Calculation of the components of the temperature measurement error by a resistance thermocouple of an installed unbalanced bridge

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Abstract. The article has devoted to solving an urgent problem related to the determination and calculation of the components of the temperature measurement error. A grain drying machine had selected as the object of research, in which the temperature of the grain at the exit from the machine is measured with the help of a Cu50 resistance thermocouple installed in an unbalanced bridge. It had found that the scale of the measuring device, calibrated in degrees Celsius, will have a nonlinearity error, which increases towards the end of the measurement range. For the Cu50 resistance thermocouple installed in the grain drying machine, when measuring the temperature in the range of 0 ... 100 °C in absolute terms, the nonlinearity error was 0.3 mA, in relative terms - 4.4 %, which is quite large. The measurement error has calculated with a tolerance for the nominal resistance of the thermistor ± 0.1 Ohm, which in the given form was 0.5%. The resulting value indicates that this component will have an insignificant effect on the total measurement error. The measurement error due to the supply voltage drop by 0.2 V in relative form was 4.2 %. Thus, the voltage drops when using an unbalanced bridge will have a significant effect on the measurement result.

1. Introduction

The introduction of mechanization and complex automation into production requires fast and accurate control of technological processes, which has associated with the measurement and control of various quantities [1]. A particularly large number of non-electrical quantities need to be measured and monitored in agriculture, as well as in the metallurgical, chemical (petrochemical) and food industries [2, 3, 4]. The development of measuring technology has shown that among the many methods for measuring non-electrical quantities, electrical methods have the greatest advantages, which provide:

- the ability to measure signals of very small magnitude - the use of electronic amplifiers makes it possible to measure such signals that cannot be measured by other methods;
- the possibility of transferring the measured value of the value to, therefore, the possibility of remote control of various processes;
- high accuracy and speed of measurements;
• the possibility of completing measuring and controlled automatic installations with unified electrical measuring devices. Resistance thermocouples have found wide application as temperature measurement sensors in automatic monitoring and control installations [5].

According to the material of the sensing element, they have divided into platinum resistance thermocouples (PRT) and copper resistance thermocouples (CRT) and nickel (NRT). Resistance thermocouples have produced with strictly defined resistance values, respectively, of their types and grades. The most common resistance thermocouples are copper resistance thermometers, Cu50 and Cu100, platinum - Pt50 and Pt100.

During the operation and adjustment of modern control systems, the accuracy and quality of the measurements performed are of great importance [6, 7]. Automation of the measurement process ensures the inclusion of a thermistor in an unbalanced bridge, but at the same time a rather significant error has formed, which has several components [8, 9, 10].

2. Research objectives and methods
The purpose of the research has to determine and calculate the components of the temperature measurement error in a grain drying machine using an unbalanced bridge with a Cu50 resistance thermocouple installed in it, for a measurement range of 0 ... 100 °C.

During the research, theoretical and experimental methods had used. The reliability of the calculation results has guaranteed by the use of standard methods for processing statistical data and the use of modern software.

3. Research results and analysis
A grain drying machine had selected as the object of research. At the exit from the machine, the grain temperature has controlled by a Cu50 resistance thermocouple, which has installed in an unbalanced bridge. The measurement scheme when a resistance thermocouple has connected to an unbalanced bridge has shown in figure 1. The initial data for calculating the components of the temperature measurement error have given in table 1.

![Figure 1. Temperature measurement circuit when a resistance thermocouple has connected to an unbalanced bridge.](image-url)
Table 1. Initial data for calculating the components of the temperature measurement error.

| Parameter                    | Designation | Meaning                  |
|------------------------------|-------------|--------------------------|
| Measurement range            | MR          | 0…100 °C                 |
| Resistance                   | $R_2$       | 300 Ω                    |
|                              | $R_3$       | 40 Ω                     |
| Type of resistance thermocouple | Cu50       | 50 Ω at 0 °C             |
| Supply voltage               | $U_{ab}$    | 5 V                      |

Determine the resistance $R_1$ under the condition $T_0 = 0 \, ^\circ$C. The resistance of the resistor $R_1$ has determined by Kirchhoff's law

$$
R_1 = \frac{R_2 \cdot R_4}{R_3},
$$

$$
R_1 = \frac{300 \cdot 50}{40} = 375 \, \Omega.
$$

We build a graph $I = f(T)$ in the measurement range and determine the scale division value (mA/°C). The dependence of the current strength on the change in resistance for an unbalanced bridge has determined by the formula

$$
I = U_{ab} \cdot \frac{R_1 \cdot R_3 - R_2 \cdot R_T}{R_2 \cdot R_1 \cdot (R_1 + R_T)},
$$

$$
I = 5 \cdot \frac{375 \cdot 40 - 300 \cdot R_T}{300 \cdot 40 \cdot (375 + R_T)},
$$

after transformations we get

$$
I = 0.0167 \cdot \frac{375 - 7.5 \cdot R_T}{375 + R_T}.
$$

For convenience, let's switch to milliamps:

$$
I = 16.67 \cdot \frac{375 - 7.5 \cdot R_T}{375 + R_T}.
$$

Based on dependence (3), we construct table 2 and a graph of the change in the current strength in the diagonal of the measuring bridge depending on the change in the resistance of the thermal converter and temperature within the specified measurement range, shown in figure 1.

Determine the measurement error associated with the nonlinearity of the conversion function. The largest absolute value of the error from the nonlinearity of the conversion function within the measurement range will be

$$
\Delta I = I - I_i,
$$

$$
\Delta I = -5.9696 - (-6.2350) = 0.2654 \, mA.
$$

In relative form, the error from the nonlinearity of the conversion function will be

$$
\delta I = \Delta I / I_{\max} \cdot 100 \%,
$$

$$
\delta I = 0.2654 / (-5.9696) \cdot 100 \% = -4.44 \%.
$$
Table 2. Dependence of the current strength on the value of thermal resistance and temperature.

| Temperature $T$, °C | Resistance of thermocouple $R_T$, Ω | Current strength $I$, mA | Linear function values $I_1$, mA | Value of division, mA °C |
|-------------------|-------------------------------------|--------------------------|-------------------------------|--------------------------|
| 0                 | 50.000                              | 0                        | 0                             | –                        |
| 10                | 52.130                              | – 0.6235                 | – 0.6235                      | – 0.06235                |
| 20                | 54.260                              | – 1.2408                 | – 1.2470                      | – 0.06204                |
| 30                | 56.390                              | – 1.8519                 | – 1.8705                      | – 0.06173                |
| 40                | 58.525                              | – 2.4585                 | – 2.4940                      | – 0.06146                |
| 50                | 60.655                              | – 3.0578                 | – 3.1175                      | – 0.06116                |
| 60                | 62.785                              | – 3.6512                 | – 3.7410                      | – 0.06085                |
| 70                | 64.915                              | – 4.2389                 | – 4.3645                      | – 0.06056                |
| 80                | 67.045                              | – 4.8209                 | – 4.9880                      | – 0.06026                |
| 90                | 69.175                              | – 5.3973                 | – 5.6115                      | – 0.05997                |
| 100               | 71.310                              | – 5.9696                 | – 6.2350                      | – 0.05970                |

Figure 2. Dependence of current strength on temperature.

Substitute in formula (3) the values $50 \pm 0.1 \Omega$, we get

$$I = 16.67 \cdot \frac{375 - 7.5 \cdot 49.9}{375 + 49.9} = 0.02941 \text{ mA.}$$

$$I = 16.67 \cdot \frac{375 - 7.5 \cdot 50.1}{375 + 50.1} = -0.02941 \text{ mA.}$$

The measurement error in the presence of a tolerance for the nominal resistance of the thermistor $\pm 0.1 \Omega$ will be $\Delta R = \pm 0.02941 \text{ mA.}$

Let us express the error in the form of the reduced error

$$\gamma = \frac{\Delta R}{(I_{\text{max}} - I_{\text{min}})} \cdot 100 \%,$$

$$\gamma = \pm 0.02941/(-5.9696 - 0) \cdot 100 \% = \pm 0.4927 \%. $$
Determine the measurement error when the supply voltage drops. Substitute in the formula (3) the voltage value \( U_{ab} = 5 - 0.2 = 4.8 \text{ V} \), we get

\[
I'_{\text{max}} = 16.00 \cdot \frac{375 - 7.5 \cdot 71.310}{375 + 71.310} = -5.7296 \text{ mA}.
\]

The largest absolute value of the error from the supply voltage drop will be

\[
\Delta u = I'_{\text{max}} - I_{\text{max}},
\]

\[
\Delta u = -5.7296 - (-5.9696) = 0.2400 \text{ mA}.
\]

As a relative error

\[
\delta_u = \frac{\Delta u}{I_{\text{max}}} \cdot 100 \%,
\]

\[
\delta_u = 0.2400/(-5.9696) \cdot 100 \% = -4.21 \%.
\]

4. Conclusions

The scale of a measuring device in the form of an unbalanced bridge with a Cu50 resistance thermocouple for a measuring range of 0 ... 100 °C will have a nonlinearity error that increases towards the end of the measuring range and is equal to \( \delta_l = -4.44 \% \), which is quite a lot.

The measurement error in the presence of a tolerance for the nominal resistance of the thermistor of ±0.1 Ω in this form will be \( \gamma = 0.49 \% \). The value obtained indicates that this component will not have a significant effect on the overall measurement error.

The measurement error due to a 0.2 V supply voltage drop in relative form will be \( \delta_u = -4.21 \% \), so the voltage drop when applying temperature using an asymmetric bridge and Cu50 sensor will have a significant impact on the measurement result.

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