Temperature Sensors

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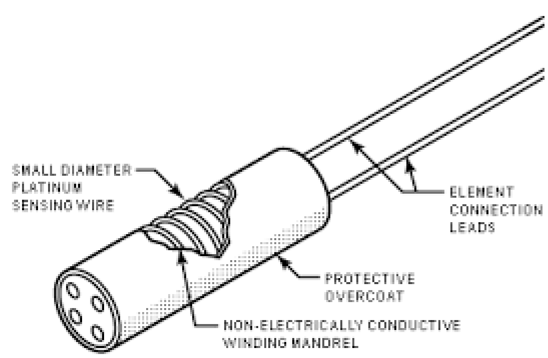
Objective : To study the commonly used temperature sensors, calibrate them and evaluate their time constants.

Theory:

Temperature measurement is the process of directly or indirectly measuring the instantaneous local temperature of a body or region for analysis or calculations. Many methods have been developed for measuring temperature. The most common device for measuring temperature is a mercury thermometer which will be used as a control for checking other devices. For our experiment, we will be studying Thermocouples, Thermistors, RTDs and Bimetallic Thermometers. The resistance of the Thermistor and RTD change with temperature which is used to estimate the temperature as we can measure the resistance.

Resistance Temperature Detector:

RTD stands for Resistance Temperature Detector. RTDs are sometimes referred to generally as resistance thermometers. An RTD is a temperature sensor that measures temperature using the principle that the resistance of a metal changes with temperature. In practice, an electrical current is transmitted through a piece of metal (the RTD element or resistor) located in proximity to the area where the temperature is to be measured. The resistance value of the RTD element is then measured by an instrument. This resistance value is then correlated to temperature based upon the known resistance characteristics of the RTD element. RTDs work on a basic correlation between metals and temperature. As the temperature of a metal increases, the metal's resistance to the flow of electricity increases. Similarly, as the temperature of the RTD resistance element increases, the electrical resistance, measured in ohms (Ω), increases. RTD elements are commonly specified according to their resistance in ohms at zero degrees Celsius (0 C). The most common RTD specification is 100 Ω, which means that at 0 C the RTD element should demonstrate 100 Ω of resistance.

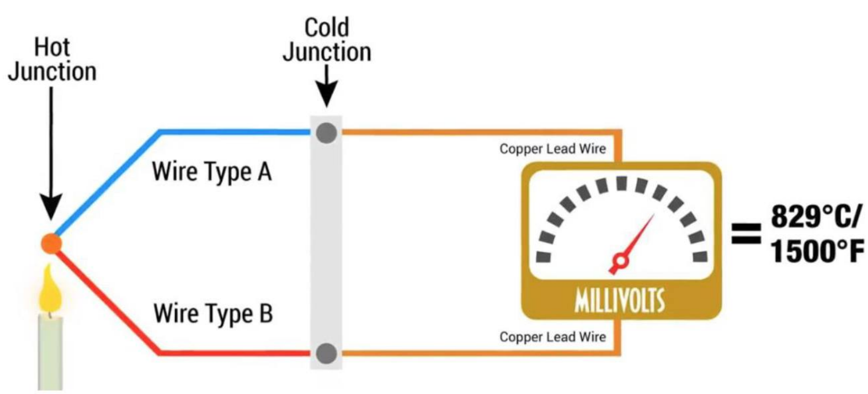


Thermistor:

A thermistor is a resistance thermometer, or a resistor whose resistance is dependent on temperature. The term is a combination of “thermal” and “resistor”. It is made of metallic oxides, pressed into a bead, disk, or cylindrical shape and then encapsulated with an impermeable material such as epoxy or glass.There are two types of thermistors: Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). With an NTC thermistor, when the temperature increases, resistance decreases. Conversely, when temperature decreases, resistance increases. This type of thermistor is used the most. A PTC thermistor works a little differently. When temperature increases, the resistance increases, and when temperature decreases, resistance decreases. This type of thermistor is generally used as a fuse. Typically, a thermistor achieves high precision within a limited temperature range of about 50ºC around the target temperature. This range is dependent on the base resistance.

Thermocouple:

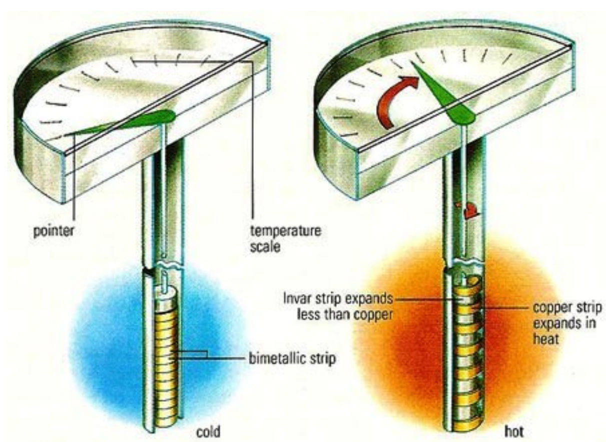
A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage as a result of the Seebeck effect, and this voltage can be interpreted to measure temperature. Thermocouples are widely used as temperature sensors.



A thermocouple works on the principle of thermal potential. There are two probes one of which is maintained at 0ºC and the other is kept on the body whose temperature we are measuring. Due to the difference in temperature, the electrons of the hot side would move to the colder side and an electric voltage will be formed on the device which varies with temperature. Two dissimilar metals are joined together at both ends in an electrical circuit. One “junction” is the measuring junction or “hot end”. The other is the reference junction or “cold end”. A sensitive voltmeter is connected to one of the conductors. Under laboratory conditions, the reference junction would be held at a known temperature, usually 0°C but in normal industrial practise the junction is left at ambient temperature and an external sensor is used to compensate for this variation (known as cold junction compensation, usually a thermistor bead is used to measure the ambient temperature). Quite simply as the temperature rises or falls at the measuring junction a voltage is generated within the circuit which correlates directly to temperature and can easily be converted by reference to the appropriate tables.

Bimetallic thermometer

A bimetallic thermometer is a temperature measurement device. It converts the media’s temperature into mechanical displacement using a bimetallic strip. The bimetallic strip consists of two different metals having different coefficients of thermal expansion. Bimetallic thermometers are used in residential devices like air conditioners, ovens, and industrial devices like heaters, hot wires, refineries, etc. They are a simple, durable, and cost-efficient way of temperature measurement. A bimetallic thermometer has two different metals connected together. When the strip is heated, both metals expand to different extensions and the radius of curvature of the strip will change with temperature. We need to get the calibration data that maps the resistance or voltage to the temperature. Using this, we can estimate the temperature if we have the reading of the device.



Once we have calibration data, we can find the time constant of each device by measuring the change in readings of the device with respect to time.

The time constant is the time when the device shows 63.2% of steady-state value

Experimental Setup:

Experimental setup consists of,

- Mercury thermometer to act as control
- Thermistor
- Thermocouple
- RTD
- Bimetallic thermometer for measuring time constant and get calibration data
- Ice bath for reference temperature of thermocouple
- Multimeter for measuring resistance or voltage of devices
- A heater for increasing temperature
- Stopwatch for taking a reading at different times while measuring the time constants.

Procedure:

1. Calibration:

- Put ice in a pot and connect the thermocouple output to the multimeter.
- Put the probes into the pot and take readings.
- Increase the temperature in steps of 10ºC and take readings.
- Repeat the above steps for RTD and thermistor.
- Plot the readings vs temperature to get characteristic curves.

2. Time constant measurement:

- Heat water till 65ºC and connect the thermocouple to the multimeter.
- Measure the output of the thermocouple at every 2-second interval till the output is the same
- Repeat the steps for RTD and thermistor.
- Plot the readings vs time.
- Find the time constant by getting required for 63.2 % of the step change value.

Observations

Calibration of Thermocouple, Thermistor, and RTD

Temperature, ^{0}C	**Thermocouple, mV**	**Thermistor, KΩ**	**RTD, Ω**
0	0	25.92	102.1
20.6	0.5	12.23	109.2
40	1.4	6.25	116.5
60	2.3	3.41	125
80	2.2	1.27	130.3

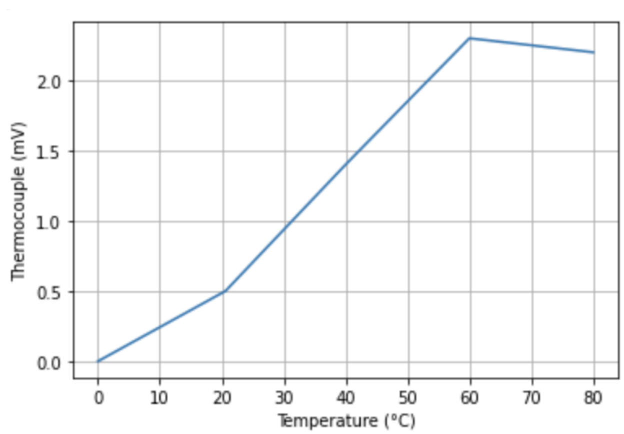
Determination of Time Constant

Time, sec	**RTD, Ω**	**Thermistor, KΩ**	**Thermocouple, mV**	**Bimetallic Thermometer, ºC**
0	113.2	9.26	0.8	27
2	115.4	8.51	0.9	29
4	119.5	7.5	1.1	34
6	122.9	6.6	1.5	38
8	124.7	5.84	1.8	40
10	125.8	5.275	2	42
12	126.2	4.38	2.2	44
14	127.5	3.84	2.3	46
16	128.4	3.56	2.4	48
18	128.6	3.195	2.5	50
20	128.8	3.151	2.6	52
22	128.8	3.007	2.7	54
24	128.9	2.922	2.7	56
26	129	2.838	2.7	57
28	129.2	2.792	2.7	58
30	129.2	2.747	2.7	59
32	129.4	2.719		60
34	129.6	2.694		61
36	129.2	2.676		62
38		2.647		62.5
40		2.626		63

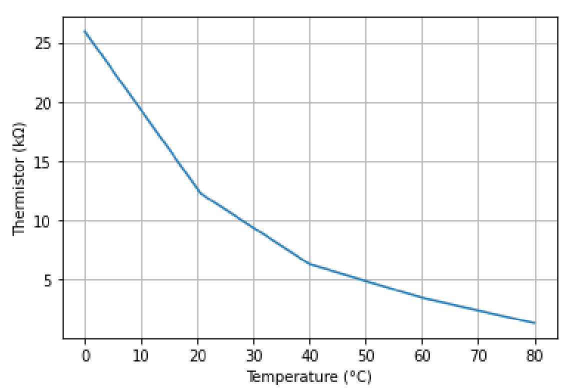
42		2.620		64
44		2.624		64
46		2.624		64
48		2.608		
50		2.603		
52		2.60		
54		2.60		

Plots & Calculations

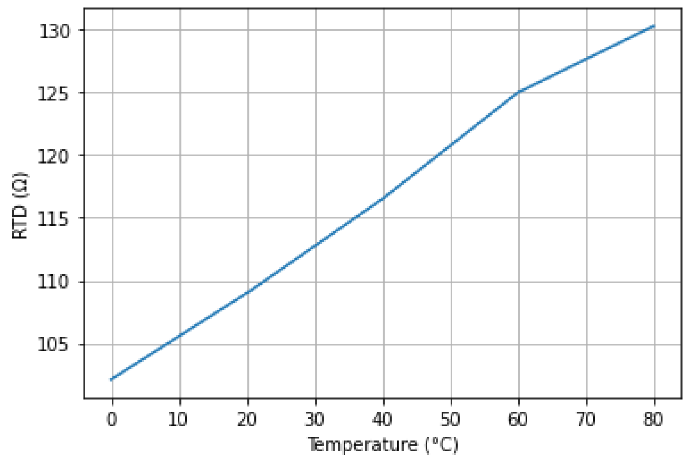
Graph of Thermocouple vs Temperature



Graph of Thermistor vs Temperature



Graph of RTD vs Temperature



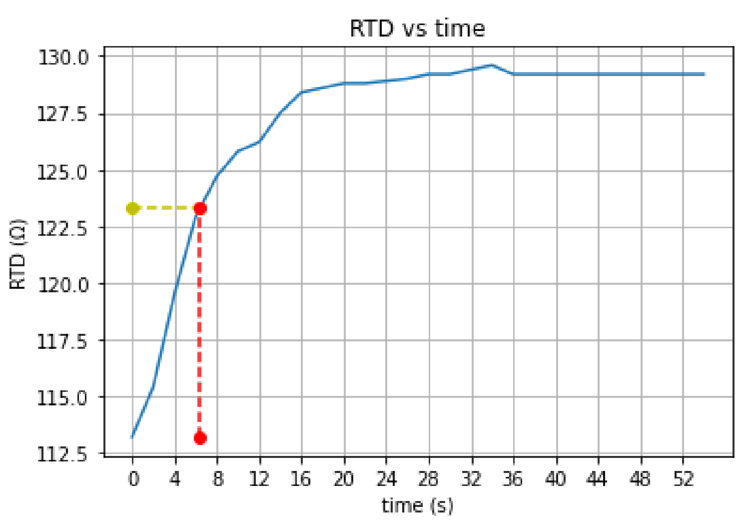
Determination of Time Constant

<u>RTD vs Time</u>

Step Change = 0.632*(129.2-113.2) + 113.2

Step Change = 123.312 Ω

Determination of Time constant by graphical analysis:

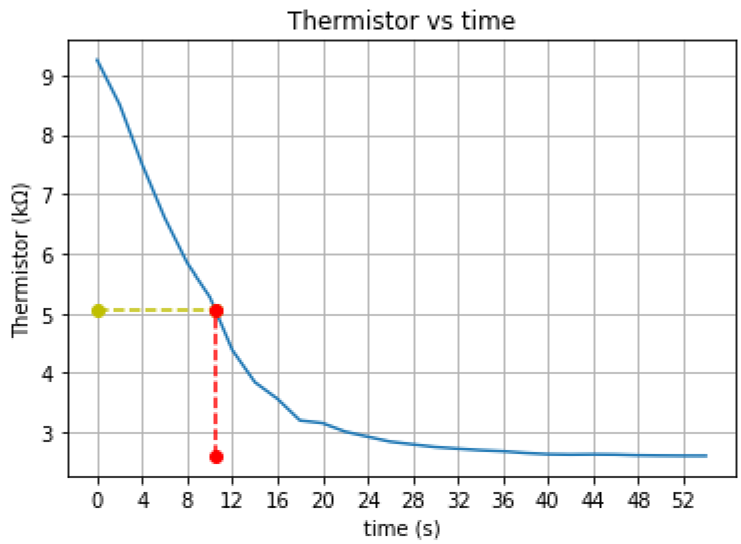


Thermistor vs Time

Step Change = 0.632*(2.6-9.26) + 9.26

Step Change = 5.051 KΩ

Determination of Time constant by graphical analysis:

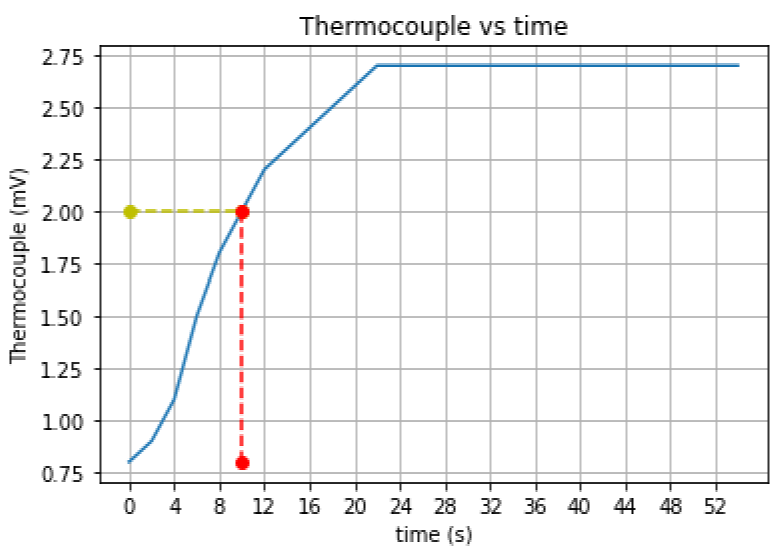


Thermocouple vs Time

Step Change = 0.632*(2.7-0.8) + 0.8

Step Change = 2 mV

Determination of Time constant by graphical analysis:

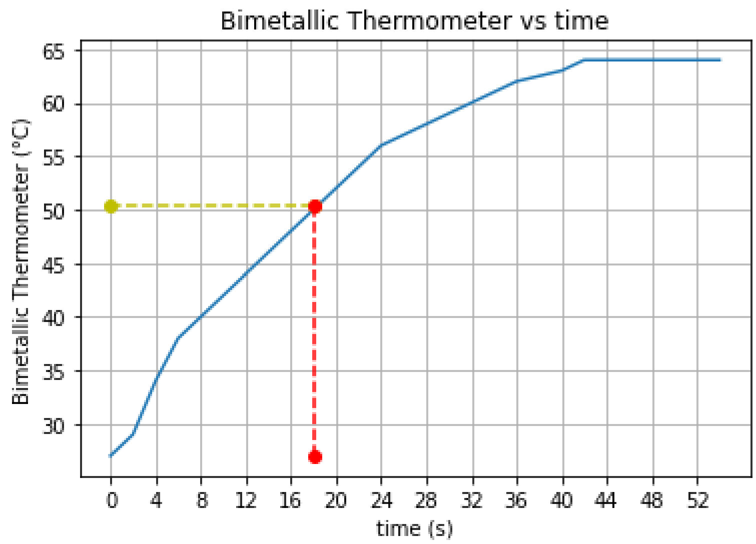


Bimetallic Thermometer vs Time

Step Change = 0.632*(64-27) + 27

Step Change = 50.384 ºC

Determination of Time constant by graphical analysis:



Results and Conclusion:

Temperature Sensor	**Time Constant**
RTD	6.3
Thermistor	10.5
Thermocouple	10
Bimetallic Thermometer	18.1

- As we can see from the graph and the readings RTD resistance have a linear growth with increase in the temperature this can be due to as RTD contain nickel copper and platinum wire as these materials have the positive temperature coefficient. This means that rise in T emperatu re result in increased resistance
- While the thermistor resistor got decreased as we increase the temperature this can be due to the thermistor semiconductor nature, electrons start to occupy the conduction band and then contribute to conduction thus lowering the conductivity
- In the case of thermocouple it produces a temperature-dependent voltage as a result of Seebeck effect, and this voltage can be interpreted to measure temperature.
- For Thermocouples, Seeback effect happen when electrons on a warmer end have a high average momentum as compared to the colder one. Therefore they will take energy.

Additional Questions:

a)

Let R_0 be the resistance at 0°c and T is temp. relative to 0°c

$$R_t = R_0 (1 + \alpha T)$$

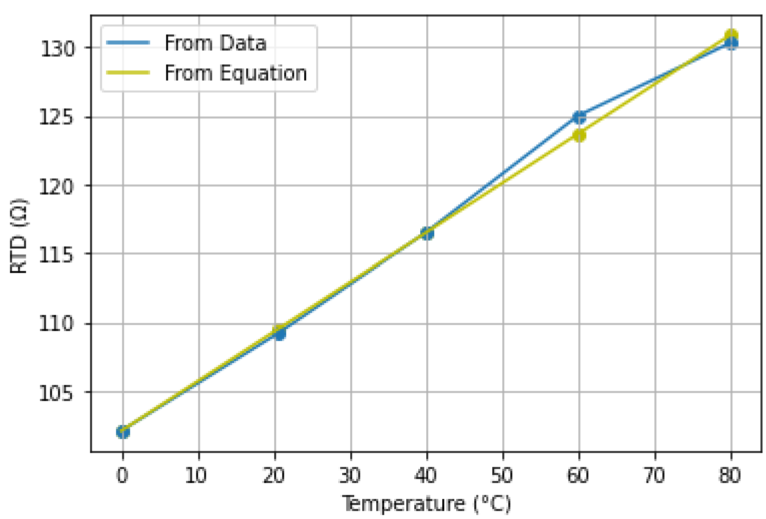
$$\therefore \alpha = \left(\frac{R_t}{(R_0 - 1)} \right) \frac{1}{T}$$

We can use the calibration data to find out the alpha of individual values

Temperature	**RTD**	**α**
20.6	109.2	0.003376
40	116.6	0.003526
60	125	0.003738
80	130.3	0.003452

Average $\alpha = 0.003523\ K^{-1}$

Let us plot both calibration data and this equation on same graph to see the accuracy



b)

let R_0 be the resistance at T_0 K and T is temperature in K

$$R_t = R_0 \exp\left(\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right)$$

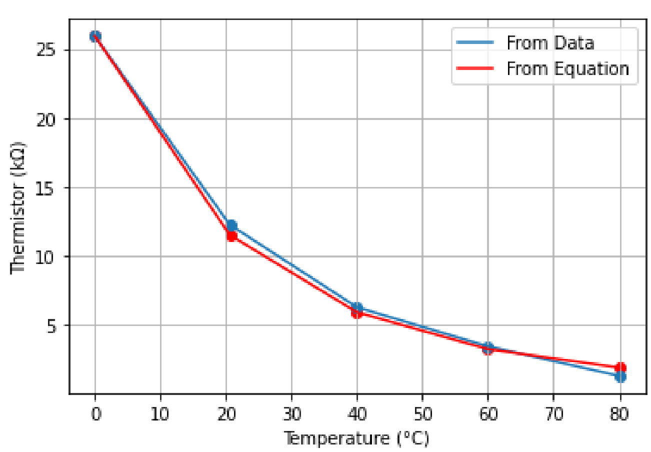
$$\therefore \beta = \ln\left(\frac{R_t}{R_0}\right)\left(\frac{1}{(1/T - 1/T_0)}\right)$$

We can use the calibration data to find out the beta of individual values

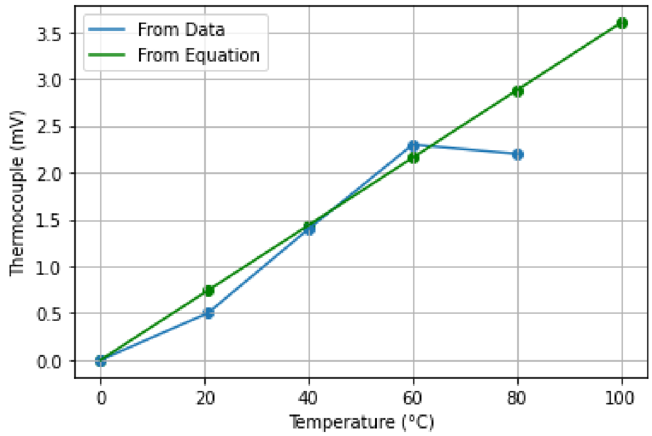
Temperature	**Thermistor**	**β**
20.6	12.23	2922.5536
40	6.25	3038.6378
60	3.41	3073.1827
80	1.27	3633.1089

Average β = 3166.8707 K

Let us plot both calibration data and this equation on the same graph to see the accuracy



c) Since thermocouple output varies linearly with temperature. We plot the best fit line for our calibration data.



At $t = 0s$, $y = 1\,mV$

Since water bath temperature is $100°c$, $y_\infty = 3.6\,mV$

At $t = 10s$,

$$-\frac{(10)}{10} = \ln\left(\frac{(y-3.6)}{1-3.6}\right) \qquad \left[\because -\frac{(t-t_0)}{\tau} = \ln\left(\frac{y-y_\infty}{y_0-y_\infty}\right)\right]$$

↳ Eqn: ①

On solving, $y = 2.64351\,mV$

At $t = 10s$, Temperature measured is $73.431°c$

Now, water bath temperature is changed to $50°c$, $y_\infty = 1.8\,mV$

using eqn: ①, at $t = 60s$

$$-\frac{(60-10)}{10} = \ln\left(\frac{y-1.8}{2.64351-1.8}\right)$$

$$\therefore y = 1.80568\,mV$$

$\therefore$ At $t = 60s$, $y = 1.80568\,mV$ and temperature is $50.1579°c$

d) The time constant of all the sensors will reduce when the medium is changed. If the heat transfer coefficient is increased, for the same area of heat exchange, more heat could be exchanged. Thus, the temperature will change faster and attain a steady-state faster, thus the time constant will decrease.