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# The Selection of Thermistors for the Temperature Measurement Gear

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## Introduction

Thermistors are used in the measurement equipment as the temperature sensors due to their high sensitivity and relatively low price. When using such type of sensors the linearization of their R(T) characteristics is one of the difficult-to-solve tasks.

The dependency of the thermistor resistance on the temperature can be described using exponential equation

$$R_T = \alpha e^{\frac{\beta}{T}} , \quad (1)$$

here $R_T$ – the resistance of the thermistor at the temperature $T$, $\alpha$ – temperature coefficient of the thermistor material resistance, $\beta$ – parameter of the thermistor material.

Coefficient α can be calculated at some certain temperature point in the following way

$$\alpha = \frac{1}{R_T}\frac{dR}{dT} , \quad (2)$$

here *dR/dT* – the gradient of the curve R(T) at the temperature point T.

Coefficient $\beta$ over the temperature range from $T_1$ to $T_2$ can be calculated as

$$\beta = \frac{\ln(R_1/R_2)}{\frac{1}{T_1}-\frac{1}{T_2}} , \quad (3)$$

here $R_1$ and $R_2$ – thermistor resistance at the temperature $T_1$ and $T_2$ respectively.

The coefficient $\beta$ calculated in this manner is called the thermistor sensitivity coefficient over the temperature range from $T_1$ to $T_2$.

Thus the values of the coefficients $\alpha$ and $\beta$ are related to the temperatures at which they were determined. Therefore the usage of the equation (1) is quite complicated in case of practical calculations. In addition the manufacturers in their production catalogues usually provide only the values of coefficient $\beta$.

It was offered to express the dependency of $1/T$ on lnR using the polynomial [1] in the form of

$$\frac{1}{T} = A + A \ln R + .... + A (\ln R) , \quad (4)$$

here $T$ – temperature in Kelvins, $A_0$, . . . $A_n$ – coefficients of the polynomial.

To approximate the thermistor *T(R)* characteristics the polynomial with three coefficients is used most often and it is known as the thermistor Steinhart-Hart equation, which is expressed as

$$T = A + A \ln R + A (\ln R) . \quad (5)$$

In their catalogs manufacturers do provide the typical values of the coefficients $A_0$, $A_1$ and $A_3$ and the temperature of the reference points for the thermistors of higher precision. The typical reference temperature values for thermistors are 0 $^0$C, 20 $^0$C and 70 $^0$C .

In order to measure the temperature with the reduced uncertainty using thermistor-based sensors it is necessary to develop better methods of approximation of T(R) characteristics or to calibrate thermistors individually and to calculate coefficients for the selected approximation polynomial.

It was found [2–5] that for the different types of thermistors it is purposeful to use different approximation polynomials.

## Methods and samples

For all thermistors the R(T) – (resistance vs temperature) characteristics were measured using the mixed hot oil thermostat, the reference FLUKE type 5610 thermistor (serial No A6B0211 absolute accuracy for temperatures for 0… 100 $^0$C range not worse than 0,015 $^0$C), and the thermometer FLUKE type Black Stack 1560 and type 2564 Thermistor readout module. The bath with the reference and the tested sensors was cooled slowly (over more than 24 hours period) from +95 $^0$C to +25 $^0$C, thus all R(T) characteristics were obtained for five sensors pieces type 103JL1A (accuracy ±0.5$^0$ C, 0 – 100$^0$ C) were tested. The measurements are carried out in cycles; the resistance and the following data is measured: reference temperatures and the resistance values are stored in the computer memory. The oil temperature gradient was not constant over the time due to the features of the thermostat. The gradient decreased with the decrease of the temperature. The duration of the measurement cycle was constant (30 s). Firstly the resistance of the reference thermistor was measured and then the resistance of the investigated thermistors was measured in the numerical order. In the range of the high temperatures (~ 950 $^0$C) the oil temperature decreased by ~ 0.2 $^0$C during the measurement cycle and this factor is reflected in the measurement results of the thermistors which happened to be the last in the measurement sequence. In the low temperature range the temperature change over the cycle duration was only ~ 0.003 $^0$C. More than 2000 reference temperature and resistance measurement values were obtained for each thermistor.

The block diagram of the measurement of the thermistor R(T) characteristics is given in Fig. 1.

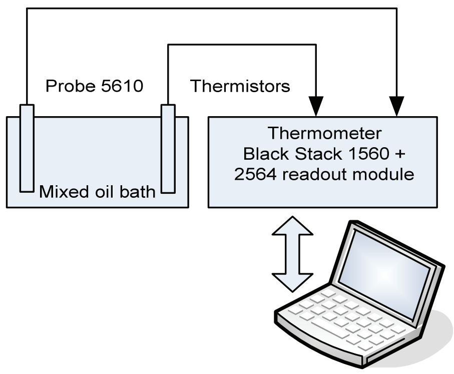


**Fig.1.** The block diagram illustrating the measurement of the thermistor R(T) characteristics

The numerical data of the R(T) characteristic of the thermistor type 103JL1A provided in the website of the producer US Sensors was used to calculate the coefficients. The R(T) characteristics of the thermistors of the same type were also measured experimentally.

For the more precise approximation of the R(T) characteristics the four-parameter Steinhart-Hart equation was adopted

$$\frac{1}{T} = A + A \cdot \ln R + A \cdot (\ln R) + A \cdot (\ln R) , \qquad (6)$$

here $A_0$, $A_1$, $A_3$, $A_4$ – constants, R – thermistor resistance, *T* – temperature in kelvins.

The data of the thermistor R(T) characteristics from at least four points are required to calculate coefficients $A_0$, $A_1$, $A_3$, $A_4$. When using the data provided by the manufacturer over the entire temperature range it is possible to calculate the optimal values of the equation coefficients, although such approach can be too expensive in case thermistors are additionally calibrated individually. In such case it is more useful to minimize the number of the calibration points. Four points were selected each time for the temperature range from 0 $^0$C to 100 $^0$C and their R(T) characteristics data was used to calculate the coefficients.

**Results of calculation and experiments**

The values of the reference temperatures and respective thermistor resistances selected in order to calculate the coefficients from the data provided by the producer are listed in the Table 1. By using the *R* and *T* values from the Table 1 the four-equation system was constructed on the base of equation (1) and it was solved for three samples of four values.

**Table 1**. The values of the reference temperature and the resistance of the respective thermistor type 103JL1A

| $T_{ref}$, $^0$C | R, Ohm | $T_{ref}$, $^0$C | R, Ohm |
|---|---|---|---|
| 0 | 32650 | 55 | 2986 |
| 5 | 25392 | 60 | 2488 |
| 10 | 19901 | 65 | 2083 |
| 15 | 15712 | 70 | 1752 |
| 20 | 12493 | 75 | 1480 |
| 25 | 10000 | 80 | 1255 |
| 30 | 8057 | 85 | 1070 |
| 35 | 6531 | 90 | 916 |
| 40 | 5326 | 95 | 786,6 |
| 45 | 4368 | 100 | 678,6 |
| 50 | 3602 | | |

The values of the reference temperatures and the values of the coefficients of the approximation equation (6) calculated for three data samples are given in Table 2.

**Table 2.** The calculated values of the equation coefficients

| No. | $T_{ref}$, $^0$C | Coefficients $A_0$, $A_1$, $A_3$, $A_5$ |
|---|---|---|
| 1 | 0<br>20<br>35<br>100 | $A_0$ = 1.13171445672454 E-3<br>$A_1$ = 2.33513664106057 E-4<br>$A_3$ = 9.35482303644332 E-8<br>$A_5$ = –2.31250500597282 E-11 |
| 2 | 0<br>15<br>40<br>95 | $A_0$ = 1.13617922617627 E-3<br>$A_1$ = 2.32582328475796 E-4<br>$A_3$ = 1.01104255435322 E-7<br>$A_5$ = –5.00738559963219 E-11 |
| 3 | 10<br>30<br>65<br>95 | $A_0$ = 1.13657522650270 E-3<br>$A_1$ = 2.32501351691839 E-4<br>$A_3$ = 1.01648669391037 E-7<br>$A_5$ = –5.13982315122295 E-11 |

By using the equation (6), the estimated coefficients and the thermistor resistance values corresponding to the respective points of the reference temperature $T_{ref}$ (Table 2), the hypothetical temperature values *T*i and the differences between the reference temperature and the calculated hypothetical temperature value $T_{ref} - T_1$, $T_{ref} - T_2$ and $T_{ref} - T_3$ were determined.

Two criteria were used for the quantitative evaluation of the approximation: the deviation of the calculated temperature $T_i$ from the reference temperature values $T_{ref}$ and the sum of the squares of these deviations, calculated in the following way:

$$\Delta T_i = T_{ref} - T_i \,, \qquad (7)$$

$$SS = \sum_{i=1}^{n} (\Delta T_i)^2 \,, \qquad (8)$$

here $\Delta T_i$ – deviations, $i$ = 1, 2, 3, $T_{ref}$ – the reference temperature values, $T_i$ – the calculated temperature values, $SS$ – the sum of the squares of deviations.

The residual plots of the differences $\Delta T_i$ over the temperature range are give in Fig. 2.

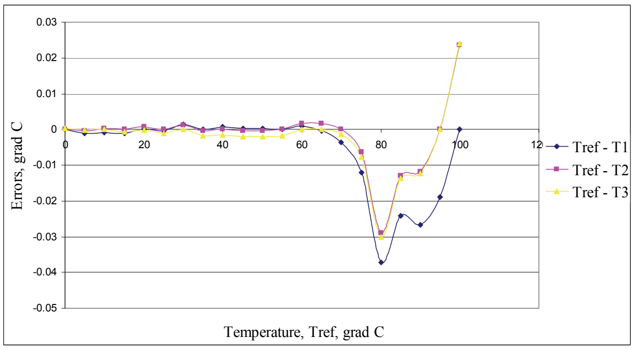


**Fig. 2**. The residual plot of the deviations $\Delta T_i$ over the temperature range

The average square deviations calculated for three samples, estimated using the data provided by the thermistor manufacturer are shown in Table 3.

**Table 3.** The sum of the squares of the temperature deviations from the reference temperature

| | Samples | | |
|---|---|---|---|
| No. | 1 | 2 | 3 |
| SS* | 0.003206 | 0.0017539 | 0,0019 |

* sum of squares

For the analyzed three cases the smallest sum of the squares of deviations was characteristic to the second sample. It can be determined from the residual plot of the deviations in which interval of the temperature range the deviations were the highest. Thus when the coefficients calculated using four reference points on the base of the numerical *R(T)* data provided by the thermistor manufacturer are used in the measurement device the measurement uncertainties over the temperature range from $0^0$ C to $100^0$ C should not exceed ± 0.04 $^0$C. Over the more narrow temperature range from 0 $^0$C to 70 $^0$C the measurement uncertainty should not exceed ± 0.005 $^0$C.

By using the determined equation coefficients the temperature values and their deviations from the reference temperature values according to the experimental data were calculated. The distributions of errors $T_{ref} - T_i$ ($i$ = 1 – 5) for five investigated thermistors are shown in Fig. 3.

The deviations over the temperature range from 20 $^0$C to 100 $^0$C do not exceed the ones provided by the thermistor manufacturer (± 0.5 $^0$C), and they do not exceed by ± 0.15 $^0$C over the temperature range up to 70 $^0$C.

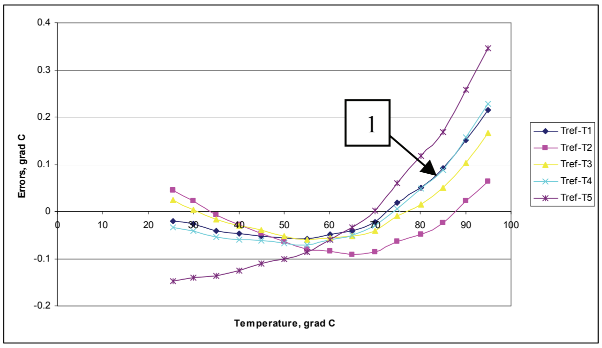


**Fig. 3**. The distribution of errors $\Delta T_i$ over the temperature range

By using four temperature reference points obtained from the experiment and respective resistance values of the thermistor No. 1 (Fig. 3 and 4) the values of the calculated coefficients of the equation (6) are given in Table 4.

**Table 4.** The values of the equation coefficients calculated on the basis of the experimental data (for the thermistor No.1)

| No. | $T_{ref}$, $^0$C | Coefficients $A_0$, $A_1$, $A_3$, $A_5$ |
|---|---|---|
| 1 | 25,5<br>40<br>60.02<br>94.94 | $A_0$ = 1.03994796929266 E-3<br>$A_1$ = 2.52754679144314 E-4<br>$A_3$ = – 8.52669793549282 E-8<br>$A_5$ = 6.68642367865425 E-10 |

By using the values of the coefficients of the equation (6) calculated from the experimental data (of thermistor No.1) (Table 4) and the thermistor resistance values measured at the four reference temperature points (Table 4), the values of the temperature and their deviations from the reference temperature values were calculated respectively. The residual plots of the errors over the temperature range is shown in Fig. 4.

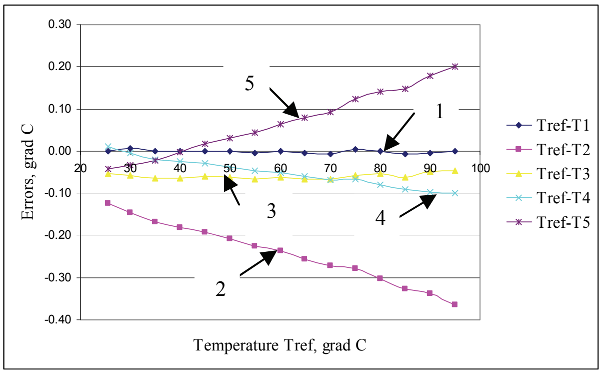


**Fig. 4.** The residual plot of the errors $\Delta T_i$, calculated from the experimental data; 1, 2, 3, 4, 5 – the numbers of the thermistors

The sums of squares of the errors are listed in Table 5.

**Table 5.** The sums of squares of the errors for five thermistors

| | Thermistor No. | | | | |
|---|---|---|---|---|---|
| No | 1 | 2 | 3 | 4 | 5 |
| SS* | 2.285E-4 | 0.949 | 0.0539 | 0.0546 | 0.153 |

Note: * sum of squares

By individually measuring the value of the thermistor resistance only at four reference temperature points and by using equation (6) for the approximation and after calculating the equation coefficients from the measurement data it is possible to anticipate that when measurement is done by such sensor the uncertainty of the temperature measurement will not exceed ± 0,01$^0$C. For the other thermistors (No. 2 and No. 4) the temperature measurement uncertainties should not exceed ± 0,1 $^0$C, and the uncertainties are higher for the thermistors No. 2 and No. 5.

The trends of the error variation for thermistors No. 2 and No. 5 differ from the remaining three thermistors. More extensive research is required in order to determine the cause of such phenomenon. It was unknown for us if all the thermistors were from the same production party.

The utilization of the experiment data provides the advantage since the error distributions (Fig. 4) are practically linear compared to the distributions illustrated in Fig. 3.

The approximation of characteristics of the semiconductor temperature sensors using experimental data is relevant also when using sensors of other types [6].

The stable and reliable temperature sensors thermistors it can be successfully used in the systems of biotronics and increase the effectiveness of dynamic systems [7, 8].

## Conclusions

1. When selecting the temperature sensors – thermistors – for the usage in the measurement devices it is possible to achieve lower measurement uncertainties by calculating the coefficients of T(R) approximation equation from the numerical data of R(T) dependence provided in the manufacturer data sheets.
2. After measuring the thermistor R(T) dependencies experimentally and after calculating the approximation equation coefficients from the data and after their application to process the thermistors from the same production party it is possible to reduce the measurement uncertainty more than by using only the data from the catalogs.
3. The residual plots of the errors can be used to determine in which range the maximal deviations persist; this can not be determined by analyzing only the statistical characteristics – standard deviation or sum of squares.

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**J. Leskauskaite, A. Dumcius. The Selection of Thermistors for the Temperature Measurement Gear // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 5(111). – P. 59–62.**

The parameters represented on manufacturer datasheet are usually insufficient for the optimum selection of thermistors. Some manufacturers give generalized numerical data of *R(T)* dependences. Using this data it is possible to select successfully the most suitable thermistor and equation for describing of *T(R)* dependence. It is shown that by selecting four points in the generalized characteristic it is possible to calculate the coefficients of the approximation equation. By the application of these coefficients in the calculations the temperature measurement errors can be decreased by an order. The results of calculations and experiment are given. Ill. 4, bibl. 8, tabl. 5 (in English; abstracts in English and Lithuanian).

**J. Leskauskaitė, A. Dumčius. Termistorių parinkimas temperatūros matavimo prietaisams // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 59–62.**

Termistorių gamintojų pateikiamų parametrų kartais nepakanka, kai reikia parinkti prietaisų sensorius temperatūrai matuoti tiksliau. Kai kurie termistorių gamintojai pateikia apibendrintas skaitines *R(T)* charakteristikas. Naudojant šias priklausomybes galima geriau parinkti sensorius ir lygtis *T(R)* priklausomybėms aproksimuoti. Parodyta, kad, panaudojus *R(T)* duomenis keturiuose atraminės temperatūros taškuose ir nustačius lygties koeficientus, galima gerokai sumažinti temperatūros matavimų neapibrėžtį. Pateikti skaičiavimų ir eksperimento rezultatai. Il. 4, bibl. 8, lent. 5 (anglų kalba; santraukos anglų ir lietuvių k.).