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AUTOMATION AND COMPUTERIZATION OF PROCESSES OF MEASURING THERMOELECTRIC PARAMETERS OF MATERIALS FORMING PART OF GENERATOR AND COOLING THERMOELECTRIC MODULES

The results of development of automation system for measuring thermoelectric parameters of materials forming part of thermoelectric modules by the absolute method are presented. The measurement control unit is built on the basis of a multi-channel analog-to-digital converter. Processing and display of measurement results is carried out using a computer to which the measurement unit is connected via a standard USB channel. The results are displayed in the form of graphs and tables.

The developed automation system is universal and makes it possible to measure the thermoelectric properties of materials both as part of generator and as part of cooling thermoelectric modules. Bibl. 9, Fig. 3.

Key words: electrical conductivity, thermoEMF, thermal conductivity, thermoelectric material, automation, computerization.

Introduction

General characterization of the problem.

It is known that the quality control of thermoelectric power converters (modules) plays an important role both in the development and in the creation on the basis of these modules of thermoelectric devices for cooling and generation of electric energy. This control is carried out by measuring the parameters of thermoelectric modules, namely 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 is the absolute method [1, 2]. The main advantages of this method are the determination of the parameters of the modules in the real conditions of their operation and the possibility of instrumental minimization of the main sources of measurement errors [3].

Moreover, the absolute method makes it possible to additionally 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. This information is useful both for optimizing the thermoelectric material for its specific applications and for improving the design of modules [4 - 6].

The implementation of these methods requires complete automation of the measurement process. In addition, this will eliminate possible subjective errors of operators when measuring electrical signals, processing them to determine σ, α, κ, Z, when plotting graphs and tables.

Therefore, *the purpose of the work* was to create a computerized measurement control system to automate the processes of determining the thermoelectric properties of materials forming part of thermoelectric power converters, processing and displaying their results.

Requirements for automation of measurements

The diagrams of the absolute method taken as a basis for creation of automated equipment for determining the parameters of generator and cooling thermoelectric modules are given in Fig.1 and Fig.2, respectively.

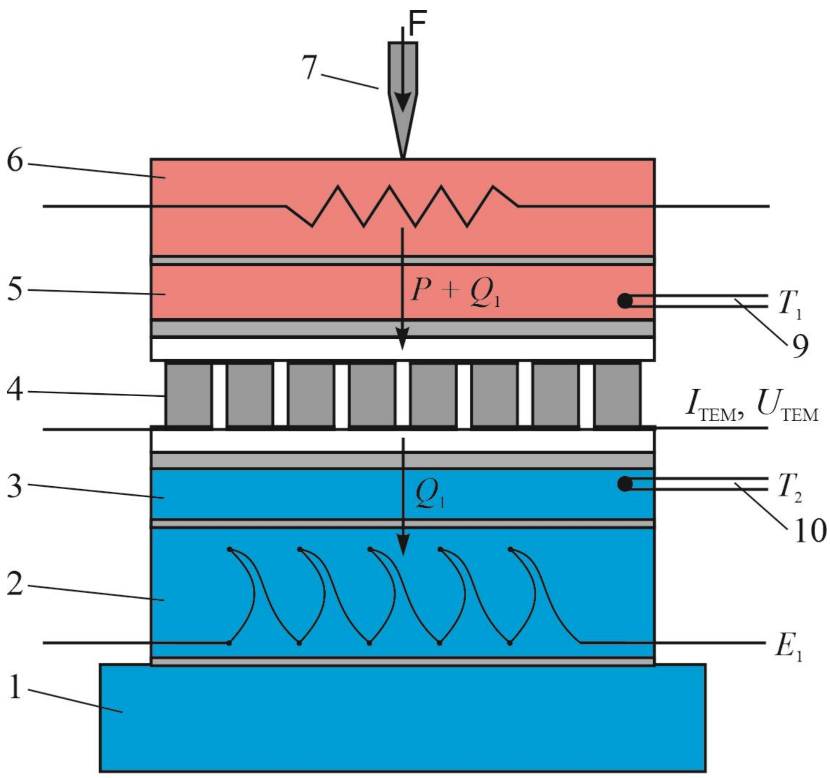

Fig. 1. Absolute method for measuring parameters of thermoelectric generator modules: 1 – thermostat; 2 – heat meter, 3, 5 – heat equalizing plates; 4 – module under study; 6 – heater; 7 – clamp; 9, 10 – thermocouples.

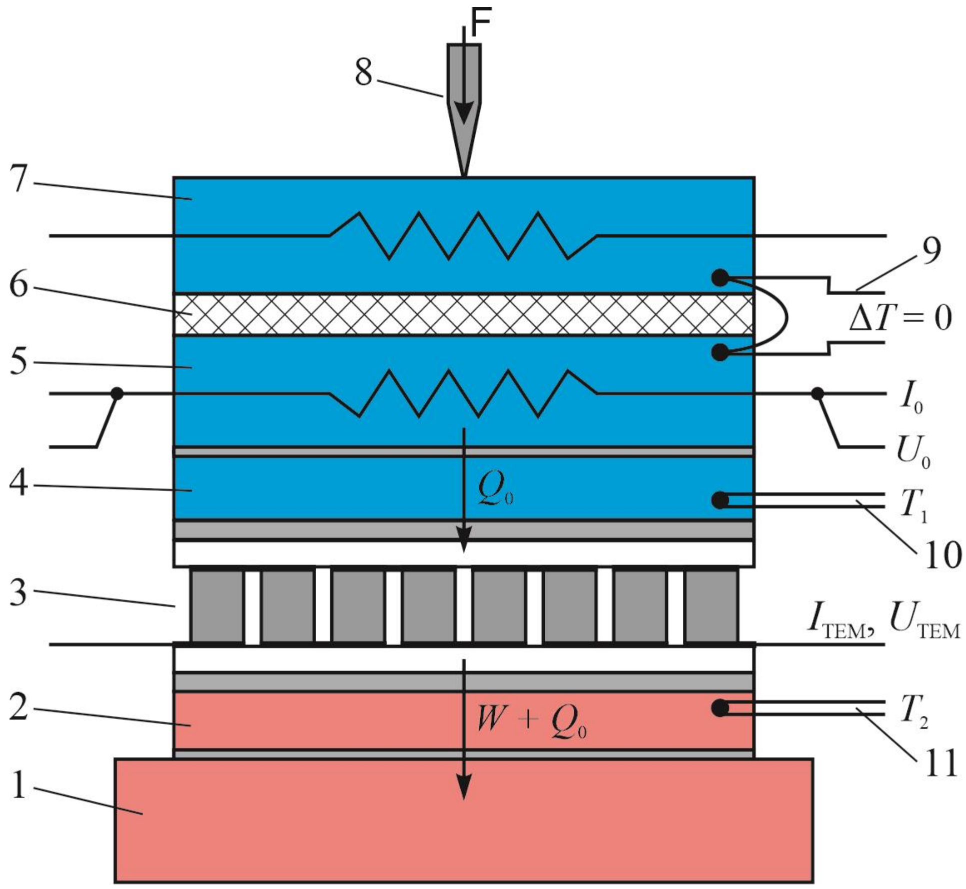

Fig. 2. Absolute method for measuring parameters of thermoelectric cooling modules:
1 – thermostat; 2, 4 – heat equalizing plates; 3 – module under study;
5 – reference heater; 6 – thermal insulation; 7 – protective heater;
8 – clamp; 9 – zero thermocouple; 10, 11 – thermocouples.

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. 1). The other side of the heat meter is in contact with the thermostat. By means of the electric heater a given temperature difference is created on the module and the thermoEMF E_{TEM} that occurs on the module wires is measured. After that, the matched electrical load is connected to the module wires, whereby the voltage at the module wires will be equal to half of the EMF. The values of the electric current I_{TEM} passing through the module, the voltage on its wires 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 the module P and the efficiency η are determined by 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 flux which is removed from the cold side of the module and determined by means of the heat meter, F is clamp.

When determining the parameters of cooling modules, a protective heater is additionally used to prevent heat loss from the heater through the clamping mechanism (Fig. 2). 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 are current through the heater and voltage drop thereon, T_1 is the temperature of the "cold" side of module, T_2 is the temperature of the "hot" side of module, W is electrical power consumed by the module.

To find the properties of the thermoelectric material forming part of the modules, the method described in detail in [4, 6] was used.

The average values of electrical conductivity, thermoEMF, thermal conductivity and figure of merit 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 the AC module resistance; a_1 x b_1 is the cross-section of legs; h_1 is the height of legs; N is the number of pairs; E is the EMF of module; ΔT is the temperature difference between thermocouples arranged on the heat equalizing plates between which a module under study is located; Q is the thermal flux through the module; K_1 - K_3 are correction factors to reduce the value of measurement errors calculated for given module design and measuring equipment or determined experimentally.

To implement this method, the measurement control system must have:

– means for setting and maintaining the temperature of the measuring thermostat in a wide temperature range (temperature controller, power supply, control thermocouple, etc.);
– adjustable power supply for passing current through the module, current switch;
– adjustable power supply of the reference heater;
– means for maintaining zero temperature difference between the reference heater and the protective shield (temperature controller, power supply, control zero-thermocouple, etc.);
– high-precision voltage meter with a resolution of at least 1 μV;
– the ability to work out the necessary cyclogram for switching on / off power supplies and recording the measurement results of all measuring channels (temperatures of "hot" and "cold" thermocouples, voltage drop between modules, current and voltage values through the module, current and voltage supply of the reference heater, etc.);
– the possibility of transferring the measurement results to a computer for further processing, plotting graphs and tables, generating a module passport.

Description of measurement control system

Universal units with discrete control inputs and corresponding analog outputs have been developed. By combining these units and controlling them according to the required cyclograms with the help of a programmable controller, one can create different installations that make it possible to implement any method of measuring the parameters of thermoelectric modules.

The block diagram of the automation system for measuring the parameters of thermoelectric modules is shown in Fig. 3. 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). ADC differential inputs allow high-precision voltage measurements in electrical circuits of different units, which can have different power supplies.

The system also includes electronic load 18, which utilizes a range of state-of-the-art MOSFETs with low on-resistance to reduce heat generation and eliminate the need for heat sinks.

The holder of the thermoelectric module 1 uses an interchangeable heating heat exchanger, which includes a reference heater 15, with a temperature sensor in the heat equalizing plate 14, a shield heater and a differential zero-thermocouple. The heat exchanger through the block 19 is connected to the power supply units of the reference 27 and shield 24 heaters, as well as to the current / voltage meters of the reference heater 26 and the zero node 25. All these elements are included in the power unit 2.

To perform the measurement algorithm, a control unit 3 is used, containing a 4-channel precision ADC 20 and an electronic load 18, as well as control systems for the electronic load and a cooling thermostat. The electronic load control system includes a control unit 22 and a current/voltage converter of the electronic load 21. The thermostat control system includes power supplies 23 for thermostat elements and circuits of the control unit itself. The central processor 29 controls all elements of the control unit and also provides the output of the received information to the digital indicator 28. The control unit contains a power key 30 for the reference heater 15.

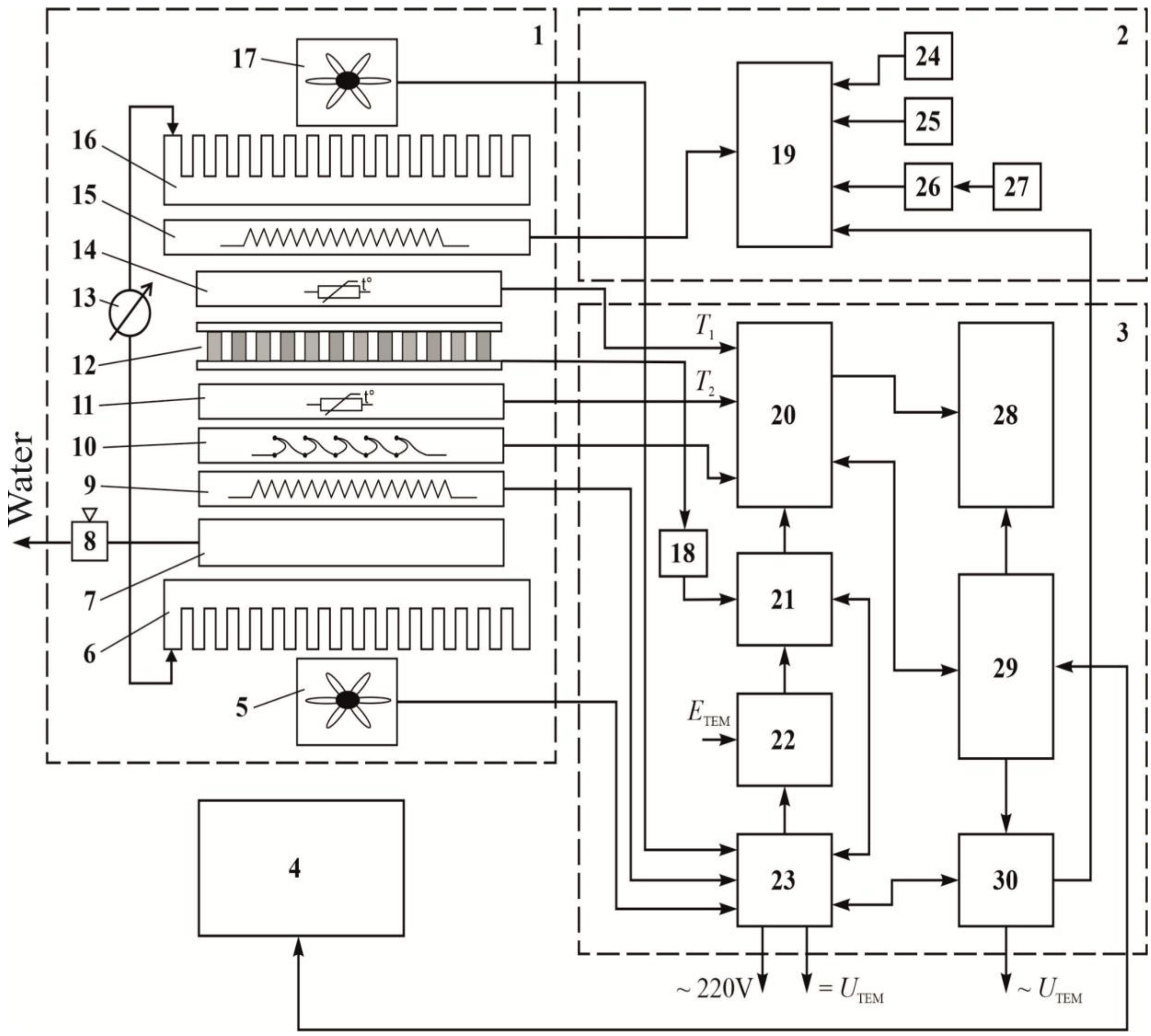

Fig. 3. Block-diagram of automation system for measuring parameters of thermoelectric modules by the absolute method: 1 – thermoelectric module holder; 2 – power unit; 3 – control unit; 4 – personal computer; 5, 17 – fans; 6, 16 – air heat exchangers; 7 – water heat exchanger; 8 –tap; 9 –thermostat electric 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 thermostat of the device contains a base-radiator 6 with a fan 5, a water heat exchanger 7 with a control water tap 8 and an additional heater 9. A heat meter 10 is placed above the thermostat to determine the heat flux. The thermoelectric module 12 under study is placed between the heat meter and the heater. The thermostat elements 7–11 can also be changeable, depending on the type of the module under study and different measurement conditions. Fans 5 and 7, as well as heater 9, are auxiliary and are used if necessary. The heating heat exchanger, the module and the thermostat in the holder are pressed against each other during measurement by the clamping unit, the force of which is controlled and determined by the dynamometer 13.

The measuring unit via the USB channel is connected to the personal computer 4, where the cyclograms of measurements are set, the necessary calculations are performed, the corresponding graphs are built, measurement protocols are formed.

To measure the parameters of the thermoelectric module, the required temperature is set on the thermostat, which is maintained on the heat equalizing plate 11. The temperature is maintained at a given level by regulating water consumption in the heat exchanger 7 and adjusting it with an additional heater 8 using a PID-PWM controller. The temperature is also set on the hot side of the thermoelectric module, which will be determined by the readings of the sensor in the plate 14 of the heating heat exchanger. The reference heater 15, through the key 30, is energized to heat the hot side of the module to the required temperature. By monitoring the zero-thermocouple signal, the shield heater automatically heats up to the temperature of the hot side of the module, thus compensating as much as possible for heat losses from the reference heater. The error in maintaining temperatures is not more than ± 0.1 °C. The heat flux passing through the module also passes through the heat meter, the signal of which is measured by the ADC. Moreover, the ADC measures the current and voltage of the reference heater through unit 26.

Depending on the chosen measurement algorithm, the heat flux can be determined both by the heat meter and by the power of the reference heater, provided that heat losses are compensated by the shield heater. This makes it possible to implement various algorithms for measuring the parameters of both generator modules and cooling modules. For example, when determining the parameters of generator modules, the thermal power from an electric heater passing through the module generates an electrical voltage at its wires. Until the temperature on the heat equalizing plates reaches the set levels, the electronic load is switched off and the thermoEMF of the module is measured with the help of an ADC. After the specified temperature difference is reached, the processor turns on the electronic load and measures the module current. In so doing, the temperature controllers of the thermostat and the heating heat exchanger automatically compensate for the thermal disturbance caused by the Peltier effect due to the action of the module current. All measured signals are fed to the controller, where they are normalized to specific physical quantities. The values of electrical voltages, currents and temperatures are displayed on a digital indicator 28, and are also sent 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 measurement automation system is given in Fig. 4.

The developed system is universal. The number and characteristics of control and measuring channels allows it to be applied to other measurement methods, such as the Harman method.

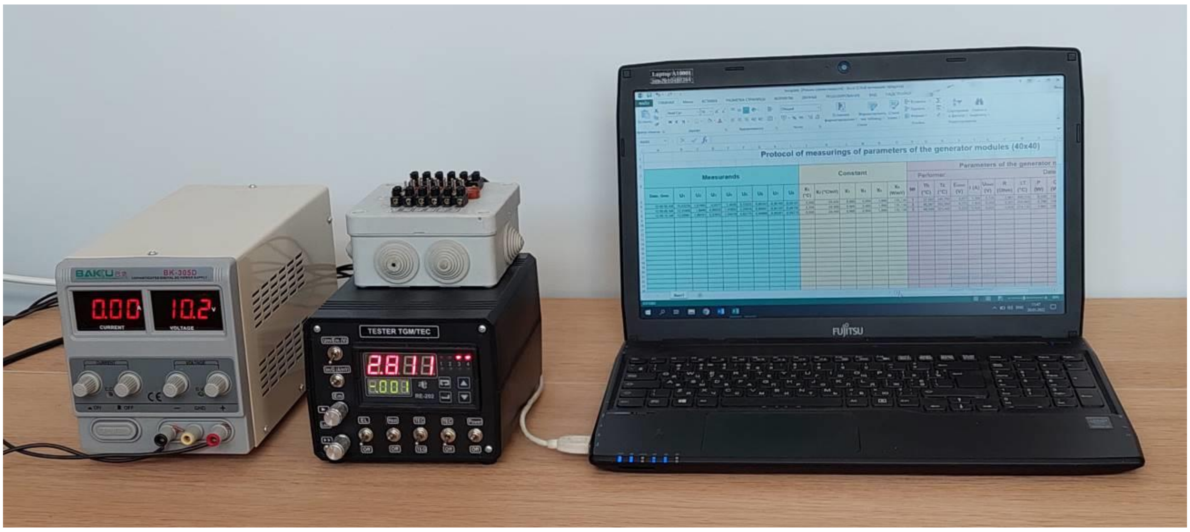

Fig. 4. Appearance of automation system for measuring parameters of thermoelectric modules.

Based on the developed control system, automation of equipment was carried out for measuring the parameters of thermoelectric generator modules with dimensions from 10×10 to 72×72 mm in the temperature range from 30 to 600 °C and cooling modules of similar sizes – from -50 to 100 °C, as well as determining the properties of thermoelectric materials within these modules.

Conclusions

1. A universal electronic control system has been developed that makes it possible to measure the parameters of thermoelectric generator and cooling modules by the absolute method, as well as to determine the properties of thermoelectric materials forming part of these modules. Automated measuring equipment based on such a system allows measurements in 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 computerization of the measurement process has been carried out. The equipment created on the basis of the developed control system makes it possible to perform real time measurements, process their results, display the measurement results in the form of graphs and tables, save them in a computer, and print out the passport of the studied module.

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АВТОМАТИЗАЦІЯ ТА КОМП'ЮТЕРИЗАЦІЯ ПРОЦЕСІВ ВИМІРЮВАНЬ ТЕРМОЕЛЕКТРИЧНИХ ПАРАМЕТРІВ МАТЕРІАЛІВ У СКЛАДІ ГЕНЕРАТОРНИХ ТА ХОЛОДИЛЬНИХ ТЕРМОЕЛЕКТРИЧНИХ МОДУЛІВ

Представлено результати розробки системи автоматизації процесу вимірювань термоелектричних параметрів матеріалів у складі термоелектричних модулів абсолютним методом. Блок керування вимірюваннями побудовано на основі багатоканального аналогово-цифрового перетворювача. Обробка та відображення результатів вимірювань проводяться за допомогою комп'ютера, до якого блок вимірювань підключається по стандартному каналу USB. Результати відображаються у вигляді графіків і таблиць. Розроблена система автоматизації є універсальною та дозволяє реалізовувати вимірювання термоелектричних властивостей матеріалів як у складі генераторних, так і у складі холодильних термоелектричних модулів. Бібл. 6, рис. 4.

Ключові слова: електропровідність, термоЕРС, теплопровідність, термоелектричний матеріал, автоматизація, комп'ютеризація.

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АВТОМАТИЗАЦИЯ И КОМПЬЮТЕРИЗАЦИЯ ПРОЦЕССОВ ИЗМЕРЕНИЙ ТЕРМОЭЛЕКТРИЧЕСКИХ ПАРАМЕТРОВ МАТЕРИАЛОВ В СОСТАВЕ ГЕНЕРАТОРНЫХ И ХОЛОДИЛЬНЫХ ТЕРМОЭЛЕКТРИЧЕСКИХ МОДУЛЕЙ

Представлены результаты разработки системы автоматизации процесса измерений термоэлектрических параметров материалов в составе термоэлектрических модулей абсолютным методом. Блок управления измерениями построен на основе многоканального аналогово-цифрового преобразователя. Обработка и отображение результатов измерений производятся с помощью компьютера, к которому блок измерений подключается через стандартный канал USB. Результаты отображаются посредством графиков и таблиц. Разработанная система автоматизации универсальна и позволяет реализовывать измерения термоэлектрических свойств материалов как в составе генераторных, так и в составе холодильных термоэлектрических модулей. Библ. 6, рис.4.

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

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