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EQUIPMENT FOR DETERMINING THE PARAMETERS OF THERMOELECTRIC COOLING MODULES

The results of the development of the design of equipment for measuring the parameters of thermoelectric cooling modules, as well as determining the thermoelectric properties of materials in these modules, are presented. 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 measurement control unit is built on the basis of a multichannel analog-to-digital converter. Processing and display of measurement results are carried out using a computer; the results are displayed through graphs and tables. Bibl. 5, Fig. 6.
Key words: thermoelectric module, cooling, electrical conductivity, thermoEMF, thermal conductivity, thermoelectric material, automation, computerization.

Introduction

General characterization of the problem.

It is known that the quality control of thermoelectric energy converters (modules) plays an important role both in their development and in the creation on the basis of these modules of thermoelectric cooling devices. Such control is carried out by measuring the parameters of thermoelectric modules, namely cooling capacity, coefficient of performance and temperature difference on the module, as well as their temperature dependence [1]. One of the best measurement methods in this case is the absolute method. The main advantages of this method are the determination of module parameters in real operating conditions and the possibility of instrumental minimization of the main sources of measurement errors [4].

Moreover, the absolute method makes it possible to obtain additional 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 [5]. This information is useful both for optimizing thermoelectric material for its specific applications and for improving the design of modules.

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

Description of measurement method

The schematic of the absolute method, taken as a basis for the creation of automated equipment for determining the parameters of thermoelectric cooling modules, is shown in Fig.1. To determine the parameters of the thermoelectric module, the latter is placed between two heat equalizing plates, which in turn are located between the electrical heater and the thermostat. Additionally, a protective heater is used, the temperature of which is maintained equal to the temperature of the reference heater, which prevents heat loss from the heater through the clamping mechanism. The electrical current is passed through the module and its value is selected at which the temperature difference between the cold and hot surfaces of the module will reach the maximum value ΔT_{max}. After that, the electrical current through the heater is turned on and gradually increases to a value at which the temperature difference across the module becomes equal to zero.

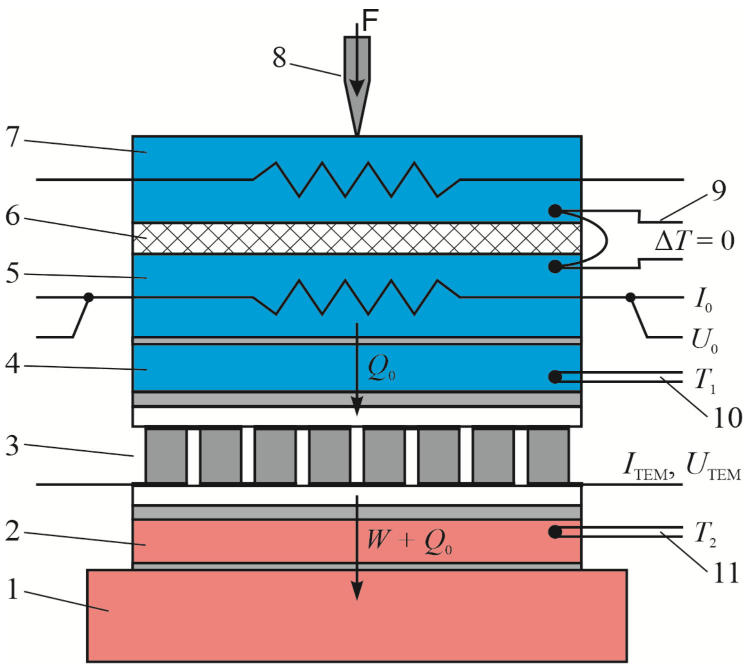

Fig. 1. Absolute method of measuring the parameters of thermoelectric cooling modules: 1 – thermostat; 2, 4 –heat equalizing plates; 3 – module under study; 5 – reference heater; 6 – thermal insulation; 7 – protective heater; 8 – clamp; 9 – zero thermocouple; 10, 11 – thermocouples

The maximum cooling capacity of the module is considered to be equal to the electrical power, which is released by the electrical heater.

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 the electrical power consumed by the module.

To find the properties of the thermoelectric material forming part of the modules, the technique described in detail in [5] was used. It is as follows:

- determination of the electrical conductivity σ by the measured module resistance on the alternating current and the known module design;
- creation on the module of temperature difference by means of the electrical heater (with current through the module switched off);
- determination of the Seebeck coefficient α by the measured values of module EMF and temperature difference on the module;
- determination of the thermal conductivity κ by the measured values of heat flux through the module (electrical heater power) and temperature difference on the module.

The average values of the 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.

Description of measuring equipment design

The equipment for determining the parameters of a thermoelectric cooling module consists of a thermoelectric module holder, an electronic measuring unit and a thermal control unit, an electrical power supply unit, hydraulic fittings for connecting the holder to the water cooling line. The measuring unit has an interface for connection to a PC for measurements and processing of their results. The holder of the cooling module is a mechanical design in which the investigated module is placed. The design of the holder is shown in Fig. 2.

The holder provides the supply of current and heat load through the module and the removal of information from the module about the created temperature differences and heat energy transfers. The transfer of thermal energy through the module is carried out by means of supply current between two heat exchange units - from the heating unit to the heat removal unit.

The heating unit has a main reference heater for the cold side of the cooling module and temperature and heat flux control elements: thermocouples, shield thermoelectric heater/cooler, and an air cooler.

The heat removal unit on the hot side of the module has a main water heat exchanger, temperature control elements: thermocouples, an auxiliary thermoelectric table, heaters and an air cooler.

To increase measurement accuracy and for versatility, the heat exchange units have replaceable elements designed for specific cooling module sizes and which can be easily changed as needed.

The heat exchange units have slide bearings, with which they can move up and down along two steel racks fixed on a steel frame. The heat exchange units have working platforms between which the studied module is clamped during the 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 using a jack-type screw mechanism. Even higher, above the heating block on the racks, a device for pressing the studied cooling module between the working platforms of the heat exchange blocks is fixed. The clamping force is fixed by a lever-spring method, and is set using a jacking mechanism. A standard dynamometer is used as a spring.

An electrical terminal block is attached to the heat removal unit for connecting the wires of the cooling module. The terminal block is connected to the electronic units with a cable.

The source of thermal power for the cooling module in the device is the heating unit, from which it is transferred to the heat removal unit. If there is no inflow of heat from the heating unit - the module operates in the mode of the maximum temperature difference. When a thermal load occurs, the resulting temperature difference will be less and the module will operate in cooling capacity mode. 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 - a working platform for thermal contact with the surface of the module and heat load heaters. For different standard sizes of cooling modules, elements proportionate to them are provided – work platforms and heaters. The structure of the heating unit is shown in Fig. 3.

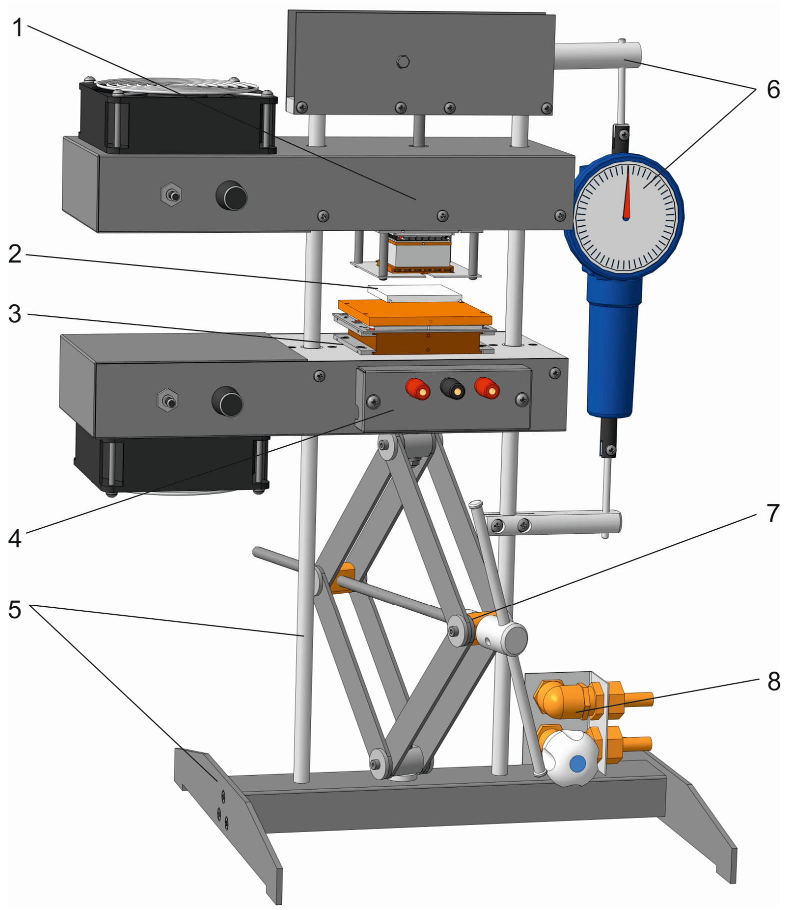

Fig. 2. The design of the module holder for measuring the parameters of thermoelectric cooling modules: 1 – heating unit; 2 – module under study; 3 – heat removal unit; 4 – electrical terminal block; 5 – load-bearing steel frame; 6 – lever-spring clamping mechanism; 7 – jack-screw mechanism for moving the heat exchanger; 8 – hydraulic fittings

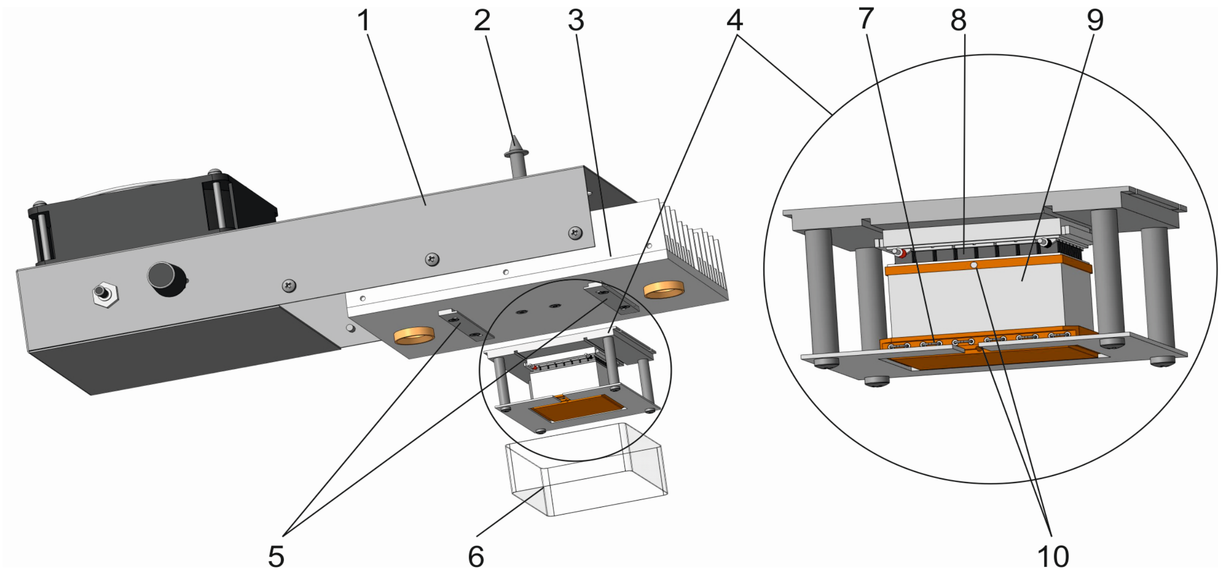

Fig. 3. The structure of the measuring equipment heating unit:
1 – casing with fan; 2 – clamping assembly rod; 3 – finned radiator;
4 – heating unit and the receiving work platform for cooling module;
5 – fixing assembly for replaceable heating units; 6 – heater assembly cover;
7 – reference heater with receiving platform; 8 – shield heater/cooler;
9 – thermal insulation gasket; 9 – holes for mounting thermocouples

The electrical supply current flowing through the cooling module creates a temperature difference on its working surfaces and in the presence of thermal contact between the module and the working platforms of the heat exchange units, a heat flux will appear in the direction from the heater unit to the heat removal unit. External heat can be generated both by the reference heater and absorbed from the environment. To cut off heat from the external environment, passive thermal insulation of the working platform and the use of a shield heater/cooler are used, the operation of which is controlled by electronic units.

The structure of the heat removal unit is shown in Fig. 4. The basis of the design of the unit is also an aluminum finned radiator, to which all its components are attached: elements of movement, clamps and a replaceable unit of water heat exchanger and additional corrective thermotable - heater or cooler, as needed.

For different types of cooling modules, removable, proportionate water heat exchangers are provided with working platforms or thermotables placed on them. With the help of corrective heaters or thermoelectric modules of the thermotable, it is possible to change the temperature range for measuring the parameters of the cooling modules over a wide range.

Attached to the center of the finned radiator, at the bottom, is a bracket that is connected to the upper movable jack pad. With this jack, the heat sink moves up and down.

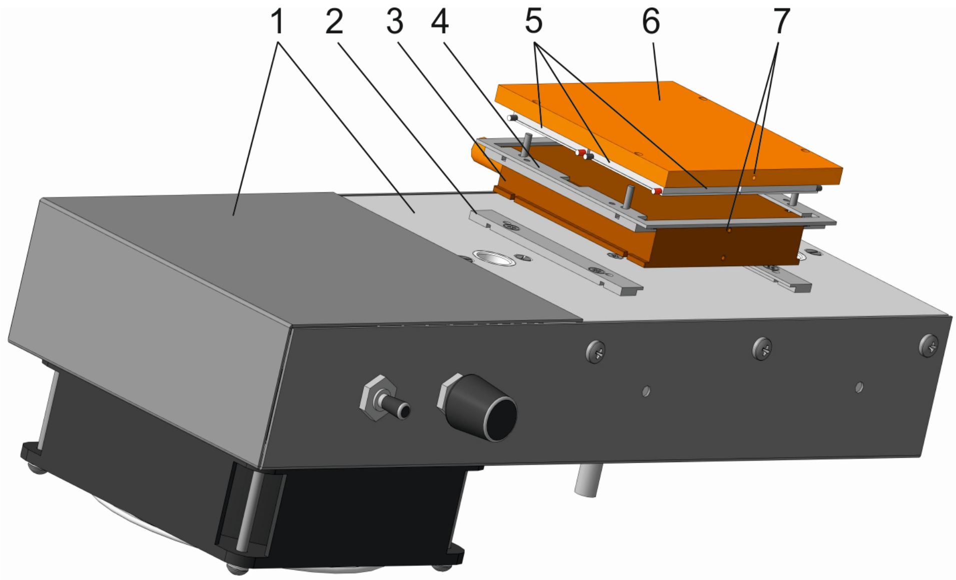

Fig.4. Design of unit for heat removal from cooling module:
1 – finned radiator with a blower fan; 2 – fixing assembly for replaceable heat exchangers;
3 – water heat exchanger; 4 – centering plate for thermotable; 5 – thermoelectric modules of thermotable; 6 – working platform for installation of cooling nodule;
7 – holes for installation of thermocouples

To increase the accuracy of measuring the parameters of a thermoelectric cooling module, it is necessary that the heat generated by the upper heat exchanger and removed through the module by the lower heat exchanger passed with the least losses. The imperfection of the working surfaces of the heat exchangers and the cooling module, which is measured, leads to the fact that the temperatures on the surfaces of the heat exchangers differ from the temperatures on the working surfaces of the module. The actual difference on the module will be less than the measured difference between the heat exchangers, but it is in the heat exchangers that the temperature sensors are located for technological and design reasons.

To improve thermal contact, thermal drivers are also used - liquid substances with a fairly high (relative to air) coefficient of thermal conductivity. These can be various heat-conducting pastes, oils, etc. When using such substances, they fill the air gap between the unevenness of the surfaces of the module and heat exchangers. To improve the thermal contact, the module surfaces between the heat exchangers should be pressed with such force that the excess material of the thermal driver is displaced from the interlayer, and the solid surfaces of the heat exchangers and the module rest against each other only by the nearest protrusions. The holder design makes it possible to apply a compression force from 0 to 200 kg to the module (for example, a standard ALTEC-22 thermoelectric module with a total area of about 10 cm^2 of legs must be compressed between heat exchangers with a force of about 80 kg).

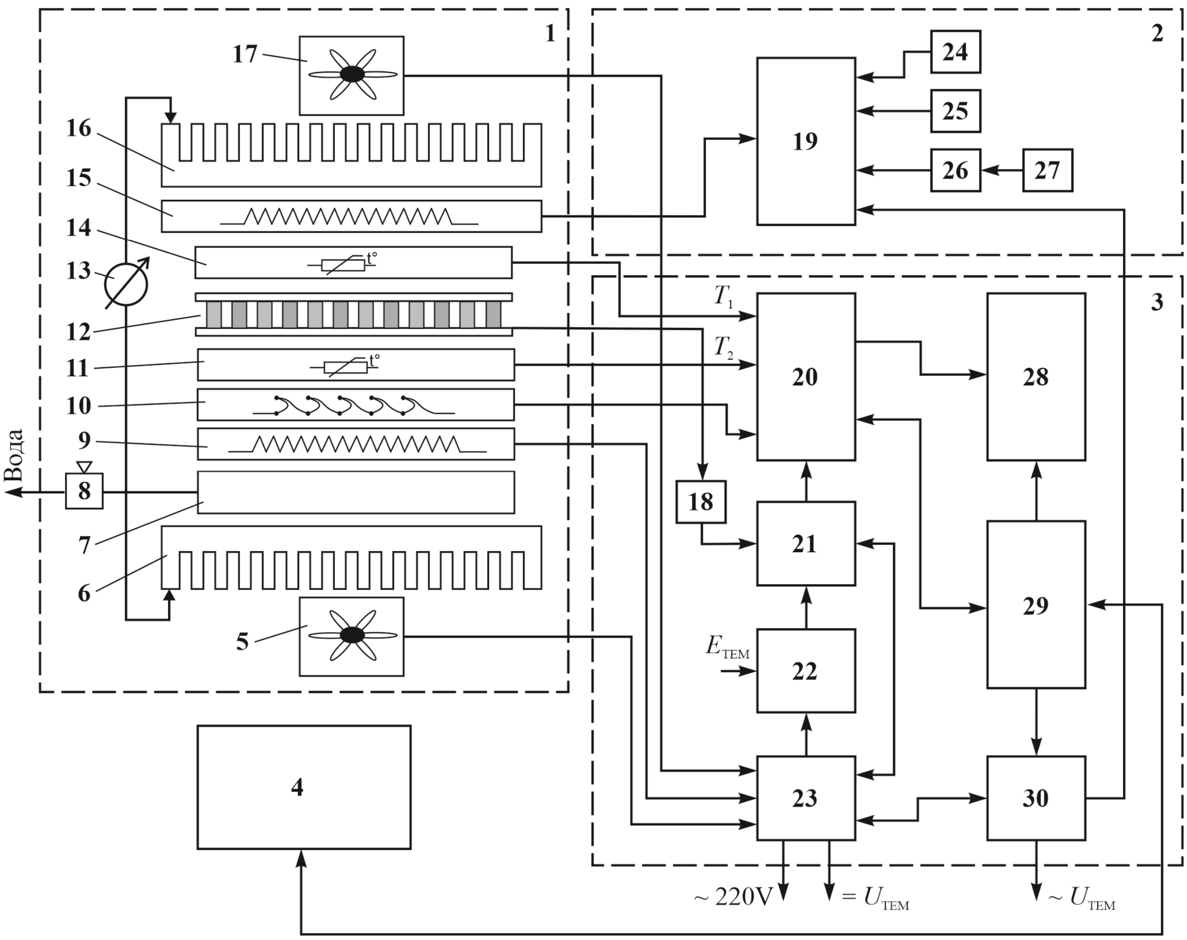

Fig. 5 – Block diagram of the automation system for measuring the parameters of thermoelectric modules by the absolute method:
1 – thermoelectric module holder; 2 – power unit; 3 – control unit; 4 – personal computer; 5, 17 – fans; 6, 16 – air heat exchangers; 7 – water heat exchanger; 8 –tap; 9 –thermostat electric heater; 10 – heat meter; 11, 14 – heat equalizing plates with embedded temperature sensors; 12 – thermoelectric module under study; 13 – dynamometer; 15 – module heater; 18 – electronic load; 19 – heater connection block; 20 – 4- channel precision ADC; 21 – electronic load current/voltage converter; 22 – electronic load control unit; 23 – thermostat power supply; 24 –shield heater power unit; 25 – zero node; 26 – reference heater current/voltage meter; 27 – reference heater power unit; 28 – digital indicator; 29 – control processor; 30 – triac heater control key

The equipment is computerized to eliminate possible human errors and increase the accuracy and speed of measurements. The block diagram of the automation system for measuring the characteristics of thermoelectric modules is shown in Fig.5. It is based on a 4-channel analog-to-digital converter (ADC) with differential inputs, the measured voltage range of which is ±(5 μV - 2.5 V). Differential ADC inputs allow high precision voltage measurements in electrical circuits of different units, which may have different power sources.

Fig. 6. Appearance of equipment for measuring the parameters of thermoelectric cooling modules

The developed control system is universal. Depending on the chosen measurement algorithm, the heat flux can be determined by both the heat meter and the power of the reference heater, provided that the heat loss is compensated by the shield heater. This makes it possible to implement different algorithms for measuring the parameters of both cooling modules and generator modules. All measured signals are sent to the controller, where they are normalized to certain physical values. The values of electrical voltages, currents and temperatures are displayed on a digital indicator 28, and also supplied to a personal computer 4 for calculations and plotting in a given temperature range. The sequence of measurements and the time between them are set in the cyclogram, which is formed by the operator before the start of measurements.

The appearance of the developed equipment is shown in Fig. 6. The equipment makes it possible to measure the parameters of thermoelectric modules with dimensions from 10x10 to 72x72 mm in the range of temperatures from -50°C to 100°C, as well as to determine the properties of thermoelectric materials forming part of these modules.

Conclusions

1. The design of measuring equipment has been developed which makes it possible to measure the parameters of thermoelectric cooling modules by the absolute method, as well as to determine the properties of thermoelectric materials forming part of these modules. The equipment allows measuring the parameters of modules with dimensions from 10 × 10 to 72 × 72 mm in the range of temperatures from -50 °C to 100 °C.
2. Computerized equipment has been created that allows measurements to be made according to a given algorithm, real-time processing of their results, displaying the measurement results on the screen in the form of graphs and tables, storing them on a computer, and printing out a passport of the studied module.

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ОБЛАДНАННЯ ДЛЯ ВИЗНАЧЕННЯ ПАРАМЕТРІВ ТЕРМОЕЛЕКТРИЧНИХ МОДУЛІВ ОХОЛОДЖЕННЯ

Представлено результати розробки конструкції обладнання для вимірювання параметрів термоелектричних модулів охолодження, а також 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. 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. Бібл. 5, рис.6.

Ключові слова: термоелектричний модуль, охолодження, електропровідність, термоЕРС, теплопровідність, термоелектричний матеріал, автоматизація, комп’ютеризація.

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ОБОРУДОВАНИЕ ДЛЯ ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ ТЕРМОЭЛЕКТРИЧЕСКИХ МОДУЛЕЙ ОХЛАЖДЕНИЯ

Представлены результаты разработки конструкции оборудования для измерения параметров термоэлектрических модулей охлаждения, а также определения термоэлектрических свойств материалов в составе этих модулей. Оборудование создано на основе абсолютного метода, позволяющего определять параметры модулей в реальных условиях их эксплуатации и позволяет инструментально минимизировать основные источники погрешностей измерений. Блок управления измерениями построен на основе многоканального аналогово-цифрового преобразователя. Обработка и отображение результатов измерений производятся с помощью компьютера, результаты отображаются посредством графиков и таблиц. Библ. 5, рис.6.

Ключевые слова: термоэлектрический модуль, охлаждение, электропроводность, термоЭДС, теплопроводность, термоэлектрический материал, автоматизация, компьютеризация.

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