NTC Thermistor Sensor

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1 Introduction

The NTC thermistors display non-linear resistance characteristics with temperature. The resistance of an NTC will decrease at the temperature increases. This behaviour is related to it's constant value B. This phenomenon allows for use of an NTC thermistor as a temperature sensor. In the discussed experiments a Vishay NTCLE100E3 thermistor was used, with $B = 3977°K$.

2 Theory

2.1 R-T characteristics

In the following experiments measurements are compared against the linear sensor model:

$$O(I) = KI + a \tag{1}$$

where K is the sensor's sensitivity, I is the input, a is the y-intercept, and $O(I)$ is the sensor's output at a given input. The sensitivity is calculated by the following equation:

$$K = \frac{O(I_{max}) - O(I_{min})}{I_{max} - I_{min}} \tag{2}$$

where I_{max} and I_{min} are maximum and minimum input in the range of operation. Finally, the y-intercept can be found:

$$a = O(I_{min}) - KI_{min} \tag{3}$$

The non-linearity of a measurement is defined by:

$$N(I) = |O_{actual}(I) - K \cdot I - a| \tag{4}$$

where O_{actual} is the measured output of a sensor given input I. In the case of a NTC thermistor the input is temperature and the output is resistance. However, the relation between temperature is said to be non-linear, for the NTCLE100E3 it can be described with equation for expected intermediate temperatures, taken from the NTC's datasheet:

$$R_T(T) = R_{ref} \cdot e^{A + \frac{B}{T} + \frac{C}{T^2} + \frac{D}{T^3}} \tag{5}$$

where A, B, C, and D are constant values which are dependent on the thermistor; R_{ref} is the resistance at a reference temperature—for the thermistor used in the experiment (Brown, Black, and Orange bands) it is 10000Ω,and the constant values:

R_{ref}	10000Ω
A	−14.6337
B[1]	4791.842
C	−115334
D	$-3.730535 \cdot 10^6$

Since, the temperature T in the equation 5 is in $°K$ for measurements in $°C$ conversion is required:

$$T_K = T_C + 273.15° \tag{6}$$

When considering the equation 5 the thermistor is expected to have significant non-linearity. This error can be reduced, the Siemens Handout describes how the output can be linearised in a range by use of a prallel resistor. The equation for the value of such resistor is given by:

$$R_p = R_{T_{ctr}} \cdot \frac{B - T_{ctr}}{B + 2 \cdot T_{ctr}} \tag{7}$$

where $R_{T_{ctr}}$ and T_{ctr} are thermistor's resistance and temperature at the center of the temperature range, and B is the B (β) value of the thermistor.

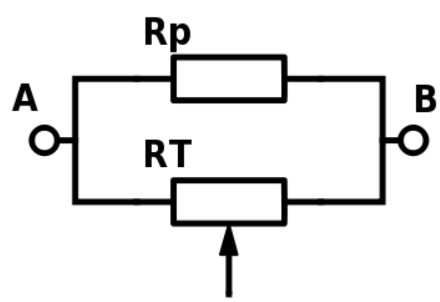

Figure 1: Parallel circuit

The expected output $R_{AB}(T)$ for a linearised thermistor setup shown in Fig.2.1 can be derived from a basic equation for resistor:

$$R_{AB}(T) = \frac{R_p \cdot R_T(T)}{R_p + R_T(T)} \tag{8}$$

[1]Note that this value is different to the β "B" value of a thermistor, constants from this table should only be used in combination with eqation 5

3 Experiments

Two experiments were conducted. First, to determine characteristics of the non-linear response of the NTC: resistance-temperature R-T and tempera resistance T-R, maximum non-linearity $\hat{N}$ as % of $f.s.d$ (full scale deflection); response of a system linearised by a parallel resistor. Second, to find the time constant τ of the measurement system. Raw data from all measurements is presented in the Appendix.

3.1 R-T Characteristics

To measure the R-T characteristics the resistance was measured with an AMPROBE AM-510-EUR multimeter, and recorded over temperature range 90–45$°C$. This was achieved by measuring the temperature of water in a cup, which was cooled from 100° to 45°.

To determine the parallel resistor value $R_{T_{ctr}}$ was recorded at $T_{ctr} = 72.5°C$ and calculated using the eqation.

3.2 Time Constant

4 Results

Here, the data from each part the experiments are analysed and discussed. Important graphs, equations, and tables are shown directly in these subsections. Complete calculated data will be put into tables, graphs that can be seen in the Appendix.

4.1 R-T Characteristics

4.1.1 Non-Linear

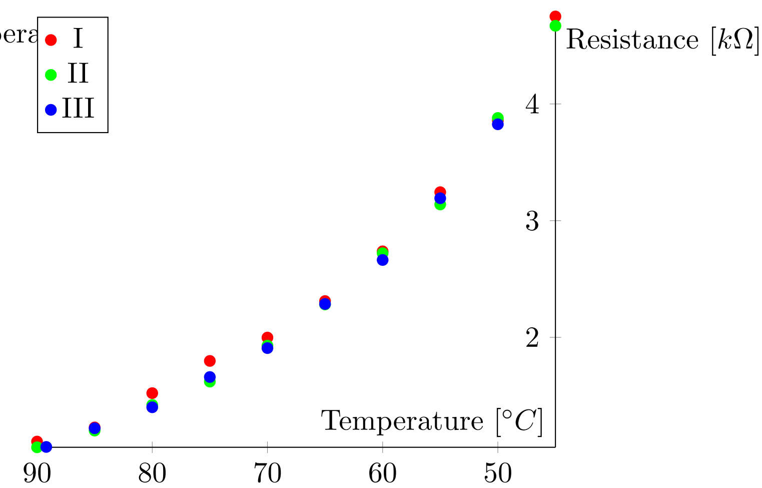

Fig. 4.1.1 Raw non-linear R-T

The equation for the ideal straight line for input range 45–90° was found using the equations 5 and 6:

$$\begin{aligned} K &= \frac{R_T(90) - R_T(45)}{90 - 45} \\ &= \frac{0.915443 - 4.37181}{90 - 45} \\ &= -0.07681 \frac{k\Omega}{°C} \end{aligned} \tag{9}$$

$$\begin{aligned} a &= R_T(45) - K \cdot 45 \\ &= 4.37181 + 0.07681 \cdot 45 \\ &= 7.828 k\Omega \end{aligned} \tag{10}$$

The sensitivity and y-intercept of measured data were found by taking the mean of sensitivities and y-intercept of all runs. Shown in the table **??**.

Run	K	a
I	-0.07628	8.183
II	-0.07697	8.134
III	-0.06792	7.222
Mean	-0.07373	7.846

Next, the maxium non-linearity $\hat{N}$ was found by use of equation 4:

$$\begin{aligned} \hat{N} &= |N(60) = O_{actual}(60) - K(60) - a| \\ &= |2.663 + 0.07681 \cdot 60 - 7.828| \\ &= 0.5564 k\Omega \end{aligned} \tag{11}$$

So $\hat{N}$ as a percentage of $f.s.d$ is

$$\hat{N}\ as\ \%\ of\ f.s.d = \frac{0.5564}{4.75 - 1.058} \cdot 100\% \\ = 15.1\% \tag{12}$$

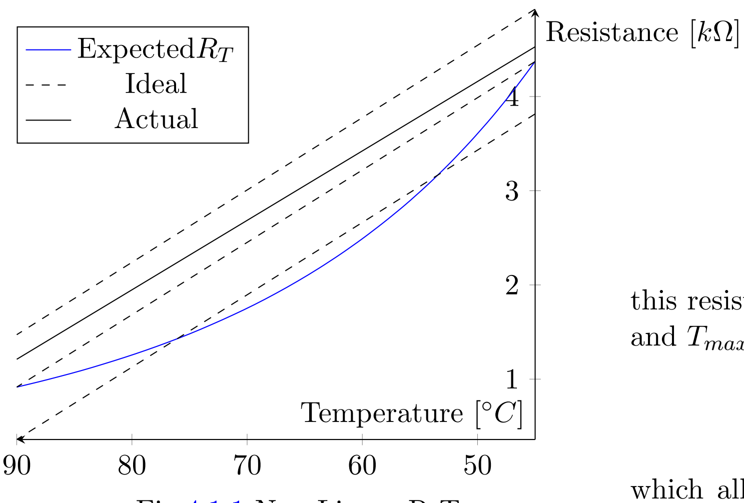

Fig.4.1.1 Non-Linear R-T

From the Fig.4.1.1 it can be seen that the thermistors output is non-linear, and the curve shape is similar to the expected response. However, a static offset can be observed, which will be discussed the Error Discussion **??**.

4.1.2 Linear

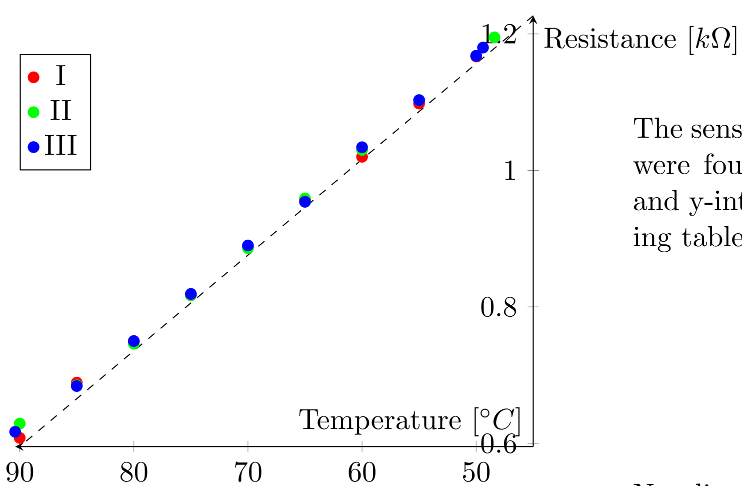

Fig.4.1.2 Raw linear R-T

Using the eqation **??** R_p was calculated for linear range 45–90$°C$. B value is given in $°K$ in the datasheet, but temperature range and measurements are in $°C$, therefore for the calculations it must be converted to Celsius:

$$B_C = B_K + 273.15 \\ = 3977 - 273.15 \\ = 3703.85°C \tag{13}$$

$$T_{ctr} = \frac{90 - 45}{2} + 45 \\ = 72.5°C \tag{14}$$

$$R_p = 1807 \cdot \frac{3703.85 - 72.5}{3703.85 + 2 \cdot 72.5} \\ = 1.705k\Omega \tag{15}$$

this resistance is then used to find R_{AB} at T_{min} and T_{max}

$$R_{AB}(45) = 1.227k\Omega \\ R_{AB}(90) = 0.5956 \tag{16}$$

which allows finding the sensitivity and the y-intercept for the ideal straight line:

$$K = \frac{R_{AB}(T_{max}) - R_{AB}(T_{min})}{T_{max} - T_{min}} \\ = \frac{0.9154 - 4.372}{90 - 45} \\ = -0.01403 \tag{17}$$

and y-intercept

$$a = R_{AB}(I_{min}) - K \cdot I_{min} \\ = 1.227 + 0.01403 \cdot 45 \\ = 1.858 \tag{18}$$

The sensitivity and y-intercept of measured data were found by taking the mean of sensitivities and y-intercept of all runs. Shown in the following table:

Run	K	a
I	-0.01382	1.858
II	-0.01380	1.863
III	-0.01384	1.864
Mean	-0.01382	1.862

Non-linearity:

$$\hat{N} = |N(90) = R_{actual}(90) - K \cdot 90 - a| \\ = |0.629 + 0.01403 \cdot 90 - 1.858| \\ = 3.37\Omega \tag{19}$$

Table 1: Non-Linear R-T Data I

$T, ^\circ C$	$R, k\Omega$
90	1.107
85	1.228
80	1.522
75	1.798
70	1.998
65	2.311
60	2.737
55	3.244
50	3.858
45	4.75

and $\hat{N}$ as a percentage of $f.s.d$:

$$\hat{N}\ as\ \%\ of\ f.s.d = \frac{3.37}{1.195 - 0.608} \cdot 100\% \\ = 0.574\% \tag{20}$$

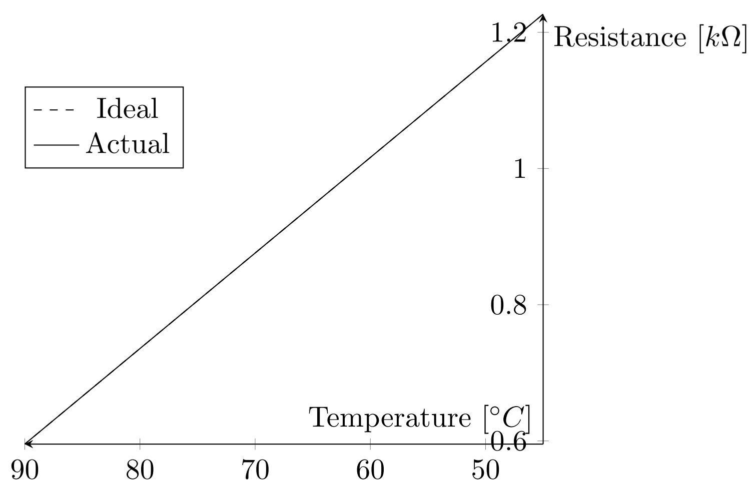

Fig.4.1.2 Linear R-T

Using the parallel resistor greatly decreased the $\hat{N}$ of the response.

5 Error Discussion

6 Conclusion

7 Tables

Table 2: Non-Linear R-T Data II

$T, ^\circ C$	$R, k\Omega$
90	1.058
85	1.201
80	1.421
75	1.621
70	1.929
65	2.282
60	2.721
55	3.139
50	3.88
45	4.67

Table 3: Non-Linear R-T Data III

$T, ^\circ C$	$R, k\Omega$
89.2	1.061
85	1.221
80	1.401
75	1.66
70	1.908
65	2.286
60	2.663
55	3.192
50	3.826

Table 4: Linear R-T Data I

$T, ^\circ C$	$R, k\Omega$
90	0.608
85	0.689
80	0.749
75	0.817
70	0.888
65	0.958
60	1.02
55	1.098
50	1.167

Table 5: Linear R-T Data II

$T, ^\circ C$	$R, k\Omega$
90	0.629
85	0.685
80	0.746
75	0.817
70	0.886
65	0.959
60	1.03
55	1.103
50	1.168
48.4	1.195

Table 6: Linear R-T Data III

$T, ^\circ C$	$R, k\Omega$
90.4	0.617
85	0.684
80	0.75
75	0.819
70	0.89
65	0.954
60	1.034
55	1.103
50	1.168
49.4	1.18