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ANALYSIS OF INACCURACY SOURCES IN TEST SETUP FOR NEW METHOD OF DETERMINING ELECTRIC AND THERMAL CHARACTERISTICS OF PELTIER DEVICES

STRESZCZENIE *The analysis of inaccuracy sources in test setup for a new method of determining the electric and thermal characteristics of Peltier devices is presented. An improved experimental setup, including a new method of two-stage cooling, based on liquid coolant, is proposed.*

Keywords: *Peltier device, determination of Peltier device characteristics*

1. INTRODUCTION

Thermoelectric modules are commonly used as cooling devices in electronic elements like high power laser diodes or microprocessors [1-3]. Recently, there has been considerable interest in the generation of power based on thermoelectricity [5].

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Peltier devices are increasingly applied in mass-market products, automotive industry or even space missions [6]. A low figure of merit of thermoelectric materials is favourable for efficient optimization during designing TEG (thermoelectric generator) or TEC (thermoelectric cooler) devices. A significant fact is that during the construction process a large number of prototype thermoelectric devices must be tested precisely, quickly, and the procedure must be inexpensive.

In this article, the research setup for a new method of determining electric and thermal characteristics of thermoelectric device [4] is described. To analyze the results obtained with the proposed method, the mathematical model of research setup was developed. A new, efficient two-stage cooling system with liquid coolant is proposed. The potential sources of inaccuracy are analyzed.

2. METHOD

In the research setup, the thermoelectric module is placed between a heat source and a cooler that causes heat flux through the tested element. The temperatures T_{h0} and T_{c0}, the heat flux Q_0, the electromotive force E_0 and the current I_0 (generated immediately after the circuit is shorted) are measured when the thermoelement approaches a thermally stable state. As soon as the measurements are conducted, the circuit is shorted and I_0 is measured with an ammeter of the lowest available resistance. Then, a change in the temperature distribution inside the Peltier device, caused by Peltier effect, takes place. When the Peltier device reaches a new thermally stable state, the temperatures T_{hz} and T_{cz}, current I_z , heat flux Q_z and voltage E_o (generated immediately after the circuit is opened) are measured [4].

The mathematical model of the research setup was developed. This virtual model gives the possibility to test various scenarios of experiment, according to which the experiment could be conducted, quickly and at low costs. Moreover, the results obtained from the experiment can be analyzed and verified.

The basic principle of the proposed method is that the heat fluxes through the surfaces at temperatures T_h and T_c are equal when no external electric load is inserted into the circuit, and when all heat flows through tested element. Due to that fact, the attention should be paid to three main areas:

a) minimizing the heat flux Q' which could flow outside the tested element directly from heater to cooler,
b) minimizing the heat flux Q'' which could flow outside the tested element to environment,
c) minimizing the resistance in external circuit.

Heat fluxes Q' and Q'' do not flow through the tested element. For this reason, these heat losses do not participate in thermal process during experiment and they are a direct source of measurement errors.

The main part of the heat flux generated in the test passes through the tested element but some part of it flows directly from the heater to the cooler on both sites of the tested Peltier device. In Fig. 1 this heat is denoted as Q'. To minimize Q' in the research setup, the materials with very low thermal conductivity are placed between the heater and the cooler. The value of the heat flux Q' is estimated using a mathematical virtual model of the experiment.

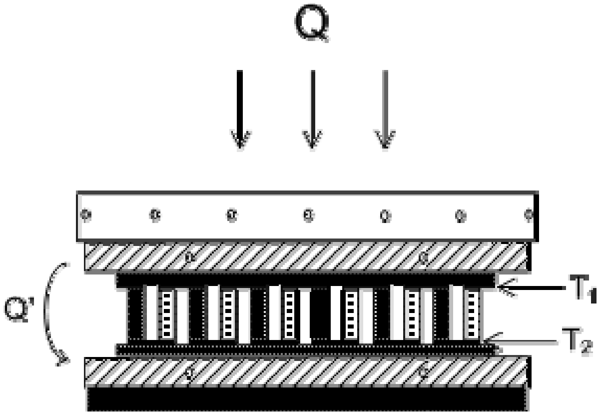

Fig. 1. Heat flux *Q'* which flows outside the tested element

The calculations were based on the following formula:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=0\,, \tag{1}$$

where T is the absolute temperature, x is the width of the sample isolation, y is the height of the sample isolation.

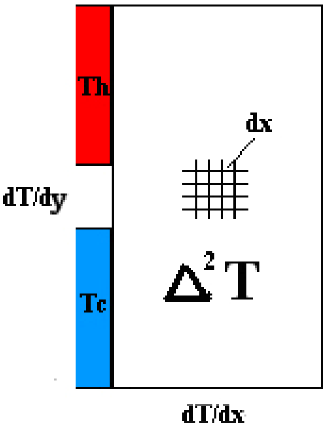

Fig. 2. Simulation schemat

For simulation parameters: X = 1,7 cm, Y = 2,6 cm, λ = 0,05 W/mK (thermal conductivity), T_h = 28°C (the temperature of the heater), and T_c = 7,8°C (the temperature of the cooler), the calculated value of Q' is 0,267 W. The parameters Q_o and Q_z used in the analyzed method [4] can be easily corrected by computed Q' value, and then Q' does not affect to the accuracy of the results.

Despite of the use of good quality heat shields, some part of the generated heat Q leaks to the environment. In this article, this heat is denoted by Q''.

For the analysis of this type of heat losses, the working research setup was monitored using infrared camera. The recorded thermograms are presented in Fig. 3.

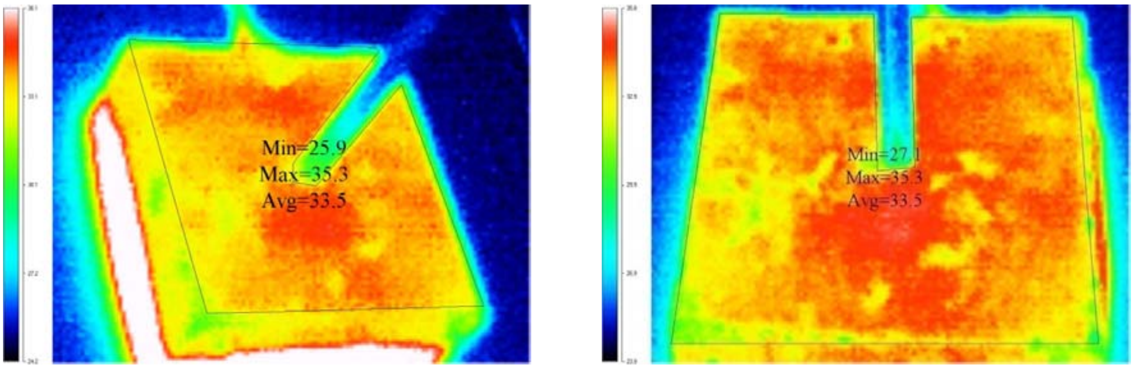

Fig. 3. Thermograms of the working research setup obtained using infrared camera

The heat flux to the environment is governed by two main phenomena: convective heat transfer, and thermal radiation. The convective heat transfer can be obtained from the following expression (2):

$$Q''_C = \alpha \cdot A \cdot (t_A - t_o)\ , \tag{2}$$

where A is the area of the surface that reflects the heat, t_A is the surface temperature, t_0 is the environment temperature, and α is the convection coefficient number:

$$\alpha = \frac{Nu \cdot \lambda}{l} \tag{3}$$

where l is the characteristic linear dimension, λ is the thermal conductivity coefficient, Nu is the Nusselt number: $Nu = c \cdot (Gr \cdot Pr)^n$ Gr is the Grashof number, and Pr is the Prandl number.

Substituting the values: $Nu = c \cdot (Gr \cdot \mathrm{Pr})^n = 0{,}702(0{,}74 \cdot 10^6)^{\frac{1}{4}} = 20{,}59$, $\lambda = 2{,}59 \cdot 10^{-2} \frac{\mathrm{W}}{\mathrm{m} \cdot \mathrm{K}}$, l = 0,1 m, A = 0,01 m^2, t_A = 33,5°C, and t_0 = 25,6°C into the above mentioned formulas, one can obtain Q_C'' = 0,42 W.

Thermal radiation of the analyzed system can be obtained from the expression (4):

$$Q''_R = A\cdot\sigma\cdot\varepsilon\cdot(T_A^{\,4} - T_o^{\,4})\ , \tag{4}$$

where σ is the Boltzmann constant, and ε is the emissivity. For the values presented above: Q'''_R = 0,37 W. The total heat flux which leaks to environment is: Q'' = Q''_C + Q''_R = 0,79 W.

All calculations were performed for t_A-$t_0 \approx$ 8°C. For this reason, the experiment should be carried out in such a way that the temperature t_h should be kept closely to the ambient temperature. This implies that the heat flux Q'' will be negligibly small.

Considering the main principle of the analyzed method that heat fluxes Q_h and Q_c are equal only when there is no external electric load inserted into the circuit, attention should be given to the external circuit resistance value R_{ex}. Once again, the numerical model gives the possibility to analyze the impact of the R_{ex} value on the errors in the resulting data.

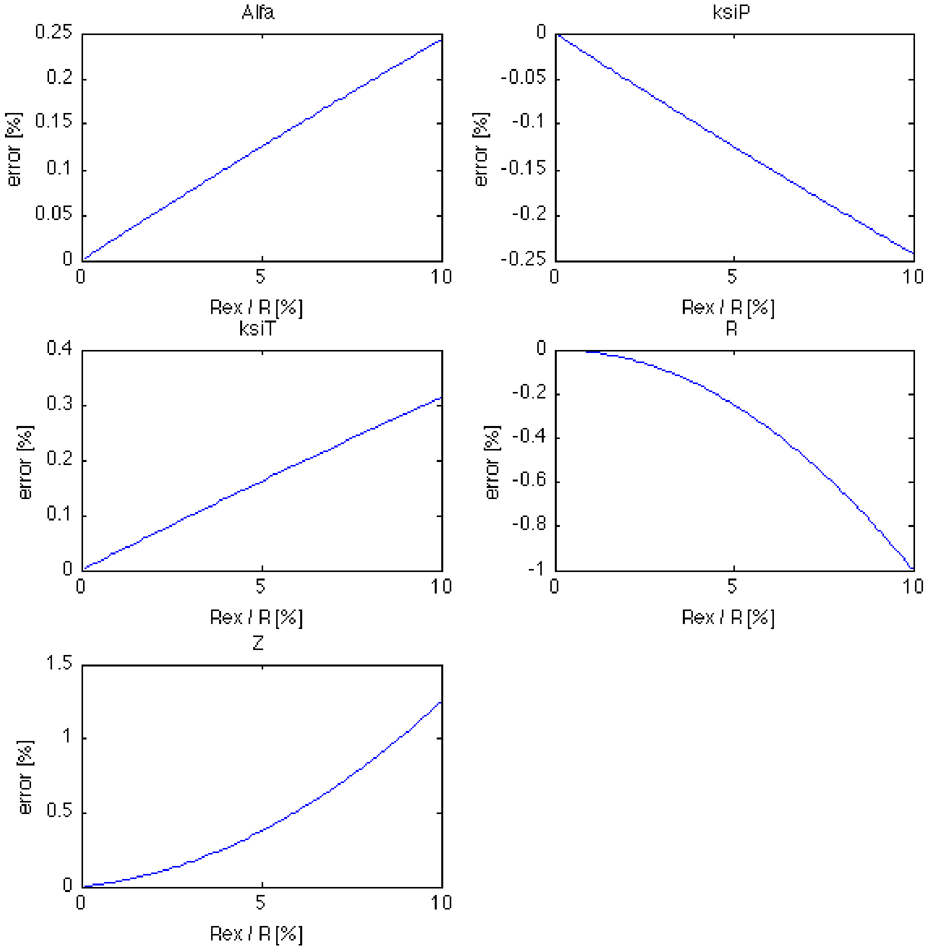

Fig. 4. Errors in the resulting data due to R_{ex} value

As can be seen in Fig. 4, when R_{ex} is equal to 10% of R, a significant errors occur in the results data. It should be noted that the resistance of a typical Peltier element approximately 1.2 Ω, which gives the maximum resistance in external circuit at 120 mΩ. Taking into account that in the external circuit there are both an ammeter and a switch, the value of R_{ex} can be easily exceeded. For example, the relays widely available on the market, have a resistance of the closed state about 70-100 mΩ. These restrictions have forced a modification of the test setup, the improved version of which is based on the usage of very low resistance switches and precise Hall effect current transducer, instead of the traditional ammeter. The modified external circuit has a resistance level R_{ex} = 20 mΩ which does not affect the results.

Fig. 5 Hall effect current transducer[6]

For the analyzed method [4], it is also very important to measure values like I_0 and E_z immediately after electric circuit was shorted (for I_0 measurement) and opened (for E_z measurement). Any delay in the measurement time between changes in the circuit, could be a potential source of inaccuracy. The contact oscillations for low quality relay immediately after closing, are shown in Fig. 6. This can cause the transient states, the influence of which is unpredictable for the results of the experiment. For this reason, the modified research setup uses the high quality switch which does not cause the oscillations.

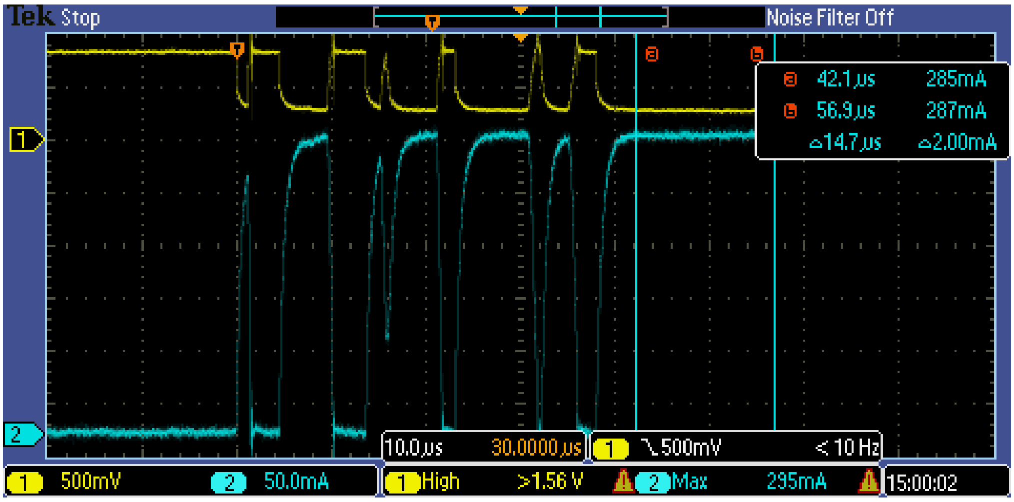

Fig. 6. Relay oscillations immediately after the closing

The changes of the values of current and voltage immediately after the circuit is shorted, can cause difficulties to measure voltages or currents with traditional measuring instruments. Instead of that, a modern digital acquisition card and LabView system are applied. This device allows a continuous acquisition of the data, started before circuit is closed/opened. The digital processing of data allows a precise determination of maxima and minima for the current and voltage values. The changes of current and voltage on Peltier device immediately after closing the circuit are shown in Fig. 7. It can be sene that during 80 ms the current changed from 309 mA to 289 mA. Such a large change in a short time prevents the usage of traditional measuring instruments.

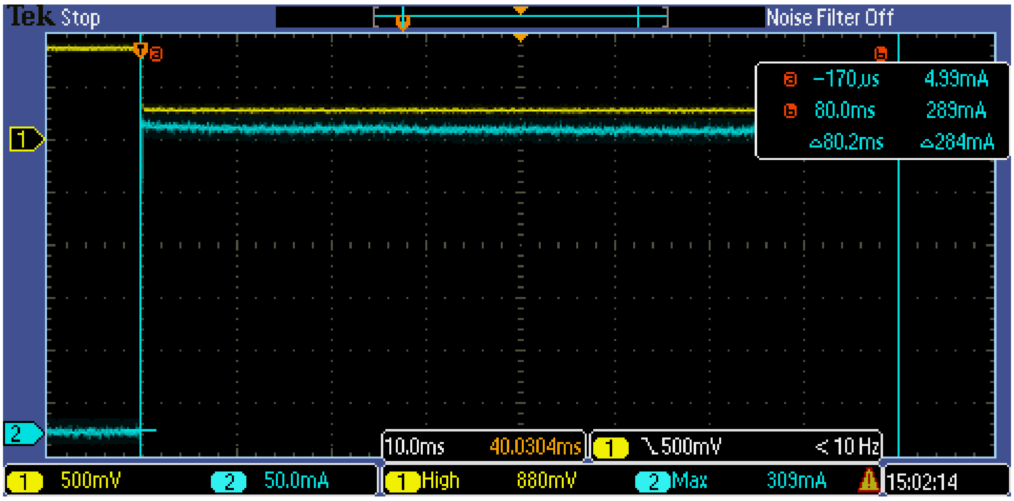

Fig. 7. Current and voltage on Peltier device immediately after closing the circuit

3. CONCLUSIONS

The analyzed method allows determining the electrical and thermal parameters of a Peltier device. The analysis of potential source of inaccuracy made it possible to build a test system which is very precise and relatively simple in construction. After completing the modifications, the results presented above and obtained from the test system, are highly repeatable and consistent with those expected on the basis of a mathematical model. Each of the presented sources of inaccuracy can be easily eliminated by calculating corrections or by making simple changes in the design of test system.

It is worth emphasizing that the presented method is very simple and has no need for any advanced measurement equipment. This fact involves a positive effect in total cost of the test setup with is very inexpensive. The proposed method could be an interesting alternative for the thermoelectric device manufacturers, and can be applied in quality control, or in the research and development laboratories.

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ANALIZA ŹRÓDEŁ NIEDOKŁADNOŚCI UKŁADU DO TESTOWANIA NOWEJ METODY WYZNACZANIA CHARAKTERYSTYK ELEKTRYCZNYCH I CIEPLNYCH MODUŁÓW PELTIERA

Oleksandra HOTRA, Piotr BYLICKI

STRESZCZENIE *Przedstawiono analizę źródeł niedokładności układu do testowania nowej metody wyznaczania charakterystyk elektrycznych i cieplnych modułów Peltiera. Zaproponowano ulepszoną wersję stanowiska badawczego z zastosowaniem metody chłodzenia dwustopniowego z wykorzystaniem ciekłego czynnika chłodzącego.*