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# CALIBRATION BENCH FOR THERMOELECTRIC CONVERTERS OF HEAT FLUX

*The results of development of the calibration bench for thermoelectric converters of the heat flux as well as their metrological characteristics analysis are provided in this paper. The calibration methods for one and two converters at a time were developed. The thermoelectric converter of a new type with simultaneous temperature and the heat flux measurements on the human body surface was developed and manufactured.*

**Key words:** calibration bench, thermoelectric converter, heat flux, volt-watt sensitivity.

## Introduction

Thermoelectric converters are promising devices used to determine local heat release on the human body surface [1 – 4]. State-of-the-art thermoelectric converters of the heat flux manufactured on the basis of highly efficient semiconductor materials are characterized by high sensitivity, response rate, technological effectiveness, optimum weight and overall dimensions, high reliability and low cost [5 – 9]. Such converters are unpretentious in service and can perform round-the-clock monitoring of the human body heat release [10 – 16] as well as the heat losses in remote heating lines.

An issue referred to the calibration of thermoelectric converters of the heat flux used in the devices for measuring integrated heat fluxes of biological objects, losses through engineering structures, heat-insulating coatings and in the heating line sections is of current interest. Typically, the calibration of such converters is carried out by an absolute method using a compensation heater and differential metering thermocouples, which are the indicators of zero temperature difference [17, 18]. However, such calibration requires the improvement in the measurement accuracy, since such converters refer to measuring equipment. It is possible to improve the accuracy by using a high-sensitivity auxiliary thermoelectric converter of the heat flux [19 – 21].

Therefore, *the purpose of this work* is to develop the calibration bench for thermoelectric converters of the heat flux using advanced method and to analyse metrological characteristics of these converters.

## HFC calibration bench design

For metrological characteristics analysis and calibration of thermoelectric heat flux converters (HFC) in the temperature range of –30 °C ÷ +130 °C, the bench shown in Fig. 1 was designed.

The bench consists of a measuring unit 1, a control unit 2 and a meter 3 (a high precision digital multimeter).

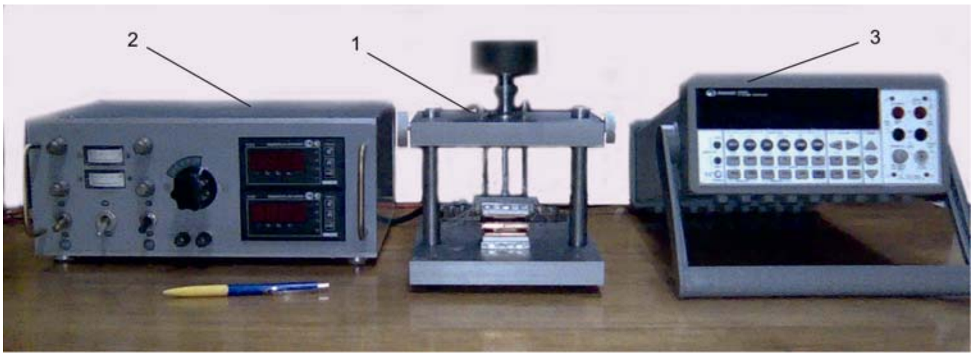


*Fig. 1. Appearance of the bench for metrological characteristics analysis and HFC calibration.*

The bench consists of a measuring unit 1, a control unit 2 and a meter 3 (a high precision digital multimeter).

In its turn, the measuring unit 1 incorporates an aluminium platform, on which liquid heat exchangers, a clamping device and a connecting bar are arranged. One or two HFC under study can be placed between hot and cold-side heat exchangers.

Schematically, the measuring unit 1 is shown in Fig. 2.

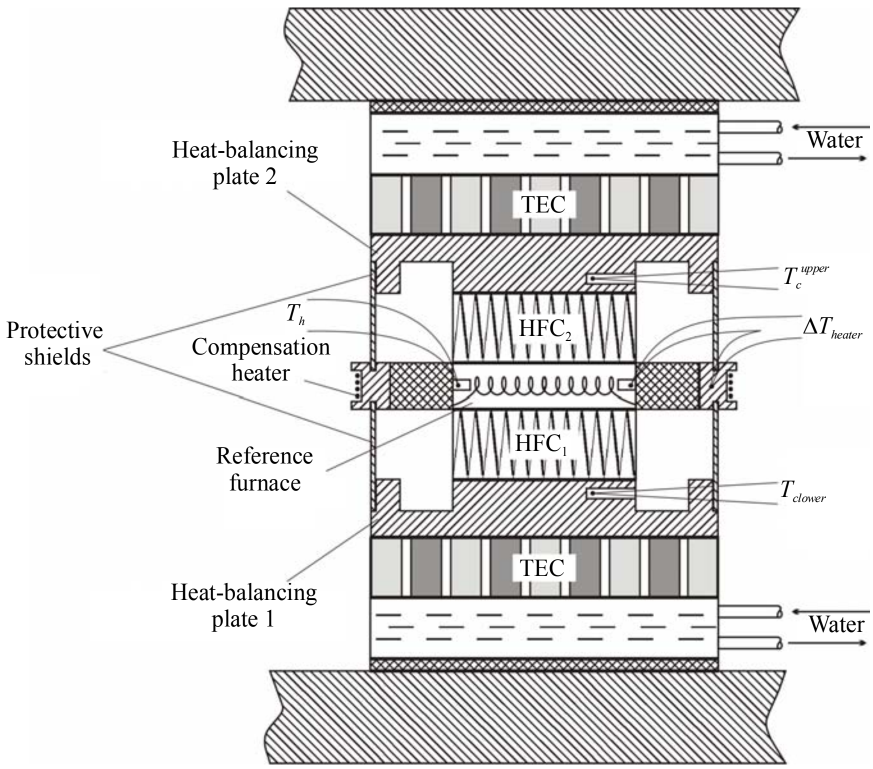


*Fig. 2. Schematic diagram of the measuring unit for HFC calibration bench.*

As shown in Fig. 1 and Fig. 2, two identical heat exchange units, which are designed to remove heat – cold-side heat exchangers, are mounted on a lower base of the aluminium platform and on a suspension of an upper base of the measuring unit 1. These heat exchangers are reverse ones, since they are manufactured on the basis of thermoelectric coolers (TEC) with liquid waste heat removal and can operate both in cooling and in heating modes depending on the direction of the electric current flow. Heat-balancing copper plates with built-in temperature sensors - platinum resistance thermometers, are fixed onto the TEO operating side. These plates in their central part are polished to achieve high-class purity flat surface - working platform. The HFC under study is placed on this platform. The other HFC side contacts the hot-side heat exchanger – a flat heater which has two (upper and lower) polished operating surfaces. The thickness of the flat heater is made thin enough, so that its lateral surface is as small as possible and can be well heated throughout its volume. The temperature sensor - platinum resistance thermometer, is mounted in the casing of the heater. The use of platinum temperature sensors makes it possible to measure and maintain the temperature of the working platforms of heat exchangers using temperature controllers with an accuracy of ± 0.1 °C minimum in the temperature range of -30 ÷ + 130 °C.

Since a lateral surface of the hot-side heat exchanger is not involved in the process of heat exchange with HFC and the heat losses are inevitable from it, a protective ring heater is mounted around its lateral surface to prevent such losses. The main task of the ring heater is to maintain the temperature to correspond to the temperature of the hot-side heat exchanger. This is achieved by using the differential thermocouple connected to a free channel of the temperature controller adjusted in such a way that the specific voltage supply to the heater of the protective ring furnace resulted in the zero signal of this thermocouple. Thus, the adiabatic isolation of the lateral surface of the hot-side heat exchanger is achieved.

The protective ring heater fulfils another important function. It transfers its temperature to a protective shield, which is positioned opposite to the lateral surface of the HFC under study. On the lower (and upper) surface of the protective ring heater, milled slots, which include "hot" end faces of the protective shields, are made. Other "cold" end faces of these shields are in thermal contact with the working platforms of the cold-side heat exchangers. Thus, the temperature gradient that corresponds to the temperature on the HFC lateral side is vertically formed on the surfaces of the protective shields. Due to this, the heat is not dissipated to the environment from the HFC lateral surface during its calibration.

Two cold-side heat exchangers are used in the bench for pair comparison calibration of two HFCs simultaneously. During calibration of a single HFC, a spare cold-side heat exchanger is used as another protective heater, in which the temperature of the hot-side heat exchanger is set using the temperature controller, and thus, adiabatic protection against heat losses from the spare surface of the heater of the hot-side heat exchanger is created. The control unit 2, which comprises regulated power supply units for TEC and heaters, two diplex microprocessor temperature controllers PE-202, connecting elements and test measuring terminals, monitors the process of temperature control in all heat exchangers.

All the outputs of electrical components from the measuring unit 1 converge in the connecting bar and are connected to the control unit 2 with a cable. The meter – a high precision digital multimeter M3500, is also connected to the control unit with the possibility of measurement results transmission to a PC in real time. Thus, the developed bench enables the calibration of thermoelectric HFCs and the analysis of their metrological characteristics under dynamic conditions.

## The calibration methods for a single HFC

The calibration of a single thermoelectric HFC using the developed bench (Fig. 1) is carried out according to the following procedure:

• Connect the measuring unit 1 to the control unit 2

• Connect the cable input of the measuring device 3 to the corresponding terminals of the control unit 2

• Connect the TEC liquid-cooled hoses to the water main, turn on and run the tap through the cooling system

• Lift and fix the top cold-side heat exchanger in upper position

• Place the HFC under study on the working platform of the lower cold-side heat exchanger

• Connect the outputs of the HFC under study to the corresponding terminals of the connecting bar

• Install the lower shield

• Install the hot-side heat exchanger with the protective ring heater on the HFC and the upper end face of the protective shield

• Install the upper protective shield

• Lower the upper cold-side heat exchanger, so that its heat-balancing plate is arranged on the upper protective shield. In this connection, the clamping force is set with the use of the additional load

• Set the temperature of the lower cold-side heat exchanger on the temperature controllers of the control unit 2

• Set up the instrument switch on the control unit 2 on the position “heater voltage”, switch on the meter 3 and switch it to the mode “DC voltage” with “Automatic” range and from the expression

$$W = U^2 / R, \tag{1}$$

(where $R$ – is the heater resistance) determine the voltage and set it in the heater of the hot-side exchanger, which would correspond to the required electric power in the range of 10 mW -1 W;

• Based on the reading “Hot-side heat exchanger temperature” at the respective channel of the temperature controller operating in the temperature measuring mode, when this temperature reaches the steady-state mode, set the same temperature value in the upper cold-side heat exchanger. In this case, the temperature of the ring heater is maintained automatically

• Set up the switch of the control unit 2 on the position “Thermoelectric HFC”

• When the set temperatures are reached in the fixed heat exchangers, determine the thermopower value of the thermoelectric HFC

• Set up the instrument switch on the position “Hot-side heat exchanger heater voltage” and “Hot-side heater exchanger heater current” in sequence and determine the precise values of the electrical signals

• Determine the heater capacity from the expression:

$$W = UI. \tag{2}$$

• Determine the volt-watt sensitivity of the thermoelectric HFC by the formula:

$$\nu = \frac{E}{W}. \tag{3}$$

## Calibration methods for two HFCs at a time

Pair calibration of two thermoelectric HFCs simultaneously is performed only when measuring similar samples. Such pair measurement of characteristics differs from the measurements of a single HFC only in the fact that the second HFC is mounted on top of the hot-side heat exchanger. The outputs of the second HFC are connected to the respective terminals of the connecting bar on the measuring unit 1 and the measurement of the HFC thermopower signal is carried out when the instrument switch of the control unit 2 is adequately positioned.

In this case, the same temperature is set in the upper cold-side heat exchanger on the temperature controller as in the lower cold-side heat exchanger.

The electric power released in the hot-side heat exchanger is divided in half, passes through two HFCs and dissipates at two cold-side heat exchangers. Since the temperatures of the hot sides of each HFC are common, and the cold-side temperatures are the same (maintained by the temperature controller), the volt-watt sensitivities of each HFC can be calculated from the following expressions:

$$\nu_1 = \frac{2E_1}{W}, \tag{4}$$

$$\nu_2 = \frac{2E_2}{W}. \tag{5}$$

where $E_1$ and $E_2$ are the thermopower values for the first and second HFCs under study, respectively. The number "2" in the numerator comes from the denominator, since the half-value power is taken for each HFC, that is

$$W_1 = W_2 = \frac{W}{2}. \tag{6}$$

## HFC parameter measurement results

By optimizing the geometry of half-cells of HFC microthermopiles, experimental samples of primary converters of improved design with increased sensitivity and response rate with dimensions of 22 × 22 × 4 mm (Fig. 3) were produced. Metrological characteristics (volt-watt sensitivity, time constant, etc.) of such converters were studied on the developed bench designed for the HFC calibration based on the abovementioned methodology.

The appearances of such HFC experimental samples are shown in Fig. 3.

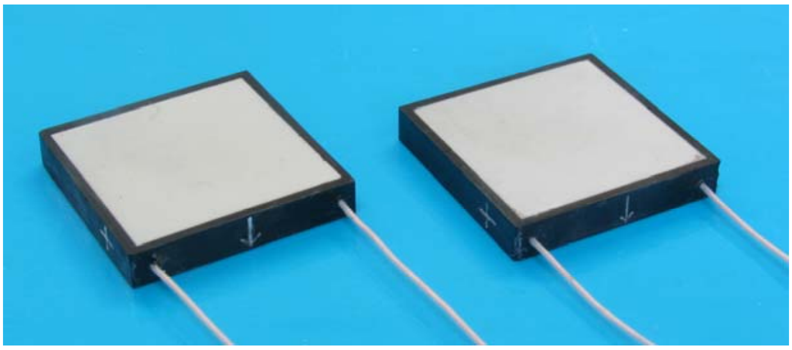

*Fig. 3. Appearances of HFC experimental samples with dimensions of 22 × 22 × 4 mm.*

Parameter measurement results for two HFC experimental samples with dimensions of 22 × 22 × 4 mm are shown in Table 1.

Table 1

*Parameter measurement results for HFC with dimensions of 22 × 22 × 4*

| № | Parameter name | HFC | |
|---|---|---|---|
| | | No.1 | No.2 |
| 1. | Heat flux range, W/m$^2$ | $10^{-2} \div 10^3$ | $10^{-2} \div 10^3$ |
| 2. | Sensitivity, V/W | 1.48 | 1.51 |
| 3. | Time constant, sec | 12 | 12 |
| 4. | Operating temperature range, °C | -30 ÷ +130 | -30 ÷ +130 |
| 5. | Thermopile overall dimensions, mm | 22 × 22 × 4 | 22 × 22 × 4 |

Besides, a new design type of thermoelectric converters that combine simultaneous measurements of temperature and the heat flux on the human body surface was developed. The appearance of HFC experimental samples with dimensions of 16 × 16 × 3 mm is shown in Fig. 4.

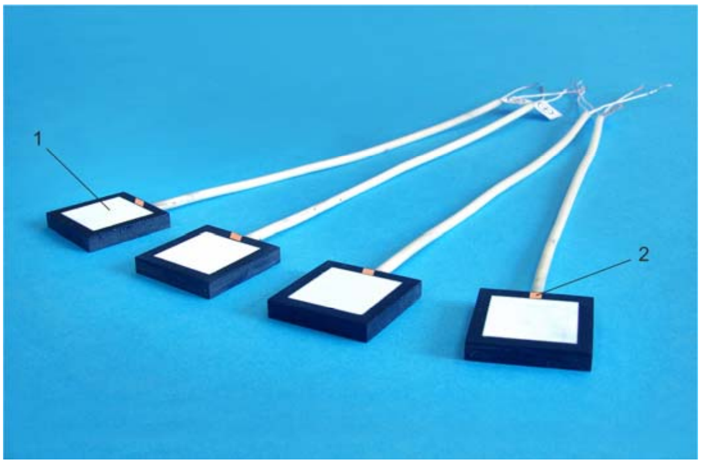


*Fig. 4. Appearance of HFC experimental samples with dimensions of 16 × 16 × 3 mm: 1 – thermoelectric heat flux sensor, 2 – temperature sensor.*

The results of determination of the main parameters of four HFC experimental samples with dimensions of 16 × 16 × 3 mm are given in Table 2.

Table 2

*Parameter measurement results for HFC with dimensions of 16 × 16 × 3 mm*

| № | Parameter name | HFC | | | |
|---|---|---|---|---|---|
| | | № 1 | № 2 | № 3 | № 4 |
| 1. | The heat flux range, W/m2 | $10^{-2} \div 10^{3}$ | $10^{-2} \div 10^{3}$ | $10^{-2} \div 10^{3}$ | $10^{-2} \div 10^{3}$ |
| 2. | Sensitivity, V/W | 3.2 | 3.32 | 3.1 | 3.25 |
| 3. | Time constant, sec | 10 | 11 | 11 | 10 |
| 4. | Thermopile overall dimensions, mm | 16 × 16 × 3 | 16 × 16 × 3 | 16 × 16 × 3 | 16 × 16 × 3 |

Time characteristics of these thermoelectric HFC are shown in Fig. 5.

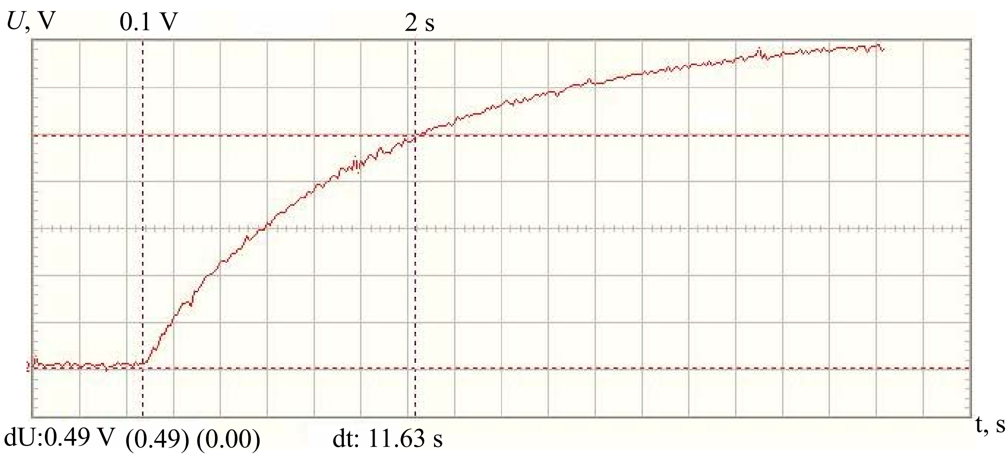


*Fig. 5. Time characteristics of HFC with dimensions of 16 × 16 × 3 mm with ceramic receiving surface.*

As can be seen from the above, the bench designed for the thermoelectric HFC calibration makes it possible to study the characteristics of the converters and transmit the measurement results to a PC in real time. The thermoelectric HFCs of a new type with simultaneous measurements of temperature and the heat flux enable monitoring of the temperature and heat condition of a human in real time.

## Conclusions

1. The calibration bench for thermoelectric converters of the heat flux, which makes it possible to study the metrological characteristics of the converters and transmit the measurement results to a PC in real time was developed and manufactured. The calibration methods for one and two thermoelectric converters at a time were developed.
2. The thermoelectric converters of a new type with simultaneous measurements of the temperature and heat flux, ensuring monitoring of the temperature and heat condition of a human in real time, were developed.
3. An advanced calibration method for thermoelectric sensors using an auxiliary high-sensitivity thermoelectric converter of the heat flux, which allows improving the accuracy of experimental determination of the volt-watt sensitivity of such sensors, was implemented.

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