V.V. Lysko, *Cand. Sc.(Phys.-Math)* [1,2]
I.A. Konstantynovych, *Cand. Sc. (Phys-Math)* [1,2]
M.V. Havryliuk, [1,2]
O.S. Rusnak [1]

[1] Institute of Thermoelectricity of the NAS and MES of Ukraine,
1 Nauky str., Chernivtsi, 58029, Ukraine;
[2] Yuriy Fedkovych Chernivtsi National University,
2 Kotsiubynskyi str., Chernivtsi, 58012, Ukraine
e-mail: anatych@gmail.com

EXPERIMENTAL STUDIES ON THE PARAMETERS OF THERMOELECTRIC GENERATOR ENERGY CONVERTERS WITH DIFFERENT HEIGHT OF LEGS

The paper describes the equipment for studying the parameters of thermoelectric generator modules Altec-10002, developed at the Institute of Thermoelectricity (Ukraine). The results of experimental studies on generator modules with a reduced height of the thermoelement legs that make up the module are presented. It is shown that the height of the legs can be reduced 1.5 – 2 times without a significant decrease in the module efficiency. In this case, the reduction of the height of the legs is hindered, first of all, by the increasing influence of the thermal resistance of the heat spreaders between the module and the surfaces of the heat source and heat sink. Bibl 24, Fig. 7, Tabl. 1.

Key words: thermoelectric module, electric energy generation, measurement, efficiency, electric power, miniaturization

Introduction

Almost all electronic equipment, industrial process equipment, heat engines (turbines, internal combustion engines, etc.), when operating, are accompanied by the release of heat dissipating into the environment. More than half of this heat is not only not used in any way, but also leads to negative consequences for the environment - to its thermal pollution. At the same time, the majority of heat waste, more than 66%, falls at temperatures up to 230°C, and another 23% - up to 300°C [1-4]. This temperature range is favorable for heat recovery through thermoelectric conversion of thermal into electrical energy [5-16].

Autonomous thermoelectric power sources that operate using heat obtained from burning various fuels are also promising. Such sources can have a long service life, are highly reliable and resistant to climatic and impact loads, are universal, silent in operation and easy to use. Thermoelectric generators with an electrical power of 2–20 W, which are designed for charging mobile phones, MP3 players, and navigators during travel and hiking, have been developed by a number of companies (TES, Biolite, etc.) [17-19].

The main obstacle to the widespread practical use of thermoelectric energy converters is their relatively high cost, primarily due to the high price of the thermoelectric materials they are made of.

One of the ways to reduce the cost of thermoelectric modules is their miniaturization, so *the* *purpose of this work* was to conduct experimental studies on the influence of leg height on the parameters of generator thermoelectric modules.

1. Description of measuring equipment

To study the parameters of thermoelectric generator modules, the Altec-10002 equipment, developed at the Institute of Thermoelectricity (Ukraine), was used.

To study the parameters of thermoelectric generator modules, the absolute measurement method and the equipment ALTEK-10002, developed at the Institute of Thermoelectricity (Ukraine), were used [20-24].

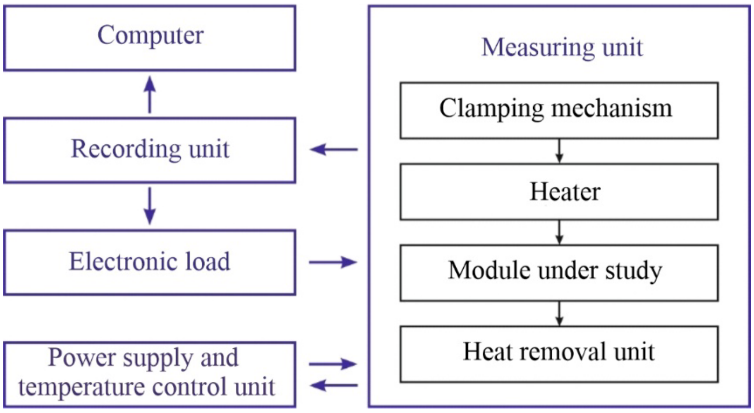

Fig. 1. Block diagram of equipment for measuring parameters of generator thermoelectric modules.

The equipment consists of a measuring unit, a recording unit, a temperature control unit connected to a power supply, an electronic load and a computer. The block diagram of the equipment is shown in Fig. 1.

In turn, the measuring unit contains a clamping mechanism, a heater and a heat removal system. The schematic diagram of the measuring unit is shown in Fig. 2. The thermoelectric module 7 under study is located between two heat equalizing plates 5 and 8. The plates are adjacent to the heater 13 on the upper side, and to the heat meter 4 on the lower side. In turn, the heat meter is located on the plate 20, in which the electric heater is mounted. The plate is located on a liquid cold heat exchanger 1 with an electrically controlled valve 22 in the coolant circuit. The module heater 13 is thermally insulated from the environment by high-temperature thermal insulation 12. The temperature of the unit elements is controlled and regulated by thermocouples: thermocouple 9 determines the temperature of the module heater; thermocouple 16 determines the temperature of the heat equalizing plate 8, which is in contact with the hot side of the module, and thermocouple 18 determines the temperature of the heat equalizing plate 5, which is in contact with its hot side.

The design of the measuring unit includes a central clamp for the module, which ensures uniform distribution of force over the entire surface of the module.

The measurement process is as follows. First, the temperature of the cold part of the module is set using a cold heat exchanger and a heater. After that, the hot heat exchanger is heated to the required temperature. After the steady-state mode is established (after ~15-20 minutes), the module EMF is measured at contacts 6 and 17. After connecting the module to an external electrical load, a new temperature regime is formed due to the Peltier effect, therefore it is necessary to increase the power of the heater 13 to restore the set hot temperature and to increase the heat removal by the cold heat exchanger to restore the set cold temperature. In this case, the temperatures of the hot and cold surfaces of the module are automatically maintained by the thermostat in all measurement modes. The temperature of the cold side of the module is set in the range from 30 to 400 °C. For temperatures above 90°C, heat-insulating gaskets are used between the heat meter and the heat equalizing plate. The temperature of the hot side can be set and maintained in the range from 50 to 600 °C.

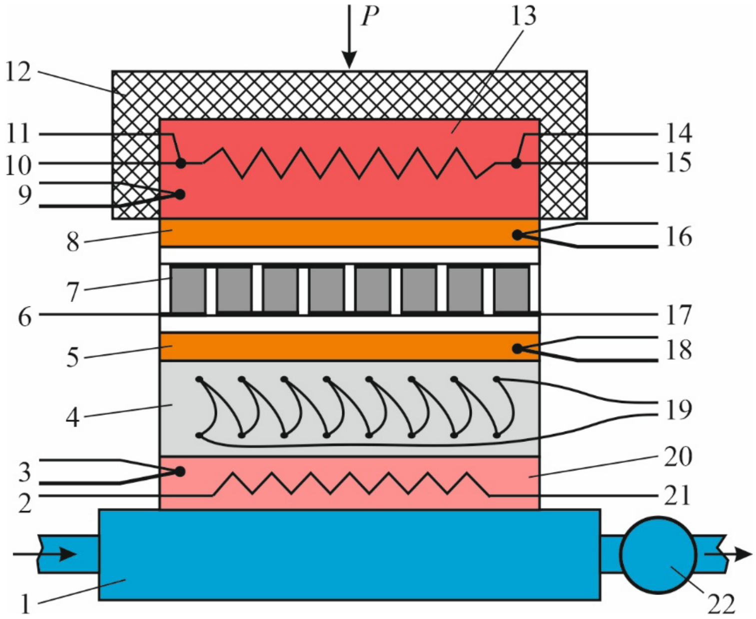

Fig. 2. Schematic of the measuring unit of equipment for measuring the parameters of generator thermoelectric modules: 1 – cold heat exchanger; 2, 21 –terminals of the cold heat exchanger heater of the generator thermoelectric modules: 3 – thermocouple of the cold heat exchanger; 4 – heat meter; 5, 8 – heat equalizing plates; 6, 17 – generator module terminals; 7 – generator module under study; 9 – thermocouple of the hot heat exchanger; 10, 15 – current terminals of the hot heat exchanger heater 11, 14 – potential terminals of the hot heat exchanger heater; 12 – thermal insulation; 13 – heater; 16 – thermocouple of the hot module side; 18 – thermocouple of the cold module side; 19 – heat meter terminals; 20 – cold heat exchanger heater, 22 – electrically controlled coolant valve.

Electronic loads made on the basis of field-effect transistors, which precisely set the required current value, are used as the electric load of the modules in the installation. To determine the efficiency of the module, the electric power on this load is determined. The heat flux that has passed through the cold part of the module by means of heat meter 4 and the input heat flux as the thermal power of the hot heat exchanger heater are also determined. Potential contacts 11 and 14 are used to determine the value of this power.

The power supply and temperature control unit uses a proportional integral-differential mode to regulate temperature with an accuracy of 0.1 °C. All electrical measurements, namely signals from thermocouples, electrical voltage and current from the module, heater power and a signal from the heat meter are measured by the recording unit and displayed on the screen with an absolute error of $\pm 2\cdot 10^{-6}$ V.

It is necessary to use special methods for precise determination of heat fluxes. The heat flux leaving the module is determined quite accurately using a heat meter. Special measures have been taken to eliminate heat losses from such a heater. Its calibration is carried out directly on the installation using a reference electric heater. For this purpose, the non-working surface of the reference heater was shielded by an additional electric heater, on which the temperature is created - the same as on the reference heater. The error in determining the power of the reference heater does not exceed 0.1 W. To ensure the convenience and accuracy of measurements, replaceable heat meters are used, the area of which is close to the area of the module, and replaceable hot heat exchangers of appropriate sizes.

With regard to the combination of the above approaches, the error in determining the thermal resistance of the module under study and its efficiency does not exceed 3%.

To find the parameters and temperature dependences of the module and further process the obtained results, the recording unit writes the measurement data into a memory card. The measurement results are transferred to a computer for documentation and certification of the modules.

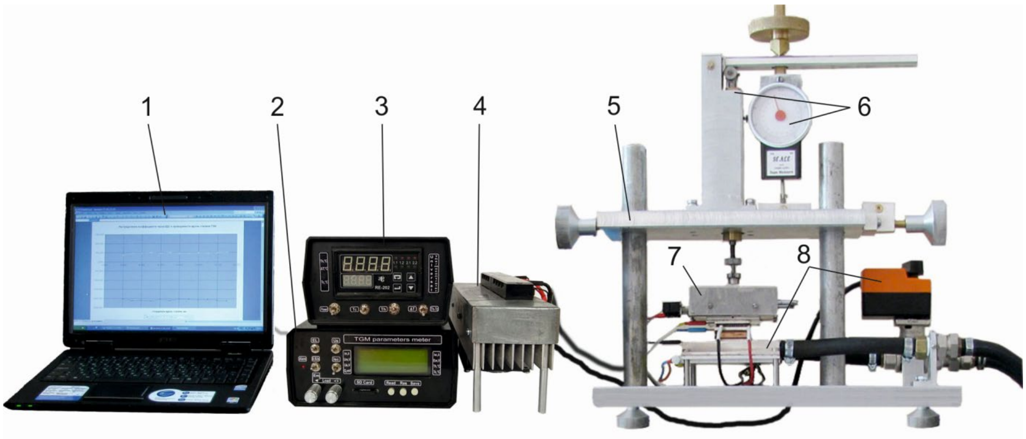

Fig. 3. Appearance of the Altec-10002 equipment for studying the parameters of thermoelectric generator modules: 1 – computer; 2 – recording unit; 3 – power supply and temperature control unit; 4 – electronic load; 5 – measuring unit; 6 – clamping mechanism; 7 – heater; 8 – heat removal unit.

The appearance of the Altec-10002 equipment for studying the parameters of thermoelectric generator modules is shown in Fig. 3, and its technical characteristics are in Table 1.

Table 1

Technical characteristics of the equipment Altec-10002 for studying the parameters of thermoelectric generator modules

№	Characteristic	Value
1	Geometric dimensions of modules under study: - area, mm^2 - thickness, not more, mm	 10×10 – 100×100 50
2	Thermal power passing through the module, W	0 – 500
3	Hot side module temperature, °C	50 – 600
4	Cold side module temperature, °C	30 – 400
5	Maximum electric voltage of module, not more, V	30
6	Range of measured currents through the module, A	0 – 30
7	Clamping force of the module to heat exchangers, kg	0 – 180
8	Dimensions (without computer), cm	70 × 40 × 40
9	Mass, kg	25
10	Consumed electric power from the AC network 220 V, 50-60 Hz, not more, W	700

2. Measurement results

To conduct research on the dependence of the efficiency and power of thermoelectric modules on the height of the thermoelement legs of which they consist, the Institute of Thermoelectricity (Ukraine) manufactured modules of the type Altec-1061 with a reduced height of the legs (Fig. 4). Each of such modules contains 56 pairs of legs made of thermoelectric material based on *n*- and *p*-type *Bi-Te*.

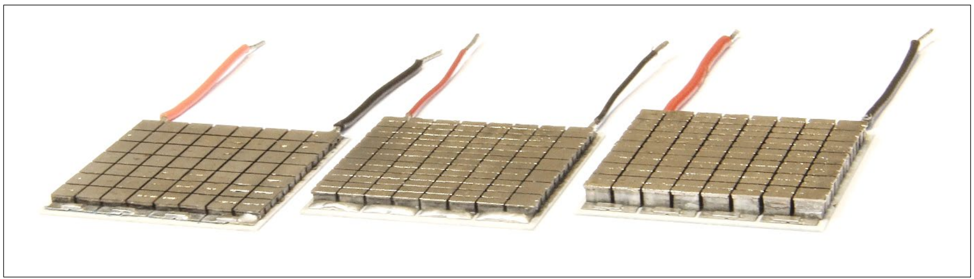

Fig. 4. External appearance of the studied thermoelectric modules of the type Altec-1061 with different leg heights.

Figs. 5 – 12 show the results of measurements of the efficiency and output electric power of the studied modules for the values of the hot side temperatures from 200°C to 300°C and the cold side - from 30°C to 110°C. The advantage of the measuring equipment Altec-10002 is that the module is studied in real conditions of its operation, including with the presence of thermal contact resistance between its surfaces and the surfaces of the heat source and heat sink. The temperatures T_h and T_c shown in Fig. 5 – Fig. 10 are the temperatures of the heat equalizing plates placed between the hot side of the module and the heater, as well as the cold side of the module and the heat meter, respectively, without introducing corrections.

As can be seen from the above dependences, the output electrical power of the module decreases slightly as the height of the legs decreases, although theoretically it should increase due to a decrease in the electrical resistance of the module. The reason for this is the decrease in the thermal resistance of the module, the growth of the heat flux through it and, as a consequence, the growth of the influence of the thermal resistance of the heat spreaders between the module and the surfaces of the heat source and heat sink on the real temperature difference on the thermoelements. The efficiency of the modules decreases as the height of the legs decreases, as could be expected.

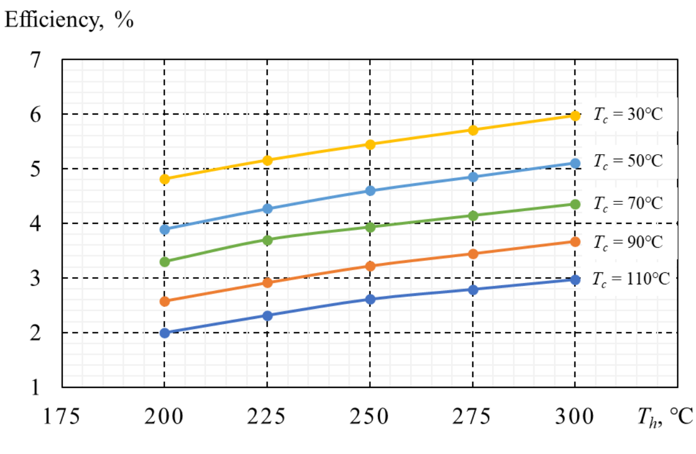

Fig. 5. Temperature dependences of the efficiency of thermoelectric modules of the type Altec-1961 with the height of legs 3.2 mm.

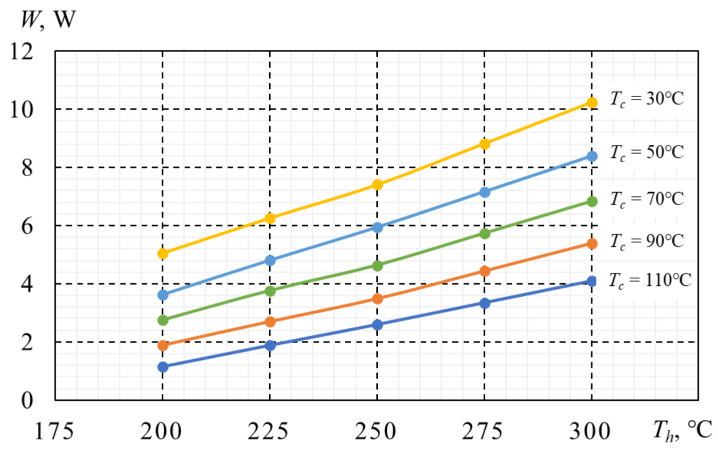

Fig. 6. Temperature dependences of the output electric power of thermoelectric modules of the type Altec-1061 with the height of legs 3.2 mm.

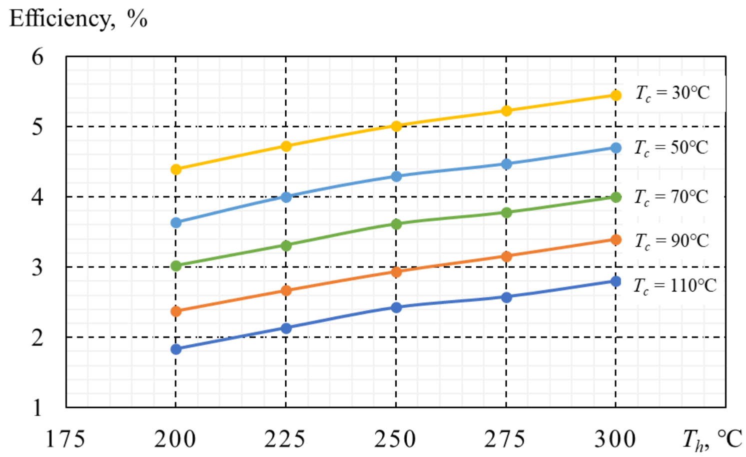

Fig. 7. Temperature dependences of the efficiency of thermoelectric modules of the type Altec-1061 with the height of legs 2.1 mm.

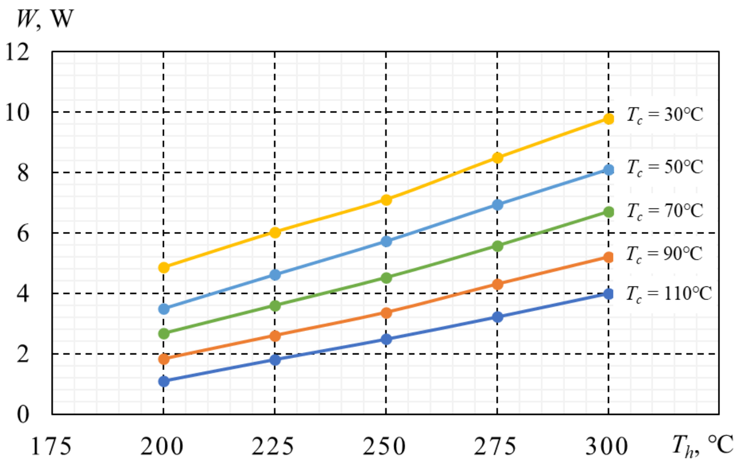

Fig. 8. Temperature dependences of the output electric power of thermoelectric modules of the type Altec-1061 with the height of legs 2.1 mm.

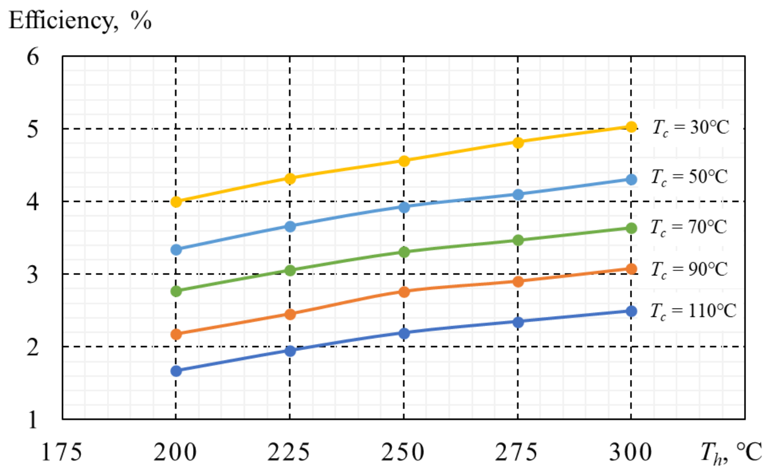

Fig. 9. Temperature dependences of the efficiency of thermoelectric modules of the type Altec-1061 with the height of legs 1.6 mm.

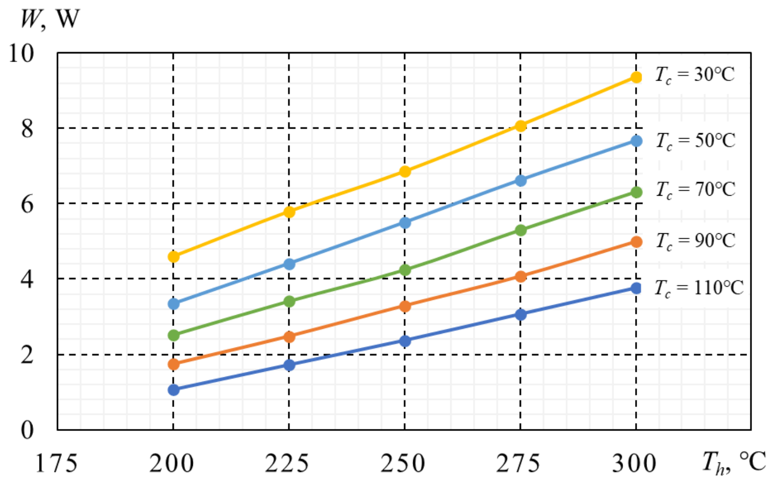

Fig. 10. Temperature dependences of the output electric power of thermoelectric modules of the type Altec-1061 with the height of legs 1.6 mm.

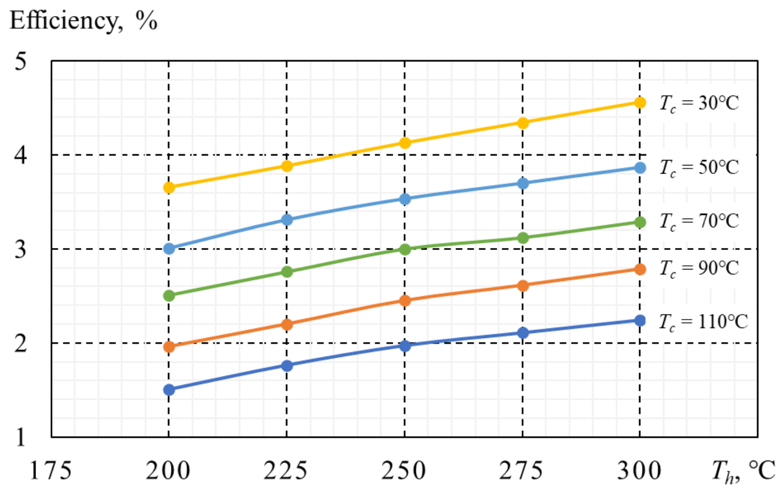

Fig. 11. Temperature dependences of the efficiency of thermoelectric modules of the type Altec-1061 with the height of legs 1.2 mm.

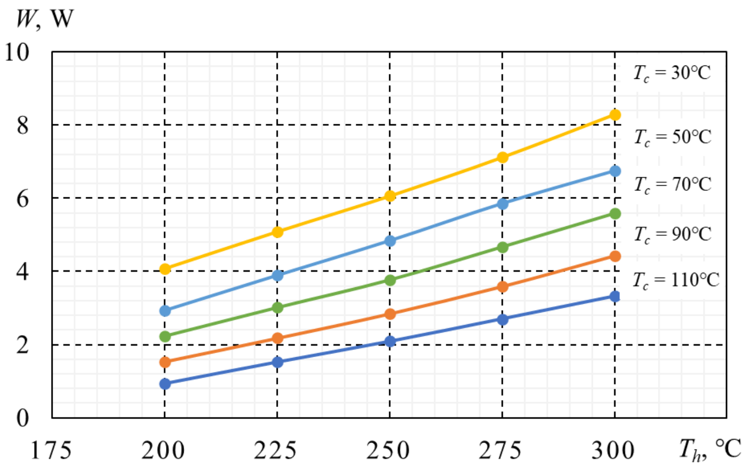

Fig. 12. Temperature dependences of the output electric power of thermoelectric modules of the type Altec-1061 with the height of legs 1.2 mm.

Fig. 13 shows the dependence of the efficiency of thermoelectric modules on the height of the thermoelement legs they are made of (at T_h = 300°C and T_c = 30°C). As can be seen from Fig. 13, even when the height of the legs is reduced 1.5–2 times, the efficiency drops by only 10–15%.

This indicates a significant potential for reducing the cost of generated electrical energy by miniaturizing modules, since, as is known, the main part of the cost of a thermoelectric energy converter is the cost of the thermoelectric material it is made of.

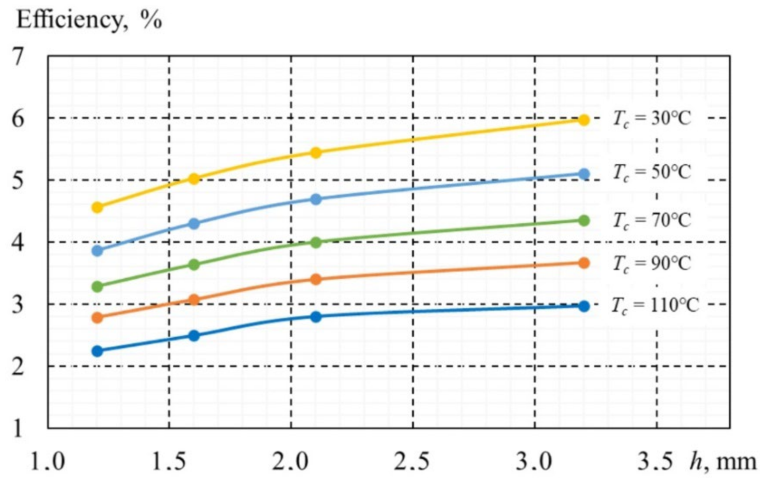

Fig. 13. Dependences of the efficiency of thermoelectric modules of the type Altec-1061 on the height of the legs they are made of (at T_h = 300 °C).

Conclusions

1. The description of the design of the equipment "Altec-10002" for studying the parameters of thermoelectric generator modules is given, its technical characteristics and advantages are presented.
2. The results of measurements of the efficiency and output electrical power of modules of the Altec-1061 type with reduced leg height for the hot side temperatures from 200 to 300°C and the cold side temperatures from 30 to 110°C are presented.
3. It is shown that even with a 1.5-2 times reduction in the height of the legs, the module efficiency drops by only 10-15%. This indicates a significant potential for reducing the cost of generated electrical energy by miniaturizing thermoelectric modules.

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Лисько В.В., *канд. фіз.-мат. наук*[1,2]
Константинович І.А., *канд. фіз.-мат. наук*[1,2]
Гаврилюк М.В.,[1,2]
Руснак О.С.[1]

[1] Інститут термоелектрики НАН та МОН України,
вул. Науки, 1, Чернівці, 58029, Україна;
[2] Чернівецький національний університет імені Юрія Федьковича,
вул. Коцюбинського 2, Чернівці, 58012, Україна

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ПАРАМЕТРІВ ТЕРМОЕЛЕКТРИЧНИХ ГЕНЕРАТОРНИХ ПЕРЕТВОРЮВАЧІВ ЕНЕРГІЇ З РІЗНОЮ ВИСОТОЮ ВІТОК

У роботі наведено опис обладнання для дослідження параметрів термоелектричних генераторних модулів «Алтек-10002», розробленого в Інституті термоелектрики (Україна). Представлено результати експериментальних досліджень генераторних модулів зі зменшеною висотою віток термоелементів, з яких складається модуль. Показано, що висота віток може бути зменшена у 1.5 – 2 рази без істотного зниження ККД модуля. При цьому зменшенню висоти віток перешкоджає, в першу чергу, зростаючий вплив теплового опору теплопереходів між модулем і поверхнями джерела тепла та тепловідводу. Бібл. 24, рис. 7, табл. 1.

Ключові слова: термоелектричний модуль, генерація електричної енергії, вимірювання, ККД, електрична потужність, мініатюризація

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