COMPUTATION OF CIRCUITS WITH THERMISTORS FOR REMOTE MEASUREMENT OF TEMPERATURE

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Relationships for selecting thermistors have been derived in [1] for remote measurements of temperature, taking into consideration variations in the transmission line resistance due to changes of ambient temperature, as well as permissible additional measurement errors produced by these variations.

Changes in the insulation resistance of the line will also produce additional measurement errors [2]. Minimum nominal values of thermistors for given parameters and lengths of transmission lines are limited by the magnitude and variations of the line loop resistance $R_l$, whereas their maximum nominal values are limited by the magnitude and variations of the line insulation resistance $R_i$ (leakance $G = 1/R_i$).

In designing remote temperature-measuring circuits two problems may arise: a) the selection of thermistor parameters for given parameters and lengths of line, or b) evaluation of the maximum length of a line for given thermistor and line parameters, a permissible error in transmitting the measured quantity, and a given temperature-measurement range.

Figure 1 shows the relationship of a thermistor to temperature $R_T = f(T)$. Thermistor values $R_{T1}$ and $R_{T2}$ at temperatures of $T_1$ and $T_2$ and resistance variations of $\Delta R_T$ can be evaluated from formulas (3) as

$$
\begin{align*}
R_{T1} &= R_{T0} \cdot \exp \left( \frac{B}{T_1} - \frac{B}{293} \right) = a R_{T0}, \\
R_{T2} &= R_{T0} \cdot \exp \left( \frac{B}{T_2} - \frac{B}{293} \right) = \beta R_{T0}, \\
\Delta R_T &= R_{T1} - R_{T2} = (a - \beta) R_{T0} = \delta R_{T0}
\end{align*}
$$

where $R_{T0}$ is the nominal (rated) thermistor value determined at $\Theta = 20^\circ C$, $B$ is a constant quantity expressed in *K and depending on the properties of thermistors, $T$ is the absolute temperature in *K.

The computation of circuits for remote measurements of temperature should not be based on the values of (1) but the effect of line parameters on variations of the total resistance should be accounted for. In a general case resistance $R$ (Fig. 2a) of a dc measuring circuit consisting of a line with length $l$, conductor resistance $R_0$, leakance $G_0$, and a load $R_L$ is equal to [4]

$$
R = \frac{R_T + Z_0 \gamma \theta l}{1 + R_T \frac{\theta l}{Z_0}}
$$

where $Z_0 = \sqrt{R_0 G_0}$ is the characteristic impedance of the line, $\gamma = \sqrt{R_0 G_0}$ is the propagation constant of the line.
The computed value of resistances for the circuit in Fig. 2a in the temperature interval from $T_1$ to $T_2$ measured on a thermistor is equal to

$$\Delta R_C = R_{C_1} - R_{C_2}, \tag{3}$$

where $R_{C_1}$ and $R_{C_2}$ are the values of resistances determined from (2) for $R_T = R_{T_1}$ and $R_T = R_{T_2}$ respectively and for computed values of $Z_0$ and $\gamma_0$.

Curve $R_C = f(T)$, where $T$ is the temperature measured on a thermistor in the presence of shunting resistors (insulation resistance) will pass below curve $R_T = f(T)$ (see Fig. 1). In the presence of a resistance (loop resistance) connected in series with $R_T$ the curve will pass above curve $R_T = f(T)$. In a general case the curve $R_C = f(T)$ will also be exponential if in a given temperature interval the condition $R_i > R_T$ is met, since curve $R_C = f(T)$ will then be free from inflection points [3].

Since the line parameters do not remain constant, the values of resistances (2) and (3) in the same temperature-measurement range of $T_1$ to $T_2$ will differ from the computed values and amount at the thermistor temperature of $T_1$ to $R'_{C_1}$ or $R''_{C_1}$, and at a thermistor temperature of $T_2$ respectively to $R'_{C_2}$ or $R''_{C_2}$, i.e., curve $R = f(T)$ will pass either above or below curve $R_C = f(T)$. Therefore, the measured value (temperature) in these cases will be determined with a certain additional error equal to

$$\delta = \frac{R'_{C_1} - R_{C_1}}{\Delta R_C} \cdot 100\% \tag{4}$$

or

$$\delta = \frac{R_{C_1} - R''_{C_1}}{\Delta R_C} \cdot 100\%. \tag{4a}$$

Similar relationships can be deduced for evaluating errors at any other point of the temperature range measured with a thermistor. However, the largest errors in the presence of leakance will occur at points with thermistor temperatures of $T_1 < T_2$.

By substituting in (4) or (4a) for the resistances their values from (2) and (3) and assuming a tolerated additional measurement error $\delta$ we can obtain an equation relating the length and parameters of a line with the thermistor parameters and the temperature-measurement range.

In a general case for the circuit in Fig. 2a as well as for equivalent circuits consisting of quadrupoles with lumped parameters we can obtain an equation for determining the nominal value of a thermistor in the form

$$R_{Tn}^3 + A_1 R_{Tn}^2 + A_2 R_{Tn} + A_3 = 0. \tag{5}$$

Equation (5) contains cumbersome coefficients $A_1$, $A_2$, and $A_3$ which make it inconvenient for practical use.

In cable lines the insulation resistance is large ($Z_0 = 10^{-9} \, \Omega \cdot \text{km}$) and relatively constant. In such a case it is possible to use for a short line the circuit represented in Fig. 2b, for which the following expression has been obtained in [1]:

$$R_{Tn} = \frac{100 \cdot Z_0 l \frac{\Delta \theta}{\delta f}}{\gamma f} = \gamma_1 R_{Grl} = \gamma_1 R_1. \tag{6}$$