METHODS AND DEVICES FOR MEASURING
THE PELTIER COEFFICIENT OF AN
INHOMOGENEOUS ELECTRIC CIRCUIT

Yu. A. Skripnik and A. I. Khimicheva

Existing methods of determining the Peltier coefficient of an inhomogeneous electric circuit are analyzed. The proposed algorithmic method of determining the Peltier coefficient is more accurate than the methods analyzed, because it excludes the influence of Joule heat and the Seebeck coefficient on the results of the measurement.

In recent years the Peltier effect has been employed widely in measuring devices for forming thermophysical tests that are used to correct the errors of temperature-measuring instruments and a series of thermophysical quantities [1, 2]. The technical and reference literature, however, gives scanty information about the values of the Peltier coefficient for various thermoelectrodes and its temperature dependence.

In the article we consider existing methods of measuring the Peltier coefficient and evaluate possible regions where those methods can be applied.

Shtenbek and Baranskii [3] described a method of determining the Peltier coefficient of an inhomogeneous electric circuit. The method is based on passing a constant current through a specimen of the material under study, which is in contact with copper electrodes. The difference of the temperatures at the ends of the specimen is measured, the cooled electrode is heated additionally, and the Peltier coefficient \( r \) is determined (when the temperature difference becomes zero) is determined from

\[
W = 0.5 W I,
\]

where \( W \) is the compensating power of the additional heating and \( I \) is the constant current.

A compensating action is effected by means of electric heaters inside the copper electrodes. A fraction of the electrical power used directly to compensate for the Peltier effect cooling is difficult to evaluate since part of the power goes to cover the loss due to heat transfer into the ambient medium. As a result the Peltier coefficient is determined with a large error, especially in measurements over a wide temperature range.

Higher accuracy is assured by the method of Kuritnik et al. [4], where a constant current is passed through an electrical circuit containing two electrodes of different materials (forming a common junction); that current cools the junction, the TEMF the terminals of the circuit and the current in the circuit are measured, and the Peltier coefficient \( r \) calculated from the formula. At the same time, that current is passed through a similar junction of materials in the opposite direction, causing the junction to heat; the TEMF at the circuit terminals with cooled and heated common junctions is measured and the Peltier coefficient is found from

\[
r = c m \Delta T / (2 I t),
\]

where \( c \) and \( m \), respectively, are the specific heat and mass of the materials of the junction, \( \Delta T \) is the temperature difference, and \( t \) is the time for which current flows.

The method employs two calorimeters while the junctions heated and cooled are adiabatically and the temperature difference is measured with a differential thermocouple. The main difficulty in the measurements is posed by adiabatization,
Fig. 1. Block diagram of the device for determining the Peltier coefficient of an inhomogeneous electric circuit: 1) constant voltage supply; 2) variable resistor; 3) gauge of thermoelectric thermometer; 4) milliammeter; 5, 6) three-pole switch; 7) regulated constant voltage supply; 8) heater; 9, 10) electrodes of the materials under study; 11) constant resistor; 12) differential amplifier; 13) millivoltmeter; 14) regulated voltage divider.

especially at high temperatures, to eliminate the influence of lateral losses. The end losses due to the thermal conductivity of the materials studied are difficult to eliminate and they do affect the results of the measurements. Considerable errors are due to the instability and unequal heat capacities and masses of the two calorimeters, as well as to the low accuracy of temperature difference measurement by the thermocouples, the thermoelectromotive force (Seebeck coefficient) TEMF of which is unstable and depends on the junction temperature. As a result, the error of the Peltier coefficient measurements by the above method over a wide range of temperatures reaches 7-10%.

Kuritnik et al. [4] also considered a device containing a constant-voltage supply, milliammeter, electrodes of the materials under study, a millivoltmeter, and two three-pole switches. The device also includes two differential calorimeters and a differential thermocouple, with the millivoltmeter connected to its output. The electrodes of the materials under study are series-connected and their junctions are put into the calorimeters separately. Auxiliary comparison electrodes of different materials with precisely known Peltier coefficient are required for determining the Peltier coefficient of the materials. Thermally the auxiliary electrodes should be identical with the electrodes under study and should form common junctions with them. The uncontrolled heat loss through the comparison electrodes, the differences in the thermophysical characteristics of the calorimeters, and the instability of the calibration characteristics of the thermocouples connected in a differential circuit mean that the Peltier coefficient measurement cannot be measured with high accuracy.

Jimenez et al. [5] propose that the Peltier coefficient of an inhomogeneous electric circuit be measured with a device that contain a thermoelectric bridge of common junctions of different materials placed in a thermostat, a constant-voltage supply, a milliammeter, a millivoltmeter, and a constant-voltage potentiometer. Since the thermophysical characteristics of the two junctions inevitably are different and the results of the measurements depend on the junction heating time the Peltier coefficient cannot be measured with a high degree of accuracy.

The analysis of the known methods of measuring the Peltier coefficient has shown that they are not applicable for operative inspection. Moreover, the result of the measurement is affected strongly by the Joule heat, which is dissipated by the thermoelectric and other elements of the thermoelectric circuits. Below we propose a new method of measuring the Peltier coefficient of an inhomogeneous electric circuit.

A constant current is passed through an electric circuit, consisting of two electrodes which are made of different materials and form a common junction. The direction of current flow is chosen so that in the general case the common junction would absorb the Peltier heat and thus be cooled. The junction temperature decreases by

$$-\Delta T_j = T_2 - T_1,$$

where $T_1$ is the temperature of the electrodes and $T_2$ is the temperature of the junction of the electrodes.

When the Peltier effect in the plane of the junction and the release of Joule heat into the bulk of the electrodes (we ignore the Thomson effect) we can assume that half of the Joule effect from the electrodes is transferred to the cold junction.
and half to the circuit input terminals, where it is dissipated into the ambient medium. Thus, the heat absorbed by the cold junction per unit time is

\[ q = -\pi I + I^2 r / 2, \]

where \( \pi \) is the Peltier coefficient, which depends on the electrode materials, \( r \) is the total resistance of the electrodes, and \( I \) is the current of the electric circuit.

If the direct heat exchange between the junction and the ambient medium is ignored, the heat balance as a result of the Peltier effect is expressed by

\[ -\pi I + I^2 r / 2 = \lambda_0 (T_2 - T_1). \]

where \( \lambda_0 \) is the thermal conductivity of the electrodes.

The current through the junction is chosen from the condition for maximum cooling of the junction:

\[ \frac{dq}{dT} = -\pi + I_0 r = 0. \]

When the current flowing through the junction \( I_0 = \pi / r \), which is optimal for cooling, the temperature drop is maximum:

\[ (T_2 - T_1)_{\text{max}} = \pi^2 / (2 \lambda_0 r). \]

Here

\[ r = I \left[ (q_1 F_1)^{-1} + (q_2 F_2)^{-1} \right]; \]
\[ \lambda_0 = \frac{1}{2} (\lambda_1 F_1 + \lambda_2 F_2); \]

\( q_1 \), \( q_2 \) and \( \lambda_1 \), \( \lambda_2 \) are electrical conductivities and thermal conductivities, respectively, \( F_1 \) and \( F_2 \) are the cross-sectional areas of the electrodes, and \( l \) is the electrode length.

Cooling of the common junction causes a TEMF to appear on the terminals of the electric circuit,

\[ \Delta E_1 = -S \Delta T_1 = \frac{S}{\lambda_0} \left( \pi I + I^2 r / 2 \right), \]

where \( S \) is the thermoelectric (Seebeck) coefficient of the junction.

When Eq. (1) is taken into account the maximum value of TEMF is

\[ \Delta E_{\text{max}} = S \pi^2 / (2 \lambda_0 r). \]

Varying the current in the circuit, we obtain \( \Delta E_{\text{max}} \), and measure it with a millivoltmeter. The optimal current \( I_0 \) is also measured.

Next we reverse the direction of the current flowing through the junction. Since the Peltier coefficient is reversible, the junction is heated when the direction of the current through it is reversed. The TEMF through it initially decreases, changes sign, and increases to

\[ \Delta E_2 = S \Delta T_2 = \frac{S}{\lambda_0} \left( \pi I_0 + I^2 r / 2 \right). \]
The steady-state value of the TEMF $\Delta E_0$ is measured with the millivoltmeter. Then we calculate the sum and difference of the measured TEMFs,

$$\Delta E_2 + \Delta E_1 = 2\pi l_0/\lambda_0,$$

$$\Delta E_2 - \Delta E_1 = SI_0^2 r/\lambda_0,$$

and from their ratio we obtain the value of the Peltier coefficient,

$$\pi = \frac{(\Delta E_2 + \Delta E_1)I_0}{2(\Delta E_2 - \Delta E_1)}.$$

(2)

It follows from the last expression that the Peltier coefficient is determined by the measured TEMFs $\Delta E_1$, the optimal current $I_0$ through the junction of the electric circuit, and the circuit resistance $r$. At the same time the determination of $\pi$ is unaffected by the thermal conductivity $\lambda_0$ of the electrodes and, therefore, the rate of heat exchange by the circuit with the ambient medium, nor is it affected by the thermoelectric coefficient $S$, which is unstable, depends on the temperature of the junction and, hence, is not known exactly.

To determine the Peltier coefficient at various temperatures we preheat (or precool) the junction of an inhomogeneous circuit to the required temperature $T_0$ and measure the corresponding TEMF $E_0$. When the junction is then cooled by a current $I_0$ we measure the decreased value of the TEMF $E_1$ and when the current is reversed we measure the increased value of the TEMF $E_2$. Then we calculate the TEMF increment,

$$\Delta E_1 = E_1 - E_0; \quad \Delta E_2 = E_2 - E_0.$$

The Peltier coefficient for $T_0$ is found from a ratio analogous to (2):

$$\pi r_0 = \frac{(E_2 + E_1 - 2E_0)I_0}{2(E_2 - E_1)}.$$

(3)

Varying the junction temperature $T_0$ and measuring the TEMFs $E_0$, $E_1$, and $E_2$, we can obtain the dependence of the Peltier coefficient on the temperature of the junction in the electric circuit. The amounts of Peltier and Joule heat in this case are separated completely and taken into account when calculating the Peltier coefficient.

The block diagram of the device for determining the Peltier coefficient of an inhomogeneous electric circuit is shown in Fig. 1. The circuit functions as follows.

First, the switches 5 and 6 are set in the middle position. The common junction of the electrodes 9 and 10, placed in a metal (or glass) bottle, is heated by the heater 8; the meter 3, with a Celsius scale, monitors the junction temperature. The voltage of the ac supply is regulated to set the required temperature drop $T_0$. From the output terminals of the electrodes 9 and 10 the millivoltmeter 13 measures the TEMF $E_0$ corresponding to the temperature $T_0$. An ac bridge (not shown in Fig. 1) is used to measure the resistance $r$ on the side of the input terminals of the electrodes 9 and 10. Then the TEMF $E_0$ from the output terminals of those electrodes are added in the resistor 11 together with part of the output voltage of the voltage divider 14, which produces a compensating voltage of the opposite polarity. The voltage difference is amplified by the differential amplifier 13. Regulation of the voltage divider 14 by the zero reading of the millivoltmeter 13 balances out the TEMF $E_0$ of the electrodes at the given junction temperature $T_0$. The switches 5 and 6 are then put in the top position, whereupon a constant current begins to flow through the input pair of half-electrodes 9 and 10, cooling of the middle junction. The current flowing through the junction is regulated by the variable resistor 2 and is measured by the milliammeter 4. Periodically putting the switches 5 and 6 in the middle position after each regulation of the current establishes the conditions for maximum cooling of the junction according to the highest reading of the millivoltmeter 13. The optimal current $I_0$ is measured by the milliammeter 4 and the difference TEMF $\Delta E_1(E_1 = E_0 - \Delta E_1)$ is measured by the millivoltmeter 13 from the side of the output pair of half-electrodes 9 and 10. The switches 5 and 6 are then set in the bottom position. This reverses the flow of current through the junction of the input pair of half-electrodes 9 and 10; the TEMF of the input pair of half-electrodes begins to decrease, reaches zero, and then begins to increase because of additional heating of the common junction. The steady-state values of the difference TEMF $\Delta E_2(E_2 = E_0 - \Delta E_2)$ is measured by the millivoltmeter 13 from the side of the output pair of half-electrodes 9 and 10.

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The measured values of $E_0$, $E_1$, and $E_2$ or $\Delta E_1$ and $\Delta E_2$ without preheating are used with Eqs. (3) or (2) to calculate the Peltier coefficient for a given temperature or the ambient temperature.

Our studies have demonstrated that the Peltier coefficient of various materials can be determined in the range 0.01-0.5 mW/mA at 20-100°C with a relative error of less than 0.5%. A special electric circuit to compensate for the Joule heat in the junction has become unnecessary since in the method used the Peltier and Joule effects are separated and are used together to calculate only the Peltier coefficient.

REFERENCES