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EXPERIMENTAL STUDIES OF THERMOELECTRIC PARAMETERS OF MATERIALS FORMING PART OF THERMOELECTRIC MODULES

The design of equipment for measuring the parameters of thermoelectric generator and cooling modules is presented, as well as a description of the method for determining the thermoelectric properties of materials used in these modules. The equipment was created on the basis of the absolute method, which makes it possible to determine the parameters of modules in real conditions of their operation and allows instrumental minimization of the main sources of measurement errors. The results of experimental studies of the parameters of thermoelectric modules carried out using the developed equipment are presented.
Key words: thermoelectric module, electrical conductivity, thermoEMF, thermal conductivity, thermoelectric material, measurement.

Introduction

General characterization of the problem

Quality control of thermoelectric converters of modules plays an important role in their development, as well as in the creation on the basis of these modules of thermoelectric devices for cooling and generation of electricity. Such control is carried out by measuring the parameters of thermoelectric modules - cooling capacity, coefficient of performance and temperature difference on the module for thermoelectric coolers; efficiency, electric power – for thermoelectric generators. One of the best measurement methods in this case is the absolute method [1, 2], which allows one to determine the parameters of modules in real conditions of their operation, makes it possible to instrumentally minimize the main sources of measurement errors, and also obtain information about the properties of the material forming part of the module, namely thermoEMF, electrical conductivity and thermal conductivity of a pair of thermoelectric legs [3 – 5].

The Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine has developed a universal electronic control system and automated measuring equipment based on it, which makes it possible to measure the parameters of thermoelectric modules and the thermoelectric properties of materials forming part of them for a wide range of operating temperatures: from – 50 to 100 °C for cooling modules and from 30 to 600 °C for generator modules [6 – 8].

The purpose of this work is to conduct experimental studies of the developed equipment and confirm its expected capabilities.

1. Description of method and equipment for determining the properties of thermoelectric materials forming part of thermoelectric power converters

The appearance of the developed equipment for measuring the parameters of thermoelectric modules and determining the thermoelectric properties of materials forming part of them is shown in Fig. 1.

Fig. 1. Appearance of equipment for measuring parameters of thermoelectric modules.

Diagrams of the absolute method, taken as a basis for creating equipment for determining the parameters of generator and cooling thermoelectric modules, are shown in Fig. 2 and Fig. 3, respectively.

To determine the parameters of the generator thermoelectric module, the latter is placed between two heat-equalizing plates, which in turn are located between the electric heater and the heat meter (Fig. 2). The other side of the heat meter is in contact with the thermostat. With the help of an electric heater, a given temperature difference is created on the module and the EMF E_{TEM} which occurs at the module wires, is measured. Following that, a matched electrical load is connected to the module wires, whereby the voltage on the module wires will become equal to half the EMF. The values of the electric current I_{TEM} passing through the module, the voltage on its wires $\mathrm{U_{TEM}}$ are measured, and with the help of a heat meter, the value of the heat flux Q_1, removed from the cold side of the module to the thermostat, is determined. The electrical power of module P and its efficiency η are determined by the formulae

$$P = I_{\mathrm{TEM}} \cdot U_{\mathrm{TEM}}, \tag{1}$$

$$\eta = \frac{P}{Q_1 + P_{\mathrm{TEM}}} \tag{2}$$

where I_{TEM} and U_{TEM} is current and voltage of module, Q_1 is heat flux which is removed from the cold side of module and determined by means of a heat meter.

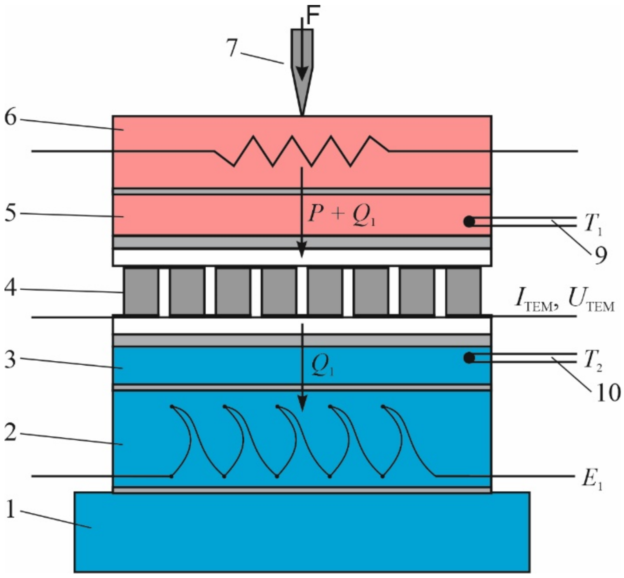

Fig. 2. Absolute method of measuring parameters of thermoelectric generator modules: 1 – thermostat; 2 – heat meter; 3, 5 – heat-equalizing plates; 4 – module under study; 6 – heater; 8 – clamp; 10, 11 – thermocouples.

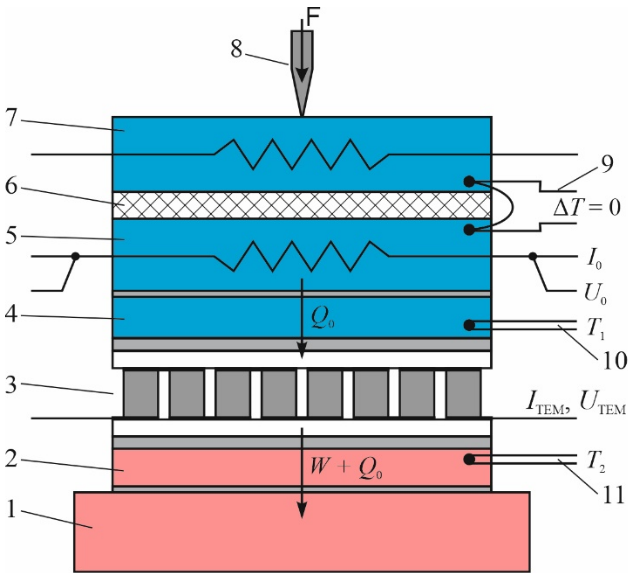

Fig. 3. Absolute method of measuring parameters of thermoelectric cooling modules: 1 – thermostat; 2, 4 – heat-equalizing plates; 3 – module under study; 5 – reference heater; 6 – thermal insulation; 7 – protective heater; 8 – clamp; 9 – zero thermocouple; 10, 11 – thermolcouples.

When determining the parameters of the cooling modules, a protective heater is additionally used, which prevents heat loss from the heater through the clamping mechanism (Fig. 3). The values of cooling capacity Q_0, temperature difference ΔT and coefficient of performance ε are determined by the formulae

$$Q_0 = I_0 \cdot U_0 , \tag{3}$$

$$\Delta T = T_1 - T_2 , \tag{4}$$

$$\varepsilon = \frac{Q_0}{W} , \tag{5}$$

where I_0 and U_0 is current through the heater and voltage drop thereupon, T_1 is the cold side temperature of module, T_2 is the hot side temperature of module, W is electrical power consumption of the module.

To find the properties of the thermoelectric material forming part of the modules, the technique described in detail in [3, 5] was used.

The average values of electrical conductivity, thermoEMF, thermal conductivity and figure of merit of the material of thermoelectric module legs are determined by the formulae

$$\sigma = \frac{1}{R_M / 2N} \frac{h_1}{a_1 \cdot b_1} \cdot K_1 , \tag{6}$$

$$\alpha = \frac{E / 2N}{\Delta T} \cdot K_2 , \tag{7}$$

$$\kappa = \frac{Q / 2N}{\Delta T} \frac{h_1}{a_1 \cdot b_1} \cdot K_3 , \tag{8}$$

$$Z = \frac{\alpha^2 \sigma}{\kappa} , \tag{9}$$

where R_M is module resistance measured on the alternating current; a_1 x b_1 is cross-section of legs; h_1 is the height of legs; N is the number of pairs; E is module EMF; ΔT is temperature difference between thermocouples placed on heat-equalizing plates with a module under study arranged between them; Q is heat flux through the module; K_1 – K_3 are correction factors to reduce the magnitude of measurement errors, calculated for a given design of the module and measuring equipment or determined experimentally.

2. Results of experimental studies

Figs. 4 and 5 show an example of the results of measuring the parameters of an Altec-22 type thermoelectric module on the developed equipment, namely, the dependence of the cooling capacity (Fig. 4) and the coefficient of performance (Fig. 5) on the power supply and temperature difference at T_h = 20 °C.

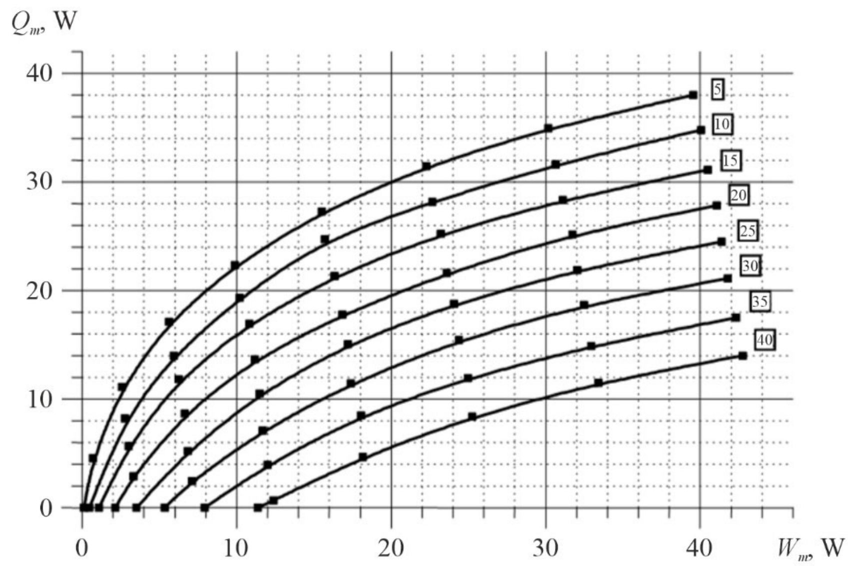

Fig. 4. Dependence of cooling capacity Q_m of thermoelectric module of the type Altec-22 on the power supply of module W_m and temperature difference thereupon at T_h = 20 °C.

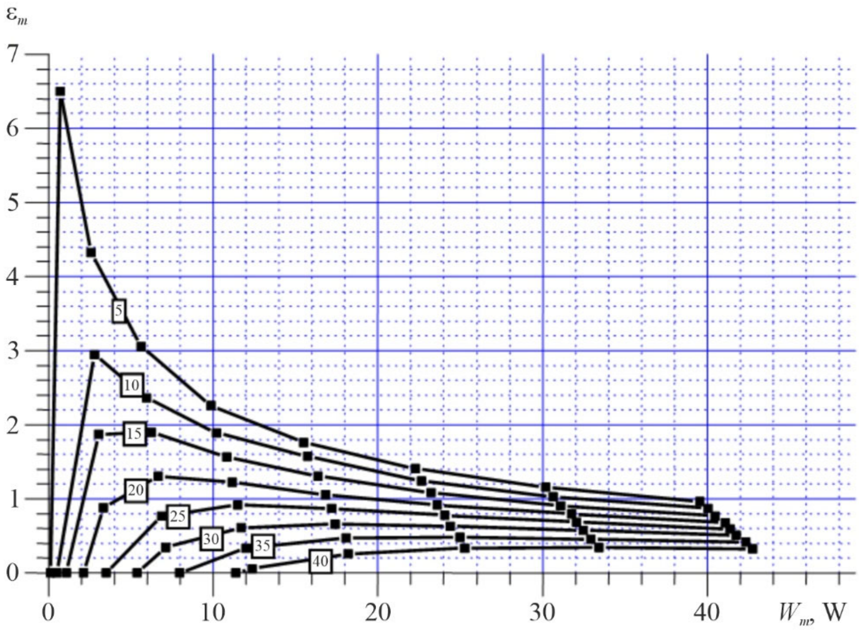

Fig. 5. Dependence of coefficient of performance ε_m of thermoelectric module of the type Altec-22 on the power supply of module W_m and temperature difference thereupon at T_h = 20 °C.

Figs. 6, 7 show an example of the results of measuring the parameters of an Altec-1061 type thermoelectric module on the developed equipment, namely, the dependence of the efficiency and maximum useful electrical power of module on the hot side T_h and cold side T_c temperatures of module.

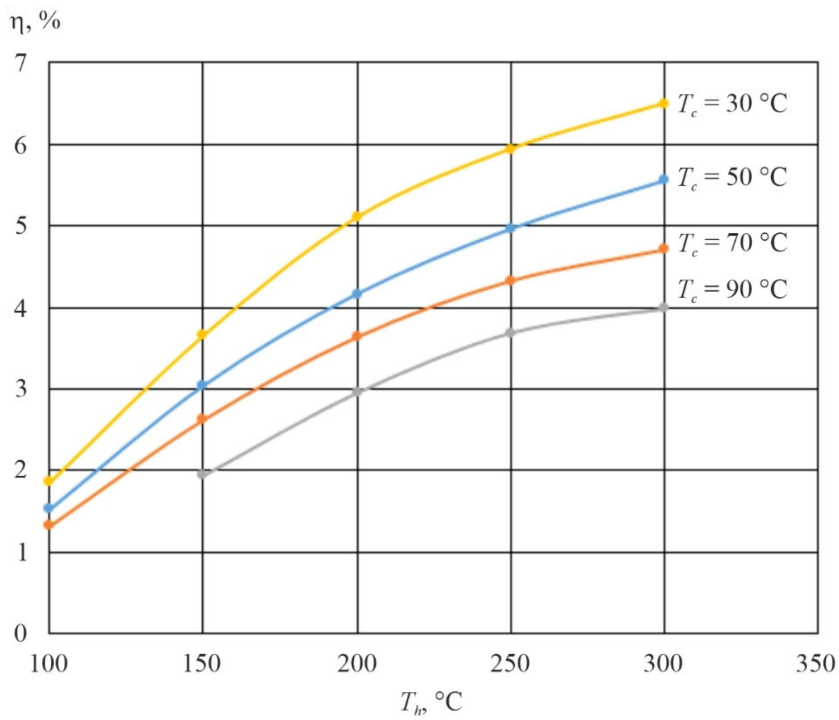

Fig. 6. Dependence of the efficiency η of thermoelectric module of the type Altec-1061 on the hot side T_h and cold side T_c temperatures of module.

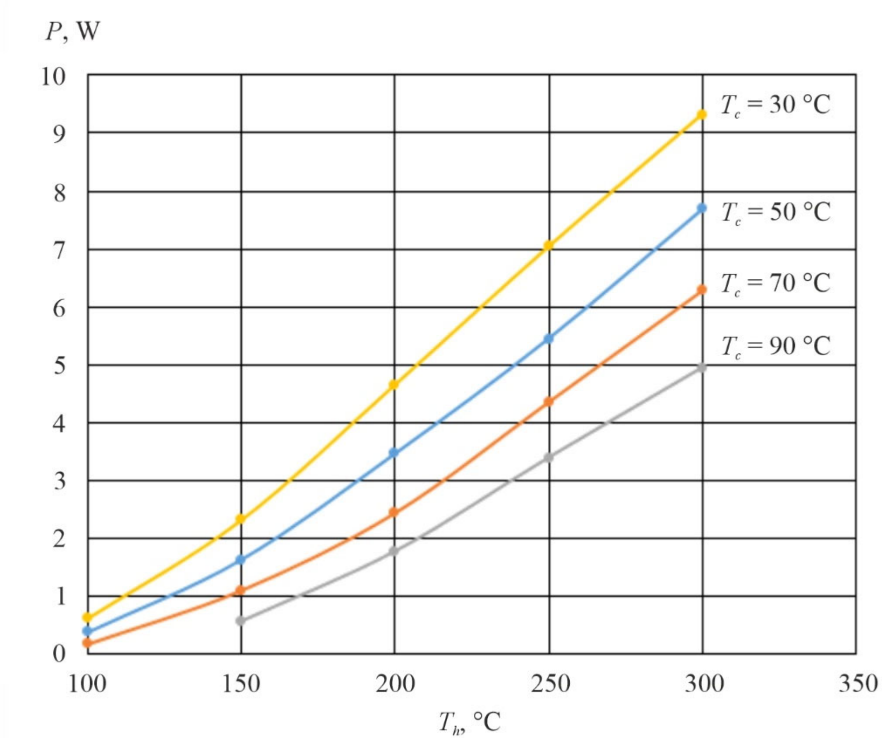

Fig. 7. Dependence of maximum useful electrical power P of thermoelectric module of the type Altec-1061 on the hot side T_h and cold side T_c temperatures of module.

According to the method detailed in paragraph 1, the thermoelectric properties of materials forming part of the cooling module of Altec-22 type and the generator module of Altec-1061 type were determined. The research results are presented in Table 1 and Table 2, respectively.

Table 1

Results of determining the properties of thermoelectric materials used in cooling module of the type Altec-22

T_1, °C	T_2, °C	T_{ave}, °C	σ, Ohm^{-1}·cm^{-1}	α, μ/°C	κ, W/(m·°C)	Z·10^3, 1/°C
100	90	95	661	222.0	1.62	2.02
80	70	75	687	222.5	1.59	2.14
60	50	55	780	220.4	1.54	2.45
40	30	35	854	216.0	1.55	2.57
20	10	15	937	209.3	1.58	2.60
0	– 10	– 5	1028	200.3	1.64	2.52
– 20	– 30	– 25	1078	194.9	1.68	2.44

Table 2

Results of determining the properties of thermoelectric materials used in generator module of the type Altec-1061

T_1, °C	T_2, °C	T_{ave}, °C	σ, $Ohm^{-1}\cdot cm^{-1}$	α, μ/°C	κ, W/(m·°C)	$Z\cdot 10^3$, 1/°C
40	30	35	1674	141.0	1.99	1.67
80	30	55	1550	147.3	1.92	1.75
120	30	75	1435	152.7	1.89	177
160	30	95	1328	157.2	1.89	1.74
200	30	115	1231	160.7	1.93	1.64
240	30	135	1142	163.3	2.01	151
280	30	155	1062	165.0	2.13	1.36
320	30	175	991	165.8	2.28	1.19

The errors of the method used (with regard to corrections) are: when determining electrical conductivity – 2 – 3 %, thermoEMF – 3 – 5 %, thermal conductivity – 5 – 7 %.

Comparison of the obtained results with the properties of the initial materials used to manufacture these modules, determined on the high-precision equipment "ALTEC-10001", allows obtaining information about such important module parameters as the effect of contact and interconnect resistance on its efficiency. This information is extremely important for improving modules design.

Conclusions

1. The design of automated equipment for measuring the parameters of thermoelectric generator and cooling modules is described, as well as a method for determining the thermoelectric properties of materials in these modules. The equipment was created on the basis of the absolute method, which makes it possible to measure the parameters of thermoelectric modules and the thermoelectric properties of materials in them for a wide range of operating temperatures: from – 50 to 100 °C for cooling modules and from 30 to 600 °C for generator modules.
2. The developed equipment was used to study the parameters of serial thermoelectric cooling modules of Altec-22 type and generator modules of Altec-1061 type. The possibility of determining the properties of thermoelectric materials forming part of these modules has been experimentally confirmed.

References

1. Kolodner P. (2014). High-precision thermal and electrical characterization of thermoelectric modules. *Review of Scientific Instruments*, 85(5), 054901/1-054901/11.

2. Anatychuk L.I., Havrylyuk M.V. (2011). Procedure and equipment for measuring parameters of thermoelectric generator modules. *J. Electronic Materials*, 40 (5), 1292 – 1297.
3. Anatychuk L.I., Lysko V.V. (2021). Method for determination of thermoelectric parameters of materials forming part of thermoelectric cooling modules. *J. Thermoelectricity*, 1, 49 – 54.
4. Anatychuk L.I., Lysko V.V. (2020). Determination of thermoelectric parameters of materials forming part of thermoelectric generator modules. *J. Thermoelectricity*, 3, 70 – 80.
5. Anatychuk L.I., Lysko V.V. (2021). Determination of the temperature dependences of thermoelectric parameters of materials used in generator thermoelectric modules with a rise in temperature difference. *J. Thermoelectricity*, 2, 53 – 57.
6. Anatychuk L.I., Havryliuk M.V., Lysko V.V. (2021). Computerization of processes of measuring thermoelectric parameters of materials forming part of generator and cooling thermoelectric modules. *J. Thermoelectricity*, 2, 62 – 66.
7. Anatychuk L.I., Havryliuk M.V., Lysko V.V. (2021). Automation and computerization of processes of measuring thermoelectric parameters of materials forming part of generator and cooling thermoelectric modules. *J. Thermoelectricity*, 3, 60 – 70.
8. Anatychuk L.I., Lysko V.V. (2021). Method for determining the thermoelectric parameters of materials forming part of thermoelectric cooling modules. *J. Thermoelectricity*, 3, 71 – 82.

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ТЕРМОЕЛЕКТРИЧНИХ ПАРАМЕТРІВ МАТЕРІАЛІВ У СКЛАДІ ТЕРМОЕЛЕКТРИЧНИХ МОДУЛІВ

Наведено конструкцію обладнання для вимірювання параметрів термоелектричних генераторних та холодильних модулів, а також опис методики визначення термоелектричних властивостей матеріалів у складі цих модулів. Обладнання створено на основі абсолютного методу, що дозволяє визначати параметри модулів у реальних умовах їх експлуатації та дає можливість інструментально мінімізувати основні джерел похибок вимірювань. Представлено результати експериментальних досліджень параметрів термоелектричних модулів, проведених за допомогою розробленого обладнання.

Ключові слова: термоелектричний модуль, електропровідність, термоЕРС, теплопровідність, термоелектричний матеріал, вимірювання.

Література

1. Kolodner P. (2014). High-precision thermal and electrical characterization of thermoelectric modules. *Review of Scientific Instruments*, 85 (5), 054901/1-054901/11.
2. Anatychuk L.I., Havrylyuk M.V. (2011). Procedure and equipment for measuring parameters of thermoelectric generator modules. *J. Electronic Materials*, 40 (5), 1292 – 1297.
3. Анатичук Л.І., Лисько В.В. Методика визначення термоелектричних параметрів матеріалів у складі термоелектричних модулів охолодження // Термоелектрика. – 2021, №1. – С. 49 – 54.
4. Анатичук Л.І., Лисько В.В. Визначення термоелектричних параметрів матеріалів у складі генераторних термоелектричних модулів // Термоелектрика. – 2020, №3. – С. 70 – 80.
5. Анатичук Л.І., Лисько В.В. Визначення температурних залежностей термоелектричних параметрів матеріалів у складі генераторних термоелектричних модулів при зростаючому перепаді температур // Термоелектрика. – 2021, №2. – С. 53 – 57.
6. Анатичук Л.І., Гаврилюк М.В., Лисько В.В. Комп'ютеризація процесів вимірювань термоелектричних параметрів матеріалів у складі генераторних та холодильних термоелектричних модулів // Термоелектрика. – 2021, №2. – С. 62 – 66.
7. Анатичук Л.І., Гаврилюк М.В., Лисько В.В. Автоматизація та комп'ютеризація процесів вимірювань термоелектричних параметрів матеріалів у складі генераторних та холодильних термоелектричних модулів // Термоелектрика. – 2021, №3. – С. 63 – 72.
8. Анатичук Л.І., Лисько В.В. Методика визначення термоелектричних параметрів матеріалів у складі термоелектричних модулів охолодження // Термоелектрика. – 2021, №3. – С. 73 – 85.

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