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Estimation of relatively small temperature differences with the use of resistive temperature sensors. Part 1

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The method of estimating relatively small temperature differences using 4 resistive temperature sensors electrically connected in a bridge circuit is described. An example of experimental estimation of the temperature difference on the opposite outer surfaces of ceramic plates of a thermoelectric module and examples of testing some elements of the estimation system are described. Factors that may affect the results of the specified estimation are considered.

Keywords: temperature difference measurement, resistive temperature sensors, thermoelectric module.

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Introduction

Some applications (for example, those described in [1 – 5]) of thermoelectric heat pumps (THPs) based on thermoelectric modules (TEMs) may involve the operation of these THPs and TEMs at relatively small temperature differences between their respective heat-generating and heat-absorbing heat exchange parts. In this regard, the experimental assessment of relatively small temperature differences is relevant. Data on relatively small temperature differences can also be used in studies of the properties, parameters, and characteristics of thermoelectric materials and elements [6]. Experimental information on relatively small temperature differences may also be required in the implementation or study of other processes.

The purpose of this work is to estimate relatively small temperature differences based on experimental data obtained using resistance temperature detectors (RTDs) [7 – 15].

To achieve this purpose, *the objectives of this work* is to obtain an example of using 4 resistive temperature sensors, which are electrically connected in a bridge circuit to evaluate relatively small temperature differences, to obtain information about the features of such their application, and to obtain the results of testing some elements of the evaluation system.

I. Description of the estimation methodology and features of its realization

In this work, the scheme shown in Fig. 1 was used to estimate relatively small temperature differences. The scheme shown in Fig. 2 can also be used to estimate relatively small temperature differences. In this work, the scheme shown in Fig. 2 was used for comparison.

In Fig. 1 shows a diagram of the appropriate use of 4 RTDs. In Fig. 2 shows a diagram of the appropriate use of 2 RTDs.

In the diagram in Fig. 1: *R1 – R4* – RTDs; *r5 – r12* – resistances of connecting conductors, for example, RTDs leads, contacts, wires and other connecting elements; *K1* – switching element (switch, key). In this case, sensors *R1* and *R2* have a temperature of T_1, and sensors *R3* and *R4* have a temperature of T_2.

In the diagram in Fig. 2: *R1 – R2* – RTDs; *r3 – r6* – resistances of connecting conductors, for example, RTDs leads, contacts, wires and other connecting elements; *K1* and *K2* – switching elements (switches, keys). In this case, sensor *R1* has a temperature of T_1, and sensor *R2* has a temperature of T_2.

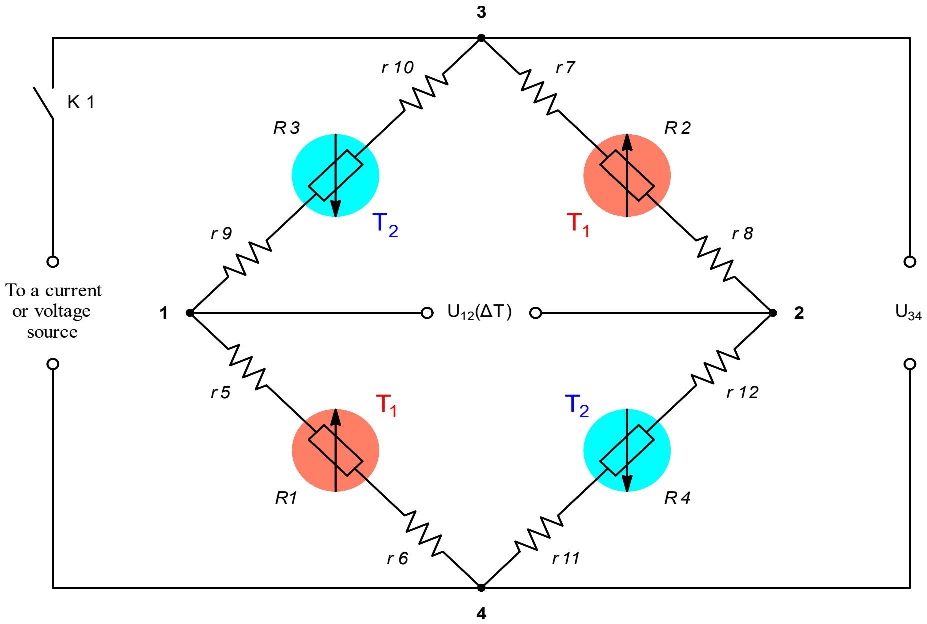

Fig. 1. Connection scheme of 4 RTDs for evaluating relatively small temperature differences and, when using a current source, the average temperature.

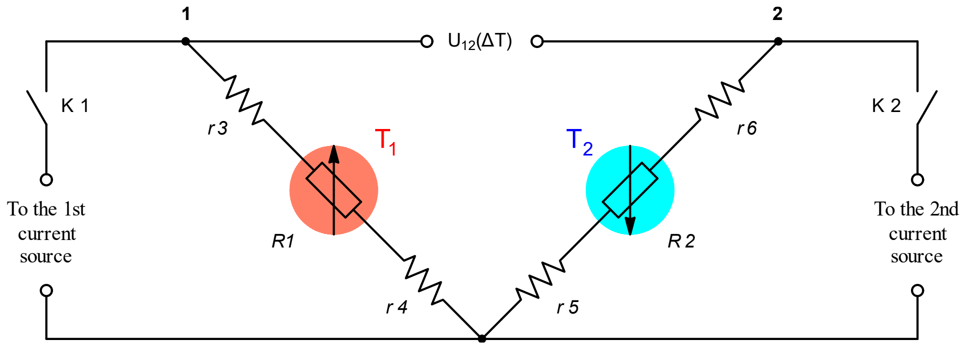

Fig. 2. Connection scheme of 2 RTDs for evaluating temperature differences.

In particular, the voltage value between nodes 1 and 2 in Fig. 1 U_{12} and the voltage between nodes 1 and 2 in Fig. 2 U_{12} can be used to estimate (determine) the temperature difference ΔT:

$$\Delta T = T_1 - T_2 \tag{1}$$

and change in temperature difference φ:

$$\varphi = (\Delta T)_A - (\Delta T)_B, \tag{2}$$

where $(\Delta T)_A = (T_1 - T_2)_A$ is the temperature difference under conditions A; $(\Delta T)_B = (T_1 - T_2)_B$ is the temperature difference under conditions B.

If conditions B are such that the temperature difference has the value $0\,°C$, then we can be considered that the temperature difference and the change in the temperature difference are the same (then $\Delta T = \varphi$).

The voltage between nodes 3 and 4 U_{34} in Fig. 1 in the case of using a current source depends, in particular, on the temperatures T_1 and T_2. In particular, the value of the voltage between nodes 3 and 4 in Fig. 1 U_{34} in this case can be used to estimate (determine) the average temperature T_{av}:

$$T_{av} = \frac{T_1 + T_2}{2} \tag{3}$$

In the experiments in this work, RTDs were used in the required quantity out of a total of 8 RTDs with a nominal resistance a temperature of 0 °C 1000 Ω, dimensions of approximately 2.3 mm × 2.1 mm × 0.9 mm and a leads length of approximately 6 mm. The RTDs were connected to other elements of the corresponding circuit by mounting wires approximately 22.5 cm long and with a resistance of approximately 0.09 Ω (the parameters are given for one individual mounting wire).

Calibration of all RTDs and their selection by parameters were not carried out in this work. Only a simplified testing of one of the RTDs together with its connecting conductors was carried out. For this testing, a TMP117 temperature sensor with a corresponding computerized recording system was used. The RTD under test was attached (fastened) directly to the TMP117 temperature sensor. Both sensors were placed in a volume in which the temperature gradually changed over time. The resistance of the RTD under test was measured (determined) using two multimeters (for recording current and voltage) with the MS8218 data acquisition (registration) function and a computer. To matching (relevant data) the experimental data obtained from different meters, the Excel "LOOKUP" function was used. The results of this simplified testing are presented in Fig. 3 and Fig. 4.

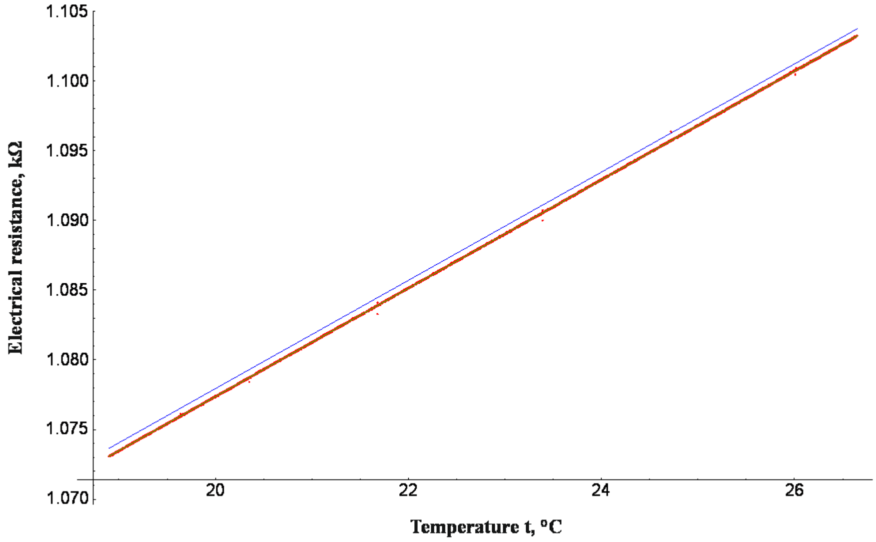

Fig. 3. Results of a simplified test of one of the RTDs along with its connecting conductors: the experimental values of the electrical resistance of the RTD along with its connecting conductors, which correspond to the RTD temperature values, which were determined from the TMP117 sensor data, are shown in red; the blue color shows a graph of an approximate dependence that can be used for platinum RTDs, which at temperature 0°C have an electrical resistance of 1kΩ $R_{t,(Pt,1k\Omega)} = 1k\Omega \cdot 1 + 3.9083 \cdot 10^{-3} \frac{1}{°C} \cdot t - 5.775 \cdot 10^{-7} \frac{1}{(°C)^2} \cdot t^2$, where $R_{t,(Pt,1k\Omega)}$ – is the approximate value of the electrical resistance of the specified platinum RTD at temperature t, which is expressed in °C [8]; the green color shows a graph of the approximate dependence for one of the RTDs together with its connecting conductors (which were tested), which approximately corresponds to the dependence $R_t = 1k\Omega \cdot (0.99998 + 3.8528 \cdot 10^{-3} \frac{1}{°C} \cdot t + 81138 \cdot 10^{-7} \frac{1}{(°C)^2} \cdot t^2$, where R_t – the approximate value of the electrical resistance of the RTD together with its connecting conductors at RTD temperature t, which is expressed in °C.

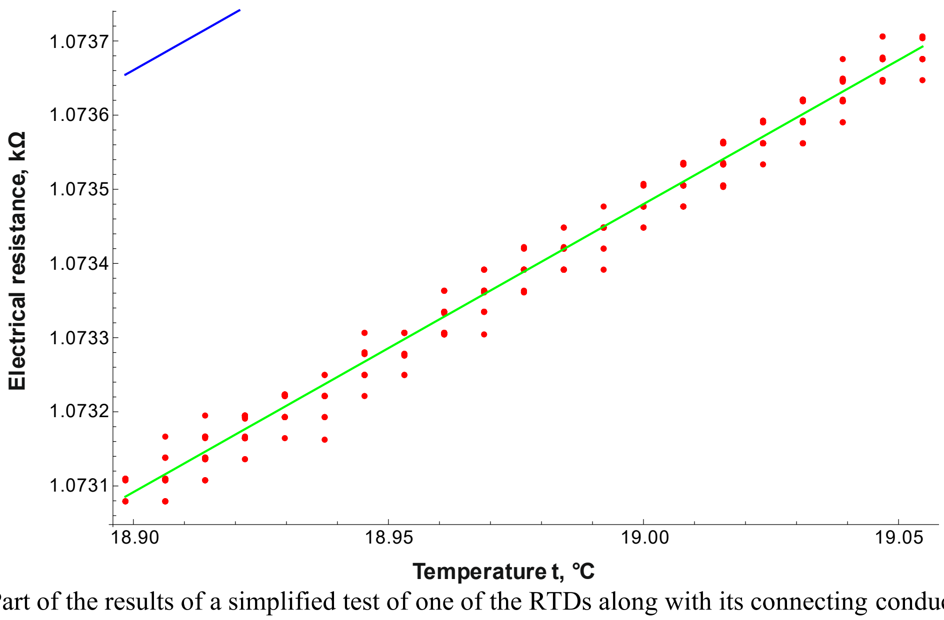

Fig. 4. Part of the results of a simplified test of one of the RTDs along with its connecting conductors: the experimental values of the electrical resistance of the RTD along with its connecting conductors, which correspond to the RTD temperature values, which were determined from the TMP117 sensor data, are shown in red; the blue color shows a graph of an approximate dependence that can be used for platinum RTDs, which at temperature 0°C have an electrical resistance of 1kΩ $R_{t,(Pt,1k\Omega)} = 1k\Omega \cdot 1 + 3.9083 \cdot 10^{-3} \frac{1}{°C} \cdot t - 5.775 \cdot 10^{-7} \frac{1}{(°C)^2} \cdot t^2$, where $R_{t,(Pt,1k\Omega)}$ – is the approximate value of the electrical resistance of the specified platinum RTD at temperature t, which is expressed in 0°C [8]; the green color shows a graph of the approximate dependence for one of the RTDs together with its connecting conductors (which were tested), which approximately corresponds to the dependence $R_t = 1k\Omega \cdot (0.99998 + 3.8528 \cdot 10^{-3} \frac{1}{°C} \cdot t + 8.1138 \cdot 10^{-7} \frac{1}{(°C)^2} \cdot t^2$, where R_t – the approximate value of the electrical resistance of the RTD together with its connecting conductors at RTD temperature t, which is expressed in °C.

The approximate dependence of the electrical resistance of one of the RTDs together with its connecting conductors (which were tested) on the RTD temperature (the graph of this function approximated to the experimental data in Fig. 3 and Fig. 4 is displayed in green) was obtained in Wolfram Mathematica using the "FindFormula" and "Fit" functions. An approximate expression of this approximate dependence is given in the descriptions of Figs. 3 and 4.

In this work, stabilized electric current sources were used (in particular, for RTDs excitation). An example of the results of testing one of these sources is shown in Fig. 5 (current and voltage were recorded using MS8218 multimeters).

Taking into account that the results of the estimation of changes in differences and temperature differences when using the schemes of Fig. 1 and Fig. 2 depend, in particular, on the voltages values U_{12}, a simplified estimation of the instability of voltages values U_{12}, was carried out when using the schemes of Fig. 1 and Fig. 2 with the above RTDs at room temperatures. At the same time, to create conditions in which the temperature differences between individual RTDs could have stable values over a long period of time (from a practical point of view), the specified RTDs were placed at small distances from each other in a copper cylindrical beaker with an outer diameter of approximately 14 mm, an inner diameter of approximately 10 mm, and an inner length along the axis of approximately 40 mm, which, in turn, was placed in a thermally insulated volume. To excite two RTDs according to the scheme of Fig. 2, two stabilized electric current sources with approximately the same current values of approximately 1 mA were used. To excite four RTDs according to the scheme of Fig. 1, exactly those two stabilized electric current sources were used, which were connected in parallel (current sources intended for such a connection were used) so that the total current value was approximately 2 mA. The voltages U_{12}, in the schemes of Fig. 1 and Fig. 2 were recorded using a multimeter MS8218. One of the factors that can influence the voltage U_{12}, measurement results is the possible instability of the source(s) of electric current excitation of the RTDs. Fig. 6 presents the results of this assessment. Fig. 6 shows that the voltage U_{12}, instability when using 4

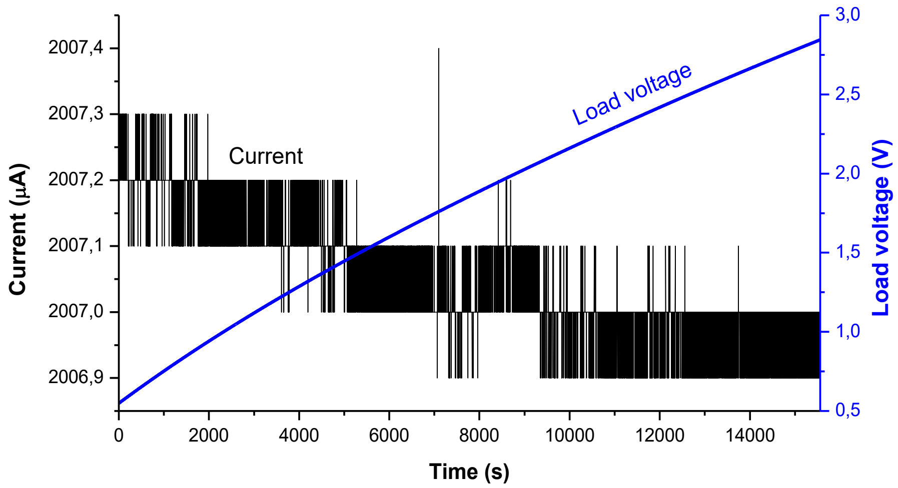

Fig. 5. Plots of dependences of the current strength through a series-connected stabilized current source and its load and the voltage on the load on time.

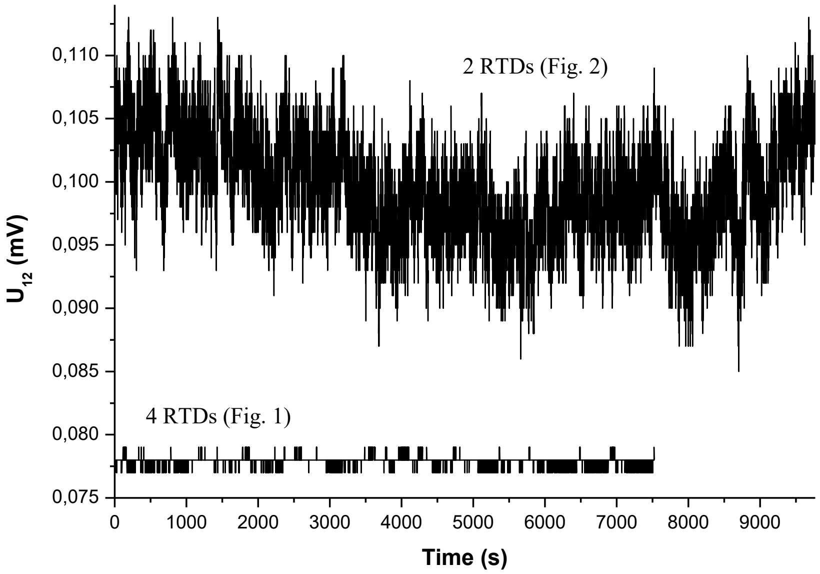

Fig. 6. Dependences of voltages U_{12} in the schemes of Fig. 1 and Fig. 2 on time (experiments using 4 RTDs (Fig. 1) and 2 RTDs (Fig. 2) were not carried out simultaneously).

RTDs, which are connected according to the bridge circuit of Fig. 1, is significantly less than the voltage U_{12}, instability when using 2 RTDs according to the circuit of Fig. 2.

Further in this work, when using the scheme in Fig. 1 to estimate (determine) the change in the temperature difference and temperature difference in an individual experiment, we will simplified consider the current strength generated by the current source I to be a constant value.

It is known that to determine the electrical resistance of platinum RTDs for the temperature range from 0°C to 850°C can use the expression [8]:

$$R_{t,(Pt)} = R_{0,(Pt)} \cdot \left(1 + 3.9083 \cdot 10^{-3} \frac{1}{°C} \cdot t - 5.775 \cdot 10^{-7} \frac{1}{(°C)^2} \cdot t^2\right), \quad (4)$$

where t is the sensor temperature expressed in 0°C; $R_{t,(Pt)}$ is the resistance of the platinum RTD at a temperature t; $R_{0,(Pt)}$ is the resistance of the platinum RTD at a temperature 0°C.

To determine the temperature t using platinum RTDs, which at $0\,°C$ have a resistance of 1000 Ω, based on (4) we obtain (after solving the quadratic equation):

$$t \approx 0.08658 \cdot \left(39083 - 3.31662 \cdot \sqrt{1.59862 \times 10^{8} - 21000 \cdot R_{t,(Pt,1000\Omega)} \frac{1}{\Omega}}\right) °C, \quad (5)$$

where $R_{t,(Pt,1000\Omega)}$ is the resistance of a platinum RTD, which at 0°C has a resistance of 1000 Ω, at a temperature of t.

Suppose that a platinum RTD at 0°C has a resistance of 1000 Ω. If we use expression (4), then the resistance of such a sensor at a temperature of 100°C $R_{100,(Pt,1000\Omega)}$ will be:

$$R_{100,(Pt,1000\Omega)} \approx 1385.055\Omega \quad (6)$$

If we differentiate (4), we get:

$$\frac{dR_{t,(Pt)}}{dt} = R_{0,(Pt)} \cdot \left(3.9083 \cdot 10^{-3} \frac{1}{°C} - 1{,}155 \cdot 10^{-6} \left(\frac{1}{°C}\right)^2 \cdot t\right) \quad (7)$$

$$\frac{dR_{t,(Pt,1000\Omega)}}{dt} = 1000\Omega \cdot \left(3.9083 \cdot 10^{-3} \frac{1}{°C} - 1{,}155 \cdot 10^{-6} \left(\frac{1}{°C}\right)^2 \cdot t\right) \quad (8)$$

In fig. 7 presents the dependence graph (8).

Taking into account the results of the above-described testing of one of the RTDs, further in this work, to determine relatively small temperature differences and changes in temperature differences using the scheme of Fig. 1 at certain values of the average temperature expressed in °C t_{av}, for simplification, fixed values of $\frac{dR_{t,(Pt,1000\Omega)}}{dt}$ were used, taken from dependence (8) and from the graph of Fig. 7 for these values t_{av}

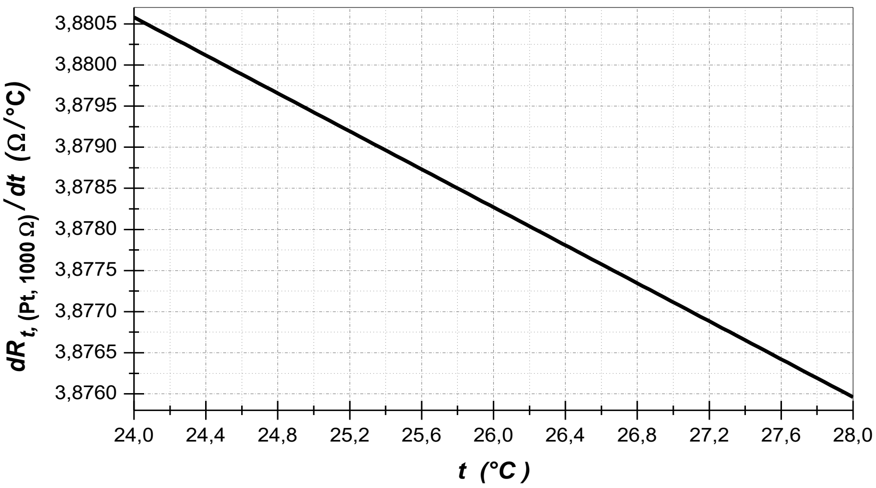

Fig. 7. Graph of the dependence of $\frac{dR_{t,(Pt,1000\Omega)}}{dt}$ on t, which is obtained based on expression (8) (for platinum RTDs, the resistance of which at 0°C has a value of 1000Ω).

$\left(\frac{dR_{t,(Pt,1000\Omega)}}{dt}\right)_{t=t_{av}}$. The change in temperature difference simplified determined by the formula:

$$\varphi \approx \frac{\frac{(U_{12})_A-(U_{12})_B}{0.5I}}{\left(\frac{dR_{t,(Pt,1000\Omega)}}{dt}\right)_{t=t_{av}}}, \tag{9}$$

where $(U_{12})_A$ is the voltage U_{12} under conditions A; $(U_{12})_B$ is the voltage U_{12} under conditions B; $(U_{12})_A-(U_{12})_B$ is the change in voltage U_{12}.

The average temperature t_{av} when using the scheme in Fig. 1 was being determined in a simplified way by the expression that can be obtained from (5):

$$t_{av} \approx 0.08658 \cdot \left(39083 - 3.31662 \cdot \sqrt{1.59862 \times 10^8 - 21000 \cdot \frac{(U_{34})_A+(U_{34})_B}{2I}\frac{1}{\Omega}}\right) ^\circ\mathrm{C}, \tag{10}$$

where $(U_{34})_A$ is the voltage U_{34} under conditions A; $(U_{34})_B$ is the voltage U_{34} under conditions B; $\frac{(U_{34})_A+(U_{34})_B}{2}$ is the average value voltage U_{34}.

II. An example of the application of the described technique for estimation the change in the temperature difference on opposite heat exchange surfaces of a TEM

The above-described technique using 4 RTDs according to the scheme in Fig. 1 was used to estimate the change in the temperature difference on the opposite heat exchange surfaces of the TEM (on the opposite outer surfaces of the ceramic plates of the TEM). RTDs *R1* and *R2* were attached to one outer surface of a ceramic plate of a TEM labeled TEC1-12706, and RTDs *R3* and *R4* were attached to the other (opposite) outer surface of the ceramic plate of the same TEM (to create corresponding thermal contacts). To excite the RTDs, the exactly that stabilized current source was used, the test results of which are shown above in Fig. 5 with the same value of the current (approximately 2 mA). For a relatively small change in the temperature difference over time on the opposite heat exchange surfaces of the TEM, another stabilized current source was used (to which the TEM was connected at a certain point in time) with a current value of approximately 50 µA. The current which flowed through the TEM was recorded using an MS8218 multimeter. The voltages U_{12}, U_{34} and the voltage on the TEM were recorded using MS8218 multimeters. The results of the corresponding experiment are presented in Fig. 8 – Fig. 11.

The change in voltage U_{12}, in the graph of Fig. 8 is displayed in relation to the minimum value of voltage U_{12}, in the time interval from 0 s to 7.5 s, when the current through the TEM was absent (Fig. 9). If we assume that at minimum values of voltage U_{12}, in this time interval $\Delta T = 0°C$, then the change in temperature difference in the graph of Fig. 8 can be considered as a temperature difference. The change in temperature difference was calculated using formula (9). In this case, for t_{av}, the simplified value was approximately 24.461$°C$ (Fig. 11), and for *I,* the simplified value was 2007 µA (2.007 mA).

III. An example of testing the sensitivity of the scheme of Fig. 1

To test the sensitivity of the circuit in Fig. 1, the following experiment was carried out. The exactly those RTDs were used and in the same spatial and thermal conditions as in the simplified estimation of instability of the values of the voltages U_{12} described above using the schemes of Fig. 1 and Fig. 2 (the results of which are shown in Fig. 6). In this experiment, a stabilized current

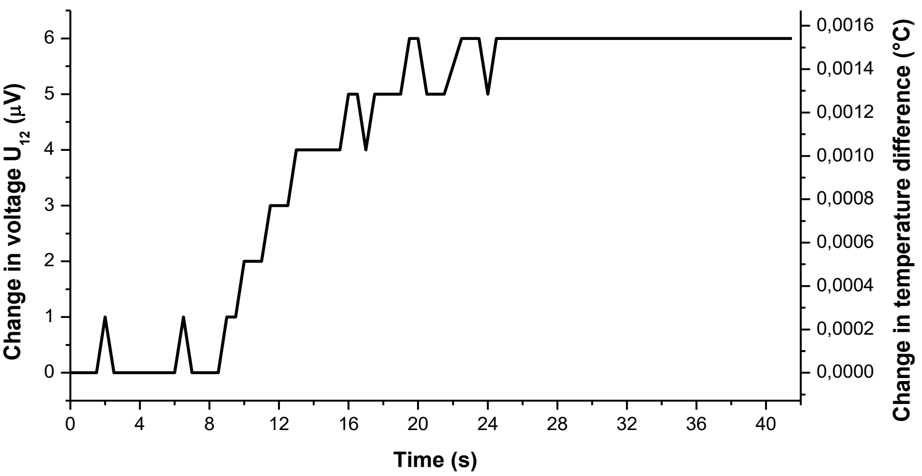

Fig. 8. The dependence of the change in the temperature difference (which was determined, in particular, by the change in voltage U_{12} (Fig. 1)) on the opposite outer surfaces of the ceramic plates of the TEM under the action of the change in the current through the TEM (Fig. 9) on time.

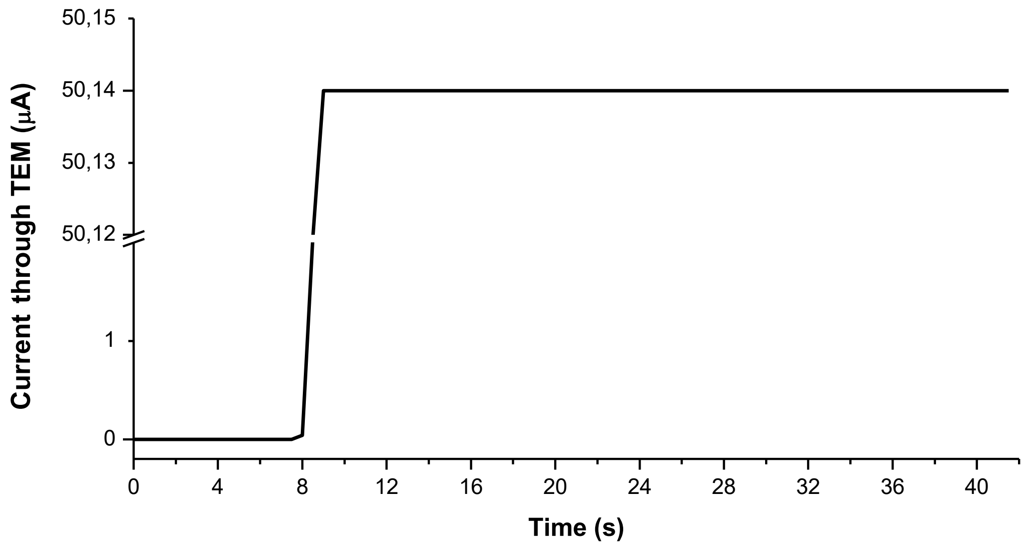

Fig. 9. Dependence of current through TEM on time.

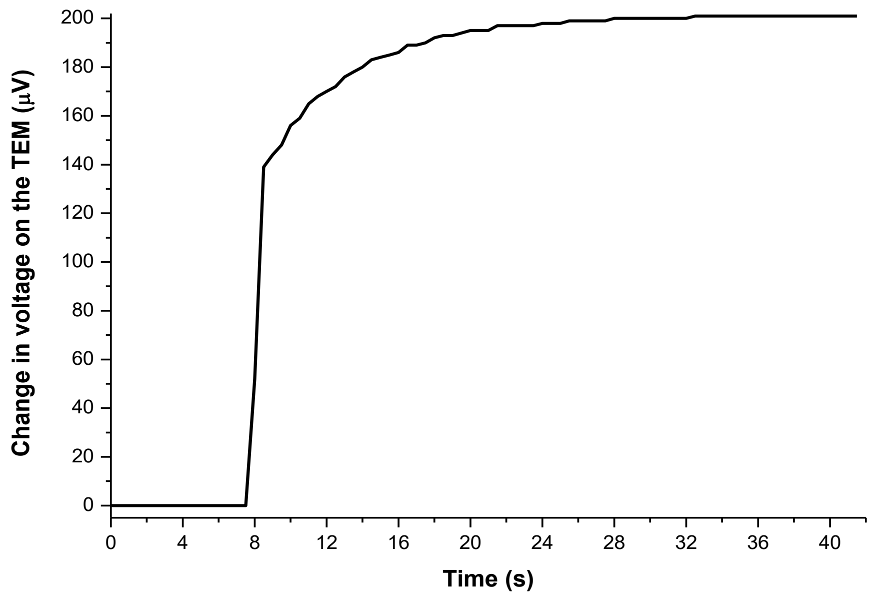

Fig. 10. Dependence of the change in voltage on the TEM when the current changes through this module (Fig. 9) on time.

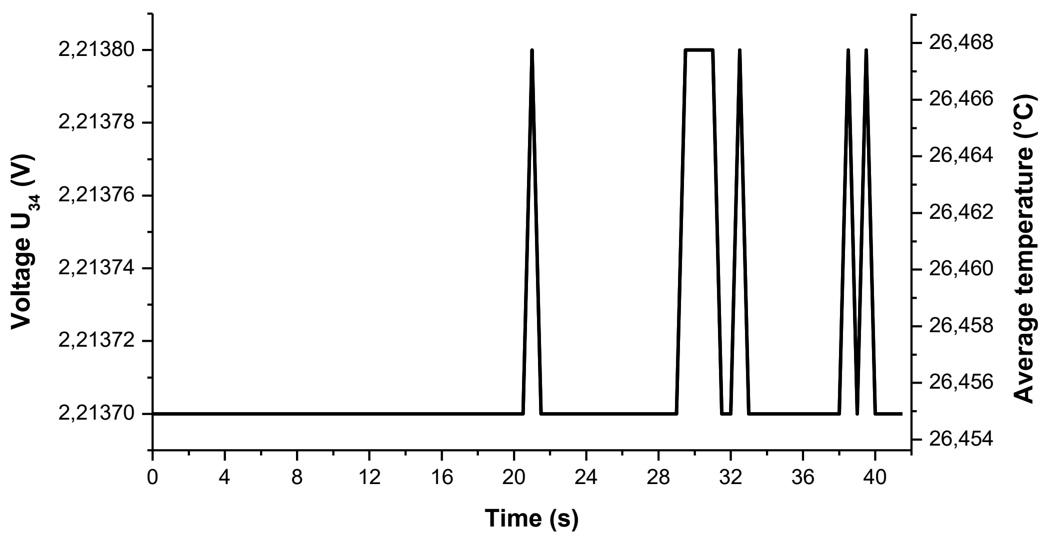

Fig. 11. The dependence of the average temperature t_{av}, (which was determined, in particular, by the value of the voltage U_{34} (Fig. 1)) on the opposite outer surfaces of the ceramic plates of the TEM on time.

source with a current value of approximately 3 mA was used to excite the RTDs. Separated from the 4 RTDs at the distance of an air gap of several millimeters was the heater (another RTD of similar dimensions was used as the heater). The heater was on for approximately 3-4 seconds. The power of the heater at the same time was approximately 2.5 mW.

Experimental data on the change in voltage U_{12} were obtained by a voltage recorder with an input resistance of approximately 10 MΩ based on, in particular, a 32-bit analog-to-digital converter.

In Fig. 12 shows the result of this experiment.

The change in voltage U_{12} in the graph of Fig. 12 is displayed in relation to the average value of voltage U_{12} in the time interval from 0 seconds to 25 seconds in the same graph of Fig. 12.

The values of the equivalent change in the temperature difference in Fig. 12 are identical to the values of φ calculated by formula (9). In this case, for $\left(\frac{dR_{t,(Pt,1000\Omega)}}{dt}\right)_{t=t_{av}}$, the simplified value was taken as $3.88\,\frac{\Omega}{°C}$ (Fig. 7), and for I, the simplified value was taken as 3000 μA.

If we assume that throughout the experiment the temperatures of RTDs *R1* and *R2* were the same (Fig. 1) and the temperatures of RTDs *R3* and *R4* were also the same (Fig. 1), then the equivalent change in temperature difference in Fig. 12 can be considered a change in temperature difference. The actual values of the temperatures of RTDs *R1* – *R4* during the experiment are unknown.

If, in addition to the previous assumption, we also assume that the temperatures of all 4 RTDs (Fig. 1) with the heater not activated (in the absence of heating for approximately the first 25 seconds in the graph of Fig. 12) are the same (for example, in the case when all 4 RTDs are the same and are in the same heat exchange conditions with their environment), then it can be considered that the equivalent change in temperature difference in Fig. 12 is the temperature difference.

IV. Brief information about the factors that can influence the estimation results and the features of the estimation method used

The estimation results are the result of the interaction of the research object and the estimation system. The estimation results may be influenced to a greater or lesser extent by the following factors:

heat exchange processes (conduction, convection, radiation) that are associated with the use of an estimation system, in particular, RTDs;

mass transfer processes that are associated with the use of the estimation system, in particular, RTDs (if available; for example, air flows);

properties (parameters, characteristics) of RTDs;

properties (parameters, characteristics) of the current or voltage source(s) used to excite the RTDs;

resistances (in particular, their temperature dependences) of the conductors used for RTDs connections in the corresponding scheme (circuit);

Joule heat released when excitation current flows through the RTDs;

thermoelectric phenomena (if present, from a practical point of view);

properties and features of thermal contacts between the RTDs and the object under study;

features of the location of the RTDs and the object under study;

properties, parameters, characteristics, features of meters (measuring devices), for example, input electrical resistance, drift, noise, nonlinearity;

features of using meters (measuring devices);

transient processes in the studied system, which includes the object of study and the estimation system (in particular, in measuring devices);

electromagnetic disturbances, interference, induction, guidance;

galvanic or signal connections (if available) between meters (measuring devices);

features of synchronization of meters (measuring devices);

features of matching data (relevant data) from different meters or measuring devices;

features of mathematical processing of experimental data.

It is possible to reduce the effect of Joule heat, which is released when the excitation current flows through the RTDs (and, in particular, can cause a change in the temperatures of the RTDs and the object under study) on the system under study and, accordingly, on the estimation results, if the measurement is carried out during short-term pulses of the excitation current of the RTDs (which can be created when using the scheme of Fig. 1, for example, using the switching element *K1*). The use of short-term pulses of the RTDs excitation current can also contribute to increasing the sensitivity of the estimation (measuring) system.

The influence of RTDs parameters on the evaluation results can be reduced by calibrating each individual sensor (as an option, together with its connecting wires) and selecting the RTDs (as an option, together with their connecting leads) by parameters. The estimation error associated with RTDs parameters can also be reduced by using separate approximation polynomials for each individual sensor (as an option, together with its connecting wires) for the applicable temperature range.

In Fig. 1, RTDs *R1* and *R2* have the same temperature. In a real situation, the temperatures of these sensors may differ slightly due to their different spatial arrangement, possibly different parameters, thermal conditions, and excitation currents. The same can be said about RTDs *R3* and *R4*. The estimation error associated with this factor can be reduced by designing, manufacturing and using appropriately specialized RTDs, for example, sensors in which two separate RTDs with close to identical parameters would have improved thermal contact with each other and would be placed in one housing at a minimized distance relative to each other (for example, electrically insulated resistive elements would be structurally placed in one housing one above the other or one next to the other).

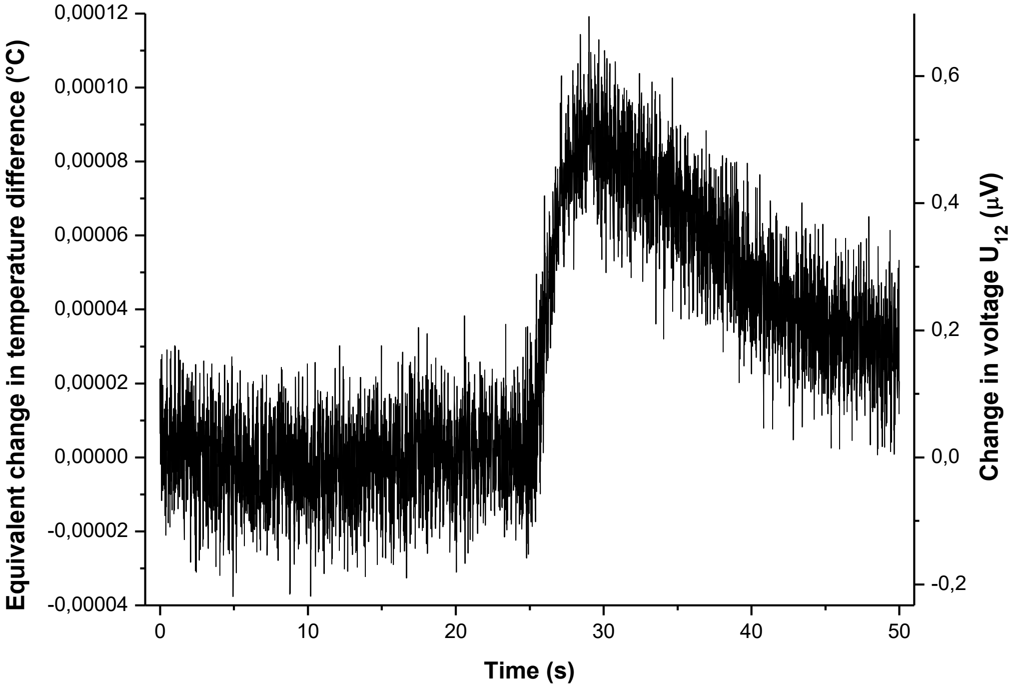

Fig. 12. Dependence of the voltage change U_{12} (Fig. 1;$I \approx 3\ mA$) and the equivalent change in the temperature difference on time (in particular, when the heater operated for approximately 3 – 4 seconds).

Other factors may also influence the results of the estimation of changes in temperature differences, temperature differences, and temperatures.

Of course, for a complete, practically comprehensive estimation of the resulting possible error in the estimation of changes in temperature differences, temperature differences, and temperatures, it is necessary to take into account all factors that, from a practical point of view, can influence the result of the relevant studies.

Conclusion

Using 4 RTDs according to the scheme in Fig. 1 needs to use of only one source of electric current to excite the RTDs. Instead, the use of 2 RTDs according to the scheme of Fig. 2 needs to use of two sources of electric current to excite the RTDs.

Using 4 RTDs according to the scheme of Fig. 1 compared to using 2 RTDs according to the scheme of Fig. 2 can significantly reduce the instability of voltage U_{12} (Fig. 6). In particular, using the values of voltage/voltages U_{12}, relatively small temperature differences are evaluated.

With unchanged temperature sensitivity, the use of 4 RTDs according to the scheme of fig. 1 in comparison with the use of 2 RTDs according to the scheme of fig. 2 increases by approximately 2 times the Joule heat release in sensors that have thermal contact with the object of study.

The use of 4 RTDs according to the scheme in Fig. 1 when using a current source compared to using 2 RTDs can reduce the error in determining the average temperature while simultaneously determining the temperature difference or simplify the technical implementation of "parallel", when using 2 RTDs, non-simultaneous determination of the average temperature and temperature difference.

There may be a need to design, build, and use specialized for use in the circuit of Fig. 1 RTDs.

The studies described above are of an evaluative (to some extent approximate) nature. Therefore, other studies may be needed to obtain more precise experimental results.

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[1] O.S. Kshevetsky, *Estimation of the efficiency of partial case of heat and mass transfer processes between heat pumps and moving substance, part 1*, Journal of Thermoelectricity, (6), 39 (2017).
[2] O.S. Kshevetsky, *Estimation of the efficiency of partial case of heat and mass transfer processes between heat pumps and moving substance, part 2*, Journal of Thermoelectricity, (2), 56 (2018).
[3] O.S. Kshevetsky, O.V. Orletskyi, *Estimation of the efficiency of partial case of heat and mass transfer processes between heat pumps and moving substance, part 3*, Journal of Thermoelectricity, (4), 40 (2019).
[4] O.S. Kshevetsky, R.G. Cherkez, Yu.I. Mazar, *Estimation of the efficiency of partial case of heat and mass transfer processes between heat pumps and moving substance. Part 4*, Journal of Thermoelectricity, (4), 64 (2023); https://doi.org/10.63527/1607-8829-2023-4-64-75

[5] O. Kshevetsky, *About some of the possibilities of using heat pumps in processes that involve the movement of substance,* Thermophysics and Thermal Power Engineering, 41(3), 70 (2019); https://doi.org/https://doi.org/10.31472/ttpe.3.2019.10.
[6] S. Bhattacharya, H.J. Goldsmid, *Determination of the thermoelectric figure of merit through the maximum temperature depression using the peltier cooling effect*, Journal of Thermoelectricity, (1), 26 (2018).
[7] S. Shantanu, *Platinum RTD sensor based multi-channel high-precision temperature measurement system for temperature range −100°C to +100°C using single quartic function*, Cogent Engineering, 5(1), 1558687 (2018); https://doi.org/10.1080/23311916.2018.1558687.
[8] L. Piechowski, A. Muc, J. Iwaszkiewicz, *The Precise Temperature Measurement System with Compensation of Measuring Cable Influence*, Energies, 14, 8214 (2021); https://doi.org/10.3390/en14248214.
[9] A. Idzkowski, Z. Warsza, *Temperature difference measurement with using two RTD sensors as example of evaluating uncertainty of a vector output quantity*, Robotic Systems and Applications, 1(2), 53, (2021); https://doi.org/10.21595/rsa.2021.22143.
[10] L. Anatychuk, R. Kobylianskyi, V. Lysko, A. Prybyla, I. Konstantinovych, A. Kobylyanska, M. Havrylyuk, V. Boychuk, *Method of calibration of thermoelectric sensors for medical purposes*. Journal of Thermoelectricity, (3), 37, (2023); https://doi.org/10.63527/1607-8829-2023-3-37-49.
[11] L. Anatychuk, R. Kobylianskyi, I. Konstantinovich, Y. Rozver, V. Tiumentsev, *Calibration bench for thermoelectric converters of heat flux*, Journal of Thermoelectricity, (5), 65 (2016).
[12] L. Anatychuk, R. Kobylianskyi, I. Konstantinovich, O. Nitsovych, R. Cherkez, *Technology for manufacturing thermoelectric microthermopiles*, Journal of Thermoelectricity, (6), 49 (2016).
[13] R. Kobylianskyi, A. Prybyla, I. Konstantynovych, V. Boychuk, *Results of experimental research on thermoelectric medical heat flow sensors*, Journal of Thermoelectricity, (3–4), 68 (2022); https://doi.org/10.63527/1607-8829-2022-3-4-68-81.
[14] R. Kobylianskyi, V. Lysko, A. Prybyla, I. Konstantynovych, A. Kobylianska, N. Bukharayeva, V. Boychuk, *Technological modes of manufacturing medical purpose thermoelectric sensors*, Journal of Thermoelectricity, (4), 49 (2023); https://doi.org/10.63527/1607-8829-2023-4-49-63.
[15] R. Kobylianskyi, K. Przystupa, V. Lysko, J. Majewski, L. Vikhor, V. Boichuk, O. Zadorozhnyy, O. Kochan, M. Umanets, N. Pasyechnikova, *Thermoelectric Measuring Equipment for Perioperative Monitoring of Temperature and Heat Flux Density of the Human Eye in Vitreoretinal Surgery*, Sensors, 25(4), Article number: 999 (2025); https://doi.org/10.3390/s25040999.

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Оцінка порівняно малих різниць температур з використанням резистивних датчиків температури. Частина 1

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Описана методика оцінки порівняно малих різниць температур з використанням 4-х резистивних датчиків температури, які електрично з'єднані за мостовою схемою. Описані приклад експериментальної оцінки різниці температур на протилежних зовнішніх поверхнях керамічних пластинах термоелектричного модуля та приклади тестування деяких елементів оціночної системи. Розглянуті фактори, які можуть впливати на результати вказаної оцінки.

Ключові слова: вимірювання різниці температур, резистивні датчики температури, термоелектричний модуль.