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EI191058
Test And Calibration Lab

Characterize the temperature sensor(Thermocouple)

Aim: To understand the working Principle of Thermocouple.

Objective:-

1. Understand thermoelectric effects.
2. Study static and dynamic characteristics of Thermocouple.
3. Study effect of thermowell on thermocouple performance.

Prerequisite

Before performing the experiments on thermocouples, students must have knowledge of:

1. Importance of temperature measurement
2. Different temperature scales
3. Various methods of temperature measurement

Theory:

Thermoelectric effect:

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates a voltage when there is a difference in temperature on each side. Conversely when a voltage is applied to it, it creates a temperature difference.

There are three basic effects that explain the working principle of a thermoelectric device.

1. Seebeck Effect: When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit. German-Estonian physicist Thomas Seebeck made this discovery in 1821. This is now known as the **thermoelectric effect** or **Seebeck effect**.

2. Peltier Effect: Peltier found that the junctions of dissimilar metals get heated or cooled, depending upon the direction in which an electrical current passed through them. Heat generated by current flowing in one direction is absorbed if the current is reversed. The effect always involves pairs of junctions. The Peltier effect is found to be proportional to the first power of the current, not to its square, as is the irreversible generation of heat caused by resistance throughout the circuit. In effect it transfers the heat from one side of a device to other.

3. Thompson Effect: This describes the existence of temperature gradient while heating or cooling of a conducting material. Any current - carrying conductor (except superconductor), with a temperature difference between two points, will either absorb or emit heat, depending on the material.

Introduction to Thermocouple

What is thermocouple?

A thermocouple is a junction between two different metals that produces a voltage related to a temperature difference. When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit (the thermoelectric effect or Seebeck effect).

Need for reference junction(cold junction):

In thermocouples, voltage is developed due to flow of electric current. This current flow depends upon the difference in temperatures at the two ends of conducting wire. That is thermocouples always measure difference in temperatures and not absolute temperature. To measure

the temperature of one junction, the other junction is kept at some reference temperature. As this is done by using ice bath, it is normally called at cold junction.

Using ice bath for constant temperature is useful for laboratory calibration, but is not convenient for most measurement and control applications. Instead of ice bath, an effect of cold junction is added using a thermally sensitive device such as a thermistor or diode. This is also called as isothermal block. Special care is taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction is applied. This is known as cold junction compensation.

Software compensation is the most versatile technique used for measuring thermocouples. Many thermocouples can be connected on the same block. The technique is independent of the types of thermocouples. All of the conversions are performed by the computer. The disadvantage is that the computer requires additional time to calculate the reference junction temperature. For maximum speed we can use hardware compensation.

Hardware compensation can be viewed as inserting a battery that cancels the offset voltage produced by the reference junction. These commercially available circuits provide an electronic ice point reference. Their main advantage is speed while the disadvantage is that it is suited to compensate only a particular type of thermocouple.

Thermocouple properties:

The selection criteria for thermocouple materials:

1. Temperature Range
2. Melting point
3. Reaction to various atmospheric conditions
4. Thermoelectric output in combination
5. Electrical conductance
6. Stability
7. Interchangeability
8. Repeatability
9. accuracy
10. resolution
11. Cost
12. Availability
13. Chemical properties
14. Abrasion and vibration resistance
15. Installation requirements
16. Magnetic properties
17. Ease of handling and fabrication

Things to remember:

Wire Size of Thermocouple: Selecting the wire size used in the thermocouple sensor depends upon the application. Generally, when longer life is required for the higher temperatures, the larger size wires should be chosen. When sensitivity is the prime concern, the smaller sizes should be used.

Length of Thermocouple Probe: Since the effect of conduction of heat from the hot end of the thermocouple must be minimized, the thermocouple probe must have sufficient length. Unless there is sufficient immersion, readings will be low. It is suggested the thermocouple be immersed for a minimum distance equivalent to four times the outside diameter of a protection tube or well.

Location of Thermocouple: Thermocouples should always be in a position to have a definite temperature relationship to the work load. Usually, the thermocouple should be located between the work load and the heat source and be located approximately $\frac{1}{3}$ the distance from the work load to the heat source.

Types of thermocouples based on metal combination:

Different types are best suited for different applications. They are usually selected based on the temperature range and sensitivity needed. Thermocouples with low sensitivities (B, R, and S types) have correspondingly lower resolutions.

Need for thermowell:

Thermowells are used in industrial temperature measurement to provide isolation between a temperature sensor (often a thermocouple) and the environment whose temperature is to be measured.

They are intrusive fittings and are subjected to static and dynamic fluid forces. These forces govern their design. Vortex shedding is the dominant concern as it is capable of forcing the thermowell into flow-induced resonance and consequent fatigue failure. The latter is particularly significant at high fluid velocities.

Thermowells are used to facilitate the repair of temperature sensing devices without interrupting the process being monitored.

Thermowells are available in three main barrel or shank design types. The barrel, or shank, is the container style apparatus, which is inserted into the process flow. Since thermowells are inserted directly into the process flow, the goal is to allow for measurement while causing as little restriction of flow as possible.

When selecting between the available types of thermowells, points considered are:

Stem length (length from bore to the end of the well) and bore diameter of the thermowell.
 The temperature and viscosity of the media into which the thermowell will be seated.
 Lagging extensions through which the sensor will have to pass.

Thermocouple Types:

Thermocouple Type	Thermocouple Materials	Useful Application Range	Properties and applications
B	Platinum 30% Rhodium (+) Platinum 6% Rhodium (-)	32 -3100F 0-1700C	Limited use below 50 °C
C	Tungsten 5% Rhenium (+) Tungsten 26% Rhenium (-)	32-4200F 0-2300C	Must not be used in presence of oxygen above 260 °C. Well suited for Vacuum Furnaces at extremely high temperature.
E	Chromel (+) Constantan (-)	-200-1650F -95-900C	Sensitivity 68µV/°C Non magnetic Most suited for cryogenic use
J	Iron (+) Constantan (-)	-58-1650F -50-900C	Sensitivity 55 µV/°C Magnetic properties restrict use above 770 °C
K	Chromel (+) Alumel (-)	-328-2300F -200-1260C	Most common Sensitivity 41 µV/°C Inexpensive linear Restricted use above 350°C due to magnetic properties of nickel.
R	Platinum 13% Rhodium (+) Platinum (-)	160-2640F 70-1450C	Type B, R, and S thermocouples are usually used only for high temperature measurements due to their high cost and low sensitivity.
S	Platinum 10% Rhodium (+) Platinum (-)	1800-2640F 80-1450C	
T	Copper (+) Constantan (-)	-330-660F -200-350C	Sensitivity 43 µV/°C Often used for differential measurement.

Characterize the temperature sensor(Thermocouple)

The procedure for using simulator is as follows:

Expt. 1: Static Characteristics of Thermocouple

Aim: Study the change in emf of a thermocouple in response to the process temperature.

Step by step Procedure:

1. Select the type of Thermocouple to be used for experimentation.
1. Select the 'Reference Temp' to set the temperature of reference junction from drop down menu.
1. Click on 'Get Temperature' green colour box. The temperature will be displayed for which output (mV) is to be found.
1. Click on 'thermocouple Reference Table' link below the sketch to refer to standard thermocouple charts. From the particular type of thermocouple chart, find the output millivolt value corresponding to the temperature. Enter it in the box provided and submit.
1. Enter the output millivolt in the answer box. If the answer is correct, it will get indicated in the box below the answer. If not verify it and enter correct output value. If wrong answer is submitted repeatedly for 3 times, the correct answer gets pop-up.
1. Go to step 3. Repeat the procedure at least for 3 times.
1. After finishing the required set of readings 'Plot', 'Next set' and 'Level 2' tabs are enabled. See the graph by clicking on '**Plot**' tab.
1. By clicking **Next** set tab, Repeat the procedure for different types of Thermocouples at various reference temperature values.
1. Click on '**Plot**' to see the graphs for comparative study. When you click on 'Level 2' tab, you can verify the Dynamic response of the thermocouple.

Expt. 2: Dynamic characteristics

Aim: Study the dynamic response of Thermocouple

In this experiment, the response of thermocouple for a step change in the input is plotted. The maximum temperature the thermocouple attains, is same as the temperature displayed by ' Measurement Tab' in Static part.

Step by step Procedure:

1. The type of thermocouple selected as bare element is by default. It is the same you selected in 'Level 1'. With the standard dimensions considered for bare element, the time constant value will get displayed in the output box. Verify this by using equation given under **Get formula** tab.
 2. Now select the thermocouple dynamic performance **with sheath**. Select appropriate material and thickness value. The time constant value will get displayed in the output box. Verify this by using equation given under formula tab.
 3. Observe the change in the time constant values with different materials with different thickness.
 4. Now select the thermocouple dynamic performance **with thermowell**. Select appropriate material, thickness and filling material. The time constant value will get displayed in the output box when thermowell material, thickness and filling material is selected. Verify this by using equation given under formula tab.
 5. Observe the change in the time constant values with different materials with different thickness. Also see the effect of change in filling material.
 6. Click on enabled **Plot** button , to observe the dynamic response (Time Vs Temperature).
 7. Observe and verify response time of Thermocouple which is generally 5 times the time constant value.
- After completion of both the parts, you can proceed to Post Test to find out if you have understood all aspects of the experiment.

The procedure for using simulator is as follows:

Expt. 1: Static Characteristics of Thermocouple

Aim: Study the change in emf of a thermocouple in response to the process temperature.

Step by step Procedure:

1. Select the type of Thermocouple to be used for experimentation.
1. Select the 'Reference Temp' to set the temperature of reference junction from drop down menu.
1. Click on 'Get Temperature' green colour box. The temperature will be displayed for which output (mV) is to be found.
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1. Enter the output millivolt in the answer box. If the answer is correct, it will get indicated in the box below the answer. If not verify it and enter correct output value. If wrong answer is submitted repeatedly for 3 times, the correct answer gets pop-up.
1. Go to step 3. Repeat the procedure at least for 3 times.
1. After finishing the required set of readings 'Plot', 'Next set' and 'Level 2' tabs are enabled. See the graph by clicking on '**Plot**' tab.
1. By clicking **Next** set tab, Repeat the procedure for different types of Thermocouples at various reference temperature values.
1. Click on '**Plot**' to see the graphs for comparative study. When you click on 'Level 2' tab, you can verify the Dynamic response of the thermocouple.

Expt. 2: Dynamic characteristics

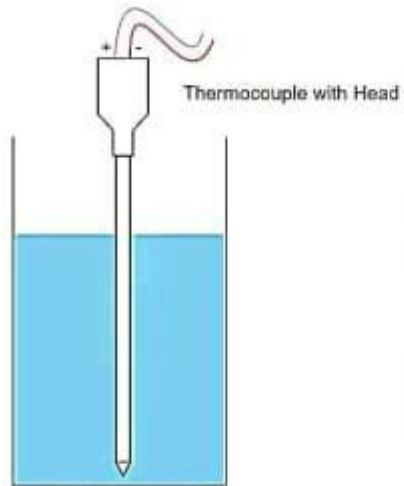
Aim: Study the dynamic response of Thermocouple

In this experiment, the response of thermocouple for a step change in the input is plotted. The maximum temperature the thermocouple attains, is same as the temperature displayed by 'Measurement Tab' in Static part.

Step by step Procedure:

1. The type of thermocouple selected as bare element is by default. It is the same you selected in 'Level 1'. With the standard dimensions considered for bare element, the time constant value will get displayed in the output box. Verify this by using equation given under **Get formula** tab.
 2. Now select the thermocouple dynamic performance **with sheath**. Select appropriate material and thickness value. The time constant value will get displayed in the output box. Verify this by using equation given under formula tab.
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 7. Observe and verify response time of Thermocouple which is generally 5 times the time constant value.
- After completion of both the parts, you can proceed to Post Test to find out if you have understood all aspects of the experiment.

Level-1 Static Characteristics



Thermocouple Reference Table

Control Panel

Thermocouple Type:

Iron(+)Versus Constantan(-)

Reference Temp:

Useful Temperature Range: 95°C to 760°C

145°C

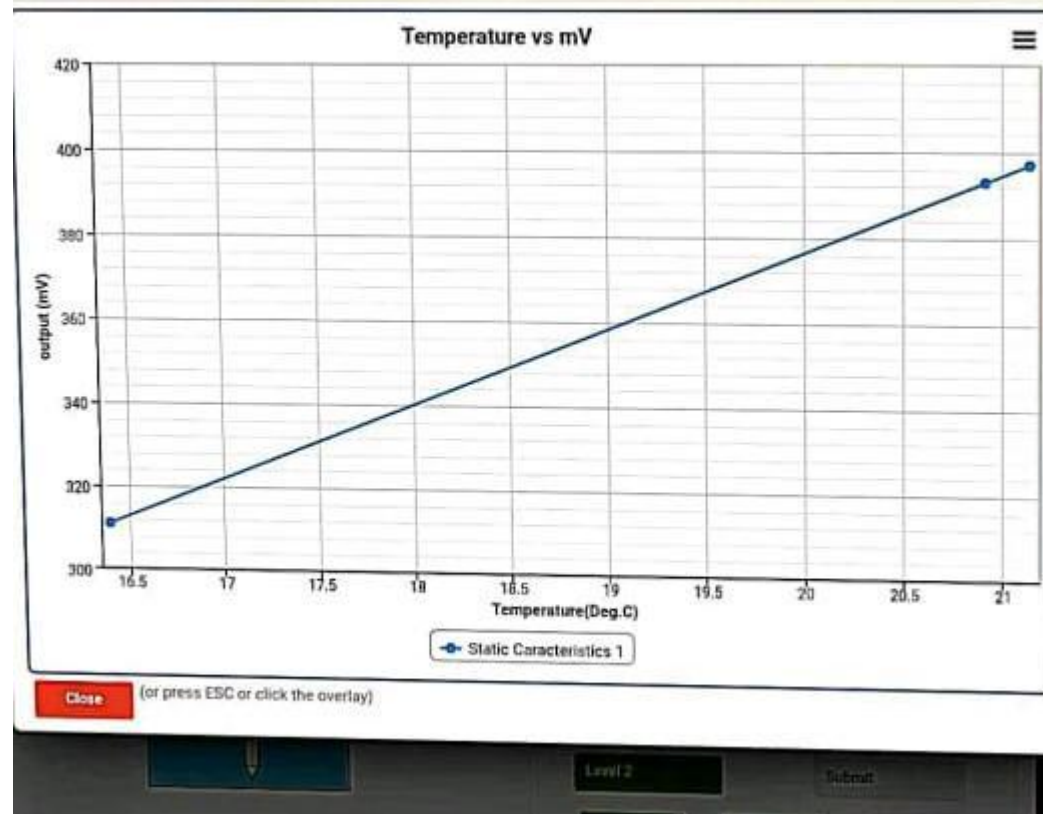
Enter Input value mV:

Selected Values:

Thermocouple Type: J

Reference Temp: 0

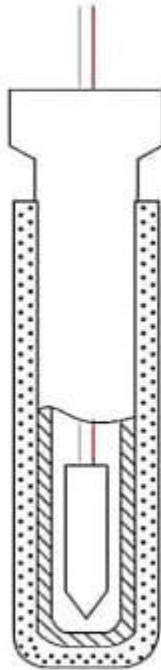
graph





Thermocouple

Level-2 Dynamic Characteristics



Bare: ☒

<<-Level-1

Thermocouple Type : J

Withsheath: ☒

Material: SS 316

Thickness: 0.75mm

Thermowell: ☒

Material: SS 316

Thickness: 1.5mm

Filling Material: MgO powder

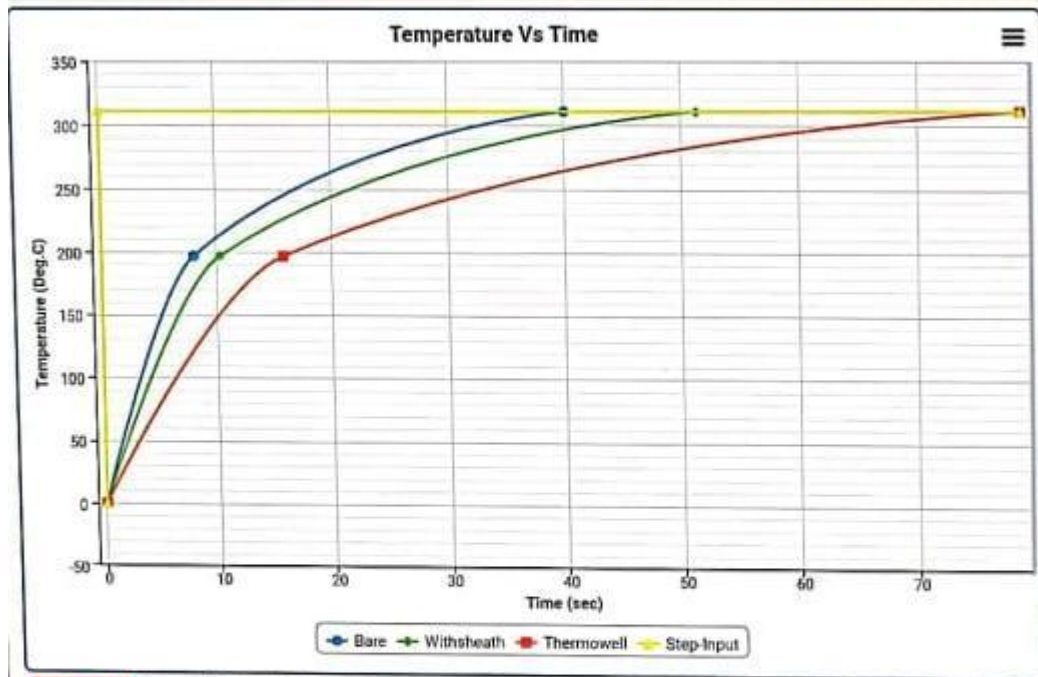
Plot

Reload

Output:

Time constant is: 8.00

Time constant for withsheath $\tau = (x/k) * P$
*L*s

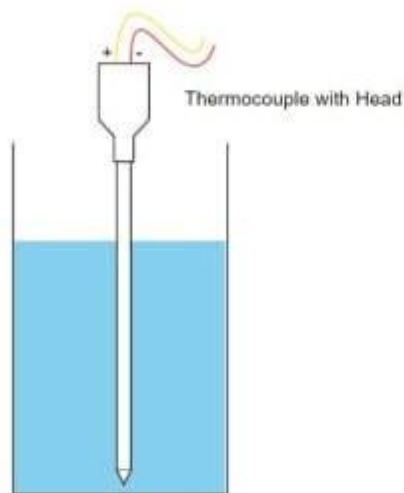


Close

(or press ESC or click the overlay)



Level-1 Static Characteristics



Thermocouple Reference Table

Control Panel

Thermocouple Type:

Nickel-10% Chromium(+)Versus
Nickel-5%(-)(Aluminum Silicon)

Reference Temp:

Useful Temperature Range: 95°C
to 1260°C

Get temperature =>

187°C

Enter Input value mV:

Level 2

Submit

Plot

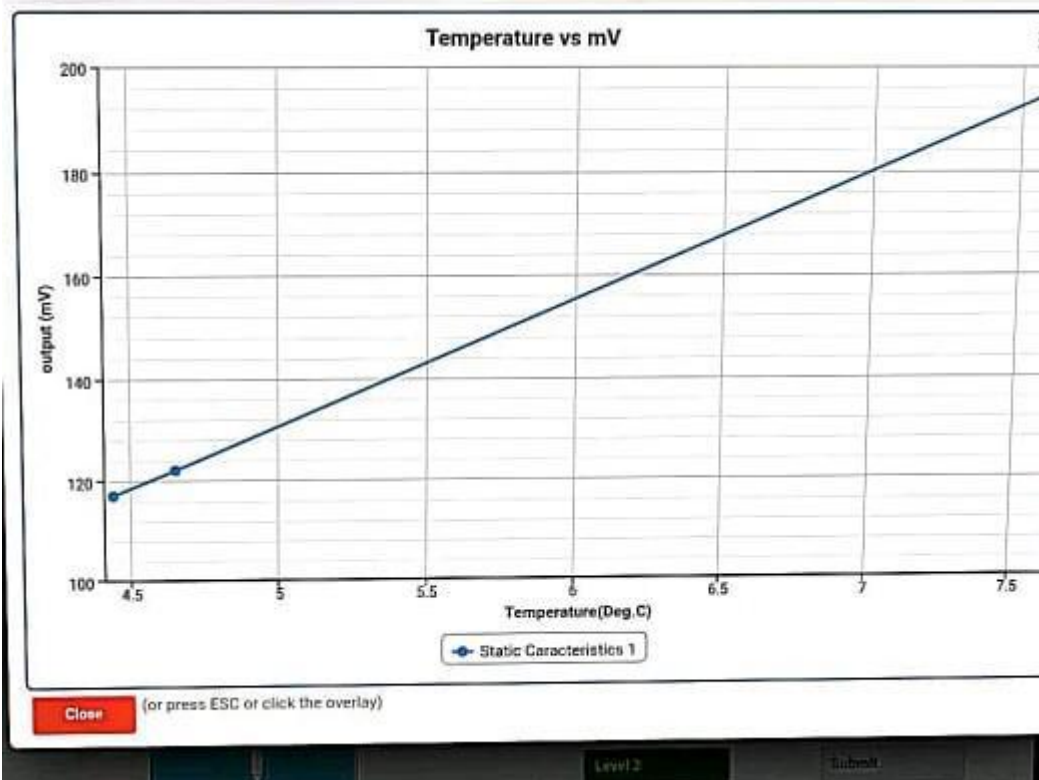
Next Set

Reload

Selected Values:

Thermocouple Type: K

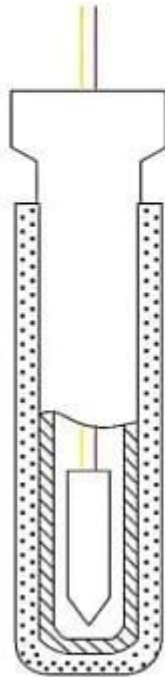
Reference Temp: 0





Thermocouple

Level-2 Dynamic Characteristics



Bare: ☒

<<-Level-1

Thermocouple Type :

Withsheath: ☒

Material:

Thickness:

Thermowell: ☒

Material:

Thickness:

Filling Material:

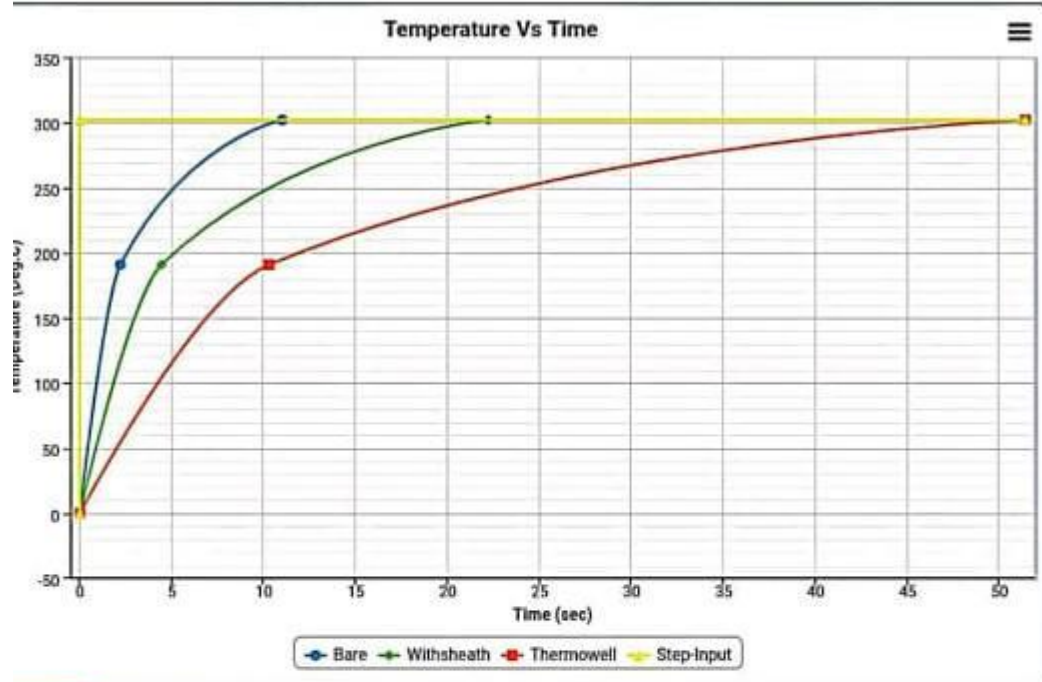
Output:

Time constant is: 11.86

Time constant for withsheath $\tau = (x/k) \cdot P \cdot L \cdot s$

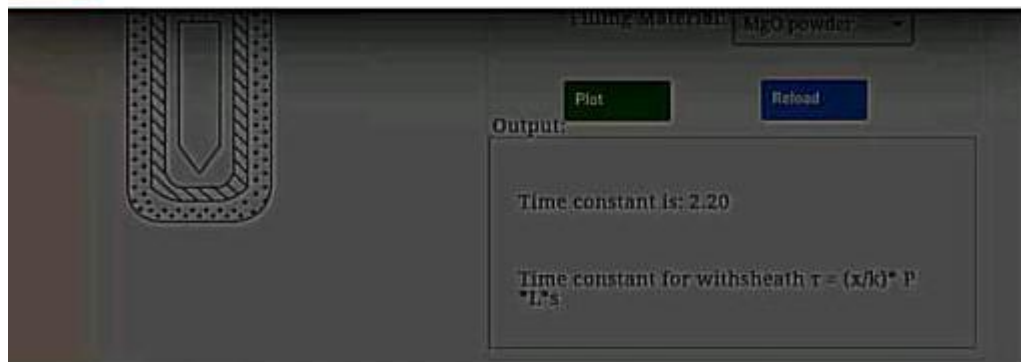
Temperature vs Time

x

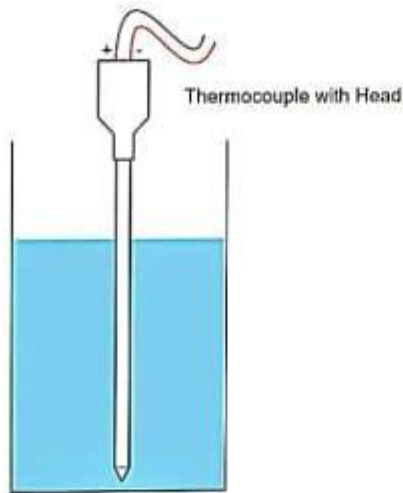


Close

(or press ESC or click the overlay)



Level-1 Static Characteristics



Thermocouple Reference Table

Control Panel

Thermocouple Type:

Platinum-13% Rhodium(+) Versus
Platinum(-)

Reference Temp:

Useful Temperature Range: 870°C
to 1450°

Get temperature =>

39°C

Enter Input value mV:

Level 2

Submit

Plot

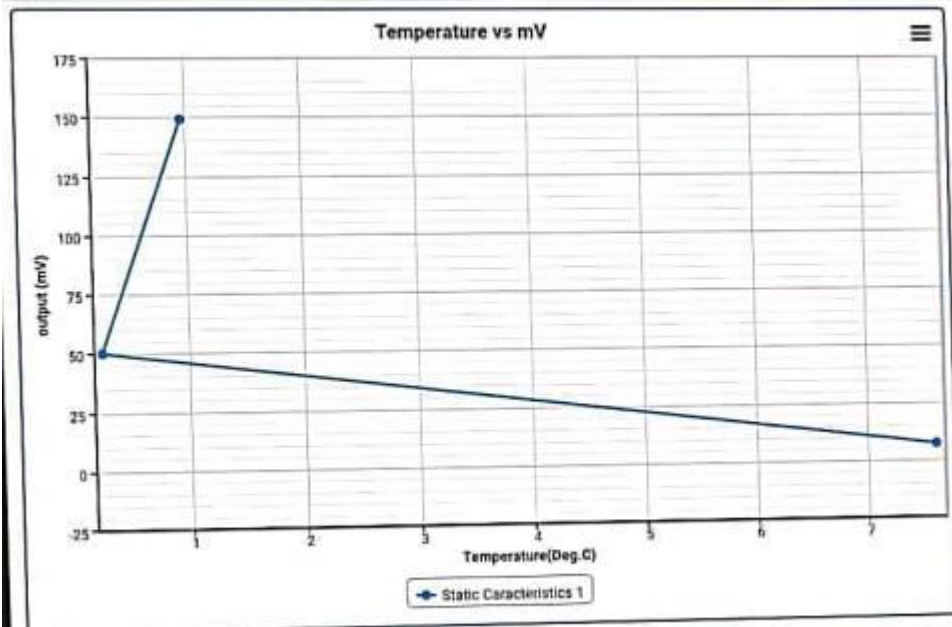
Next Set

Reload

Selected Values:

Thermocouple Type: R

Graph



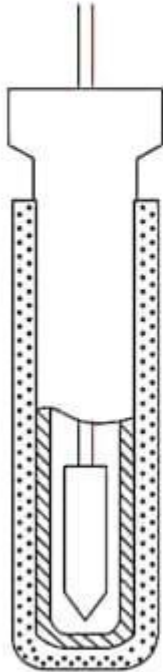
Close

(or press ESC or click the overlay)



Thermocouple

Level-2 Dynamic Characteristics



Bare: ☒

<<<Level-1

Thermocouple Type : R

Withsheath: ☒

Material: SS 316

Thickness: 0.75mm

Thermowell: ☒

Material: SS 304

Thickness: 1.5mm

Filling Material: MgO powder

Plot

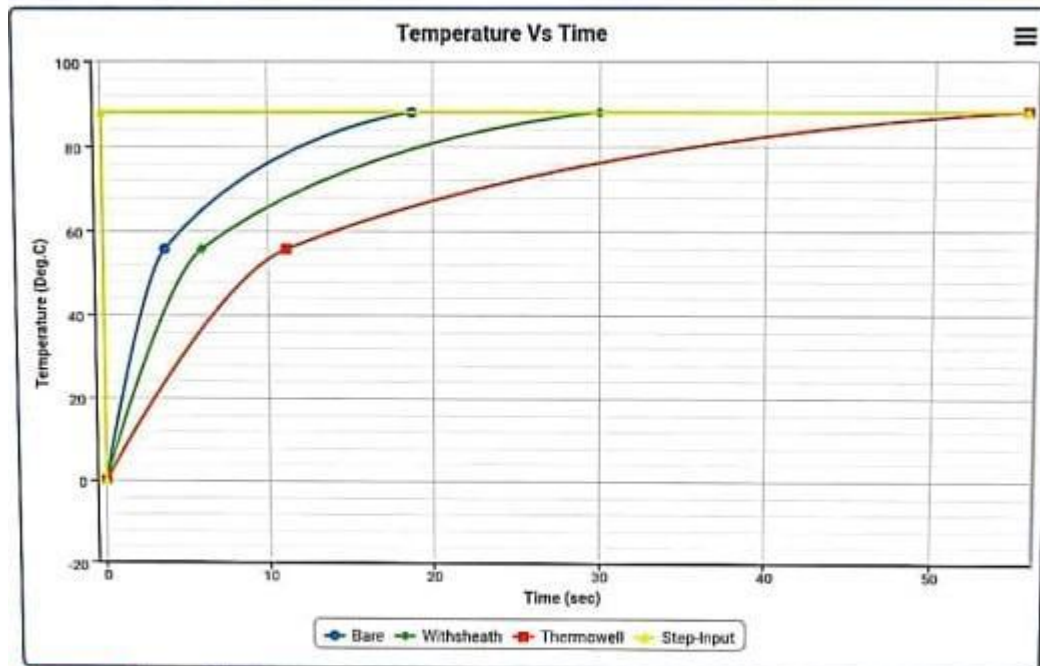
Reload

Output:

Time constant is: 3.74

Time constant for withsheath $\tau = (x/k) \cdot P$
*L*s

Temperature vs Time



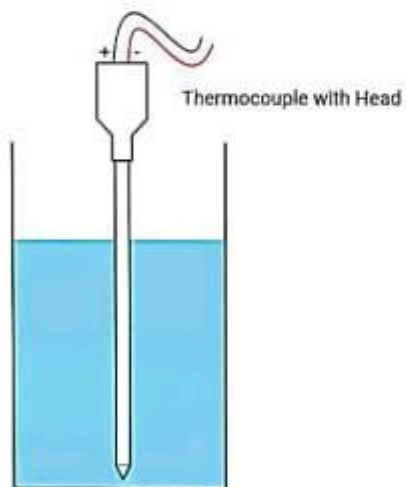
Close (or press ESC or click the overlay)





Thermocouple

Level-1 Static Characteristics



Thermocouple Reference Table

Control Panel

Thermocouple Type:

Platinum-10% Rhodium(+) Versus
Platinum(-)

Reference Temp:

Useful Temperature Range: 980°C
to 1450°C

Get temperature ==>

337°C

Enter Input value mV:

Level 2

Submit

Plot

Next Set

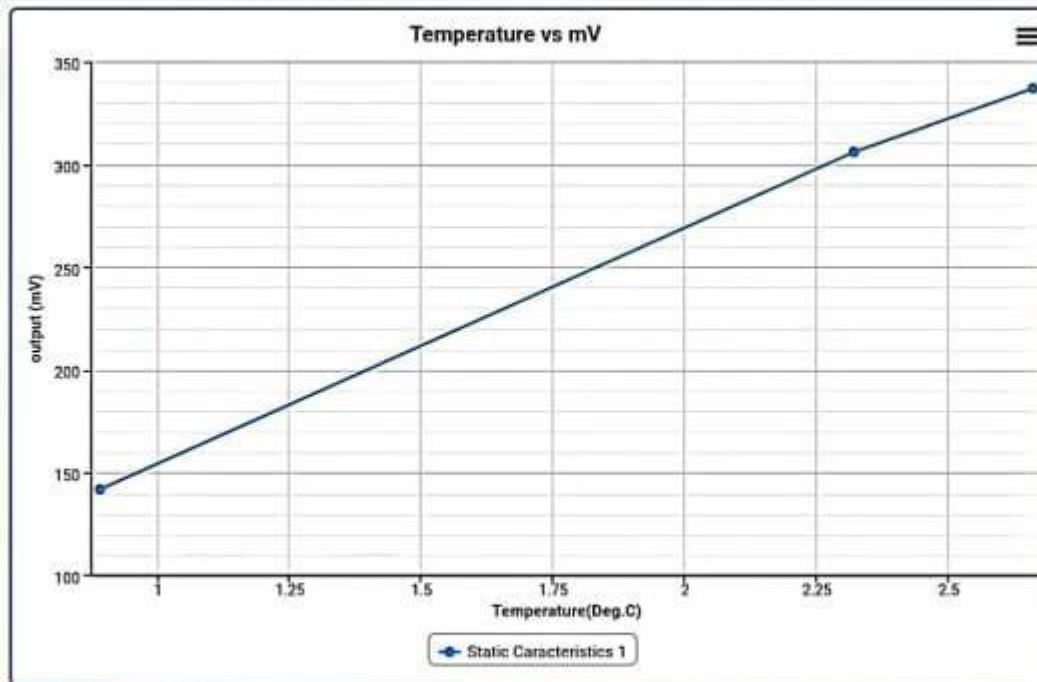
Reload

Selected Values;

Thermocouple Type: S

Reference Temp: 0

Graph



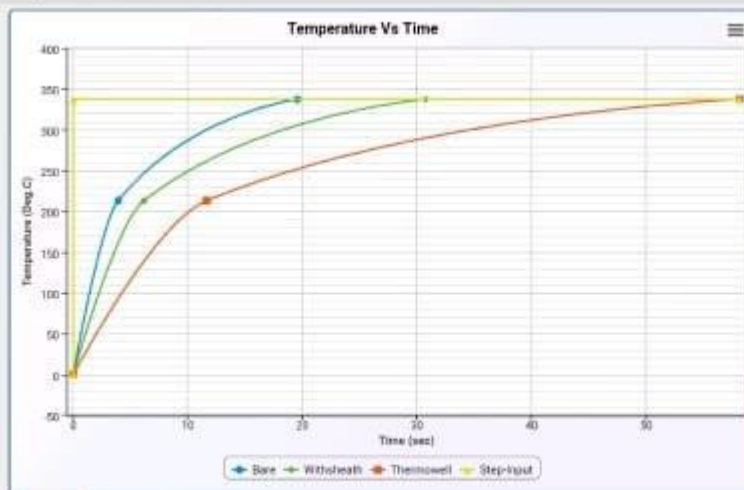
Close

(or press ESC or click the overlay)

Level 2

Submit

Temperature vs Time



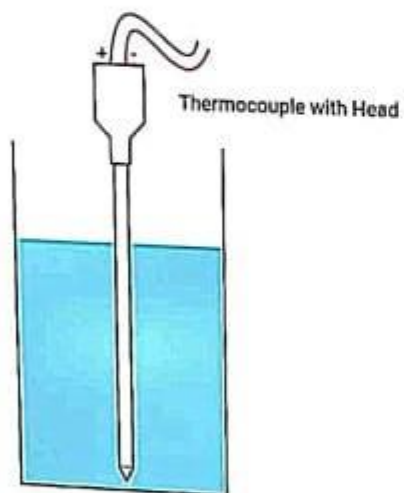
Close

(or press ESC or click the overlay)

Plot

Export

Level-1 Static Characteristics



Thermocouple Reference Table

Control Panel

Thermocouple Type:

Copper(+) Versus Constantan(-)

Reference Temp:

Useful Temperature Range: 0°C to 350°C

Get temperature ==>

302°C

Enter Input value mV:

Level 2

Submit

Plot

Next Set

Reload

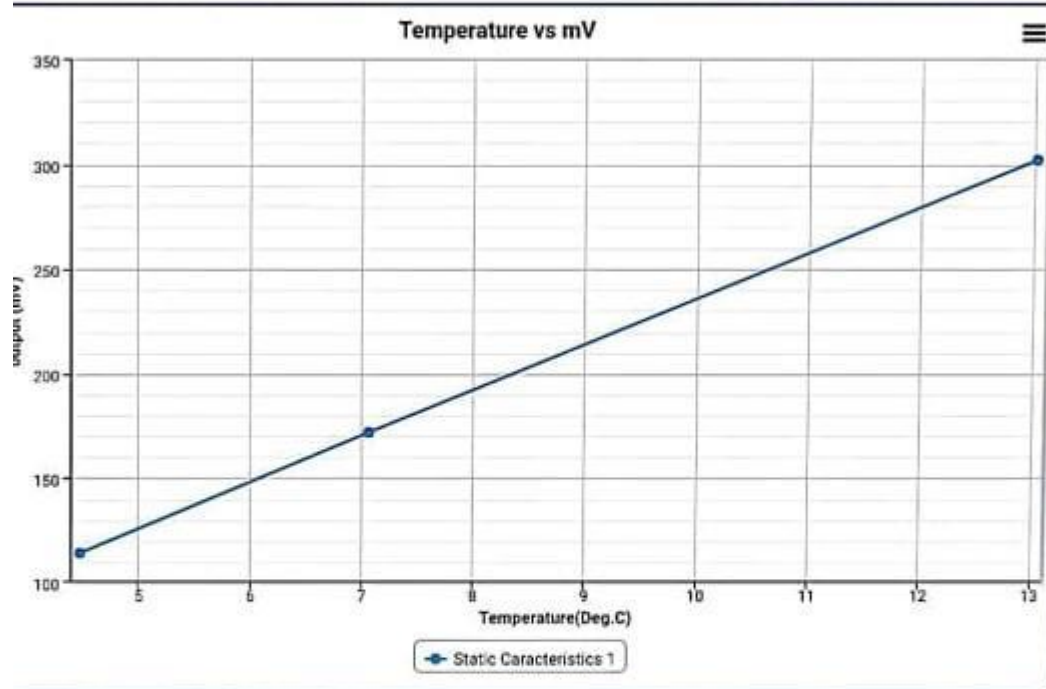
Selected Values:

Thermocouple Type: T

Reference Temp: 10

iph

x



Close

(or press ESC or click the overlay)

Level 2

Submit

Plot

Next Set

Reload

Thermocouple Reference Table

Selected Values:

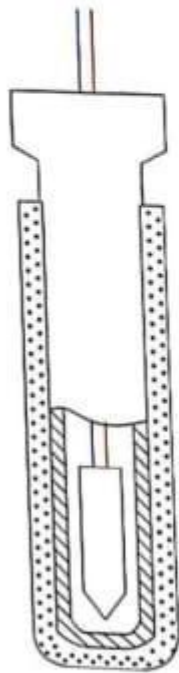
Thermocouple Type: T

Reference Temp: 10



Thermocouple

Level-2 Dynamic Characteristics



Bare: ☒

<<-Level-1

Thermocouple Type :

Withsheath: ☒

Material:

Thickness:

Thermowell: ☒

Material:

Thickness:

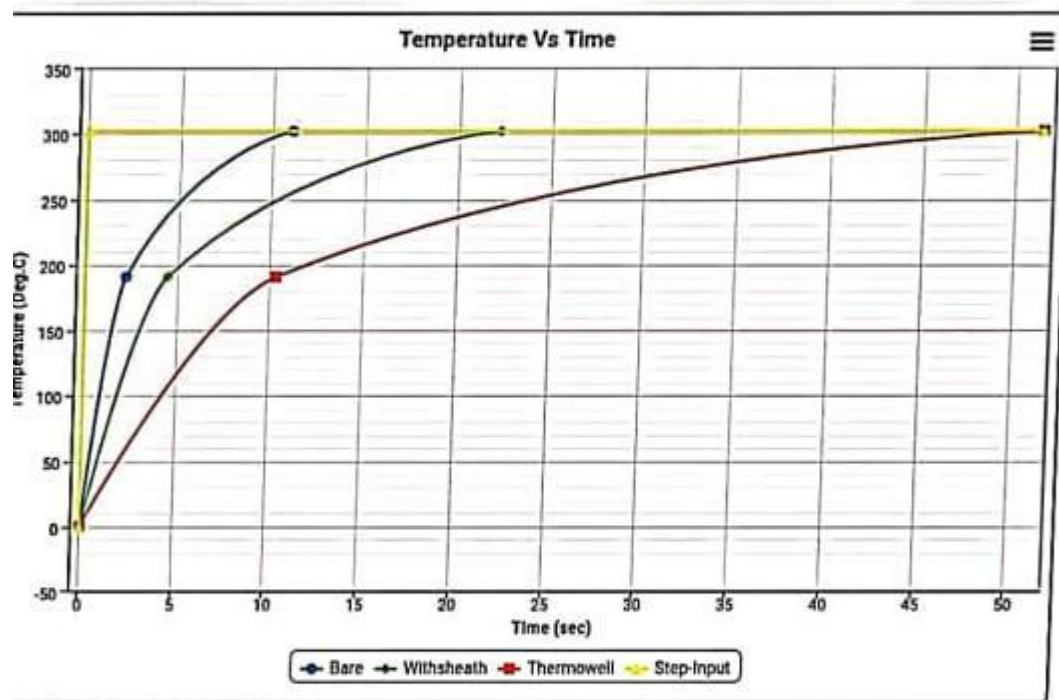
Filling Material:

Output:

Time constant is: 2.20

Time constant for withsheath $\tau = (x/k) \cdot p$
• L • s

Temperature vs Time



Close

(or press ESC or click the overlay)