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A Simple Thermistor Design for Industrial Temperature Measurement

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Abstract: *This paper presents a simple temperature measurement design using thermistor for industrial purposes. This paper establishes the characteristics of the resistance via temperature and it's constant since it has been difficult to determine if a thermistor has a positive or negative temperature coefficient. The practical approach was adopted to determine its characteristics where it was revealed that all thermistors are nonlinear in nature. In this design, the empirical and the practical design were compared; its implementation considers the temperature within the ranges of 35^0C to 60^0C which is 308K to 333K respectively. Other considerations were given to the output voltages between 0.155V – 1.055V, ambient temperature of $0^0C – 25^0C$, Percentage non-linearity as low as 0.16, and a sensitivity of 0.0367V/ºC but the resolution of this device is 1ºC.The result obtained were analysed to ascertain the functionality of the experimented design via its performance and suggestions on further improvement were made.*
Index-terms: *Industrial Temperature Measurement, Modelling, Thermistor, Empirical Concept, Practical design*

I.   Introduction

One cannot do without heat. The easiest way to determine the quantity of heat on a body is by measuring the temperature level. Temperature can be that of a body or environment (that is, ambient temperature). The thermal status of a substance can be measured in many ways one of which is the thermistor technique. This paper focuses attention on how to use the thermistor in designing a temperature measuring device for industrial application. Thermistor method may or may not involve physical contact. This particular design is a contact method. They are of two major types: Positive Temperature Coefficient (PTC) which increase in resistance as a result of increase in temperature and Negative Temperature Coefficient (NTC), whereby the resistance decreases with increasing temperature (Morris, 2001).
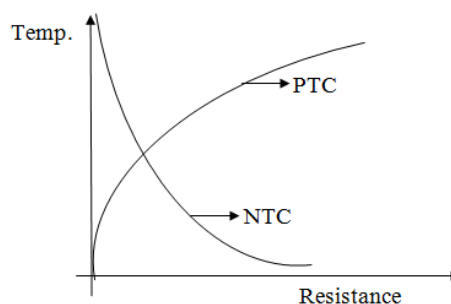

Figure 1: The thermistor temperature characteristic curve

In Figure 1, the thermistor temperature characteristic curve illustrates the temperature response to the change in resistance which is the thermal sensitivity offered by the change in resistance as the temperature changes. In general terms they are NTC and PTC.Thermistors have a merit of relatively high resistance. At 25^0C its resistance ranges from hundreds to millions of ohms. Therefore, the effect of inherent resistances in the lead wires which normally cause errors with low resistance devices like RTDs are minimized. An important temperature measurement characteristic of thermistors is their extremely high sensitivity. The small size of the bead of thermistor also yields a very fast response to temperature measurement (Bentley, 2005). An important improvement for the high resistance and sensitivity of the thermistor is its high non-linearity output and relatively limited operating range. Depending on the type of thermistor, upper ranges are limited to around 300^oC (Morris, 2001) this design has a specific temperature range it intends to cover, in view of this, other research works on this regard will be considered in the view of determining the most suitable approach to be incorporated since it targets industrial usage.

II.   Related Design Literature

Many works have been published on temperature measurement by different authors. The aim of this heading is to attempt a review of the contents of those works and consequently their comprehensive application. Nedic & Eric (2014) worked on temperature measurement technique known as tool-work thermocouple. This method is based on the principle that two metals, when they are in contact, produce a small amount of voltage which is proportional to temperature variation. If the two metals are a tool (e.g. hack saw) and a work piece (e.g. metal rod), on calibrating, the temperature between them can be measured. This involves contact measurement, thus result shows that its shortcoming includes that if there are debris, method is inaccurate; cooling fluid and lubricants cannot be applied to the working surface; it requires regular calibration for each change in machining condition; the machine has to be isolated from the tool and work-piece.

According to Nedic & Eric (2014), metal cutting temperature was measured with artificial thermocouple and metal machine-ability was analyzed from aspect of cutting temperature. In Sui *et al.* (2012), LM35 and PIC16F873 microcontroller was used to build a device which can measure safely the indoor temperature in firm buildings such as greenhouses, warehouses or silos. Afsarimanesh and Ahmed (2011) used AT89C51 and LM35 to build a system which measures temperature and stores them in the EEPROM of the microcontroller. Their design was tested under different conditions like room temperatures, at low temperatures, at different temperatures, readings taken over long time and the system performed accurately.

Dunn (2005) designed and developed Platinum/Rhodium sensors for exhaust gas temperature measurement. The sensors were able to endure harsh temperature environments up to 950^0C. Also Bentley, (2005) described the design of probes used in plume temperature measurement. He chose Tungsten-Rhenium thermocouples because they have the combined properties of strength, high thermoelectric e.m.f, and resistance of chemical attack. He also made use of shielded probe to protect the thermocouple junction and to minimize radiative heat losses. Afsarimanesh and Ahmed (2011) proposed a system for measuring the temperature up to 330^0C for harsh environment. The system is based on a hybrid MEMS placed inside the measuring chamber constituting solely of passive components and an external reading unit, located in the safe environment. This design tends to improve other related work in the area of making a simplified thermistor design that can still give an efficient temperature measurement which is applicable in industries and other works of life.

III.   Purpose of the Task

The main purpose of this design is to investigate the use of a simple thermistor design for temperature measurement for industrial purpose with special consideration to the following specifications:
1. The proposed design covers the Temperature range: 35ºC - 60ºC (308K – 333K) but the 25^oC (the ambient temperature) will be considered at the starting at first instance to end on 60^oC.
2. Output voltage range: (0 – 1) V.
3. Ambient Temperature range: 0^oC - 25^oC
4. Desired Non-linearity: less than 1%
5. Resolution: 5^oC or better.

IV.   Statement of the Task

1. To develop and investigate the performance of the thermistor as a transducer in terms of its basic input/output characteristics.
2. To decide on the type of signal conditioning that is necessary to satisfy the criteria already listed.
3. To build a simple thermistor for temperature measurement for industrial application and critically evaluate its performance.
4. To established the characteristics of a 5kΩ Thermistor RS 484-0133 NTC identity.

V.   The Design Apparatus and Components

This design will consider the following items: An electromagnetic hotplate with an attached retort stand, a magnetic stirrer, a beaker water mixture, a test tube, a Mercury-in-glass thermometer, cotton wool, an electric soldering iron, lead/solder, a lead sucker, screw drivers, a pair of cutting pliers, crocodile clips, cable leads, a pair of goggles, a digital multi-meter, DC power supply source, 5KΩ thermistor RS 484-0133, standard resistors (from Wheatstone bridge numerical model), an electronic circuit board (vero board) and Connecting wires.

Design Mathematical Model
The response or behaviour of thermistors can best be described mathematically by an exponential function given by:

$$R_T = A \, exp(\frac{\beta}{T})$$ [1]

where R_T is the thermistor's resistance at temperature T in absolute (kelvin) temperature K, while A and β are constants of the thermistor measured in ohms and absolute temperature respectively.

By the empirical method, a linear model of the thermistor response function is given in equation (1) and then the temperature constant (β) value was deduced from a linear graph of the thermistor resistance versus temperature as obtained from equation (1)

$$ln\,A \, + \frac{\beta}{T} \qquad\qquad\qquad [2]$$

Step 1

Experimental design investigates the relationship that exists between resistance and temperature. In order to determine the characteristics of a thermistor under study (NTC). Special consideration is given to the temperature in the order of 25°C and in step variation of 5°C to 90°C. The thermistor is mounted with the thermometer on the retort stand with clamp together with the test tube and the cotton wool covering in order to prevent the heat from the isolated wire. The beaker of water containing the stirrer is placed on the heating electric stove which is connected to a DC power supply source. In this stage, the design made use of empirical excel model and circuitries to accomplish this task.
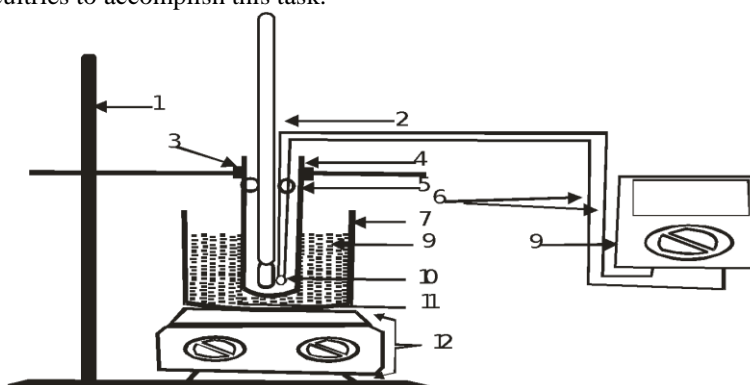

Figure 2: The thermistor Investigation setup

Procedural Approach

With all the materials, component and apparatus in figure 2, each terminal of the thermistor was connected to a wire of about 0.6m in length and soldered. The thermistor and the thermometer were then put into the test-tube and the top covered with a piece of cotton wool to minimise the rate of heat loss due to convection. The test-tube was then inserted into a beaker containing water and was placed on the hot plate.

The free ends of the wires connected to the thermistor were then connected to a digital multimeter which was set to measure resistance. As the beaker was heated gradually, the resistance values given by the multimeter were recorded against the corresponding temperatures at which they were obtained and the results obtained were tabulated below:

VI.   Results Presentation and Analysis for a Non-linear System

The resistance of the thermistor starting from room temperature was measured as: $R_{25°C} = 4.98K\Omega$.

Table 1.0: Table showing resistance of the thermistor with corresponding temperature

Temp (C)	Temp (K)	Resistance Value at increasing (KΩ) with Temperature.	Resistance Value at decreasing (KΩ) with Temperature.
25	298	4.98	4.96
30	303	4.02	4.24
35	308	3.29	3.64
40	313	2.74	3.17
45	318	2.34	2.73
50	323	1.99	2.36
55	328	1.69	2.04
60	333	1.43	1.76
65	338	1.23	1.53
70	343	1.07	1.30
75	348	0.93	1.13
80	353	0.82	0.96
85	358	0.73	0.80
90	363	0.63	0.63

The table 1.0 presents the result that a direct measurement of temperature offers changes in resistance. The temperature considered from ambient corresponding to 298K and ends on 363K.The corresponding increase value of 4.98 and decrease value of 4.96 in resistance were read from the multi-meter for 25°C(298K) whereas the result shows that 0.63 resistance value was registered for 90°C (363K).
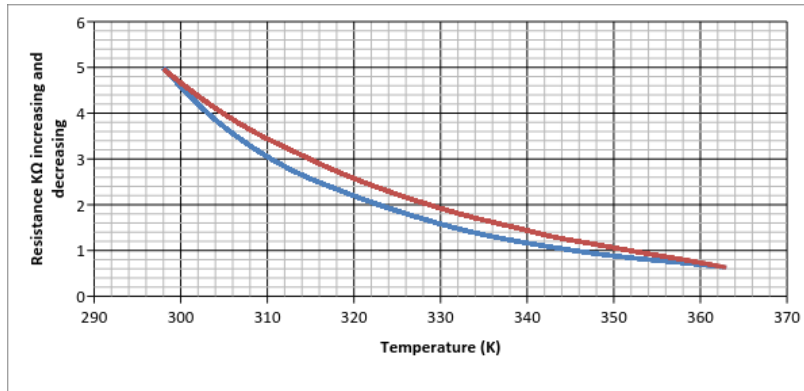

Figure 3: The increasing and decreasing value of resistances due to temperature changes.

Result Analysis

Figure 3 presents the result of the NTC 5kΩ thermistor, the Red line represents the value of the increasing resistance and the Blue line represents the decreasing value of the resistance with respect to the temperature in kelvin.

$$Sensitivity = \frac{change\ in\ Resistance}{Change\ in\ Temperature} = \frac{2.74 - 1.07}{343 - 313} = \frac{1.67}{30} = 0.0557$$

$$Non - linearity$$
$$= \frac{The\ maximum\ deviation\ in\ the\ thermistor\ resistance\ value}{Output\ span(max - min)\ of\ the\ thermistor\ resistance.}$$

$$Non - linearity = \frac{2.60-2.20}{4.96-0.60} = \frac{0.4}{4.36} = 9.17\%$$

The result of the non-linear graph in figure 3 and the confirmatory deduced value via computation which gave 9.17% above depict the exponential relationship that exists between the resistance and the temperature of the 5KΩ thermistor under study.

Linearization of Mathematical Model Concept for Step 1

A model will be developed in order to establish a linear system.

$$R_{(T)} = Ae^{\frac{\beta}{T}} \qquad\qquad [3]$$

In order to obtain the value of the constant A and β in equation (3) necessary conversion is required. Here the natural logarithm of both sides of the equation (3) will give:

$$InR(T) = \beta.\frac{1}{T} + InA \qquad\qquad [4]$$

The normal straight line equation is given by $Y = mx + c$ [5]

When comparing equation (4) with a normal straight line equation (5), It was found that a graph of $InR(T)\ versus\ \frac{1}{T}\ will\ give\ a\ slope\ equal\ to\ \beta$ and an intercept equal to InA .Hence$A = e^{InA}$ .The

values of $InR(T) and\ \frac{1}{T}$ are calculated for in Table 2 and show how heating and cooling of the thermistor were achieved.

$$V_T = V_s \times \frac{R_4}{R_4+R_T} \qquad\qquad [6]$$

Table 2: Linear Model findings

Temp (C)	Temp. (K)	Resistance increasing K□	Resistance decreasing K□	$\frac{1}{T}$ (K)	Ln R increase (K□)	Ln R decrease (K□)	R$_T$K□	V$_{T\ (v)}$
25	298	4.98	4.96	0.0034	1.6054	1.6014	5.1914	0.7325

| 30	303	4.02	4.24	0.0033	1.3913	1.4446	4.3123	0.8205
35	308	3.29	3.64	0.0032	1.1909	1.2919	3.6037	0.9086
40	313	2.74	3.17	0.0031	1.0079	1.1537	3.0288	0.9952
45	318	2.34	2.73	0.0031	0.8502	1.0043	2.5595	1.0792
50	323	1.99	2.36	0.0031	0.6881	0.8587	2.1744	1.1596
55	328	1.69	2.04	0.0030	0.5247	0.7129	1.8563	1.2355
60	333	1.43	1.76	0.0030 0	0.3577	0.5653	1.5923	1.3065
65	338	1.23	1.53	0.0029	0.2070	0.4253	1.3721	1.3723
70	343	1.07	1.3	0.0029	0.0677	0.2624	1.1875	1.4328
75	348	0.93	1.13	0.0029	-0.0726	0.1222	1.0319	1.4881
80	353	0.82	0.96	0.0028	-0.1985	-0.0408	0.9004	1.5383
85	358	0.73	0.8	0.0028	-0.3147	-0.22314	0.7886	1.5837
90	363	0.63	0.63	0.0028	-0.4620	-0.4620	0.6932	1.6246
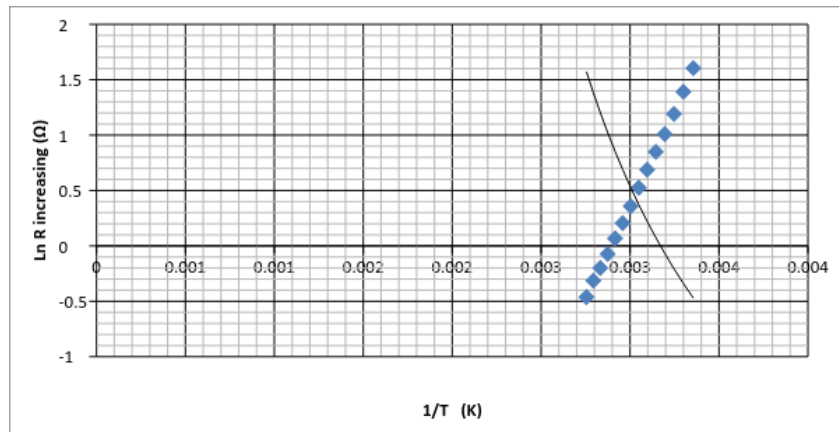
Figure 4: Thermistor linearization graph for the increasing resistance against the reciprocal of temperature in kelvin

From figure (4) the graph of lnR against 1/T, it is established that it is a straight line with $ln\,R = \beta\,\frac{1}{T} + ln A$. Similarly, the $Y = mx + c$ = 3400.7x-9.8394. Comparing this with $ln\,R = \beta\,\frac{1}{T} + ln A$, it was established that: β_1 = 3400.7 and lnA = -9.8394 such that A_1 = 0.0000533 with the goodness of fit of 0.9995.
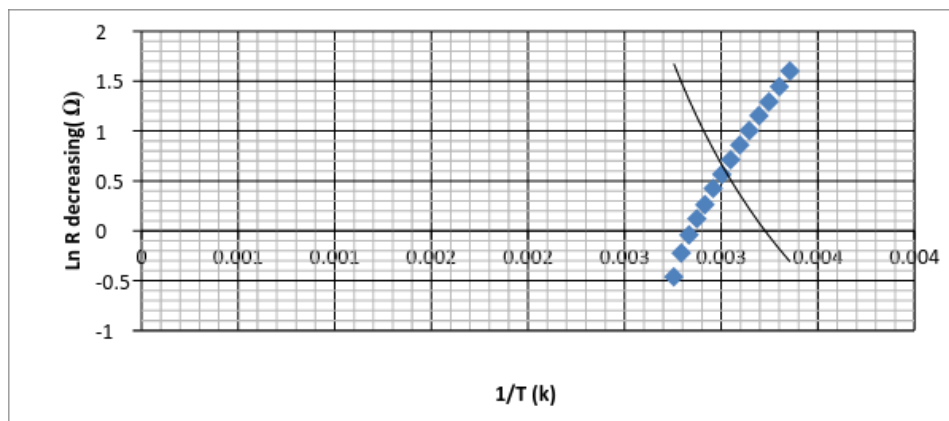

Figure 5: Thermistor linearization graph for the decreasing resistance against the reciprocal of temperature in kelvin

From figure (5) the graph of lnR against 1/T, it is established that it is a straight line with $ln\,R = \beta\,\frac{1}{T} + ln A$. Similarly, the $Y = mx + c$ =3300.8x-9.4021. Comparing this with $ln\,R = \beta\,\frac{1}{T} + ln A$, it was established that: β_2 = 3400.8 and lnA = -9.4021 such that A_2 = 0.00008255 with the goodness of fit of 0.9909. From figure (4) and (5) the average for A_T =0.000067925 and the average for β_T= 3350.75

Step 2

Design of model for the Linearization Concept

This section considers the design of the signal conditioning circuit using a numerical method. It is imperative that before this circuit was built, the values of the real resistors given in the laboratory be measured. Excel spreadsheet is adopted for this computation. The measured and the computed results will be compared with that of the numerical design model.

The bridge circuit will be used as a signal conditioning circuit for this thermistor conditioning circuit.
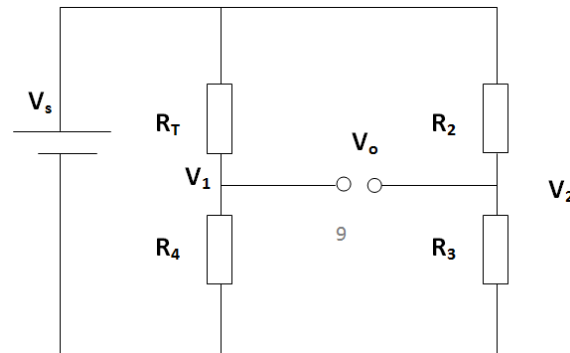
Figure 6: The bridge circuit used in linearizing the thermistor

$$R(T) = 0.000067925 exp(\frac{3350.75}{T}).$$

$$V_{TH} = V_s \times \frac{R_4}{R_4 + R_T}$$

The following design constant will be considered:

$A_T = 0.000067925$, $\beta_T = 3350.75$, Vs =3.67v, R_3=1KΩ, R4=1.615kΩ, R_T = 3.603667. The temperature range is 35°C to 60°C with step change of one for this design to realize linearity. R_2 from calculation gave 2.23KΩ

Table 3: shows the design of the model linearization concept of the thermistor.

Temp (C)	Temp (K)	R_T(KΩ)	V_1(V)	V_{th} or MT+C	R_{th} = V_{th}-V_o	Absolute R_{th}
35	308	3.603667363	1.13574014	1.13574014	0	0
36	309	3.478999422	1.163535664	1.164229062	0.000693397	0.000693397
37	310	3.359407318	1.191508781	1.192717983	0.001209202	0.001209202
38	311	3.244656057	1.219643927	1.221206905	0.001562978	0.001562978
39	312	3.134522753	1.247925383	1.249695827	0.001770444	0.001770444
40	313	3.028795946	1.276337305	1.278184749	0.001847444	0.001847444
41	314	2.927274957	1.304863765	1.306673671	0.001809906	0.001809906
42	315	2.829769288	1.333488786	1.335162592	0.001673807	0.001673807
43	316	2.736098055	1.362196376	1.363651514	0.001455139	0.001455139
44	317	2.646089452	1.390970564	1.392140436	0.001169872	0.001169872
45	318	2.559580257	1.419795437	1.420629358	0.000833921	0.000833921
46	319	2.476415354	1.448655169	1.44911828	0.000463111	0.000463111
47	320	2.396447296	1.477534058	1.477607201	7.31439E-05	7.31439E-05
48	321	2.319535888	1.506416555	1.506096123	-0.000320432	0.000320432
49	322	2.245547795	1.5352873	1.534585045	-0.000702255	0.000702255
50	323	2.174356169	1.564131144	1.563073967	-0.001057177	0.001057177
51	324	2.105840311	1.592933183	1.591562889	-0.001370294	0.001370294
52	325	2.039885334	1.621678783	1.62005181	-0.001626972	0.001626972
53	326	1.976381862	1.650353604	1.648540732	-0.001812872	0.001812872
54	327	1.915225736	1.678943627	1.677029654	-0.001913973	0.001913973
55	328	1.856317742	1.70743517	1.705518576	-0.001916594	0.001916594
56	329	1.799563352	1.735814917	1.734007498	-0.001807419	0.001807419
57	330	1.744872481	1.764069926	1.76249642	-0.001573507	0.001573507
58	331	1.692159256	1.792187657	1.790985341	-0.001202316	0.001202316
59	332	1.641341802	1.820155979	1.819474263	-0.000681716	0.000681716
60	333	1.592342034	1.847963185	1.847963185	0	0

From table 3, the design of a signal conditioning circuit using Wheatstone bridge technique was realized with the output voltage having a span of 0V – 1V as a function of temperature. This is based on a numerical method. Bentley (1995) gave the following conditions (mid-temperature method): The ratio of R_2 and R_3 was a critical factor in this design thus, the ratio R_2 and R_3 was replaced with R.

Then the equation for the bridge circuit becomes:

$$V_o = V_s \left[\frac{R_1}{R_1 + R_T} - \frac{R_2}{R_2 + R_3} \right] \qquad [7]$$

Where V_O is the output voltage of the bridge in Volts, V_s is the supply voltage in Volts, R_T is the resistance of the thermistor at temperature T (K) in Ω and R_1, R_2 and R_3 are resistances in the bridge circuit in Ω. The values of V_O for a range of 35ºC - 60ºC (308K – 333K) produces:

1. $V_O = 1.13574014V$ at the initial temperature; thus $R_T = R_{308k}$.
2. $V_O = 1.50641655V$ at the middle temperature; thus $R_T = R_{321k}$.
3. $V_O = 1.85479319V$ at the final temperature; thus $R_T = R_{333k}$.

There is a need to limit the electrical power ($i^2 i^2\ R_T$) in the thermistor to enable it to be released as heat flow to the surrounding fluid (where i is the amount of current flowing through the thermistor).

Using the values of A and β calculated in step 1, the relationship $R_{(T)} = A e^{B/T} e^{B/T}$, values of R_T were calculated at different temperatures and used to calculate the values of V_s, R_2 and R_3. It should be noted that the values of A and β were used to get R_T instead of those recorded in the experiment because they were obtained using a line of best fit, hence will give more accurate values for R_T. The calculation was done using excel spreadsheet (spreadsheet below) and the results are given in table 3.

$$V_{th} = \left[\frac{V_{omax} - V_{0min}}{T_{max} - T_{min}} \right] \times T + C = MT + C \qquad [8]$$
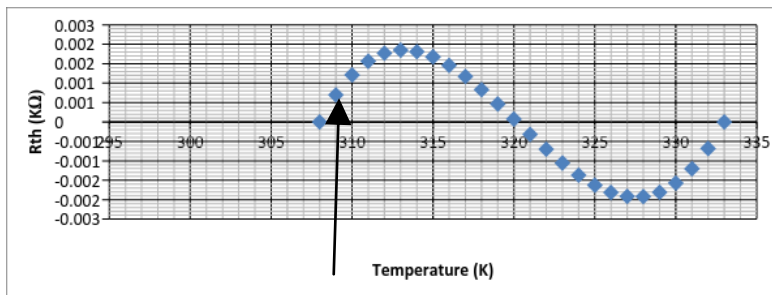

Figure 7: Percentage Non-linearity against Temperature (K) using designed resistor values

Figure (7) shows the percentage rate at which the voltage measured across the thermistor varies from the positive 0.002 to negative 0.002 as it responds to temperature changes.
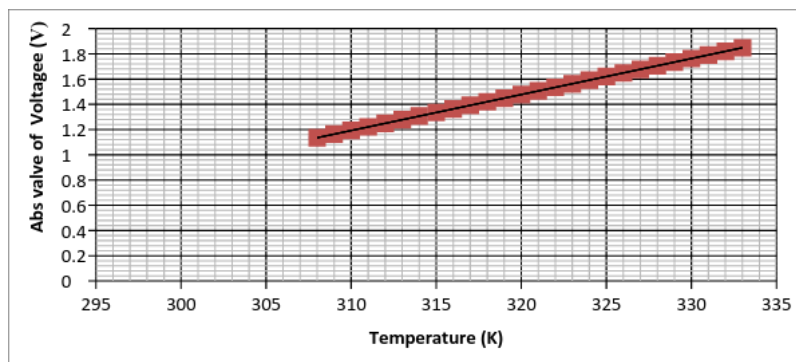

Figure 8: The absolute value V_o against Temperature (K) using the designed values of resistors.

Figure (8) shows the Linear Model Characteristics of RS 484-0133 thermistor. The linear model was designed for the purpose of estimating the actual β value within the given tolerance of $\pm 1\%$ stated in table 1 which will meet the required process temperature specification range.

The model equation of the linear function is extracted from the graph as: $y = .0285x - 7.6388$

Comparing equations (2) and (3):

$\beta = .0285; \quad ln A = -7.6388\Omega, \Longrightarrow A = e^{-7.6388} = 0.00048141\Omega$

Therefore the justification of calculated β value in terms of tolerance from the standard datasheet, β constant = $0.0285 \pm 1\%$. Thus, the range of β constant is given as $3960 \pm 28.5E - 3$. Since the calculated β value falls within the range specified by the tolerance, it is therefore suitable for the fore-going analysis. On this note, the calculated β ($3974K$) value is justified for onwards application for the specified process temperature range of $35°C$ to $65°C$. In discussing the results from table 3 and figure (7) and (8) of results, the designed temperature range for the instrument with input range 35ºC - 60ºC gives the output range 1.13574014V – 1.847963185V with the designed % non-linearity of the system as 8.74%.

The behavior of the model using the real values of the resistors reveals that after the design, the exact values of the resistors calculated were not available so values as close as possible were used for the design. The following values of the resistors used as against the designed values are: R_4 = 1.6KΩ instead of 1.615 KΩ, R_2= 2.2KΩ instead of 2.23KΩ, and in both cases R_3 = 1KΩ and V_s = 3.67V. The following results were obtained: The range of the instrument using the real resistor value with Temperature Input range: 35ºC - 60ºC gave an output range voltage: 1.13579014V – 1.84796318V and the % Non-linearity of the system as 3.6%. And there was a dc shift in the value of the output voltage. Comparing the theoretical values with that of the design value. The following conclusions were drawn: The span of the output voltage is 0.712223V and the % Non-linearity of the system is 1% .There was a dc shift in the output voltage when the real values of resistors were used. The sensitivity of the constructed system is 0.028487V/ºC. These differences are as a result of the fact that the bridge balance was altered when the real values of resistors were used (this is as a result of a decrease in the ratio R_3: R_2 from 0.44843 with designed values of resistors to 0.4545 when the real resistors were used.

Step 3
Implementation
This is where the complete circuit of the developed temperature measuring system using thermistor was built alongside signal conditioning system.
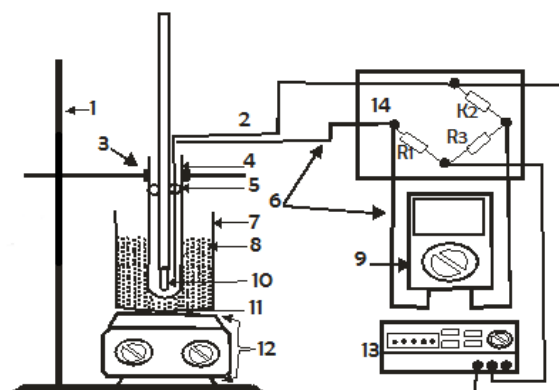

Figure 9: Diagram showing the experimental set-up to measure the performance of the built circuit.

1.Retort stand 2. Thermometer 3. Clamp 4. Test tube 5. Cotton 6. Isolation 7. Beaker 8. Water 9. Multimeter 10. Thermistor 11. Stirrer 12. Stove 13. DC supply voltage 14. Electrical board.

Figure (9) shows how the circuit was constructed and the input terminals were connected to a dc power supply while the output terminals were connected to the digital multimeter. The thermistor and the thermometer were then put into the test-tube and the top covered with a piece of cotton wool to minimise the rate of heat loss due to convection. The test-tube was then inserted into a beaker containing a mixture of ice and water which was placed on the electric stove. Values of output voltage of the circuit were taken for different temperature values. This was carried out twice and the values recorded.

Table 4: The measured values of V_o and the calculated values of V_T and % Non-linearity from the constructed circuit.

T (oC)	T (K)	Vo₁ (v)	Vo₂ (v)	Vo (V)	VT(v)=MT+C	Deviation	% Non-linearity
35	308	0.21	0.1	0.155	0.383	0.228	0.253333333
36	309	0.26	0.13	0.195	0.419	0.224	0.248888889
37	310	0.31	0.16	0.235	0.455	0.22	0.244444444
38	311	0.35	0.19	0.27	0.491	0.221	0.245555556

39	312	0.4	0.21	0.305	0.527	0.222	0.246666667
40	313	0.43	0.24	0.335	0.563	0.228	0.253333333
41	314	0.47	0.27	0.37	0.599	0.229	0.254444444
42	315	0.5	0.3	0.4	0.635	0.235	0.261111111
43	316	0.55	0.33	0.44	0.671	0.231	0.256666667
44	317	0.59	0.37	0.48	0.707	0.227	0.252222222
45	318	0.63	0.4	0.515	0.743	0.228	0.253333333
46	319	0.67	0.43	0.55	0.779	0.229	0.254444444
47	320	0.71	0.45	0.58	0.815	0.235	0.261111111
48	321	0.75	0.48	0.615	0.851	0.236	0.262222222
49	322	0.79	0.51	0.65	0.887	0.237	0.263333333
50	323	0.83	0.54	0.685	0.923	0.238	0.264444444
51	324	0.87	0.56	0.715	0.959	0.244	0.271111111
52	325	0.91	0.59	0.75	0.995	0.245	0.272222222
53	326	0.94	0.63	0.785	1.031	0.246	0.273333333
54	327	0.98	0.67	0.825	1.067	0.242	0.268888889
55	328	1.01	0.7	0.855	1.103	0.248	0.275555556
56	329	1.06	0.73	0.895	1.139	0.244	0.271111111
57	330	1.1	0.76	0.93	1.175	0.245	0.272222222
58	331	1.15	0.79	0.97	1.211	0.241	0.267777778
59	332	1.23	0.82	1.025	1.247	0.222	0.246666667
60	333	1.26	0.85	1.055	1.283	0.228	0.253333333

$V_o = \frac{Vo1 + Vo2}{2}$, $V_T = [\frac{Vomax - Vo\,min}{Tmax - Tmin}]T + C$ where C is the intercept of the line. Yt=mt+c

The term M or $[\frac{Vomax - Vo\,min}{Tmax - Tmin}] = \frac{1.055 - 0.155}{333 - 308}$ = 0.036V/K. Using C from graph C = -10.705

Therefore, V_T = 0.036 × T – 10.705 (V), Tout= $To\,max - To\,min$ = 333 -308 =25 K and Output span for Vo= $Vomax - Vo\,min$; Output span = $1.055 - 0.155$ =0.94v
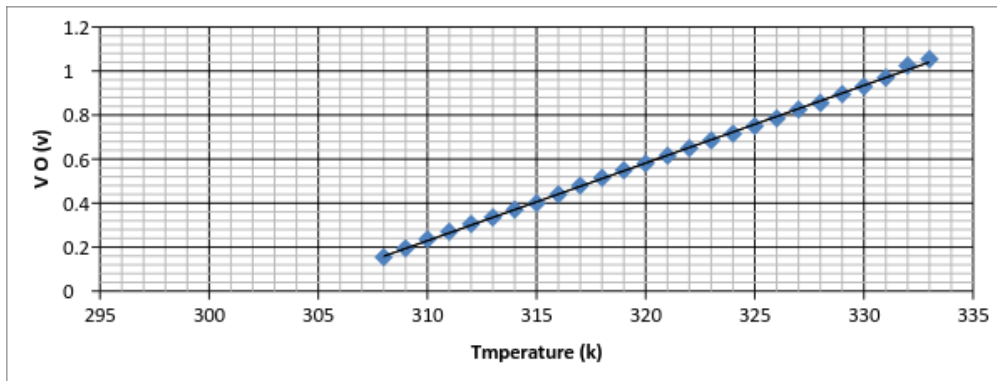

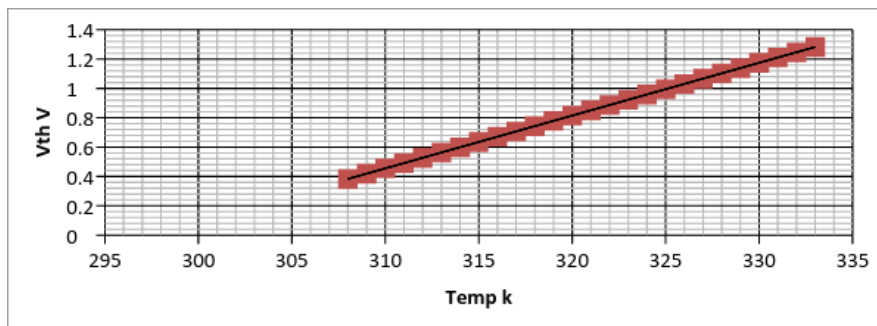**Figure10:** Output Voltage against Temperature for the developed circuit

Figure 11: The thermistor voltage against Temperature for the constructed circuit.

V_T= $1.283 - 0.383 = 0.9$,T_{th}=333-308=25 K.V_o and V_T against Temperature (K) showing the non-linearity of the output voltage of the constructed circuit, V_o with respect to the terminal output V_T.

Analysis for Vo and Vth: Output span for Vo = 0.94v, T_{out} =25 K; Output span $= 0.9$, Tth =25 K and Percentage Non-linearity = 0.16%

In discussing the developed temperature measuring system, the range of the instrument using the real resistor value with an input range from 35ºC to 60ºC gave the output range of 0.155V to 1.055V corresponding to input temperatures. The % Non-linearity of the system was 0.16%. The result reveals that there was an increase in the dc shift in the value of the output voltage. The sensitivity of the constructed system is 0.0367V/ºC.

Comparison of Results

Comparing the results obtained from the built circuit to that obtained using the real resistors in the designed model; the following conclusions were drawn: The theoretical non-linearity in the design stage is almost symmetrical in the negative and positive directions but that of the constructed circuit is predominantly in the positive direction; the % Non-linearity in the constructed circuit is higher than that the theoretical value of % Non-linearity in the designed circuit (8.74% as against 0.16 %); the DC offset increased in the output of the constructed circuit compared to the theoretical value in the designed circuit (1.13574014V as against 1.84796318V). Comparing the result from the real value of the resistor with the constructed circuit result, it is clear that both modifying and interfering inputs affected the performance of the constructed circuits. This is seen from the trend lines inserted in both graphs which shows both a change in slope (sensitivity – presence of modifying inputs) and intercept (offset – presence of interfering inputs). The sensitivity of the constructed circuit is less than the theoretical sensitivity (0.028487V/ºC as against 0.0367V/ºC).

The following sources of error could have contributed to the deviations in the results of the built circuit from the theoretical results expected:
1. The heating element causes uneven heating of the thermistor during the experiment.
2. The circuit alters the output voltage since it is dependent on the input voltage.
3. Presence of noise voltages affects the circuit (interfering inputs) and modification were done in order to achieve a desired input/output requirement.
4. Self-heating of the thermistor affect the experiment by making the temperature of the thermistor higher than that recorded by the thermistor.

VII.   Suggestions on Further Improvement

The following suggestions can improve the performance of the system:
1. The use of a high gain negative feedback and zero drift operational amplifier at the output of the circuit to improve the output voltage by removing loading effects and DC offsets.
2. Shielding the circuit to eliminate the effect of noise voltages.
3. Using a temperature measuring device whose response time is as close as possible to that of the thermistor and which has a better resolution with a digital display.
4. Using regulated power supply sources for heating the thermistor and as power supply to the circuit.
5. Taking measurements of voltage a number of times to minimize random errors.
6. The circuit design should be done in such a way as to further reduce the effect of self-heating.

VIII.   Conclusion

This design is suitable for temperature measurement using thermistor for industrial application. The temperature input range of 35ºC - 60ºC was considered. The design gives the following results: output range of 0.155V – 1.055V as against 0V – 1V with the % Non-linearity as low as 0.16%; an ambient temperature range of 0ºC - 25ºC and a sensitivity of 0.0367V/ºC but the resolution of this device is 1ºC as against 0.5ºC. The performance of the thermistor as a transducer was established in terms of its basic input/output characteristics and a simplified thermistor design. All these culminated to designing a temperature measuring device which can find its application in organizations like brewery, oil and gas firms, pharmaceutical firms, etc. to regulate the temperature within the specified range.

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