Oleksandra HOTRA[1], Oksana BOYKO[2]

Lublin University of Technology (1), Lviv National Medical University (2)

Compensation bridge circuit with temperature-dependent voltage divider

***Abstract**. The bridge circuit with temperature-dependent voltage divider for compensation of cold-junction temperature of thermocouple is described. The proposed circuit allows reducing the influence of cold-junction to less than 0,1°C for thermocouples of the K-type (chromel - alumel) and L-type (chromel - copel).*

***Streszczenie.** W artykule opisano mostkowy układ kompensacji wolnych końców termopary zawierający zależny od temperatury dzielnik napięcia. Opracowany układ pozwala zmniejszyć wpływ zmian temperatury wolnych końców na wynik pomiaru poniżej 0,1°C dla termopar typu K (chromel-alumel) i typu L (chromel-kopel). (**Mostkowy układ kompensacji wolnych końców termopary zawierający zależny od temperatury dzielnik napięcia**)*

Keywords:. thermocouple, temperature-dependent voltage divider, cold-junction compensation
Słowa kluczowe: termopara, dzielnik napięcia zależny od temperatury, kompensacja wolnych końców termopary

Introduction

The temperature is widely measured in modern industry, scientific experiments, materials testing etc. – practically all fields of human activity are connected with temperature measuring and control. Thus the temperature is the most often measured physical quantity. The increase in accuracy of the temperature measurement drives the production quality improvement.

For low and medium range temperature measurements, various types of temperature transducers such as thermoresistorsor, thermocouples etc. are employed. If thermocouples are employed, it is necessary to take into account the influence of cold-junction temperature of the thermocouple on the measurement accuracy [1]. For compensation of the influence of cold-junction temperature, the thermostatting devices or compensation circuits are used [2, 3]. Analogue compensation circuits produce the voltage which is equal to the thermo-emf of thermoelectric transducers at the temperature of cold-junction but of opposite sign [4]. The advantage of the analogue compensation circuits is the possibility of the usage of different types of secondary measuring devices.

In order to obtain the compensation voltage, the temperature-dependent bridge circuits are applied. The temperature-dependent resistors are inserted either in one or in two arms of the bridge [5, 6]. In this case, mainly platinum and copper thermoresistor transducers (RTD) are used. An increase of the accuracy of producing the compensation voltage implies a better overall accuracy of temperature measurements.

The process of design of cold-junction compensation circuit

The improvement in effectiveness of the resistor-based compensating bridge circuits over wide cold-junction temperature range is reached by means of including additional temperature-dependent voltage dividers [7].

The schematic of the resistor-based compensation bridge circuit with additional, temperature-dependent output voltage divider on the resistors R_4, R_{t2} is presented in Fig.1. It is necessary to maintain the same temperature of thermoresistors R_{t1}, R_{t2} and the cold-junction of the thermocouple. For this purpose, passive thermostats with heat-conducting temperature equalizers can be applied.

The compensation circuit can be fed from voltage source U_f or current stabilizer I_0.

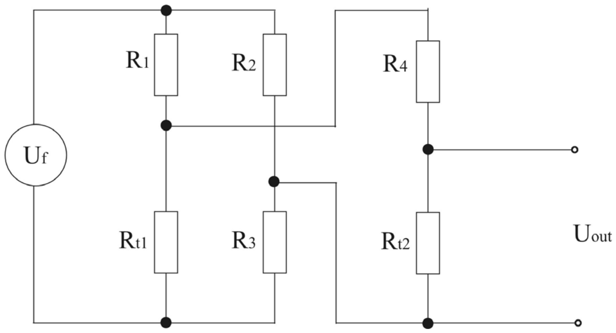

Fig.1. The compensation bridge circuit with temperature-dependent output voltage divider

If a voltage source is applied, the output voltage of the resistor-based compensating bridge circuit with additive voltage divider is calculated as:

$$(1)\quad U_{outU} = U_f\left(\frac{R_{t1}}{R_1+R_{t1}} - \frac{R_3}{R_2+R_3}\right)\cdot\frac{R_{t2}}{R_{outU}+R_4+R_{t2}},$$

where $R_{outU} = \frac{R_1 R_{t1}}{R_1+R_{t1}} + \frac{R_2 R_3}{R_2+R_3}$ is the output resistance of the resistor-based bridge circuit fed from voltage source.

If a standard current source I_0 is applied, the output voltage is described as:

$$(2)\quad U_{outI} = I_0 R_m\left(\frac{R_{t1}}{R_1+R_{t1}} - \frac{R_3}{R_2+R_3}\right)\cdot\frac{R_{t2}}{R_{out_I}+R_4+R_{t2}},$$

where $R_m = \frac{(R_1+R_{t1})(R_2+R_3)}{R_1+R_2+R_3+R_{t1}}$ is the input resistance of bridge circuit, and $R_{outI} = \frac{(R_3+R_{t1})(R_2+R_1)}{R_1+R_2+R_3+R_{t1}}$ is the output resistance of bridge circuit fed from current source.

The analysis of the formulae (1) and (2) for the output voltage of the resistor-based bridge circuit has shown that the usage of the temperature-dependent output voltage divider implies additional nonlinear terms in the output voltage formula, which increase the accuracy of the dependence reproducibility of the thermo-emf on the cold-junction temperature.

The absolute error of the formula, describing the compensating voltage, expressed as equivalent temperature change can be written as:

$$\Delta_t=\frac{(U_{out}-E)}{\Delta E_m}=\frac{(U_{out}-E)(t_{max}-t_{min})}{E_{max}-E_{min}}, \tag{3}$$

where E_{max}, E_{min}, t_{max}, t_{min} are either initial or final values of the thermo-emfs and the temperatures, respectively; E is the value of the thermo-emf of a thermocouple at the cold-junction temperature; ΔE_m is the mean value of the change of the thermocouple thermo-emf at the 1°C temperature change over the temperature range $t_{max}\ldots t_{min}$.

The investigation of the compensation circuit efficiency

The K-type (chromel-alumel) and L-type (chromel-copel) thermocouples were investigated using platinum and copper thermoresistor transducers.

The relationship between temperature and resistance for Cu RTD is linear and can be expressed as:

$$R=R_0(1+0{,}00428t), \tag{4}$$

where R_0 is the value of the resistance of the resistor at 0°C.

The relationship between temperature and resistance for Pt RTD in the range from -10 to 60°C can be described as:

$$R=R_0(1+3{,}9702\,10^{-3}t+5{,}8893\,10^{-7}t^2). \tag{5}$$

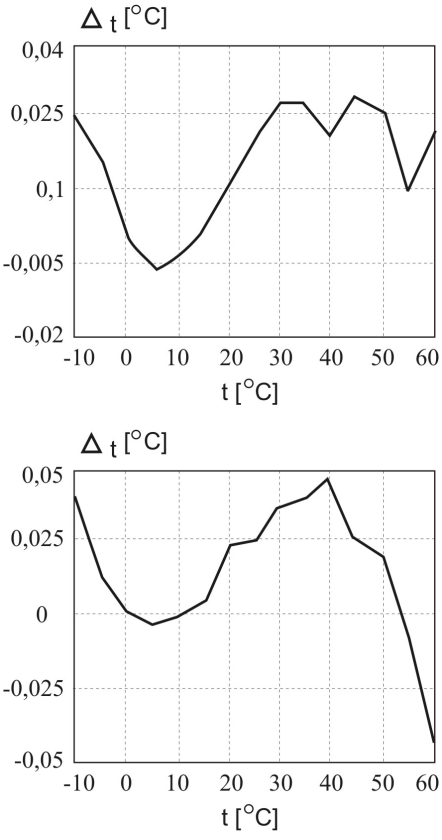

Fig.2. The relationship between the absolute compensation error and the cold-junction temperature of the bridge circuit fed from voltage sources for Pt RTD and the thermocouples: a) K-type, b) L-type

The absolute error of the compensation of the influence of the cold-junction temperature versus the temperature, for the bridge circuit fed from the voltage source, and using R_t of RTD Pt100 type, is plotted in Fig.2 (at R_3=100 Ohm, R_1=R_2=200 Ohm, R_4 = 94 Ohm, U_f = 146,2 mV for the K-type (chromel-alumel) thermocouple (Fig.2,a), and at R_3=100 Ohm, R_1 = R_2 = 350 Ohm, R_4 = 100 Ohm, U_f = 327,45 mV for the L-type (chromel-copel) thermocouple (Fig.2,b)).

In Fig.3,a the absolute error of compensation versus the cold-junction temperature of the bridge circuit fed from the current source is shown for the K-type (chromel-alumel) thermocouple (at R_3=100 Ohm, R_1 = R_2 = 60 Ohm, R_4 = 70 Ohm, I_0 = 1,2985 mA). Analogically, in Fig.3,b, for the L-type (chromel-copel) thermocouple (at R_3=100 Ohm, R_1 = R_2 = 150 Ohm, R_4 = 80 Ohm, I_0 = 1,5867 mA) the error plot is shown.

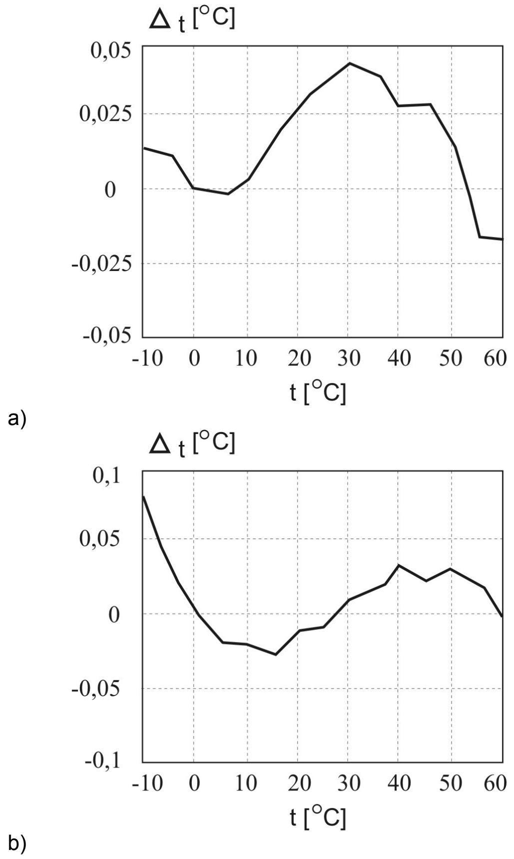

Fig.3. The relationship between the absolute compensation error and the cold-junction temperature of the bridge circuit fed from current sources for Pt RTD and the thermocouples: a) K-type, b) L-type

The absolute error of the compensation of influence of the cold-junction temperature versus the temperature, for the bridge circuit fed from the voltage source, and using R_t of RTD Cu100 type, is plotted in Fig.4 (at R_3=100 Ohm, R_1=R_2=200 Ohm, R_4 = 60 Ohm, U_f = 121,5 mV for the K-type thermocouple (Fig.4,a), and at R_3=100 Ohm, R_1 = R_2 = 350 Ohm, R_4 = 60 Ohm, U_f = 269,5 mV for the L-type thermocouple (Fig.4,b).

The absolute error of compensation versus the cold-junction temperature of the bridge circuit fed from the current source is shown in Fig.5 (at R_3=100 Ohm, R_1 = R_2 = 60 Ohm, R_4 = 50 Ohm, I_0 = 1,104 mA for the K-type thermocouple (Fig.5,a), at R_3=100 Ohm, R_1 = R_2 = 150 Ohm, R_4 = 50 Ohm, I_0 = 1,323 mA for the L-type thermocouple (Fig.5,b).

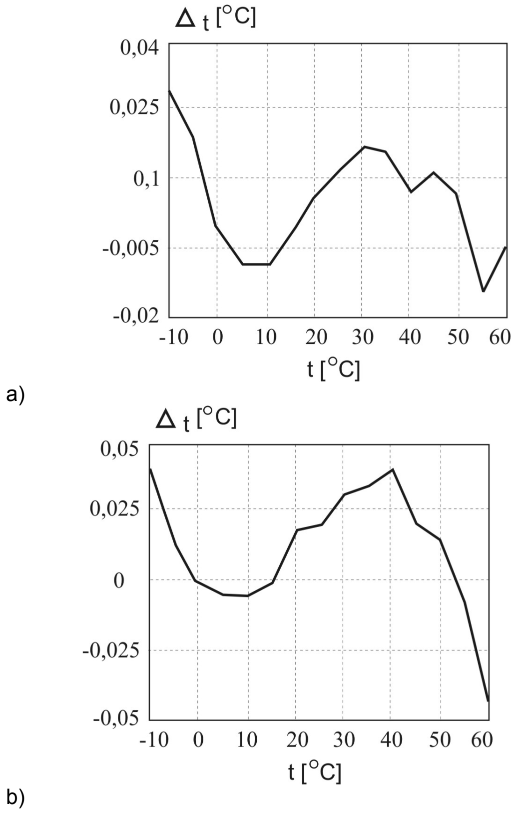

Fig.4. The relationship between the absolute compensation error and the cold-junction temperature of the bridge circuit fed from voltage sources for Cu RTD and the thermocouples: a) K-type, b) L-type

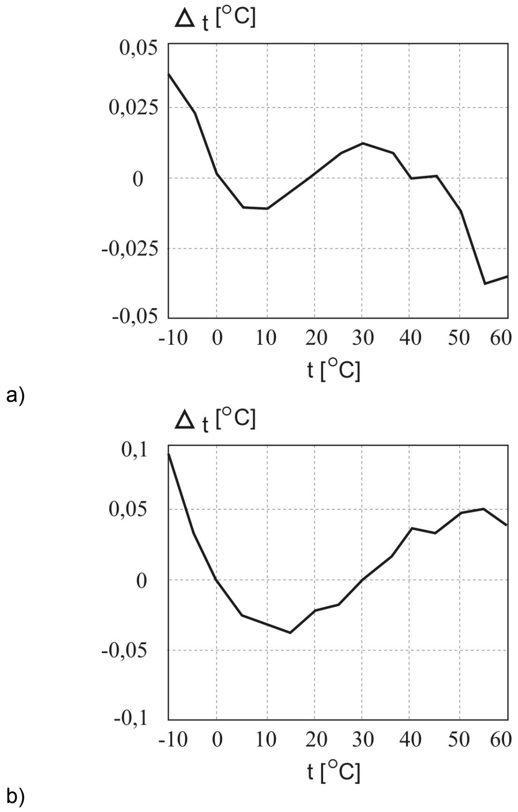

Fig.5. The relationship between the absolute compensation error and the cold-junction temperature of the bridge circuit fed from current sources for Cu RTD and the thermocouples: a) K-type, b) L-type

The analysis of the relationships between the absolute error and the temperature has shown that the discussed circuit provides the reproducibility of thermo-emf of cold-junction compensation with error less than 0,05°C for thermocouples of K-type and of L-type fed from the voltage source. If a current source is applied, then the aforementioned error is the same (0,05°C) for the K-type thermocouples, and less than 0,1°C for the L-type thermocouples. Maximum errors of reproduction for the thermo-emf of cold-junction temperature within the investigated temperature range for platinum and copper thermoresistor transducers are equal. This can be explained by the fact that the relationship between temperature and resistance for Pt RTD is approximately linear over a small temperature range. Therefore, in constructing of the compensation circuits it is better to apply copper thermoresistor transducers, that are less expensive than platinum ones as well as high corrosion-proof, and provide required metrological characteristics within the temperature range -10…60 °C.

Conclusions

The application of temperature-dependent bridge circuits supplied with additional voltage divider allows extending the acceptable change of the cold-junction temperature of thermoelectric transducers and increase in accuracy of temperature measurement. In this case, copper thermoresistor transducers are preferred for use. Experimental investigations confirmed the results of theoretical analysis of the designed compensation circuit.

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***Authors**: prof. Oleksandra Hotra, Lublin University of Technology, Faculty of Electrical Engineering and Computer Science, Chair of Electronics, 38A Nadbystrzycka Str., 20-618 Lublin, Poland, tel. +(48-81) 538 43 11, E-mail: o.hotra@pollub.pl; Ph.D Oksana Boyko, Lviv National Medical University, Chair of medical Informatics, Pekarska 69, 20-010 Lviv, Ukraine, tel. +(380 - 32) 276 78 08, E-mail: oxana_bojko@ukr.net*