A LINEAR TRANSDUCER FOR MEASURING AN INCREMENT OF RESISTANCE

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A transducer for measuring an increment of the resistance of industrial metal thermistors is described, based on the use of a voltage compensation circuit. The errors of the transducer and their sources are analyzed and recommendations are made on ways of reducing the error.

The measuring transducer considered is designed to convert an increment of resistance of industrial metal thermistors into a dc output voltage. The main requirements imposed on the transducer are as follows: linearity of the conversion characteristic, high sensitivity, zero-point stability, practically no effect of a change in the resistance of the connecting wires on the results of measurements, and no need to adjust the resistances of the connecting wires.

The various types of bridge or compensating circuits used for the circuit [1, 2] only partially satisfy the above requirements and hence a number of additional conditions are necessary. Measuring transducers based on a current compensation circuit [3] have much better metrological characteristics, but the amplifier used in it only solves the circuit problem and is unable to increase the sensitivity of the transducer. Below we consider a highly sensitive measuring transducer with a compensation circuit for measuring the voltage, which is also suitable for operation with a low-resistance thermistor.

In the basic circuit of the transducer (Fig. 1) the thermistor $R_x = R_0 + \Delta R$ is connected via a four-wire line into the circuit of a stabilized current source $I_0$ in series with a standard resistor $R_2$. A comparison resistor $R_0$ is connected in the feedback circuit of a voltage compensator, based on a photogalvanometric amplifier, the load of which is a resistor $R_1$. The current source contains a stabilized-voltage source $U_n$ and a highly stable resistor $R_n$, which enables the reference current to be regulated over a certain range in order to choose the required sensitivity of the measuring transducer. The compensator amplifier can be any type of amplifier with as large a gain as possible: here the photogalvanometric amplifier is only used in order to eliminate the bias voltage and zero drift. The main feature of the circuit is the fact that it ensures that the condition $R_1 = R_2' \gg R_0$ is satisfied, as a result of which a high sensitivity is obtained and the effect of instability of the resistance $R_2$ of the connecting wire on the result of measurements is reduced considerably.

If, to a first approximation, we can neglect the statism error of the compensator and assume that the noncompensation current $I_0 = 0$ and, by virtue of this, the input voltage $U_x = I_0 R_x$ of the compensator is equal to the compensating voltage $U_k = I R_0$, the output voltage of the transducer will be

$$U_{out} = I R_1 - I_0 R_2' = I_0 \frac{R_1}{R_0} (R_x - R_0) = m I_0 \Delta R.$$  \hspace{1cm} (1)

The nominal conversion function (1) confirms the high sensitivity to an increment $\Delta R$ in the measured resistance ($m \gg 1$) and the conversion linearity of the circuit. For amplifiers (including operational amplifiers), the resistance $R_1$ is of the order of several kΩ (usually $R_1 > 2 \text{k}Ω$), and therefore even when using a thermistor with a resistance $R_0 = 100 \text{Ω}$, the sensitivity is increased by a factor of $m = R_1/R_0 \geq 20$ compared with the usual compensation circuits for measuring an increment of the resistance. This enables us to choose small values of the measuring current $I_0$ in the circuit so as to avoid self-heating of the thermistor. The sensitivity is increased considerably if low-resistance thermistors are used. The zero of the measuring transducer is established by adjusting the resistance $R_2'$, and the sensitivity is chosen by regulating $r_n$. 

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An experimental model of the measuring transducer for making measurements in the 0–50 °C temperature range using a type 100M copper thermistor was assembled using a type Fl17/7 photogalvanometric amplifier (having a low resistance $r_1 = 50 \Omega$ and hence a higher voltage sensitivity) with the following circuit parameters: $R_1 = R_2 = 2500 \Omega$, $r_1 = r_2 = 10 \Omega$ and $I_0 = 1.87 \text{ mA}$. The resistance of the thermistor at the initial and final points of the scale are then $R_0 = R_0 = 100 \Omega$ and $R_{sf} = 121.4 \Omega$ ($\Delta R_{sk} = 21.4 \Omega$). The output voltage $U_{out}$ varies linearly over the 0–1 V range with a maximum dissipated power in the thermistor $P = I_0^2R_{sf}$ equal to 0.43 mW, for which the error due to self-heating of the thermistor can be neglected.

Of the resistances of the connecting wires the most important is $r_2$, since the output voltage is taken from this; the resistances $r_1$ and $r_3$ of the potential leads have no effect on the results of measurements due to the use of the compensation circuit, while $r_4$ is connected in the current-source circuit. However, due to the fact that there is a high-resistance reference resistor $R_2$ connected in series with $r_2$, the effect of instability of $r_2$ is reduced considerably.

In order to estimate the metrological characteristics of the measuring transducer quantitatively, we will obtain its actual conversion function. It follows from the block diagram of the voltage compensator (Fig. 2) that

$$I = \frac{K_1K_2K_b}{1+K_2K_b}R_x = \frac{K_1}{K_b}(1-\gamma_{nc})R_x,$$

where $K_1 = I_0 = U_n/\Sigma R_r$; $K_2 = (r_1 + R_x + r_3 + r_2 + R_0)^{-1}$; $K_b = R_0$; $\gamma_{nc} = (K_2K_b)^{-1}$ is the relative noncompensation error of the voltage compensator; $K_a$ is the current gain of the amplifier; and $\Sigma R_r$ is the overall resistance of the reference-current circuit.

The output voltage is

$$U_{out} = I_0 \left[ \frac{R_b(1-\gamma_{nc})R_x - (R_2 + r_2)}{R_0} \right].$$

For a type Fl17/7 photogalvanometric amplifier, the gain $K_a = 24 \times 10^{-3}$ [1], and hence in the experimental model of the transducer the error $\gamma_{nc} = (2r_1 + r_3 + R_0 + R_{sf})(R_0K_b)^{-1}$ amounts to $1.13 \times 10^{-4}$, and it can be ignored.

The voltage $U_n$ of the reference-current source is chosen to be 15 V and is stabilized with a relative error of 0.05%, which naturally produces a change in the output voltage of the same order; the overall resistance of the reference-current circuit at the initial point of the scale $\Sigma R_r = r_1 + R_x + r_2 + R_0 + r_4$ is 8 kΩ. Under these conditions a change in $R_x$ from $R_0$ to $R_{sf}$ produces a relative nonlinearity error of $\gamma_{n} = \Delta R_{sf}/\Sigma R_r$ equal to 0.27%. This error can be reduced to any required value by an appropriate increase in $U_n$ and $r_4$.

As regards the additional error due to a change in the temperature of the surroundings, we note that the elements of the measuring transducer, the parameters of which affect the results of the measurements, are highly stable, apart from the resistances of the copper connecting wires. We will represent the conversion function (3) in the form