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EQUIPMENT FOR DETERMINING THE PARAMETERS OF GENERATOR THERMOELECTRIC MODULES

The results of development of the design of automated equipment for determining the parameters of generator thermoelectric modules are presented. The equipment was created on the basis of the absolute method, which allows measuring the parameters of the modules in real conditions of their operation, instrumentally minimizing the main sources of measurement errors, as well as determining the thermoelectric properties of the materials in the composition of these modules. The measurement control unit is built on the basis of a multi-channel analog-to-digital converter. Processing and display of measurement results are carried out using a computer, the results are displayed in the form of graphs and tables.

Key words: thermoelectric module, generation of electrical energy, electrical conductivity, thermoEMF, thermal conductivity, thermoelectric material, automation, computerization.

Introduction

General characterization of the problem.

Quality control of thermoelectric generator modules plays an important role in the development of these modules and the creation of thermoelectric generators based on them. This control is carried out by measuring the parameters of the modules - electric power and efficiency, as well as their dependence on temperature [1]. One of the best measurement methods in this case is the absolute method [2, 3], which allows measurements to be made in real conditions of module operation and provides the possibility of instrumental minimization of the main sources of measurement errors.

In addition, the absolute method makes it possible to obtain additional information about the properties of the material in the module - thermoEMF, electrical conductivity and thermal conductivity of a pair of thermoelectric circuits [4, 5]. This information is useful for optimizing the material for specific module applications in thermoelectric generators of various types, as well as for improving the design of the modules themselves.

The purpose of this work is to develop the design of equipment for determining the parameters of generator thermoelectric modules, as well as the properties of the thermoelectric material in the composition of these modules.

1. Description of the measurement technique

The diagram of the absolute method for determining the parameters of generator thermoelectric modules is shown in Fig. 1. The module is placed between two heat-levelling plates, which in turn are located between the electric heater and the heat meter. The heat meter contacts the thermostat with its other side.

Using an electric heater, a given temperature difference is created on the module and the EMF E_{TEM}, which occurs at the module terminals, is measured. After this, a matched electrical load is connected to the module terminals, at which the voltage at the module terminals becomes equal to half the EMF. The values of the electric current I_{TEM} passing through the module, the voltage at its terminals U_{TEM} are measured, and the heat flow Q_1 removed from the cold side of the module to the thermostat is determined using a heat meter. The electric power of the module P and its efficiency η are determined using the formulae

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

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

where I_{TEM} and U_{TEM} are current and voltage of module, Q_1 is heat flow removed from the cold side of module and determined with the aid of a heat meter.

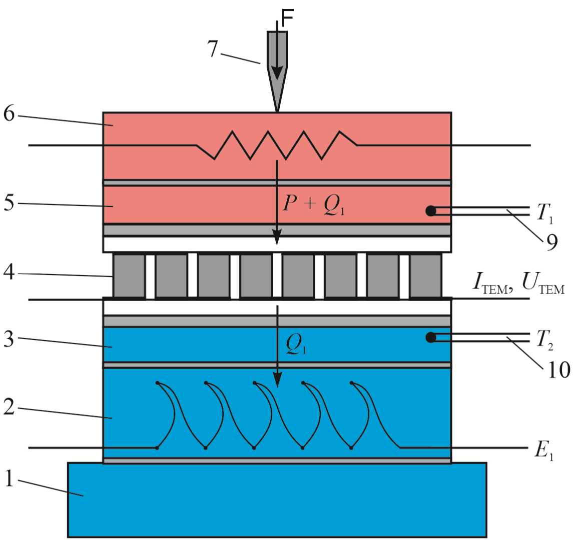

Fig. 1 – Absolute method of measuring the parameters of thermoelectric generator modules: 1 – thermostat; 2 – heat meter, 3, 5 – heat levelling plates; 4 – module under study; 6 – heater; 8 – clamp; 10, 11 –thermocouples.

To find the properties of the thermoelectric material in the modules, the method described in detail in [5] was used. The average values of electrical conductivity, thermoEMF, thermal conductivity and the figure of merit of the material of the legs of the thermoelectric module are determined by the formulae

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

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

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

$$Z = \frac{\alpha^2 \sigma}{\kappa}, \quad (9)$$

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

2. Description of the design of measuring equipment

The equipment for determining the parameters of the generator thermoelectric module consists of a module holder, an electronic measuring unit and a thermoregulation unit, an electric power supply unit, and hydraulic armature for connecting the holder to water cooling line.

The equipment is computerized to eliminate possible subjective errors and increase the accuracy and speed of measurements. The measurement automation system is built on the basis of a 4-channel analog-to-digital converter (ADC) with differential inputs, the range of measured voltages of which is ± (5 μV – 2.5 V). The differential inputs of the ADC make it possible to carry out high-precision measurements of voltages in electrical circuits of various units, which may have different power sources.

The appearance of the measurement automation system is shown in Fig. 2.

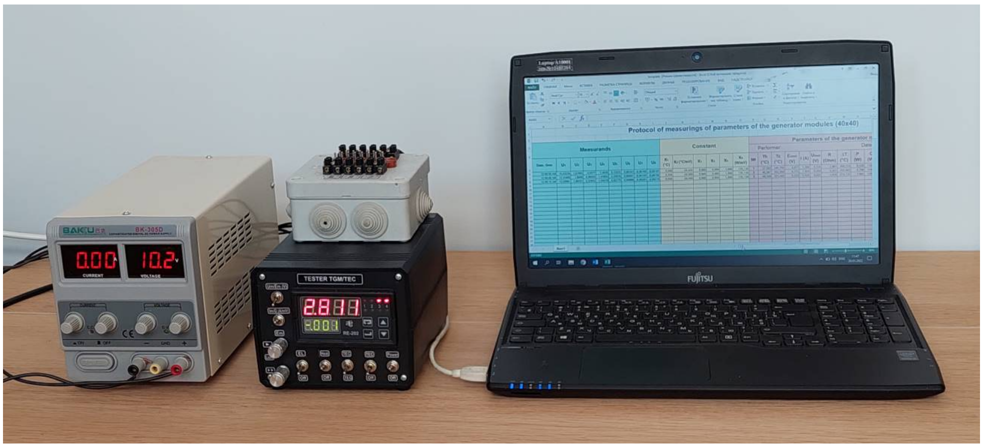

Fig. 2. Appearance of the automation system for measuring parameters of thermoelectric generator modules.

The developed control system is universal. Depending on the selected measurement algorithm, the heat flow can be determined both by the heat meter and by the power of the reference heater, with compensation for heat losses by the screen heater. This allows implementing different algorithms for measuring module parameters.

The generator module holder is a mechanical structure in which the generator module under study is placed. The holder ensures the transfer of thermal power through the module and the removal of the generated electric voltage from the module. The transfer of thermal energy through the module is performed using two heat exchange units: a heating unit and a heat removal unit. The appearance of the generator module holder is shown in Fig. 3.

The heating unit has the main reference heater of the hot side of the generator module and temperature and heat flow control elements: thermocouples, protective and screen auxiliary heaters and an air cooler.

The heat removal unit on the cold side of the module has a main water heat exchanger and temperature and heat flow control elements: thermocouples, heat meter, auxiliary heaters and air cooler.

To increase measurement accuracy and versatility, heat exchange units have replaceable elements that are designed for specific module sizes and can be easily changed.

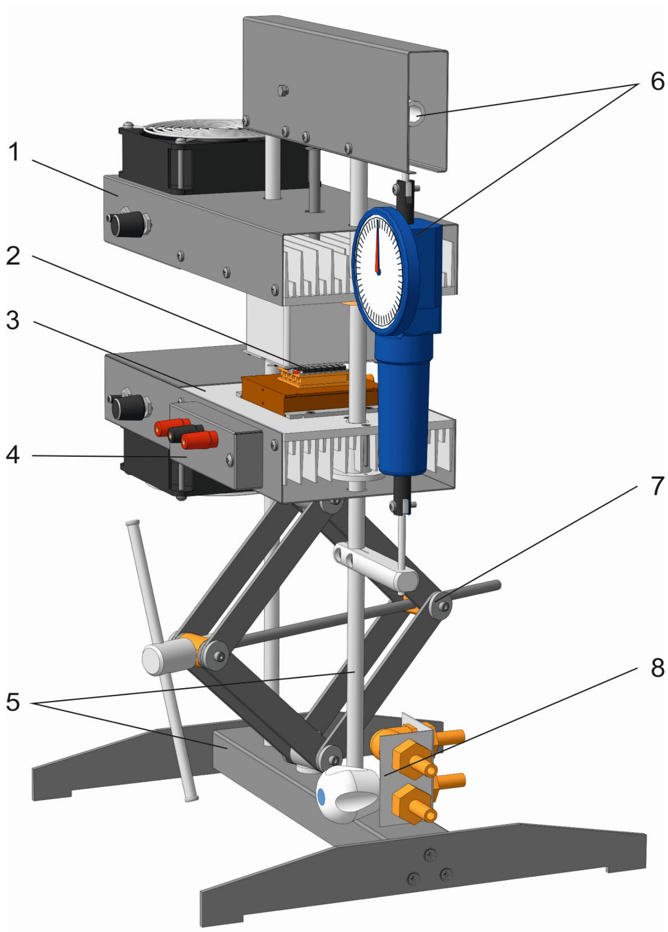

Fig. 3. Design of the generator module holder: 1 – heating unit;
2 – generator module; 3 – heat removal unit;
4 – electrical terminal block; 5 – supporting steel frame; 6 – lever-spring clamping mechanism;
7 – jack-screw mechanism for moving the heat exchanger; 8 – hydraulic armature.

The heat exchange units have sliding bearings, with the help of which they can move up and down along two steel racks fixed on the base of the steel frame. The heat exchange units have working platforms between which the generator module is clamped during measurement. The centers of the working platforms are coaxial.

The heating unit is fixed in the upper part of the racks of the frame, and the heat removal unit on the same racks is located below and can be moved up and down with the help of a jack-type screw mechanism. Even higher, above the heating block on the racks, a generator module clamping device is fixed between the working platforms of the heat exchange blocks. The clamping force is fixed using a lever-spring method, and is set using a jack mechanism. A standard dynamometer is used as a spring.

An electrical terminal block is attached to the heat sink unit for connecting the outputs of the generator module. The terminal block is electrically connected to the electronic load unit with a cable.

The source of thermal power for the generator module in the device is a heating block. The basis of the design of the heating block is an aluminum finned radiator, to which all its components are attached:

moving elements, clamping elements and a replaceable heater unit. For different sizes of generator modules, proportionate heating elements are provided. The structure of the heating block is shown in Fig. 4.

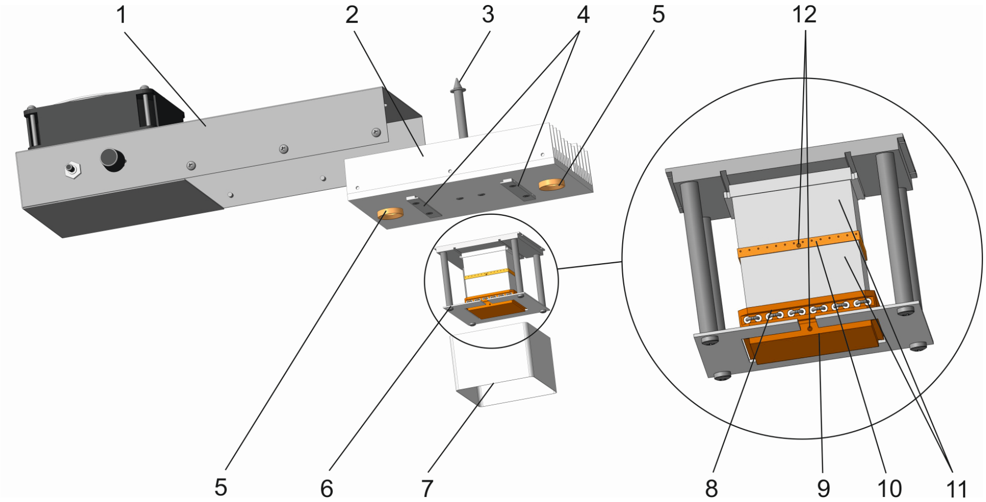

Fig. 4. Structure of the heating unit: 1 – casing with a fan; 2 – ribbed radiator; 3 – rod of the clamping unit; 4 – fastening unit for replaceable heaters, 5 – sliding bearings of the unit for moving heat exchange units; 6 – unit of heaters; 7 – casing of the unit of heaters; 8 – reference heater; 9 – heat levelling plate; 10 – screen heater; 11 – thermal insulation gaskets; 12 – holes for installation of thermocouples.

Thermal energy that flows through the working surfaces of the generator module is partially converted into electrical energy, and the rest is taken by the heat removal unit and dispersed into the environment. The basis of the design of the heat removal unit is also an aluminum finned radiator, to which all its components are attached: moving elements, clamping elements and a replaceable unit of a water heat exchanger, a heat meter and an additional corrective heater (Fig. 5).

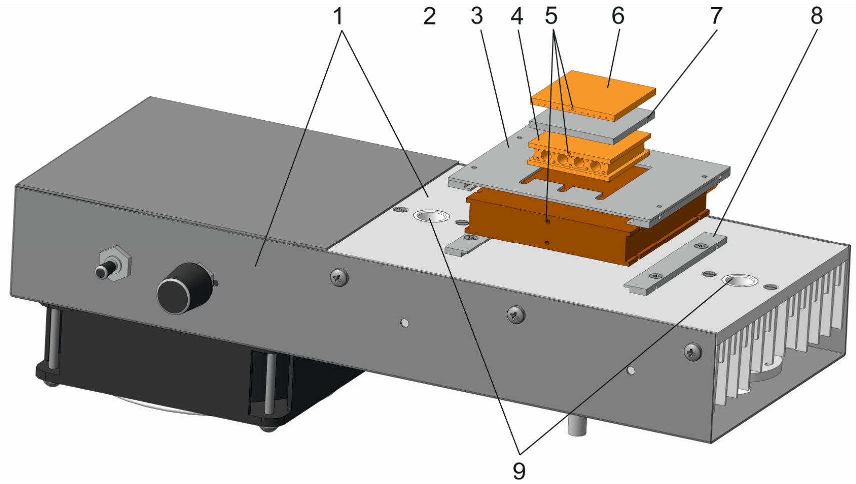

Fig. 5 – Structure of the heat removal unit: 1 – ribbed radiator with blower fan; 2 – water heat exchanger; 3 – centering plate for the thermometer; 4 – thermometer; 5 - holes for installing thermocouples; 6 - corrective heater, 7 - thermal shunt; 8 – fastening unit for replaceable heat exchangers. 9 – sliding bearings of the unit for moving the heat exchange units.

For different types of generator modules, removable, commensurate heat meters and heaters are provided. With the help of the correcting heater, it is possible to change the temperature range of measuring parameters of the generator modules within wide limits. A bracket is attached to the central part of the ribbed radiator below, which is connected to the upper movable platform of the jack. With the help of this jack, the heat removal unit is moved up and down.

The clamping device is important. To improve thermal contacts, thermal drivers are used that can work at elevated temperatures, within the range of maximum operating temperatures for the generator module.

When measuring the parameters of the module, the thermal power from the electric heater, which passes through the module, generates an electrical voltage at its terminals. By the moment the temperatures on the heat-levelling plates reach the set levels, the electronic load is turned off and the thermal emf of the module is measured using an ADC. After reaching the specified temperature difference, the electronic load is switched on at the command of the processor and the current of the module is measured. At the same time, the thermoregulators of the thermostat and the heating heat exchanger automatically compensate for the thermal disturbance caused by the Peltier effect from the action of the module current. The values of electric voltages, currents and temperatures are displayed on a digital indicator, and are also sent to a personal computer for calculations and plotting in a given temperature range. The sequence of measurements and the time intervals between them are specified in the cyclogram, which is formed by the operator before starting the measurements.

The developed equipment allows measuring the parameters of generator thermoelectric modules with sizes from 10x10 to 72x72 mm in the temperature range from 30°C to 600°C, as well as determining the properties of thermoelectric materials in the composition of these modules.

Conclusions

1. The design of measuring equipment has been developed, which allows measuring the parameters of generator thermoelectric modules by the absolute method, as well as determining the properties of thermoelectric materials in the composition of these modules. The created equipment allows measuring the parameters of modules with sizes from 10x10 to 72x72 mm in the temperature range from 30°C to 600°C.
2. The created equipment is computerized, allowing measurements to be taken according to a given algorithm, their results to be processed in real time, the results of measurements to be displayed on the screen in the form of graphs and tables, stored on the computer, and the passport of the module studied to be printed out.

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ОБЛАДНАННЯ ДЛЯ ВИЗНАЧЕННЯ ПАРАМЕТРІВ ГЕНЕРАТОРНИХ ТЕРМОЕЛЕКТРИЧНИХ МОДУЛІВ

Представлено результати розробки конструкції автоматизованого обладнання для визначення параметрів генераторних термоелектричних модулів. Обладнання створено на основі абсолютного методу, що дозволяє проводити вимірювання параметрів модулів у реальних умовах їх експлуатації, інструментально мінімізувати основні джерел похибок вимірювань, а також визначати термоелектричні властивості матеріалів у складі цих модулів. Блок керування вимірюваннями побудовано на основі багатоканального аналогово-цифрового перетворювача. Обробка та відображення результатів вимірювань проводяться за допомогою комп'ютера, результати відображаються у вигляді графіків і таблиць.
Ключові слова: термоелектричний модуль, генерація електричної енергії, електропровідність, термоЕРС, теплопровідність, термоелектричний матеріал, автоматизація, комп’ютеризація.

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ОБОРУДОВАНИЕ ДЛЯ ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ ГЕНЕРАТОРНЫХ ТЕРМОЭЛЕКТРИЧЕСКИХ МОДУЛЕЙ

Представлены результаты разработки конструкции автоматизированного оборудования для определения параметров генераторных термоэлектрических модулей. Оборудование создано на основе абсолютного метода, позволяющего производить измерение параметров модулей в реальных условиях их эксплуатации, инструментально минимизировать основные источники погрешностей измерений, а также определять термоэлектрические свойства материалов в составе этих модулей. Блок управления измерениями построен на основе многоканального аналогово-цифрового преобразователя. Обработка и отображение результатов измерений производятся с помощью компьютера, результаты отображаются в виде графиков и таблиц.

Ключевые слова: термоэлектрический модуль, генерация электрической энергии, электропроводность, термоЭДС, теплопроводность, термоэлектрический материал, автоматизация, компьютеризация.

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