Viktor LOZBIN[1,2], Piotr BYLICKI[1], Vitali CUBA[2]

Lublin University of Technology, Department of Electronics, Poland (1),
National University of Water Industry and Nature Management, Rivne, Ukraine (2)

New method of determining electric and thermal characteristics of Peltier device

Abstract. *In this article authors propose a new method for experimental research of electric and thermal characteristics of Peltier device. Presented method differs from commonly as summary Seebeck coefficient, internal resistance, thermal conductivity coefficient of thermoelectric material and summarized thermal resistance of copper connections, join surfaces with structure of a heating system are simultaneously determined without interfere into tested element structures. The main assumption of the method is the comparison of the heat fluxes flowing through the tested thermoelectric element in open and short circuits.*

Streszczenie. *W artykule proponowana jest nowa metoda eksperymentalnego wyznaczania elektrycznych i termicznych charakterystyk ogniw Peltiera. Prezentowana metoda w odróżnieniu od obecnie stosowanych umożliwia uzyskanie współczynnika Seebecka, wewnętrznej rezystancji elektrycznej, przewodności cieplnej materiału termoelektrycznego, przewodności cieplnej obudowy ogniwa wraz z powierzchniami styku w jednym eksperymencie bez konieczności ingerencji do wnętrza badanego elementu. Metoda w głównej mierze polega na porównaniu strumieni cieplnych przepływających przez badane ogniwo Peltiera znajdujące się w stanie zwarcia i rozwarcia obwodu elektrycznego. (**Nowa metoda określania elektrycznych i cieplnych charakterystyk ogniwa Peltiera**).*

Keywords: thermoelectric module, thermoelectric properties, Peltier device, thermoelectric parameters.
Słowa kluczowe: moduł termoelektryczny, właściwości termoelektryczne, ogniwo Peltiera, parametry termoelektryczne.

Introduction

The methods that are used nowadays to determine electric and thermal characteristics of the Peltier devices are based on standard principles of measurement of thermal conductivity in materials [1-6], the essence of which is to create the temperature gradient on the surface of the examined material measuring the heat flux from which thermal conductivity and thermal conductance coefficient are calculated. Measuring the electromotive force, or most commonly EMF, on Peltier device which is in open circuit is not problematic. However it is difficult to refer this value to temperature changes. The above fact is consequential to unknown temperature on the edge of thermoelectric material.

Commonly used method which helps to reduce this problem is the installation of temperature sensors directly inside the Peltier device or in the copper connections layer. This often causes damage to the device and makes it impossible to use it in the future. Additionally, this process is very time-consuming. In classical methods it is difficult to precisely measure the electrical resistance because the relation of the current to voltage in module is specified by the temperature field generated when device changes its work state (change from open to short circuit). In this method, the measurement of thermal conductivity of copper layer and ceramic casing is impossible.

In this article a different concept for testing method and processing the result data is proposed. Presented method allows to determine complete Peltier device characteristics including thermal and thermoelectric material characteristics and real electric resistance without interfere into device structures.

Method

Let us assume that the tested element located in the system from picture 1 connected without any electrical load is in stable thermal state. In this situation temperatures T_{ho} and T_{co}, heat flux Q_0, electromotive force E_0 and current I_0 (generated immediately after circuit is shortened) are measured.

Hereinafter in this article index „*0*" means values that are present when the circuit is open, and index „*Z*" means values that are present where circuit is short.

Next, the circuit is shortened through ammeter with the possible lowest resistance.

It results in the temperature layout change within the Peltier device as the outcome of the Peltier effect. When the thermal state stabilizes in the Peltier device, temperatures T_{hz} and T_{cz}, current I_z, heat flux Q_z and voltage E_z are measured immediately after the open circuit.

Below, we prove, that values measured by the above method give possibility to determine complete electric and thermal characteristics of Peltier device. They make it possible to precisely determine the characteristics of thermoelectric material and thermal resistance of the constructional elements of the device between the contact point of the thermoelectric material with the copper connections and the heating/cooling system.

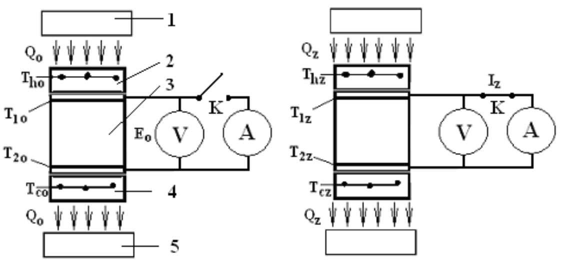

Fig.1. Suggested test system: 1 – electric heater 2, 4 – heat conducting and temperature equalizing plates, 3 – analyzed Peltier device, 4 – power measure point, 5 – cooler, V – voltmeter, A – ammeter, K – switch

Thermal balance equations for set-up presented in picture 1 are written below. Let us presume that thermoelectric material properties do not depend on temperature (it is possible when temperature difference is small between short and open circuit is and temperature at the beginning of experiment is high).

The equations for Peltier device working without electric load I_0=0 (open circuit) can be written as follows:

$$\left.\begin{aligned} Q_0 &= (T_{h0} - T_{c0})/(2\psi_t + \psi_p); \\ Q_0 &= (T_{10} - T_{20})/\psi_p; \\ E_0 &= A \cdot (T_{10} - T_{20}); \end{aligned}\right\} \quad (1)$$

where: Ψ_t – summarized thermal resistance of copper connections, joint surfaces with structure of a heating or cooling system to the level of temperature measurement points T_h or T_c, Ψ_p - thermoelectric material thermal resistance, A- real electromotive force, T_1 and T_2 – temperatures on the point where thermoelectric material contact copper connectors.

In short circuit, assuming that mutual dependence of heat fluxes can be used, and written by means of mean values of thermoelectric material, the following set of equations is obtained :

(2)
$$\left.\begin{aligned} Q_z &= (T_{hz} - T_{1z})/\psi_t; \\ Q_z &= (T_{1z} - T_{2z})/\psi_p + I_z \cdot A \cdot T_{1z} - I_z{}^2 R/2; \\ Q_z &= (T_{1z} - T_{2z})/\psi_p + I_z \cdot A \cdot T_{2z} + I_z{}^2 R/2; \\ Q_z &= (T_{2z} - T_{cz})/\psi_t; \\ I_z &= E_z/R; \\ E_z &= A \cdot (T_{1z} - T_{2z}); \end{aligned}\right\}$$

where: R – electric resistance of Peltier device, which is real thermoelectric material resistance together with electric connection layer resistance.

Heat fluxes, which flows through surfaces with temperature T_h and T_c will be equal, because there is no external electric load.

From equation (1) we can obtain the following dependence:

(3)
$$Q_0 = \frac{\Delta T_0}{\psi_p + 2\psi_t}$$

and

(4)
$$E_0 = A Q_0 \psi_p$$

where

(5)
$$\Delta T_0 = T_{h0} - T_{c0}$$

Taking into account that

(6)
$$\overline{T}_z = (T_{hz} + T_{cz})/2 = (T_{1z} + T_{2z})/2$$

both equations for heat fluxes on the point of connection between thermoelectric material and copper connection layer transform into

(7)
$$Q_z = \frac{E_z Q_0}{E_0} + I_z A \overline{T}_z$$

From above equations we obtain:

- for real electromotive force

(8)
$$A = \left(\frac{Q_z}{I_z} - \frac{Q_0}{E_0/R} \right) \frac{1}{\overline{T}_z}$$

- for thermal resistance of semiconductor part of the Peltier device

(9)
$$\psi_p = \frac{E_0}{A Q_0}$$

- for summary thermal resistance of copper connections, joint surfaces with the structure of the heating/cooling system

(10)
$$\psi_t = \frac{1}{2} \left(\frac{\Delta T_0}{Q_0} - \psi_p \right)$$

Electric resistance can be calculated both in the first and in the second part of the experiment.

(11)
$$R = \frac{E_0}{I_0} = \frac{E_z}{I_z}$$

The proposed method establishes changes against the classic method, especially in electric parameters measurement which are made immediately after circuit is shortened and opened.

Equation (8) shows, that it is possible to perform experiment in several ways. We can execute tests with

- constant mean value of temperature during the experiment- that makes it possible to eliminate inaccuracy resulting from thermal dependencies of constructional materials and the temperature.
- equal heat fluxes – that gives possibility to make experiment quicker

(12)
$$A = Q \cdot \left(\frac{1}{I_z} - \frac{R}{E_0} \right) \frac{1}{\overline{T}_z}$$

- $I_z = E_0/R$ and witch equal electric heater temperature $T_{hz} = T_{h0}$, that gives possibility to eliminate heat loss into the environment

(13)
$$A = \frac{Q_z - Q_0}{\overline{T}_z I_z} = \frac{\Delta Q}{\overline{T}_z I_z}$$

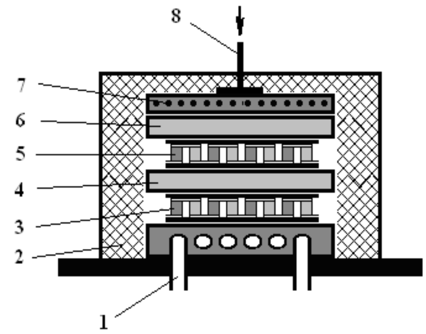

Fig.2. Investigational set-up flow sheet where 1 – cooling liquid, 2 – thermal isolation, 3 – Peltier device for temperature adjustment, 5 – tested Peltier device, 4, 6 – copper plates equalizing temperature field, 7 – electric heater, 8 – clamp

Fulfilling the above requirements solely by means of electric heater power adjustment is impossible. That is why the ability to regulate the temperature T_c is required.

Results

To confirm the above deliberations, prototype research set-up has been built. This device allows us to measure characteristics of the standard Peltier devices which are commonly used in iceboxes, refrigerators, etc. The scheme of the prototype is presented in the figure 2 and its external appearance is shown in the figure 3.

The proposed device, unlike standard constructions, have additional Peltier device, which give possibility to adjust thermal resistance between cool joins in tested element and the cooling device.

Automated control of the heater power along with the thermoelectric element power supply as well as measurement data processing is currently being realized by the National Instruments Lab View program.

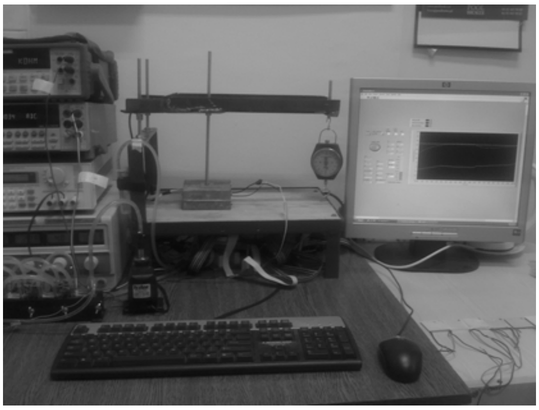

Fig.3. Prototype research set-up

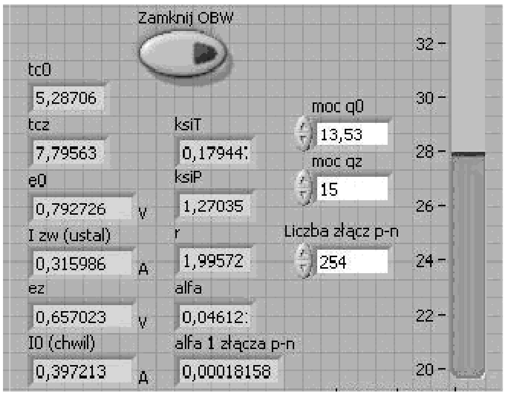

Fig.4. Result data in Lab view for TEC12710

Table 1. Five times this same TEC12710 measured values

	E_0 [V]	I_0 [A]	I_z [A]	Ψ_T [K/W]	Ψ_P [K/W]	R [Ω]	α [V/K]	T_h [°C]	T_{co} [°C]	T_{cz} [°C]
1	0,8021	0,3133	0,2561	0,3787	1,3516	2,56	0,0002012	24,45	-0,04	1,91
2	0,8200	0,3215	0,2621	0,4274	1,3168	2,55	0,0002111	24,67	-0,55	1,71
3	0,8266	0,3243	0,2659	0,4432	1,3116	2,54	0,0002125	24,96	-0,71	1,76
4	0,8350	0,3272	0,2718	0,3727	1,3560	2,55	0,0002002	25,12	-0,33	1,53
5	0,8562	0,3364	0,2746	0,4080	1,3073	2,54	0,0002068	25,67	-0,81	2,06

Table 2. Five times this same TEC12710 with additional thermal resistance

	E_0 [V]	I_0 [A]	I_z [A]	Ψ_T [K/W]	Ψ_P [K/W]	R [Ω]	α [V/K]	T_h [°C]	T_{co} [°C]	T_{cz} [°C]
1	0,6504	0,2628	0,2075	0,9101	1,4362	2,47	0,0001840	25,98	-5,58	-3,77
2	0,6571	0,2636	0,2056	0,9625	1,3204	2,49	0,0002086	25,58	-4,89	-3,71
3	0,6538	0,2627	0,2055	0,9872	1,2731	2,48	0,0002153	25,69	-4,80	-3,53
4	0,6555	0,2629	0,2060	0,9631	1,3089	2,49	0,0002100	25,69	-4,69	-3,50
5	0,6560	0,2631	0,2055	0,9499	1,3120	2,49	0,0002096	25,55	-4,61	-3,55

Tables 1 and 2 demonstrate repeatability of results data. To confirm that presented method is right this same Peltier device was tested in two measurements series. In the first series, the device was tested five times with one hour delay after each test (tab.1). In the second series, this same Peltier device was tested but with additional thermal resistance added on both sides of device (tab. 2). What is remarkable, is that table 1 and table 2 differ from each other only in Ψ_T - they contain this same semiconductor properties– what vindicates the correctness of the presented method.

Conclusions

Presented method allows us to determine complete Peltier device characteristics including thermoelectric material characteristics and real electric resistance. Moreover it is possible to determine summary thermal resistance of copper connections, join surfaces with structure of a heating or cooling system. These complete characteristics simplify optimization process and calculations during the construction of the system processing thermal energy into electric energy [7, 8] (thermoelectric generators) as well as cooling systems [9].

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Authors: *prof. dr hab. inż. Viktor Lozbin, mgr inż. Piotr Bylicki, Lublin University of Technology, Electrical Engineering and Computer Science Faculty, 20-618 Lublin, Poland, E-mail: v.lozbin@pollub.pl, piotrbylicki@wp.pl;*
Vitali Cuba National University of Water Industry and Nature Management, Rivne, Ukraine