteristics. They are used to supply power to objects remote from power lines, as well as in conditions where only modular thermoelectric generators can be the only possible one.

2. ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

In [1], to maintain the optimal value (efficiency parameter) in PbTe, carriers of only one sign are used, electrons, the concentration of which is determined by the concentration of dopants.

It is noted that materials based on Bi_2Te_3 with a large temperature difference in the legs of a thermoelement have a significantly lower overall efficiency parameter than its maximum value. It is recommended to maintain the latter, close to the maximum, at each point of the branch by changing the composition of materials along its length of the thermoelement [2].

There are at least two possibilities for increasing the efficiency of thermoelements using a variable concentration of charge carriers: optimizing the efficiency parameter Z at each point of the branch in the operating temperature range [3] and using the distributed Peltier effect [4].

The use of the distributed Peltier effect is considered one of the promising ways to increase the efficiency of thermoelectrics. The implementation of this idea involves a number of difficulties associated with mathematical modeling, determining the optimal distribution of the concentration of charge carriers, leading to the maximum efficiency of the branch, manufacturing a branch with an optimal distribution of the concentration of charge carriers. Since practically used thermoelectrics are doped n- and p-type semiconductors, then usually only majority charge carriers are considered during optimization. It is assumed that their concentration can be changed by doping with the corresponding impurities in a very wide range of its concentration, without taking into account their own charge carriers. This gives rise to the temptation to completely compensate for the Joule-Lenz heat using the distributed Peltier effect [4, 5].

In [5], it is indicated that determining the optimal impurity inhomogeneity profile is a complex mathematical problem, some methods for calculating the temperature profile of a thermoelement leg are listed, and technologies for creating inhomogeneities are considered.

Real low-temperature thermoelectrics with high efficiency do not have a wide band gap, so it is also necessary to take into account intrinsic charge carriers [6, 7].

As shown in [3], in the optimized branch with full Joule-Lenz heat compensation, the electrical conductivity at the cold end of the branch is 2 orders of magnitude higher than at the hot end, and the modulus of differential thermoelectric power is 4 times lower.

In [8], thermoelectric heat transfer intensifiers in friction pairs of brakes, mounted in their friction elements, were used. However, the dependencies were not taken into account: the temperature of the friction pairs of the brake

(T_1) on the temperature of the hot junction of the thermoelectric cooler (T_0); cooling efficiency of the brake friction pairs ($T_1 – T_0$) on their heating temperature (T_1).

Thermoelectric generators are considered in [9]. However, it did not pay attention to modular sources of conversion of thermal currents into electrical ones.

The work [10] is devoted to the Japanese FLEXTEG module presented in the form of a flexible plate with miniature thermoelectric generators operating in the mode of converting thermal energy into electric current. However, in the latter, as applied to the envelope plate, the traveling electromagnetic bending wave, which affects the performance of thermoelectric generators, was not taken insto account.

The operation of the FLEXTEG module in the thermoelectric generator mode, as well as the effects accompanying the thermoelectric generator and its current-voltage characteristic.

Justify the performance of a thermoelectric generator of a given design and indicate its main shortcomings.

3. OPERATION OF THE FLEXTEG MODULE IN THE THERMOELECTRIC GENERATOR MODE

Thermoelectric generators are a promising source of electricity generation from a relatively low-temperature environment (up to 150 °C) of thermal energy. Developments in this area have existed for quite a long time, but their wide distribution was hindered by the lack of available technological solutions – with the possibility of packaging thermoelectric generators in minimum building volumes.

Let us consider the operation of a thermopile in the mode of a thermoelectric generator (Fig. 1).

When heat is supplied to the connecting bridge 3, its temperature increases compared to the temperature T_0 of the cold ends of the rods 1 and 2 ($T > T_0$), the thermal energy of the atoms of the hot end of the semiconductors increases. This energy does the work of transferring electrons to a free state. In this regard, more free electrons appear in rod 1 at the hot end and with higher thermal energy than at the cold end. Therefore, they move to the cold end, charging it negatively. Due to the thermal motion of the atoms in rod 2, some of the electrons are carried away from the hot zone. In their place, free (unoccupied) places appear – holes with a positive charge. The direction of movement of holes as positive charges coincides with the direction of the electric field, so their movement is accelerated. The vacated places (holes) can be filled by electrons having energies close to those of a hole. But the electrons moving against the electric field slow down and move to a zone of lower speeds, and new holes form in their place. Thus, the holes move to the cold end of the rod 2, and it becomes positively charged. When the electrical circuit 4 is closed, an electric current appears in it, due precisely to the temperature difference. In fact, the Seebeck effect takes place, and the thermopile itself is a thermoelectric generator. Thermopile-thermoelectric generators are installed in friction linings 2 of the running branch 5 of the brake band 3. In this case, before the start of braking, the temperature of the thermopile junctions is the same and equal to the ambient temperature.

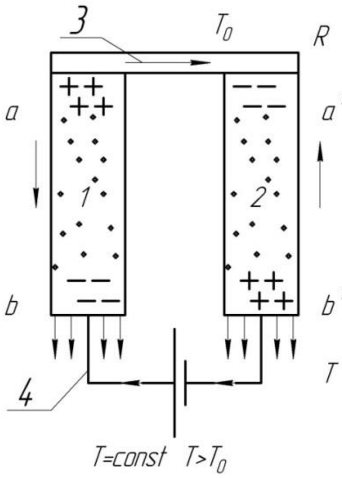
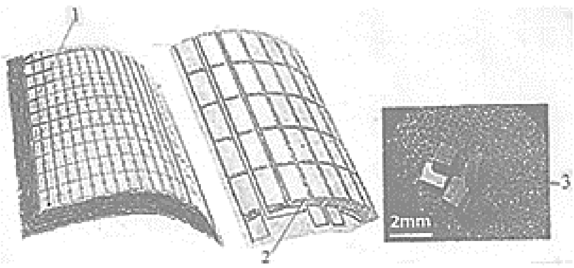


Fig. 1 – Battery of thermoelectric generator: 1, 2 – rods of conductors; 3 – connecting bridge; 4 – electrical circuit

When heat is supplied to the connecting bridge 3, its temperature increases compared to the temperature T_0 of the cold ends of the rods 1 and 2 ($T > T_0$), the thermal energy of the atoms of the hot end of the semiconductors increases. This energy does the work of transferring electrons to a free state. In this regard, more free electrons appear in rod 1 at the hot end and with higher thermal energy than at the cold end. Therefore, they move to the cold end, charging it negatively. Due to the thermal motion of the atoms in rod 2, some of the electrons are carried away from the hot zone. In their place, free (unoccupied) places appear – holes with a positive charge. The direction of movement of holes as positive charges coincides with the direction of the electric field, so their movement is accelerated. The vacated places (holes) can be filled by electrons having energies close to those of a hole. But the electrons moving against the electric field slow down and move to a zone of lower speeds, and new holes form in their place. Thus, the holes move to the cold end of the rod 2, and it becomes positively charged. When the electrical circuit 4 is closed, an electric current appears in it, due precisely to the temperature difference. In fact, the Seebeck effect takes place, and the thermopile itself is a thermoelectric generator. Thermobatteries-thermoelectric generators are installed in friction linings 2 running branch 5 of the brake band 3. In this case, before the start of braking, the temperature of the thermopile junctions is the same and equal to the ambient temperature.

If, on the contrary, along a circuit, all elements of which are in the same temperature conditions ($T = T_0$), pass an electric current in the direction indicated in Fig. 1, then the free electrons in the semiconductor rod 6 acquire a directed movement from junction a to junction b, and this movement is slow, since the electrons are decelerated by the electric field. The movement of electrons from junction a to junction b is accompanied by energy transfer. At the junction a, electrons, taking away the energy of atoms, acquire kinetic energy. At the end in, colliding with the atoms of the crystal lattice of the semiconductor, they give off energy to the specified junction. As a result, junction a cools and junction b heats up. Moreover, the accumulation of electrons at junction B contributes to the fact that this junction is charged negatively, and junction a is positively charged.

In rod 2, which has hole conductivity, the direction of the electric current coincides with the direction of movement of holes: from junction a' to junction b'. As a result, the holes are accelerated. As noted above, the formed vacancies can be occupied by electrons with an energy level close to the hole energy. Therefore, the most intense movement of electrons is observed at the junction in'. Here, electrons, colliding with atoms, increase their internal energy spent on heating this junction. As one moves from junction b' to junction a' along the thermoelement 2 branch, the energy of electrons decreases and their further movement is accompanied by the internal energy of atoms, as a result of which junction a' cools. The accumulation of electrons on this junction causes its negative charge; while the junction in' is positively charged. Thus, passing a direct electric current through a thermopile leads to a temperature difference at its junctions. At the junction a', heat is absorbed, called the Peltier heat; at the junction at', heat is released. If heat is constantly removed from the hot junction of a thermopile, then very low temperatures are obtained at its cold end (Russian patent No. 2134368)



a b c

Fig. 2 – Photo (a) and schematic representation of the FLEXTEG module (b), photo of semiconductor crystals (c) based on bismuth telluride (Bi_2Te_3)

Let's proceed directly to the design features and operation of thermogenerators embedded in the FLEXTEG module (Fig. 2a, b) [10].

For fastening small microcircuits, a unique design was used, which made it possible to place 250 semiconductors with the *n-p* type of conductivity on sections of 50 × 50 mm (Fig. 2c). At the same time, thermoelectric semiconductor chips 1 (Fig. 2 a) were placed on a flexible plate 2 and provided a reliable parallel connection of the electrical connection. Thus, an isotropic structure was obtained, in which the properties of semiconductors are independent of the direction of their location on the flexible plate 2.

Equally flexible plate 2 has a drawback, since traveling electromagnetic bending waves arise in it (Fig. 3).

Bending waves are thermal deformations, enhanced by the electromagnetic effect, propagating in the envelope plates. The wavelength in the latter is always much greater than the thickness of the plate. Plane bending waves arise in the plate, which can propagate in any direction oriented in its plane, and, in addition, cylindrical bending waves are possible. During the propagation of a bending wave, each element of the envelope of the plate is displaced perpendicular to the axis of the plane of the plate (Fig. 2). The phase velocities of bending waves are much less than the phase velocities of longitudinal waves in the plates. The phase velocity of monochromatic flexural waves is proportional to the square root of the frequency.

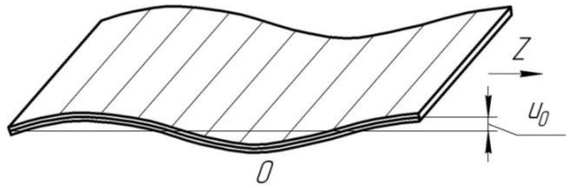


Fig. 3 – A traveling electromagnetic flexural wave in an envelope plate: u_0 is the displacement amplitude of the plate elements in a flexural wave, the z axis is the direction of wave propagation

In the plates, the dimensions of which are limited in the direction of propagation of the bending wave, standing bending waves arise as a result of reflections from their ends. Flexural waves are possible not only in flat, but also in curved plates, i.e., in shells.

Achieve a decrease in the influence of a traveling electromagnetic bending wave on its deformation in a flexible plate due to the distribution of the weight of thermogenerators on the surface of the plate. At the same time, the weight of the thermogenerators increased due to the growth and its volume level up to the plate inflection line, and then decreased.

4. EFFECTS ACCOMPANYING THE THERMOELECTRIC GENERATOR AND ITS CURRENT-VOLTAGE CHARACTERISTIC

The energy of electrons that have passed from one semiconductor to the second is reduced to the Fermi level as a result of collisions with atoms of the second semiconductor. The heat released in this case is the Peltier heat. Since the electrons come to thermal equilibrium as a result of several tens of collisions in the immediate vicinity of the contact, then all the Peltier heat is released at the contact itself. With the opposite direction of current in semiconductors, electrons can pass from energy levels located above the bottom of the conduction band, i.e., much higher than the Fermi level. In this case, thermal equilibrium is disturbed and restored due to the energy of thermal vibrations of the lattice. In this case, the Peltier heat is absorbed. This is explained by the fact that, passing from the hotter part to the colder one, the electrons transfer excess energy to the surrounding atoms, which causes heating of the generator elements [11]. In the reverse direction of the current, the electrons replenish their energy at the expense of the

Table 1 – The essence of the effects and their calculated dependencies accompanying the operation of a semiconductor thermoelectric generator

Effects and their essence	Estimated dependencies
I. T. Seebeck The essence of the Seebeck phenomenon or the phenomenon of thermo-emf. consists in the fact that in a closed electrical circuit consisting of dissimilar materials, e. d.s., if the contacts are	$E = \alpha(T_h - T_c)$ (1)

maintained at different temperatures. A circuit consisting of two materials is called a thermocouple or thermocouple.	
II. J. Peltier It is an effect opposite to the Seebeck effect, and consists in the fact that when current passes in a closed circuit consisting of dissimilar conductors, heat is released or absorbed at the points of their contacts (depending on the direction of the current).	$Q_{\Pi} = \Pi It$ (2)
III. W. Thomson It consists in the fact that if there is a temperature difference along the conductor through which the electric current flows, then heat is released or absorbed (depending on the direction of the current) in the volume of the conductor	$Q_T = It\tau(T_h - T_c)$ (3)
IV. D. Joule - E. Lenz Determines the mechanical equivalent of heat, which, according to the law of conservation of energy $A = Q$, and then we have	$Q = Iut = I^2Rt = \frac{u^2}{R}t$ (4)

Symbols: α – thermo-e coefficient. d.s.; T_h, T_c are the temperatures of the hot and cold junctions; Π – Peltier coefficient; I – current strength; t is time; τ is the Thomson coefficient; u is voltage; R is the circuit resistance

surrounding atoms, and heat is absorbed. It must also be taken into account that in the first case the electrons are decelerated by the thermal field. d.s., and in the second they accelerate, which changes the value of the Thomson coefficient.

Let us dwell on the essence of the effects and their calculated dependencies for a thermoelectric generator (Table 1):

– all effects are reversible, i.e., both with a change in the direction of the temperature gradient dT and with a change in the direction of the current dI, the sign of the effect also changes. This, for example, distinguishes Thomson's heat from the irreversible effect of Joule-Lenz heat release during the passage of electric current through a conductor, which is always released (but not absorbed) in any direction of the current. Another irreversible process that takes place in a thermoelectric circuit is the transfer of heat through conductors by thermal conduction from a hot junction to a cold one;

– both of these irreversible phenomena (Joule heat and thermal conductivity) are actually always present in thermoelectric devices and have (especially thermal conductivity) a significant impact on their operation.

However, for the initial thermodynamic analysis, we will assume that the actual thermoelectric process, which includes three reversible effects, proceeds independently of the irreversible processes of heat conduction and Joule heat release [11].

Analysis of the effects given in Table 1 showed the following:

– II-nd, III-rd and IV-th effects are associated with electric current and the time of its passage through the circuit;

– The 1st effect is related to the temperature of the junctions, and the 3rd effect is only partially related to $\Delta\tau$.

To determine the optimal values of the electric current and voltage corresponding to the maximum power condition, consider the current-voltage characteristic.

A characteristic feature of the thermoelectric generator under consideration, as in the case of T_1 = const and T_2 = const, is the dependence of the temperature difference ΔT_{pp} and, consequently, e. d.s. E on the operating mode, i.e., on the electric current I. If we use the approximate dependence of the temperature difference on the thermoelement ΔT_{pp} on the generator operating mode, then the dependence $E(I)$ can be obtained in the same way as the formula was obtained Then

$$V \cong E_{xx} - IAr_{m3}, \quad (5)$$

where A, r_{m3} – coefficients; E_{xx} – e. m. f. short circuit.

The current-voltage characteristic establishes a relationship between the dependence of the current on the voltage applied to the thermoelement of the electric circuit or the dependence of the voltage drop on the thermoelement of the electric circuit on the current flowing through it. If the electrical resistance of the thermoelement does not depend on the current, then the current-voltage characteristic is a straight line passing through the origin of the coordinate system.

Thus, the approximate current-voltage characteristic is a straight line (Fig. 4), which forms an angle β_3 with the current axis.

The straightness of the current-voltage characteristic directly implies the condition for maximum power:

$$I_0 = 0.5I_{к.з.}; \; V_0 = 0.5E_{x.x}$$

where $I_{к.з.}$ – short circuit current.

But when deriving the expression for the current-voltage characteristic, the approximate dependence $\Delta T_{pp} = f(M)$ was taken, which, naturally, should affect the conclusions, in particular, the conclusion about the straightness of the current-voltage characteristic.

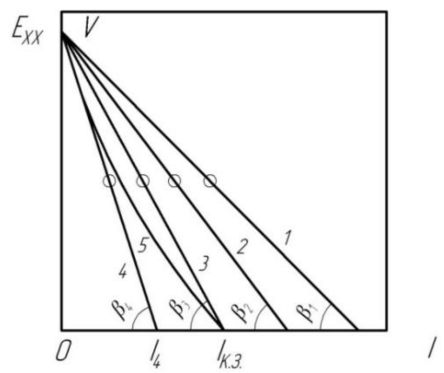


Fig. 4 – The current-voltage characteristic of thermoelectric generator at Q = const and T_h = const: 1 – at T_h = const and T_c = const: 2 and 4 – boundary; 3 – linearized; 5 – fine [11]

Based on the given value of the electric current I, the internal resistance of the thermoelectric generator is selected so that the maximum power corresponds to this value. In fact, the temperature drop across the thermoelement decreases with increasing current, and the current-voltage characteristic, as shown above, goes steeper (see Fig. 5). It is obvious that the real value power is lower and, in addition, the maximum power shifts towards lower electric current values (point 2). Let us denote the maximum power calculated based on the constancy of the junction temperatures, W_1 (point 1), the maximum power corresponding to the current-voltage characteristic W_2 (point 2), and the actual power value corresponding to the given value of the electric current, W_3 (point 3). Comparing the maximum power values

$$W_1 = E_{xx}^2 / \left(4r_{m\text{э}}\right) \text{ and } W_2 = E_{xx}^2 / \left(4Ar_{m\text{э}}\right),$$

it is easy to see that $W_1 / W_2 = A$.

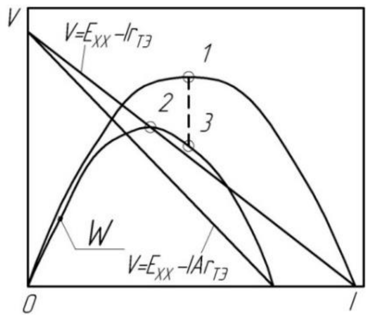


Fig. 5 – Dependence of the current-voltage characteristic in terms of power on the voltage and current of the thermoelectric generator [11]

Experimental studies have established that the power and efficiency increase with an increase in the volume of the thermoelement, since at a given heat flux Q_g and certain cross-sectional areas S_p and S_n, with an increase in the volume of the thermoelement, the temperature difference ΔT_{pp} and e.m.f. increases in proportion to the square of the volume, while the electrical resistance increases in proportion to the volume of the thermoelement and the efficiency is determined by the increase in the differential temperatures on the thermoelement, i.e., an increase in the temperature of the hot junction. Naturally, the increase in the volume of thermoelements cannot be infinite, since there are limitations that must be taken into account [12].

1. According to the temperature of the hot junction. For each thermoelectric material there is an allowable temperature.

2. By service life. There is a relationship between allowable temperature and service life, so the allowable temperature, and therefore the volume of the thermocouple, must be selected based on the required service life.

3. By weight. It is quite obvious that with an increase in volume, the weight of the entire thermoelectric generator will increase, which is sometimes limited.

4. Technological limitations. With modern methods of manufacturing thermoelectric modules (pressing, casting), there are certain difficulties associated with the manufacture of large-volume thermoelements.

5. According to the properties of thermoelectric material. At present, in calculations, the properties of thermoelectric material are considered to be constant and independent of temperature. In reality, most thermoelectric materials have reduced efficiency at high temperatures. The module has a maximum output power density of 158 mW/cm^2 at $dT = 105$°C, which corresponds to an efficiency value of 84.0 % (Fig. 6).

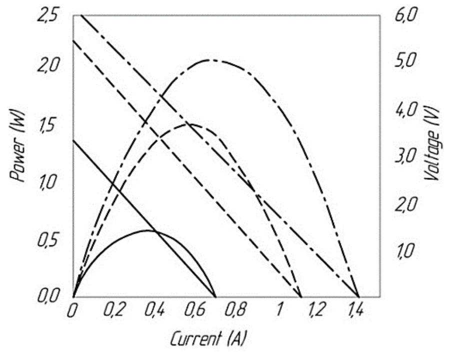


Fig. 6 – The current-voltage characteristic of thermoelectric generator at various surface temperature gradients (ΔT, °C): —— 50; – – – 85; – · – 105

Parallel equalization of electrode currents reduces the thermal load on individual thermoelectric semiconductor microcircuits, and good adhesion between the plate surface and their contacts ensures their stable operation when bent. Having created a dense array of thermoelectric semiconductor chips on a flexible substrate, we obtained reliable and stable gluing of contacts on it, ensuring efficient conversion of the waste heat.

In conventional rigid modules, arc electrodes at the edges were located perpendicular to each other, limiting the bending of the product. In FLEXTEG, these elements are built in parallel, providing flexibility in all directions. The resulting reduction in thermal load on the chips has led to increased reliability. Thermoelectric generators, which efficiently convert waste heat into electrical current, will help save energy and reduce the Peltier and Joule-Lenz effects.

5. THE DISCUSSION OF THE RESULTS

Theoretical and experimental studies of the performance of thermoelectric generators in comparison with the FLEXTEG module, made up of numerous chips with the properties of thermoelectric generators, made it possible to establish the following:

– evaluate the energy balance of thermal currents using the effects of T. Seebeck and W. Thomson, as well as electric currents in the circuit – J. Peltier and D. Joule – E. Lenz when changing the direction of their circulation;

– to obtain an isotropic design of a module of thermoelectric generators installed on an envelope flexible plate with different weights, which increases before the inflection line and decreases after it; in this case, the properties of semiconductors are independent of their location on a flexible plate;

– to reduce the influence of a traveling electromagnetic bending wave on its deformation in a flexible plate by distributing the weight of thermoelectric generators on the surface of the plate;

– evaluate the main factors affecting the properties of semiconductor materials and operating parameters of thermoelectric generators;

– present the current-voltage characteristic of a thermoelectric generator with patterns of change in the ranges of voltage (0-6.0 V), current strength (0-1.4 A), power (0-4.0 W) at various temperature gradients (5.0-105 °C), while the efficiency of thermoelectric generators was 84.0 %.

CONCLUSIONS

Thermoelectric generators are a promising technology for generating electricity from relatively low-temperature (up to 150 °C) thermal energy.

Shortcomings have been eliminated from the well-known design of the thermoelectric generator module, which made it possible to increase its efficiency.

REFERENCES

1. D.A. Volchenko, M.V. Kindrachuk, N.A. Volchenko, N.B. Klochko, A.O. Yurchuk, *J. Nano- Electron. Phys.* **12** No 6, 06020 (2020).
2. M.V. Kindrachuk, O.I. Volchenko, D.O. Volchenko, V.S. Skrypnyk, A.V. Voznyi, *Mater. Sci.* **54** No 6, 843 (2019).
3. N. Volchenko, A. Volchenko, D. Volchenko, P. Poliakov, V. Malyk, D. Zhuravlev, V. Vytvytskyi, P. Krasin, *Eastern-European Journal of Enterprise Technologies* 1/5(97), 47 (2019).
4. V.L. Kuznetsov, *Functionally Graded Materials for Thermoelectric Applications* in *CRC Thermoelectrics Handbook: Macro to Nano* (Ed. by D.M. Rowe) (CRC Press, Taylor & Francis Group, Boea Raton, London-N.Y: 2006).
5. O.I. Markov, *JTF* **91** No 11, 1722 (2021).
6. I.A. Drabkin, L.B. Ershova, *Phys. Technol. Semicond.* **56** No 1, (2021).
7. A.A. Petrik, N.A. Volchenko, P.Yu. Purgal, D.A. Volchenko, *Friction Units, Vol.* 2 (Kuban State Technological University: Krasnodar: 2003).
8. P. Küpper, *Science and Technology* No 7, 43 (2019).
9. A.S. Okhotin, A.A. Efremov, V.S. Okhotin, A.S. Pushkarsky, *Thermoelectric Generators Ed. 2nd, revised. and additional* (M.: Atomizdat: 1976).
10. O.I. Markov, *Dokl. XIII Interstate this "Thermoelectrics and their applications"*, 180 (2013).
11. S. Bhunia, D.N. Bose, *J. Appl. Phys.* **88**, 2931 (2000).

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У статті розглянуті режими роботи модуля FLEXTEG в режимі термоелектричного генератора; ефекти, що супроводжують термоелектричний генератор і його вольт-амперну характеристику. Енергетичний баланс теплових струмів оцінюється за допомогою ефектів Зеебека і Томсона, а також електричних струмів у контурі – Пельтьє і Джоуля-Ленца при зміні напрямку їх циркуляції. Отримано ізотропну конструкцію модуля теплоелектрогенераторів, встановленого на огинаючій гнучкій пластині з різною масою, яка зростає перед лінією перегину і зменшується після неї. У цьому випадку властивості напівпровідників не залежать від їх розташування на гнучкій пластині. Зменшення впливу біжучої електромагнітної згинної хвилі на її деформацію в гнучкій пластині досягнуто шляхом розподілу ваги термоелектричних генераторів на поверхні пластини. Оцінено основні фактори, що впливають на властивості напівпровідникових матеріалів та робочі параметри термоелектричних генераторів. Вольт-амперна характеристика термоелектричного генератора показує зміни інтервалів напруги (0-6,0 В), сили струму (0-1,4 А), потужності (0-4,0 Вт) при різних градієнтах температури (5, 0-105 °С) та ККД термоелектричних генераторів на рівні 84,0 %.

Ключові слова: Напівпровідниковий термоелемент, Термоелектричний генератор, Сила струму та напруга, Потужність, Вольт-амперна характеристика.