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A BENCH FOR CALIBRATING HEAT METERS FOR DETERMINATION OF PARAMETERS OF GENERATOR THERMOELECTRIC MODULES

The results of the development of a bench for calibrating heat meters to determine the heat flux through the generator thermoelectric module when measuring its parameters by the absolute method are presented. The bench allows one to study the metrological characteristics of heat meters in the required temperature range and transfer the measurement results to a personal computer in real time. Bibl. 6, Fig. 6.

Key words: thermoelectric module, heat meter, calibration, accuracy.

Introduction

General characterization of the problem

Improving the quality and reducing the cost of thermoelectric generator modules requires their use in the development and manufacture of advanced technologies and high-performance materials. At the same time, increasing the accuracy in determining the thermal and electrical parameters of the modules makes it possible to more predictably adjust the module production technology, as well as to optimally approach the direct creation of final devices based on these generator modules. The accuracy of determining the parameters of modules should be such as to reliably record the impact of new technologies and designs on the quality of modules. No less important is the metrological support in the creation of thermoelectric generators. The identity and reliability of measurements of module parameters from suppliers and consumers of modules that use them in thermoelectric products, eliminates the problems that arise.

The most reliable and accurate among the existing methods of determining the parameters of thermoelectric generator modules is the absolute method [1 – 3], which allows measuring parameters of modules in real conditions of their operation and allows instrumental minimization of major sources of measurement errors [4]. In addition, the absolute method makes it possible to additionally obtain information about the properties of the material in the composition of the module – thermoEMF, electrical conductivity and thermal conductivity of a pair of thermoelectric legs [5, 6]. This information is useful both for optimizing thermoelectric material for its specific applications and for improving the design of modules. When using the absolute method, one of the main sources of errors is the inaccuracy in determining the heat flux passing through the module, associated with the presence of heat losses due to convection and radiation from the surface of the reference heater and the module, as well as heat losses through conductors and structural elements of the measuring equipment. An effective method of reducing these errors is the use of heat meters to determine the heat flow from the cold side of the module to the thermostat [3]. It is obvious that the accuracy of calibration of the heat meter will play a crucial role.

The purpose of this work is to create a bench for calibrating heat meters for high-precision determination of the heat flux through the investigated generator thermoelectric module when measuring its parameters by the absolute method.

Description of the absolute method of measuring the parameters of thermoelectric generator modules

To measure the parameters of the generator thermoelectric modules by the absolute method, a measuring cell is used, which includes hot and cold heat exchangers, between which the investigated module is placed. An electric heating resistive element is usually used as a hot heat exchanger. Cold heat exchanger can be liquid or air cooled. Heat exchangers have built-in temperature sensors, which are placed in heat-equalizing plates to reduce measurement errors. The heat exchangers and the module are pressed together with a given force. The thermal model of such a measuring cell is shown in Fig. 1

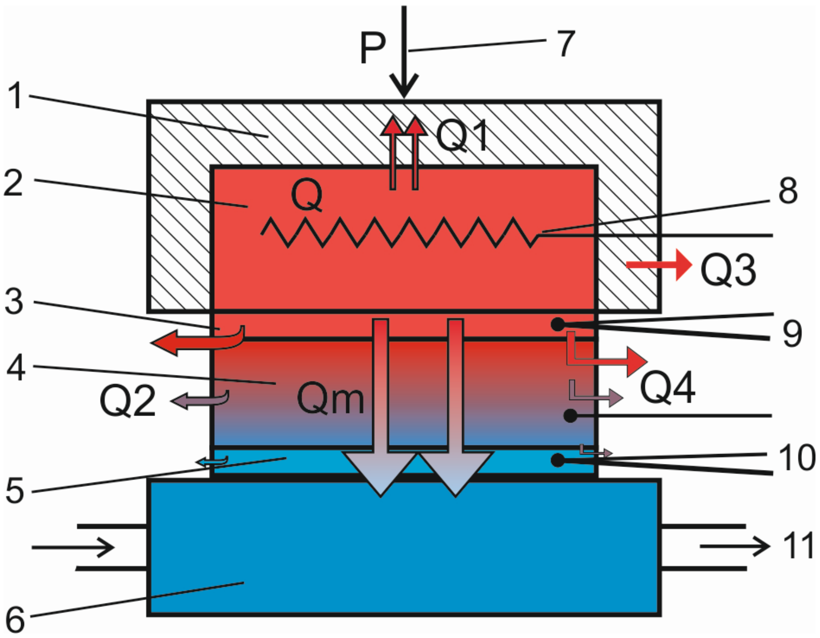

Fig. 1. The thermal model of a measuring cell to determine parameters of generator thermoelectric modules by the absolute method: 1 – hot heat exchanger; 2 – reference heater; 3 – “hot” heat-equalizing plate; 4 – generator thermoelectric module; 5 – “cold” heat-equalizing plate; 6 – cold liquid heat exchanger; 7 – clamping unit; 8 – electric wires of reference heater; 9 – thermocouple of “hot” heat exchanger; 10 – thermocouple of “cold” heat exchanger; 11 – heat carrier (liquid)

In Fig. 1, the arrows show the paths of heat generated in the reference heater. It passes through the module and is dissipated by the heat carrier in the cold heat exchanger. Schematically, the size of the arrows is proportional to the heat fluxes.

Under ideal conditions, all the heat output of the reference heater must pass through the module. But in real conditions, part of the heat capacity is dissipated into the environment. Thus, in Fig. 1: Q is heat released by the reference heater; Q_1 is heat losses on the structural elements of the hot heat exchanger housing; Q_2 is heat losses from the surface of module and heat-equalizing plates due to convection and radiation; Q_3 is heat losses in the electrical wires of the heater; Q_4 is heat losses in the electrical wires of the module and temperature sensors; Q_m is useful thermal power that passed through the module and created operating temperature difference thereupon.

Obviously,

$$Q_m = Q - Q_1 - Q_2 - Q_3 - Q_4.$$

The magnitude of heat loss depends on many factors and is usually difficult to take into account, so it is necessary to use special methods to accurately determine heat fluxes.

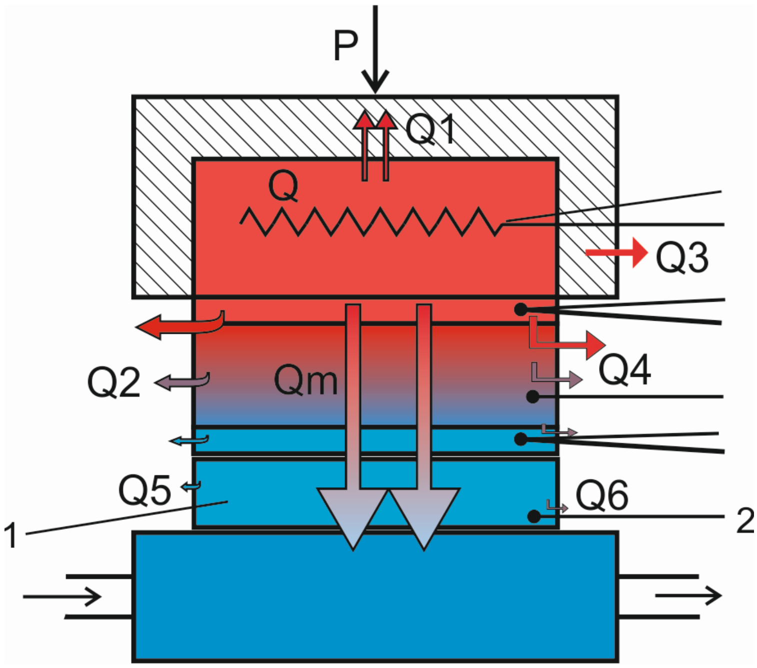

Fig. 2. Schematic of the measuring cell with a heat meter:
1 – heat meter; 2 – potential heat meter wires

The use of heat meters greatly simplifies the measurement process and increases the accuracy of determining the parameters of generator modules. The real thermal model of the measuring cell with a heat meter is shown in Fig. 2. Since the heat meter is sequentially added to the thermal circuit of the measuring cell, a temperature difference is also created on it, and heat (Q_5 and Q_6) will also be lost from the side surface of the heat meter and through the electrical wires, however, these heat losses will not be large, since the temperature the heat meter is close to the ambient temperature.

Description of the bench for calibrating heat meters

When used in equipment for determining the parameters of generator modules, a separate heat meter is produced for each of the standard sizes of modules that can be measured on this equipment. The appearance of heat meters of different sizes is shown in Fig. 3.

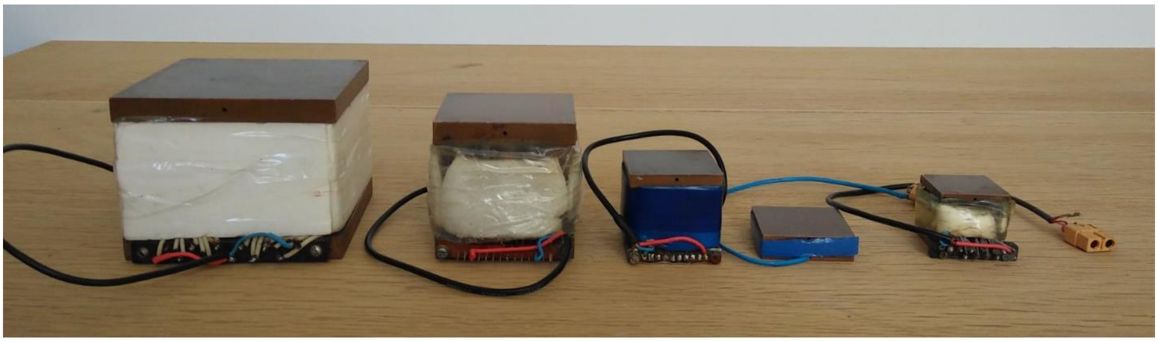

Fig. 3. Heat meters of different sizes for equipment for determining the parameters of thermoelectric generator modules by the absolute method

The heat meter consists of a monolithic body made of a material with high thermal conductivity, in which a thermopile is placed on the side surface (Fig. 4). The end surfaces of the body of the heat meter are its working surfaces, parallel to each other and made with high surface finish for high-quality thermal contact with the module and the cold heat exchanger. Junctions of thermopile thermocouples are placed on the side surface in two rows in height, each row being on its common plane, parallel to the base. The junctions are located on special pins that have good thermal contact with the body of the heat meter, but are electrically isolated from it.

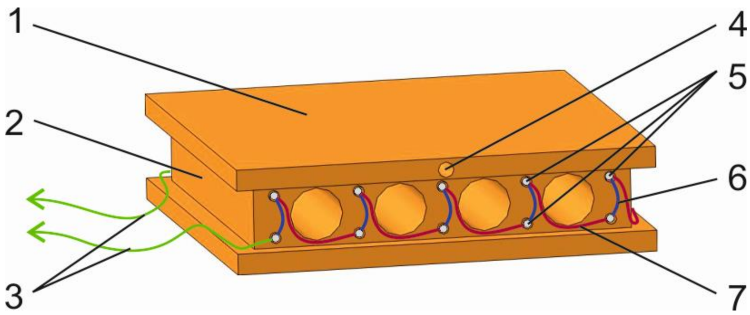

Fig. 4. Heat meter design:
1 – heat meter work area; 2 – heat meter body; 3 – heat meter electrical wires;
4 – opening for measuring thermocouple; 5 – junctions of differential thermocouples;
6 – n-legs of thermocouples; 7 – p-legs of thermocouples

General requirements for heat meters: the dimensions of the working area of the heat meter should be close to the dimensions of the working surfaces of the generator module; the height of the heat meter should be optimal to create a minimum temperature difference in the heat meter, but sufficient to ensure its high sensitivity. The conversion factor of the heat meter, its volt-watt sensitivity, must be stable over the operating temperature range.

To optimize the heat meter along the passage of the heat flux in the body, technological selections can be made (for example, in Fig. 4 it can be seen that holes are made in the body of the heat meter).

Differential thermocouples are combined into a thermopile to increase the sensitivity of the heat meter, which depends on the material of the thermocouples, the thermal conductivity of the heat meter body material and its design, the distance between the junctions, as well as the accuracy in determining the distance and quality of thermal contact between the thermocouple junction and the body. Obviously, such errors are difficult to take into account, so heat meters need to be calibrated.

The heat meter is calibrated by direct measurement of the thermopile signal from the action of the temperature difference caused by the heat flux created by the electric heater. At the same time, the electric power of this heater is determined. The voltage-watt sensitivity of the heat meter will be determined by the ratio:

$$k = \frac{E}{Q} \qquad \text{as} \qquad Q = W = Ih \cdot Uh, \qquad \text{then} \qquad k = \frac{E}{Ih \cdot Uh}$$

where k is heat meter volt-watt sensitivity, E is heat meter signal; Q is heat flux that passed through the heat meter, W is electrical power of the main heater; Ih is current of the main heater, Uh is voltage on the main heater.

The heat flux is directed only through the heat meter, and heat loss from the heater to the environment is eliminated with the help of protective and radiation shields.

The appearance of the developed bench is given in Fig. 5.

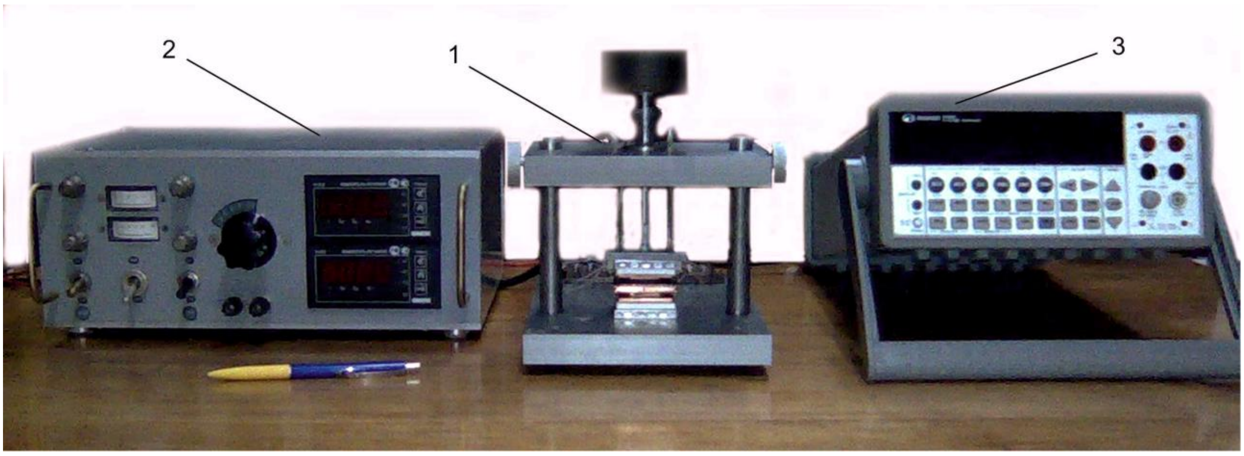

Fig. 5. Appearance of a bench for calibrating heat meters:
1 – measuring unit; 2 – control unit; 3 – high-precision digital multimeter

The bench consists of a measuring unit, a control unit and a measuring device (high-precision digital multimeter). In turn, the measuring block contains an aluminum platform on which liquid heat exchangers, a clamping device and a switching block are placed. The heat meter under study is placed between the hot and cold heat exchangers. The layout of the bench is shown in Fig. 6.

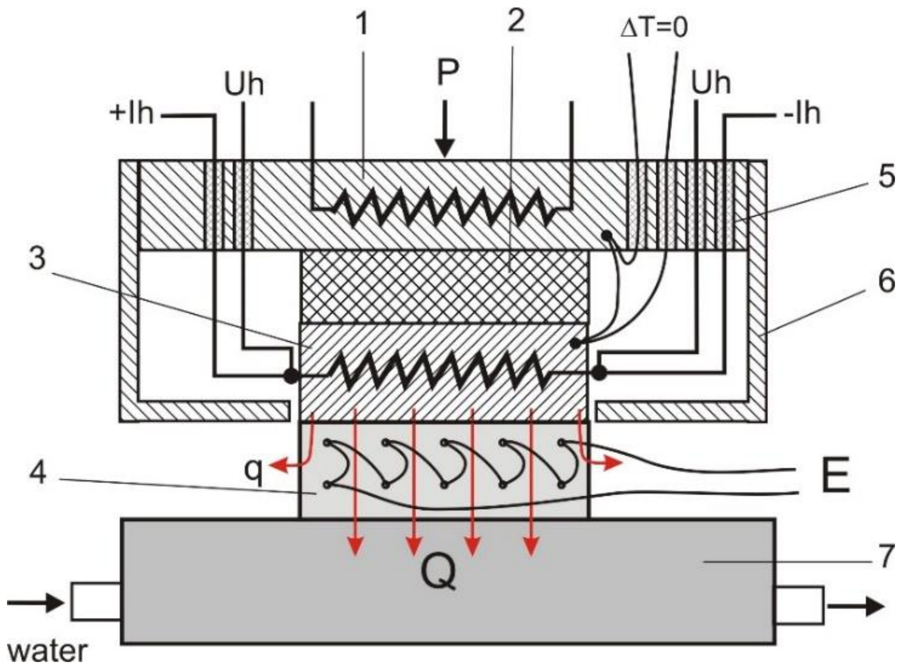

Fig. 6 – Heat meter calibration layout:
1 – protective heater; 2 – thermal insulation; 3 – main heater;
4 – heat meter; 5 – thermal locks; 6 – protective shield;
7 – heat removal unit

On the lower base of the aluminum platform and on the suspension of the upper base of the measuring unit, two identical heat exchange units are fixed, which are designed to remove heat, namely cold heat exchangers. These heat exchangers are reversible, since they are based on thermoelectric coolers (TEC) with liquid waste heat removal and can operate both in cooling and heating modes, depending on the direction of electric current flux. On the working side of the TEC, copper heat-equalizing plates with built-in temperature sensors – platinum resistance thermometers – are fixed. These plates in the central part have a flat surface polished with a high class of cleanliness – a working platform. The heat meter under study is placed on this area. The other side of the heat meter is in contact with a hot heat exchanger – a flat heater with two (upper and lower) polished working surfaces. The flat heater is made thin enough so that its side surface is as small as possible and it warms up well throughout its entire volume. A temperature sensor is also mounted in the body of this heater – a platinum resistance thermometer. The use of platinum temperature sensors makes it possible to measure and maintain the temperatures of the working areas of heat exchangers using thermostats with an accuracy of at least 0.1 ° C. During calibration, the heater is powered by a separate stabilized DC source. Measurement of the voltage on the heater is carried out by precision voltmeters with an error of 0.05 %. The current through the heater is also determined by the voltage drop across the reference resistance in the heater power circuit. The error in determining the current is about 0.1 %. In addition, there will be heat loss to the environment through electrical conductors. Therefore, measures should be taken to minimize these losses, in particular, the use of thermal locks. Thermal locks are insulators made of beryllium ceramics with high thermal conductivity, which provide local heating of the conductor section at the exit point from the heater's protective housing to the heater temperature. Thus, heat losses through underwater conductors are eliminated as much as possible. The measuring thermocouples are mounted in the same way.

Since a temperature difference is created on the heat meter along its height, the heat meter body material (usually metal – copper, aluminum, brass, etc.) has a temperature dependence of the thermal conductivity coefficient, and the thermocouple material has a temperature dependence of the Seebeck coefficient, then the heat meter must be calibrated over the entire range of operating cold temperatures of the investigated thermoelectric module.

In the developed bench, the process of thermostating all heat exchangers is controlled by a specially designed electronic unit containing adjustable power supplies for the TEC and heaters, two two-channel microprocessor-based temperature controllers RE-202, interconnect elements and measurement control terminals. All terminals of electrical components from the measuring unit converge on the terminal block and are connected to the control unit by means of a cable. A measuring device is also connected to the control unit - a high-precision digital multimeter M3500 with the ability to transfer measurement results to a personal computer in real time. Thus, the developed bench makes it possible to calibrate heat meters and study their metrological characteristics in dynamics.

An example of the temperature dependence of the volt-voltage sensitivity of a heat meter with dimensions of 40x40 mm is shown in Fig. 6.

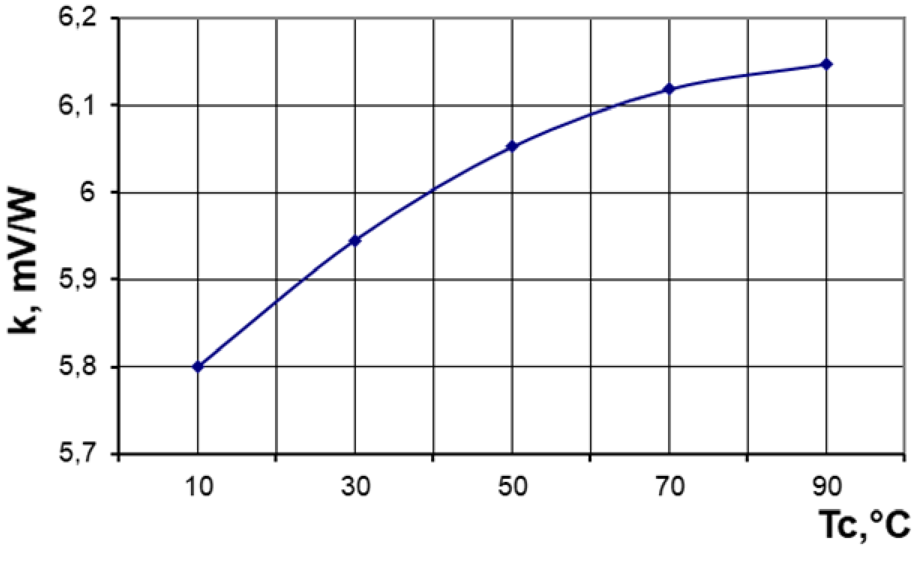

Fig. 6. The temperature dependence of the volt-watt sensitivity of heat meter with dimensions of 40x40

Conclusions

1. A bench for calibrating heat meters for determining heat flux through generator thermoelectric module when measuring its parameters by the absolute method has been developed and

manufactured. The bench allows one to study the metrological characteristics of heat meters and transfer the measurement results to a personal computer in real time.

2. An improved method for calibrating heat meters with the use of auxiliary highly sensitive heat flux converter has been implemented, which makes it possible to improve the accuracy of experimental determination of the volt-watt sensitivity of heat meters.

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СТЕНД ДЛЯ ГРАДУЮВАННЯ ТЕПЛОМІРІВ ДЛЯ ВИЗНАЧЕННЯ ПАРАМЕТРІВ ГЕНЕРАТОРНИХ ТЕРМОЕЛЕКТРИЧНИХ МОДУЛІВ

Представлено результати розробки стенду для градуювання тепломірів для визначення теплового потоку через генераторний термоелектричний модуль при вимірюваннях його параметрів абсолютним методом. Стенд дає можливість досліджувати метрологічні характеристики тепломірів у необхідному інтервалі температур та у реальному часі передавати результати вимірювань на персональний комп'ютер. Бібл. 6, рис. 6.
Ключові слова: термоелектричний модуль, тепломір, градуювання, точність.

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СТЕНД ДЛЯ ГРАДУИРОВКИ ТЕПЛОМЕРОВ ДЛЯ ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ ГЕНЕРАТОРНЫХ ТЕРМОЭЛЕКТРИЧЕСКИХ МОДУЛЕЙ

Представлены результаты разработки стенда для градуировки тепломеров для определения теплового потока через генераторный термоэлектрический модуль при измерениях его параметров абсолютным методом. Стенд позволяет исследовать метрологические характеристики тепломеров в необходимом интервале температур и в реальном времени передавать результаты измерений на персональный компьютер. Библ. 6, рис. 6.
Ключевые слова: термоэлектрический модуль, тепломер, градуировка, точность.

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