Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-11: Temperature Sensors

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Contents

Thermoelectric Effect

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa via a thermocouple. Thermoelectric devices create a voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, heat is transferred from one side to the other, creating a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.

This effect can be used to generate electricity, measure temperature or change the temperature of objects. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices can be used as temperature controllers.

The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect.

1. Seebeck Effect

The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler conductor or semiconductor. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.

Seebeck effect: Explanation

In 1821, German physicist Thomas Seebeck discovered that when two wires made from dissimilar metals are joined at two ends to form a loop, and if the two junctions are maintained at different temperatures, a voltage develops in the circuit. This phenomenon is therefore named after him.

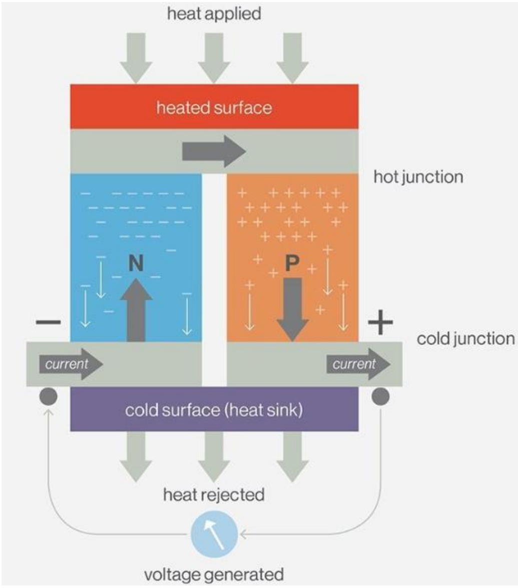
When heat is applied to one of the two conductors or semiconductors, that metal heats up. Consequently, the valence electrons present in this metal flow toward the cooler metal. This happens because electrons move to where energy (in this case, heat) is lower. If the metals are connected through an electrical circuit, direct current flows through the circuit.

However, this voltage is just a few microvolts per kelvin temperature difference. Thermal energy is continuously transferred from the warmer metal to the cooler metal until eventually, temperature equilibrium is obtained.

The Seebeck effect and its resultant thermoelectric effect is a reversible process. If the hot and cold junctions are interchanged, valence electrons will flow in the other direction, and also change the direction of the DC current.

Seebeck effect and thermocouples

The pair of metal wires forming the electrical circuit is known as a thermocouple. On a larger scale and due to the Seebeck effect, thermocouples are used to approximately measure temperature differences. They are also used to actuate electronic switches that can turn large systems on and off, a capability that is employed in thermoelectric cooling technology.



Seebeck used copper and bismuth in his experiment. Other common thermocouple metal combinations that are used today include the following:

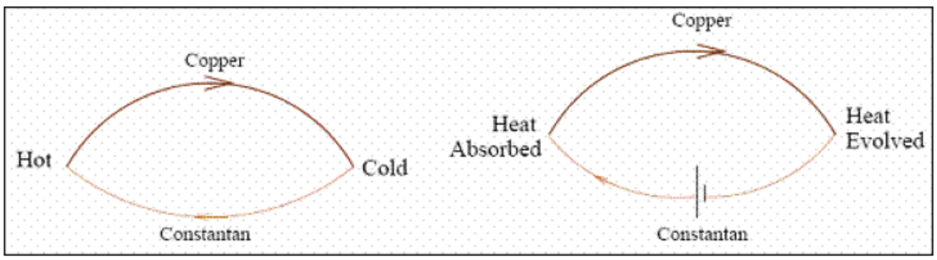
- constantan and copper
- constantan and iron

- constantan and chromel
- constantan and alumel

2. Peltier Effect

The Peltier effect is another crucial aspect of thermocouple operation. When two dissimilar metals are joined to form two junctions, and these junctions are maintained at different temperatures, an emf is generated in the circuit. This emf arises due to the temperature difference between the two junctions of the circuit.

In 1834 Jean Peltier, a french watch maker, discovered a second thermoelectric effect. If a current flow through a circuit containing junction of two dis-similar metals, it leads to an absorption or liberation of heat at the junctions. Heat is given out or absorbed depending on the pairs of metals and the direction of the current. The phenomenon of heat evolution is different from the Joule heat as Peltier effect is a reversible process while Joule loss is irreversible.



If the direction of the current at the junction is same as the direction of the Seebeck current, heat is liberated if the Seebeck junction is a hot junction or is absorbed if the junction is cold. Thus for a copper-constantan thermocouple, if the current flow at the junction is from copper (+) to constantan (-), heat is absorbed. On changing the direction of the current, heat will be liberated at the same junction, showing that the phenomenon is reversible.

Seebeck effect vs. Peltier effect

In 1834, Jean Peltier, a French watchmaker, discovered another second thermoelectric effect that was later named the Peltier effect. Peltier observed that when a current flow through a circuit containing a junction of two dissimilar metals -- similar to the setup in the Seebeck effect -- heat is either absorbed or liberated at the junction. This absorption or liberation depends on the pair of metals used and the direction of the current.

The Seebeck effect and Peltier effect both involve circuits made from dissimilar metals, as well as heat and electricity. Both are also reversible processes. But despite these similarities, there are some differences between these effects as well.

The Seebeck effect occurs when the two ends of a thermocouple are at different temperatures, which results in electricity flowing from the hot metal to the cold metal.

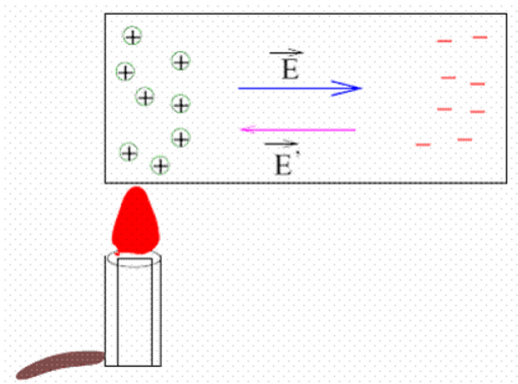
In the Peltier effect, a temperature difference is created between the junctions when electrical current flows across the terminals. In a copper-constantan thermocouple in which the current at the junction is flowing from copper (+) to constantan (-), heat will be absorbed. But if the direction of the current is reversed -- i.e., from constantan (-) to copper (+) -- it will result in heat liberation.

3. Thomson Effect

The Thomson effect relates to the heat transfer along the length of a rod. If a rod has two ends at different temperatures, and an electric current flows through the rod, heat is absorbed or released along the rod's length. The temperature of this heat is associated with the flow of current through the rod.

William Thomson (later well known as Lord Kelvin) discovered a third thermoelectric effect which provides a link between Seebeck effect and Peltier effect.

Thomson found that when a current is passed through an wire of single homogeneous material along which a temperature gradient exists, heat must be exchanged with the surrounding in order that the original temperature gradient may be maintained along the wire. (The exchange of heat is required at all places of the circuit where a temperature gradient exists.)



Thomson effect may be understood by a simple picture. A conductor has free charge carriers, which are, electrons in metals, electrons and holes in semiconductors and ions in case of ionic conductors. Consider a section of such a conductor whose one end is hotter than the other end.

Practical Application:

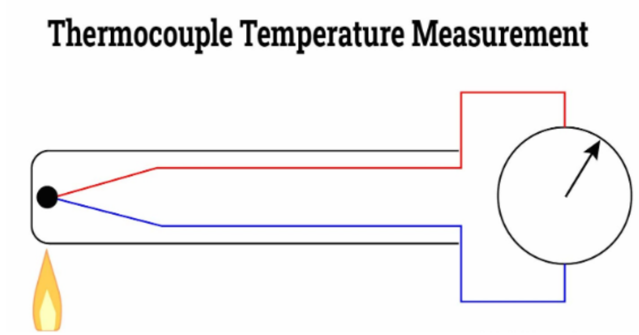
- In a thermocouple, one of the wires is connected to the body of the thermocouple and serves as the measuring junction (hot junction). This junction is exposed to the unknown temperature that needs to be measured.
- The second junction is attached to the body of a known temperature and acts as the reference junction (cold junction).
- The thermocouple measures the unknown temperature by comparing it to the known reference temperature. The difference in temperature between the two junctions generates an electromotive force (emf) according to the Seebeck effect.
- This emf is then used to calculate the temperature at the measuring junction, and the temperature information is typically displayed or transmitted for various applications.

In essence, the thermocouple's ability to generate a voltage difference (emf) due to the temperature difference between the two junctions is what allows it to measure temperature accurately. This measurement principle is based on the combined effects of Seebeck, Peltier, and Thomson, and it is widely used in various temperature measurement and control applications.

Thermocouple

1. Basic Principle:

A thermocouple is a temperature sensor that operates on the Seebeck Effect, which states that when two dissimilar metals are joined at a point (the junction), they will generate a small voltage when the temperature at the junction changes.



Thermocouple assemblies are designed for use in harsh, severe, and stressful environments. The choice of what thermocouple to use depends on the temperature range, ambient atmosphere, and the type of media. The specific size and shape of a thermocouple is determined by the application and the required accuracy and speed of response.

2. Construction:

- A thermocouple is constructed by joining two wires made from different metals to form a junction. The point where these wires are joined is where the temperature measurement takes place.

3. Voltage Generation:

- When there is a temperature difference between the junction (where the dissimilar metals meet) and the rest of the wires, a voltage is produced due to the Seebeck Effect. This voltage is directly proportional to the temperature difference and the characteristics of the metals used in the thermocouple.

4. Measurement Device:

- The voltage generated at the junction is then measured by a dedicated measuring device, often referred to as a thermocouple meter or thermometer. This device is designed to convert the voltage into a temperature reading.

5. Monitoring Temperature:

- Thermocouples are widely used for monitoring temperature in various processes and equipment. The temperature change at the junction causes a change in voltage, which is translated into a temperature reading on the measuring device.

6. Safety and Monitoring:

- Thermocouples serve as crucial safety and monitoring gauges in many applications. They are especially valuable in industrial settings, scientific research, and any situation where accurate temperature measurement is essential for maintaining processes and ensuring safety.

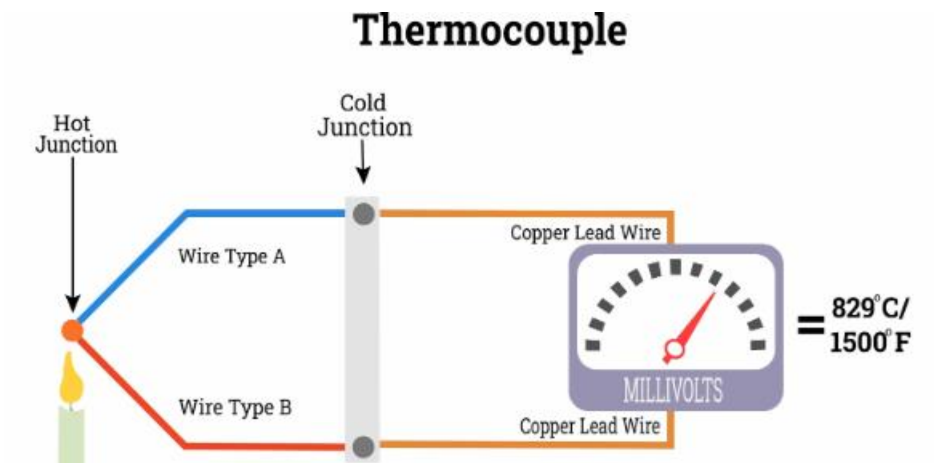
7. Temperature Display:

- The measuring device connected to the thermocouple displays the temperature change, providing real-time information about the monitored environment. The image below demonstrates this process, where an increase in temperature at the junction results in a change in the temperature displayed on the gauge.

How a Thermocouple Works

1. Thermocouple Circuit:

A thermocouple consists of two dissimilar wires, denoted as A and B, that are joined to form a junction. The two junctions are intentionally kept at different temperatures. This temperature difference is essential for the thermocouple to function.



2. Electron Movement and Temperature Gradient:

When two dissimilar metals are joined at the junctions of the thermocouple and are exposed to different temperatures, a flow of electrons is generated. Electrons move along the wire from the hotter junction to the cooler junction, creating a temperature gradient along the wire. This flow of electrons converts heat into electrical energy. This principle, discovered by scientists Volta and Seebeck, is fundamental to the operation of a thermocouple.

3. Generation of Millivolt Signal:

If the junctions of the thermocouple are at different temperatures, a unique millivolt signal is generated. This signal is specific to the pair of conductor materials used in the thermocouple and is defined in international standards (e.g., IEC 1977). Thermocouples manufactured to these standards are interchangeable, regardless of their origin.

4. Cold Junction Compensation:

For accurate temperature measurement, a thermocouple requires a cold junction compensation. This compensation is achieved by keeping the two ends of the thermocouple at the same temperature while the hot junction (the one being measured) is compared to the cold junction (the reference). The reference temperature can be set using an ice or water bath, and it acts as the baseline for temperature measurement.

5. Response Time and Sensitivity:

- The response time of a thermocouple depends on the thickness of the wire. Thicker thermocouple wires can measure higher temperatures but with a slower response time.

6. Electrical Measurement and Instrumentation:

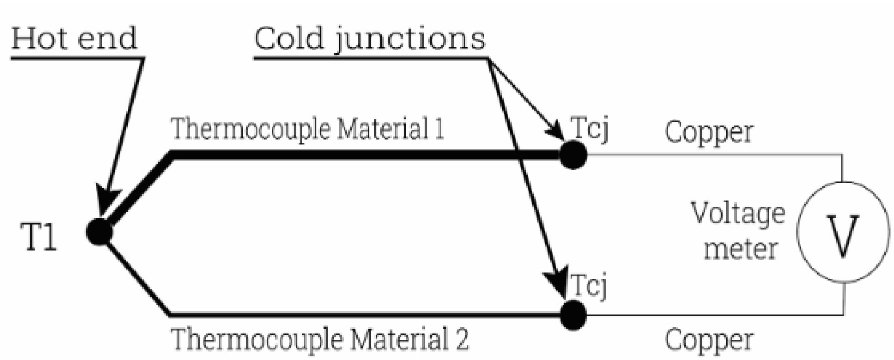
- If the temperatures at the junctions of a thermocouple are the same, an equal and opposite electromotive force (EMF) is generated at the junctions, resulting in zero current flow through the circuit. However, if the junctions have different temperatures, the EMF will not be zero, and current will flow through the circuit. The magnitude and direction of the EMF depend on the metals used and the temperature difference between the two junctions. A meter is used to measure this EMF, which can be amplified and interpreted as a temperature reading.

7. Voltage Measurement:

- The EMF generated in a thermocouple circuit is very small, typically in millivolts. Highly sensitive instruments are required to determine this small voltage. Measuring instruments are used to amplify the millivolt signal, interpret the voltage as a temperature reading, and display the result. Common instruments for this purpose include galvanometers and voltage balancing potentiometers, with potentiometers being more commonly used.

8. Cold Junction Compensation and Reference Temperature:

- To make an absolute temperature measurement, a thermocouple must be referenced to a known temperature, such as freezing (0°C or 32°F). The hot junction serves as the measuring assembly, while the cold junction acts as the reference. A cold junction compensation chip is typically located at the reference junction. The cold junction can be influenced by ambient air temperature, so it may vary. To maintain a constant reference temperature, the cold junction can be fixed by immersing it in water or ice.



9. Calibration and Adjustment:

- Ambient air can influence the reference temperature. To account for this, a reference junction compensation device can be used for calibration and adjustment, ensuring accurate temperature measurements.

Thermocouple Types

Two dissimilar metals used to create a thermocouple can be of varied types.

Different metals exhibit different properties, and the hot junction formed between these two metal wires defines the thermocouple.

To yield better results, scientists and researchers have standardized some metal combinations and segregated them as thermocouple types. Primarily there are eight types of thermocouples: B, E, J, N, K, R, T, and S type.

Thermocouples	Temperature Range (°C)
B Type	1370 to 1700
E Type	0 to 870
J Type	0 to 760
K Type	95 to 1260
N Type	650 to 1260
R Type	870 to 1450
S Type	980 to 1450
T Type	-200 to 370

B-Type Thermocouple

The alloy combination is of Platinum (6% Rhodium) and Platinum (30% Rhodium). This thermocouple exhibits a temperature range between 1370 to 1700 °C. It is mainly used in applications executed at extremely high temperatures, such as glass production. Click here for Data Sheet!

E-Type Thermocouple

Chromel and Constantan are the alloys that form an E-type thermocouple. The temperature range is between 0 to 870 °C. This thermocouple does not focus on the oxidation in the atmosphere and can be used in an inert environment. However, they need to be protected against the sulfurous environment. They are commonly used in power plants. Click here for Data Sheet!

J-Type Thermocouple

J type of thermocouple is formed with Iron and Constantan. 0 to 760 °C is its temperature range. Owing to the low-temperature range of the thermocouple, its life span reduces in high temperatures. J types thermocouple is best suited for vacuum and inert environment. Injection molding is one of the most common applications of such types of the thermocouple. Click here for Data Sheet!

K-Type Thermocouple

Chromel and Alumel form a K-type thermocouple. The temperature range is between 95 and 1260 °C. The neutral or oxidizing environment is best suited for these types of the thermocouple. It generates an EMF variation below 1800°F due to hysteresis, which restricts its use in an inert and oxidizing environment below this temperature. They are most commonly used in refineries. Click here for Data Sheet!

N-Type Thermocouple

This thermocouple is a combination of alloys Nicrosil and Nisil. The temperature range is between 650 to 1260 °C. Unlike K-type thermocouples, the N-type thermocouple offers very high resistance for degradation due to green rot and hysteresis. They are most commonly used in refineries and petrochemical industries. Click here for Data Sheet!

R-Type Thermocouple

A combination of Platinum (13% Rhodium) and Platinum forms R type thermocouple. The temperature range is between 870 to 1450 °C. It is costlier than S type thermocouple as it contains a higher percentage of Rhodium. Its high accuracy and stability make it an ideal thermocouple to used in Sulfur recovery units. Click here for Data Sheet!

S-Type Thermocouple

It is a combination of Platinum (10% Rhodium) and Platinum. The temperature range is between 980 to 1450 °C. S type thermocouple is used in applications involving very high temperatures. This type is widely used across various l industries. Click here for Data Sheet!

T-Type Thermocouple

It is formed with Copper and Constantan. The temperature range is between -200 to 370°C. This type of thermocouple is suitable for the inert atmosphere as well as the vacuum. They are widely used as they generally resist decomposition even in a moist environment. They are commonly used in food production and cryogenics. Click here for Data Sheet!

RTD VS THERMOCOUPLE

Resistance temperature detector and thermocouple are both Temperature Measuring Instruments but are different in many ways.

A) Temperature measuring range: The RTDs have a low measuring range, whereas thermocouples can be used for high temperature, such as up to 1800°C.

B) Accuracy: RTDs are known to have relatively higher accuracy than a thermocouple at lower temperatures.

C) Sensitivity: RTDs are more sensitive and react faster to any temperature change than thermocouples due to the presence of cold junction compensation in thermocouples.

D) Drift: The design of the RTD sensor allows it to produce stable readings for a longer duration of time. RTD sensor drift is smaller when compared to Thermocouples.

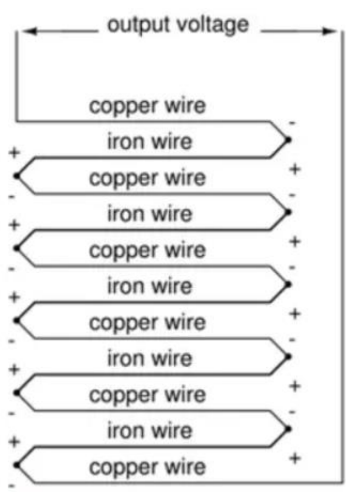
E) Cost: RTD sensors are more expensive than thermocouples, but installation and maintenance expenditure on thermocouples can make them costlier in the long term.

Thermopile

A thermopile is an electronic device designed to convert thermal energy into electrical energy. It typically consists of multiple thermocouples that are interconnected, often in a series arrangement but occasionally in parallel.

Thermocouples function by gauging temperature variations from their initial junction point to the point at which the thermocouple's output voltage is measured. They can be linked in series, forming thermocouple pairs with junctions positioned on either side of a thermal resistance layer. The resulting voltage from this thermocouple pair is directly proportional to the temperature difference across the thermal resistance layer and the heat flow through it. By incorporating additional thermocouple pairs in series, the voltage output magnitude can be enhanced. Thermopiles can be fabricated with a single thermocouple pair, which comprises two thermocouple junctions, or with multiple thermocouple pairs.

A thermopile is an array of thermocouples that are connected in series. Each thermocouple consists of two distinct materials with substantial thermo-electric power and opposite polarities. These thermocouples are strategically positioned across the hot and cold areas of a structure, with the hot junctions effectively insulated from the cold junctions. Typically, the cold junctions are located on the silicon substrate to serve as an efficient heat sink. In the hot regions, a black body is present to absorb infrared radiation, thereby raising the temperature in proportion to the incident infrared's intensity. These thermopiles utilize two different thermoelectric materials that are situated on a thin diaphragm with low thermal conductance and capacitance.



Thermopile, composed of multiple thermocouples in series. If both the right and left junctions are the same temperature, voltages cancel out to zero. However, if one side is heated and other side cooled, resulting total output voltage is equal to the sum of junction voltage differentials.

A thermopile is an assembly of multiple thermocouples connected in series. When a thermopile contains N thermocouples, its output voltage is N times larger than that of a single thermocouple. This configuration enhances the sensitivity of the transducer. By using a sufficient number of elements in the thermopile, a significant voltage can be generated, making it suitable for controlling other processes. Thermopiles are often employed in measuring heat flux.

It's important to note that thermopiles don't respond to absolute temperature; instead, they generate an output voltage that is proportional to a temperature difference or gradient.

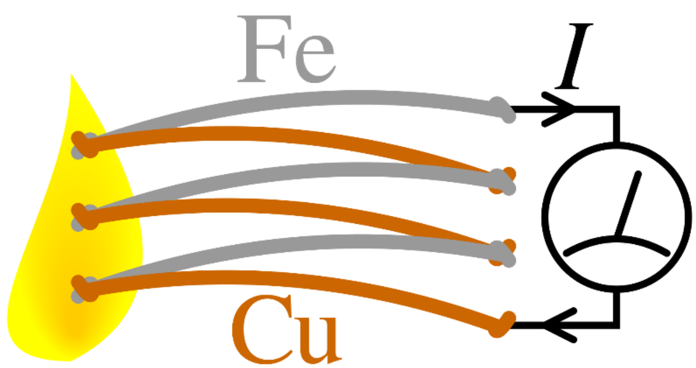
Thermopiles find various applications in temperature measurement devices, such as the infrared thermometers used in medical settings to measure body temperature. They are also utilized in thermal accelerometers to gauge the temperature profile within a sealed sensor cavity. In addition, thermopiles play a crucial role in heat flux sensors and safety controls for gas burners.

The typical output of a thermopile falls within the range of tens or hundreds of millivolts. Besides increasing the signal level, thermopiles can provide spatial temperature averaging.

Beyond temperature measurement, thermopiles are used to generate electrical energy from various heat sources, including heat from electrical components, solar radiation, radioactive materials, or combustion. This process also exemplifies the Peltier Effect, where electric current is involved in transferring heat energy from the hot to the cold junctions.

Thermoelectric Generator (TEG)

A thermoelectric generator (TEG), also known as a Seebeck generator, is a device that converts heat energy into electrical energy using the Seebeck effect. The Seebeck effect is a phenomenon where a voltage is generated when there is a temperature difference between the two ends of a conductor. TEGs are often used to capture waste heat and convert it into useful electrical power in various applications, including power generation in spacecraft and remote monitoring devices.



Construction:

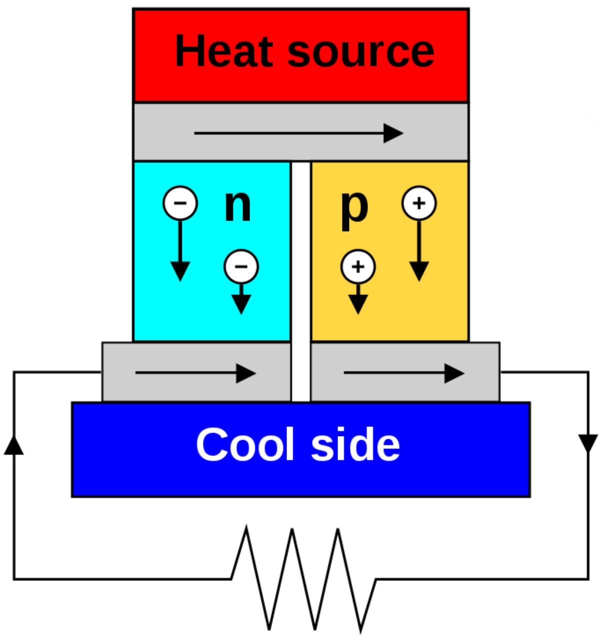
A typical thermoelectric generator consists of several thermoelectric materials, such as thermocouples, connected in series. Each thermocouple comprises two different types of semiconductors or thermoelectric materials, typically made of bismuth telluride. These materials have the property that they can generate a voltage when exposed to a temperature gradient.

The thermocouples are arranged in a way that one end is exposed to a heat source, while the other end is kept at a lower temperature. The temperature gradient between the two ends of each thermocouple is essential for the generation of electricity.

The thermocouples are usually mounted on a substrate, and the entire assembly is enclosed in a protective casing. Heat sinks or fins may be attached to the hot side to help dissipate excess heat and maintain a temperature difference.

Working Principle:

The working principle of a thermoelectric generator is based on the Seebeck effect, which is a thermoelectric phenomenon. When a temperature difference exists between the two junctions of a thermocouple (one hot and one cold), it creates a voltage across the junctions. This voltage drives a flow of electrical current through an external circuit connected to the thermocouples.



Here's a step-by-step explanation of how a TEG works:

1. **Exposure to Temperature Gradient:** One side of the thermocouple is exposed to a heat source, while the other side is kept at a lower, constant temperature. The temperature difference creates a thermal gradient across the thermocouple.
2. **Generation of Voltage:** Due to the Seebeck effect, a voltage is generated across the two junctions of the thermocouple. The magnitude of this voltage is proportional to the temperature difference.
3. **Electrical Current Flow:** The generated voltage drives an electrical current to flow through an external load or circuit connected to the thermocouple. This flow of electrons constitutes the electrical output of the TEG.
4. **Conversion of Heat to Electricity:** As long as the temperature gradient is maintained and there is a heat source, the TEG continues to convert heat energy into electrical energy. The electrical power output can be used to power electronic devices or charge batteries.

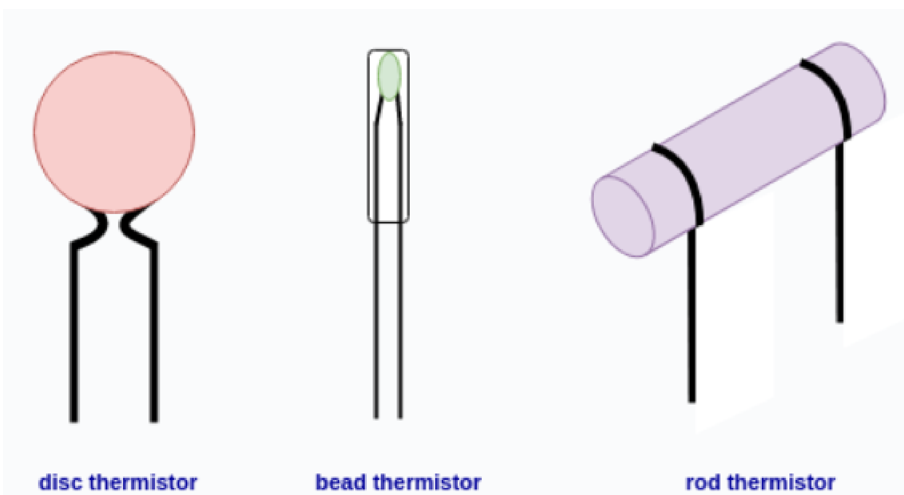
The efficiency of a thermoelectric generator depends on the choice of thermoelectric materials, the temperature gradient, and the design of the generator. TEGs are used in various applications to harness waste heat, such as in automotive exhaust systems, industrial processes, and remote power generation in challenging environments.

Thermistor

A thermistor is a type of temperature sensor that uses the electrical resistance of certain materials to measure temperature. It is a widely used device in various applications, from temperature monitoring in electronics to thermal control systems. Thermistors are known for their sensitivity to temperature changes and are commonly used for precision temperature measurement. There are two main types of thermistors: NTC (Negative Temperature Coefficient) and PTC (Positive Temperature Coefficient).

Construction:

The basic construction of a thermistor consists of a ceramic or polymer material that has been mixed with a specific type of metal oxide. This mixture is then sintered or pressed into a small bead, disc, or chip shape, depending on the intended application. The metal oxide content and the specific ceramic or polymer material used determine the thermistor's electrical and thermal characteristics.



Working Principle:

The working principle of a thermistor is based on its temperature-dependent electrical resistance. The resistance of a thermistor changes in response to temperature variations. The two main types, NTC and PTC thermistors, exhibit opposite resistance-temperature relationships:

1. **NTC (Negative Temperature Coefficient) Thermistor:**
    - In an NTC thermistor, as the temperature increases, the electrical resistance decreases.
    - The relationship between resistance (R) and temperature (T) is inversely proportional, giving it a "negative" coefficient.
    - NTC thermistors are often made of semiconductor materials, which exhibit a significant change in resistance with temperature.

2. **PTC (Positive Temperature Coefficient) Thermistor:**
    - In a PTC thermistor, as the temperature increases, the electrical resistance also increases.
    - The relationship between resistance and temperature is directly proportional, resulting in a "positive" coefficient.
    - PTC thermistors are typically constructed using ceramic materials with special properties.

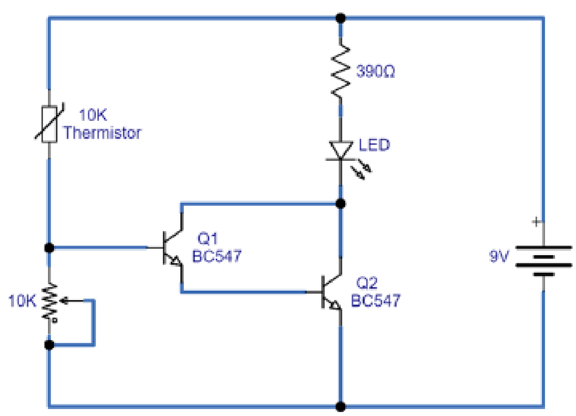
Operation: When a thermistor is exposed to a temperature change, its electrical resistance responds accordingly. The underlying mechanism involves changes in the charge carrier concentration, lattice structure, or other properties of the thermistor material with temperature variation.

Here's how a thermistor works in practice:

1. **Temperature Measurement:** When the thermistor is exposed to a temperature change, the electrical resistance of the thermistor alters in line with its NTC or PTC characteristics.
2. **Voltage or Current Variation:** The change in resistance affects the voltage or current flowing through the thermistor.
3. **Signal Conditioning:** This varying voltage or current can be conditioned and measured by an external circuit or microcontroller.
4. **Temperature Calculation:** The resistance-temperature relationship of the thermistor is known, allowing the temperature to be calculated based on the measured resistance.

Thermistors are commonly used in temperature control systems, temperature compensation, and temperature monitoring in a wide range of applications. They are highly versatile and provide accurate temperature readings due to their sensitive response to temperature changes.

Applications of Thermistors



Components:

1. **Thermistor:** The thermistor is a temperature-sensitive resistor whose resistance changes with temperature. In this circuit, it acts as a temperature sensor.

2. **Two Transistors:** The two transistors are typically connected in a Darlington configuration, where one transistor amplifies the current for the other. They serve as a switching mechanism.

3. **LED:** The LED (Light Emitting Diode) is the output indicator. It lights up when the circuit is active.

4. **Battery:** The battery provides the power source for the circuit.

Working Principle:

1. **Initial State (Cool Temperature):** When the temperature is cool, the thermistor has a relatively high resistance. This high resistance restricts the current flow through the thermistor.

2. **Transistor State:** The high-resistance thermistor keeps the base current of the first transistor (Q1) low, which, in turn, keeps Q1 in the off state. As a result, there's no current flow through the collector of Q1.

3. **Transistor Amplification:** The collector of Q1 is connected to the base of the second transistor (Q2). Since there's no current flowing through the collector of Q1, it also keeps Q2 in the off state.

4. **LED State:** With both transistors off, the LED is not illuminated, and the circuit remains in its off state.

5. **Temperature Increase:** When the ambient temperature increases (e.g., due to a change in the environment), the thermistor's resistance decreases.

6. **Transistor Activation:** As the thermistor's resistance decreases, it allows more current to flow into the base of Q1, turning it on. Q1 then amplifies this current and allows current to flow into the base of Q2, turning it on as well.

7. **LED State Change:** With Q2 turned on, current can flow from the battery through Q2 and the LED, illuminating the LED.

8. **Temperature Control:** The circuit acts as a temperature-controlled switch. When the temperature decreases, the thermistor's resistance increases, turning off both transistors and the LED. When the temperature increases, the thermistor's resistance decreases, turning on both transistors and the LED.

This circuit provides a simple temperature-dependent switch where the LED indicates the circuit's state. When the temperature exceeds a certain threshold, the LED turns on, and when the temperature falls below that threshold, the LED turns off. It's a basic example of a temperature-sensitive control system.

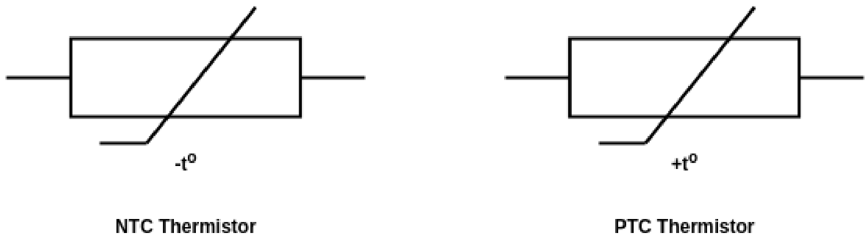
Types of Thermistors

The two basic types of thermistors available are the NTC and PTC types.

NTC Thermistor

NTC stands for Negative Temperature coefficient. They are ceramic semiconductors that have a high Negative Temperature Coefficient of resistance. The resistance of an NTC will decrease with increasing temperature in a non-linear manner.

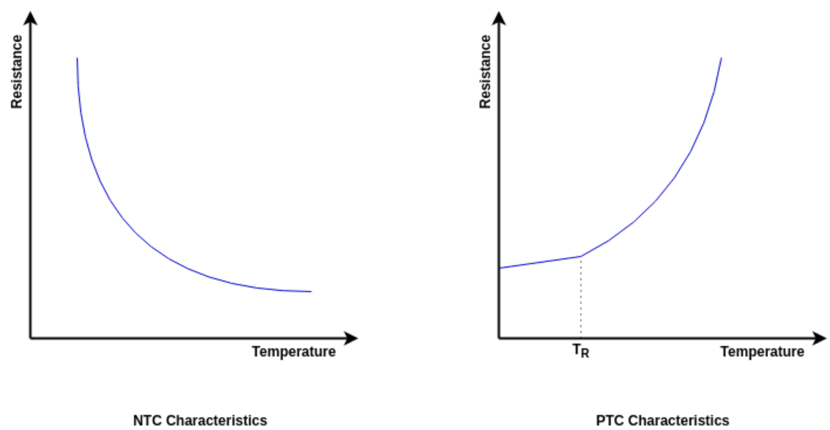
Circuit symbols of NTC and PTC thermistors are shown in the following figure.



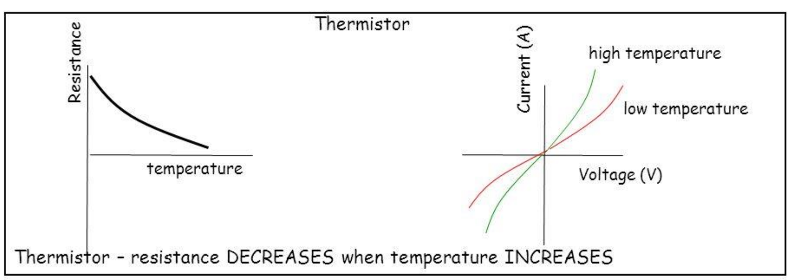
PTC Thermistor

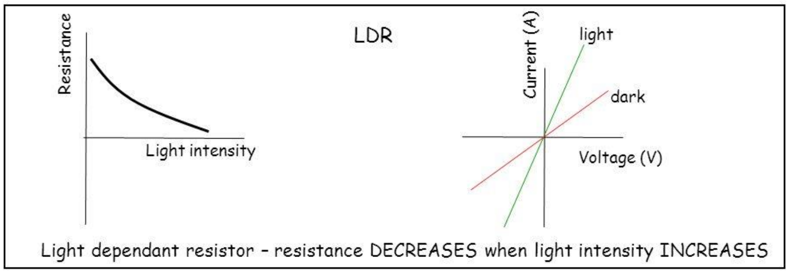
PTC thermistors are Positive Temperature Coefficient resistors and are made of polycrystalline ceramic materials. The resistance of a PTC will increase with increasing temperature in a non-linear manner. The PTC thermistor shows only a small change of resistance with temperature until the switching point(T_R) is reached.

The temperature resistance characteristics of an NTC and a PTC is shown in the following figure.



Characteristics of Thermistors





Advantages of thermistors

- Less expensive.
- More sensitive than other sensors.
- Fast response.
- Small in size.

Dis-advantages of thermistors

- Limited Temperature range.
- Resistance to temperature ratio correlation is non-linear.
- An inaccurate measurement may be obtained due to the self-heating effect.
- Fragile.

Applications of thermistors

NTC Thermistor Application

- Digital Thermostats.
- Thermometers.
- Battery pack temperature monitors.
- In-rush-current limiting devices

PTC Thermistor Application

- Over-current protection
- In-rush-current protection

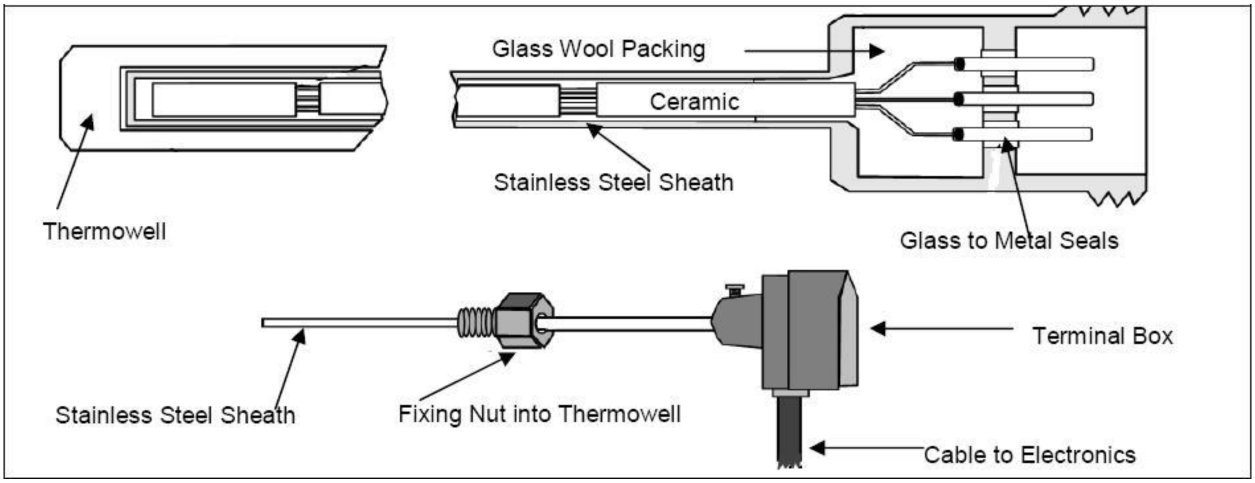
Resistance Temperature Detector (RTD)

An RTD, which stands for Resistance Temperature Detector, is a passive temperature sensor that relies on the concept that the electrical resistance of a metal undergoes alterations with temperature variations. As electrical current traverses through the sensor's element or resistor, it generates a specific resistance value. This resistance value is then quantified by a connected instrument, which interprets it in relation to temperature, taking into account the resistance traits of the RTD sensor.

When the temperature of a metal increases, its resistance to the flow of electrical current also increases. RTD sensors are designed to gauge the temperature of substances that exhibit a consistent alteration in resistance as their temperature fluctuates. These sensors are favored for their precision, consistency, and reliability.

Construction

An RTD (Resistance Temperature Detector) sensor consists of several key components:



1. **Sensing Element:** The heart of an RTD sensor is the sensing element, which is typically made of a pure metal or a platinum alloy. Platinum is commonly used due to its excellent linearity and stability over a wide temperature range. The sensing element is a fine wire or thin film of the chosen material. Its electrical resistance changes predictably with temperature variations, which forms the basis for temperature measurement.

2. **Protective Sheath:** To shield the sensing element from the environment, RTD sensors have a protective sheath. This sheath is usually made of stainless steel or other materials that can withstand the conditions of the application. The protective sheath ensures that the sensing element remains isolated from the process fluid or gas being measured and protects it from physical damage.

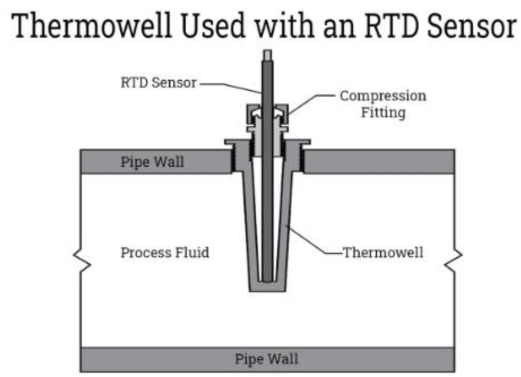
3. **Termination Wires:** RTD sensors have termination wires that connect the sensing element to external measurement and recording devices. These wires are typically made of materials like copper or platinum, and they transmit the electrical resistance of the sensing element to the measuring instrument.

4. **Insulating Material:** To maintain electrical isolation and prevent short circuits, insulating materials are used to separate the sensing element from the protective sheath and termination wires.

The construction process involves placing the sensing element within the protective sheath, ensuring it is well-insulated and securely positioned. The termination wires are connected to the sensing element, and the entire assembly is sealed to protect it from the environment. The design and materials used in the construction of RTD sensors are chosen to ensure accuracy, stability, and reliability in temperature measurement applications.

Working Principle

An RTD (Resistance Temperature Detector) sensor operates based on the principle that the electrical resistance of a metal changes with temperature. Here's how it works:



1. **Resistance vs. Temperature:** Different metals exhibit a characteristic relationship between their electrical resistance and temperature. As the temperature of the metal increases, its electrical resistance also increases in a predictable and linear manner.

2. **Sensor Activation:** In an RTD sensor, a limited amount of DC (direct current) is passed through the sensor to activate it. It's essential to ensure that the current is not excessive to prevent overheating.

3. **Thermowell:** When installing the RTD sensor in an application, it is often placed within a thermowell. A thermowell is a closed-end tube that is installed in the process stream. The thermowell's role is to protect the sensor from the process environment, ensuring that it doesn't come into direct contact with the fluid or gas being measured. Instead, heat from the process is transferred to the thermowell wall, which, in turn, conducts the heat to the RTD sensor.

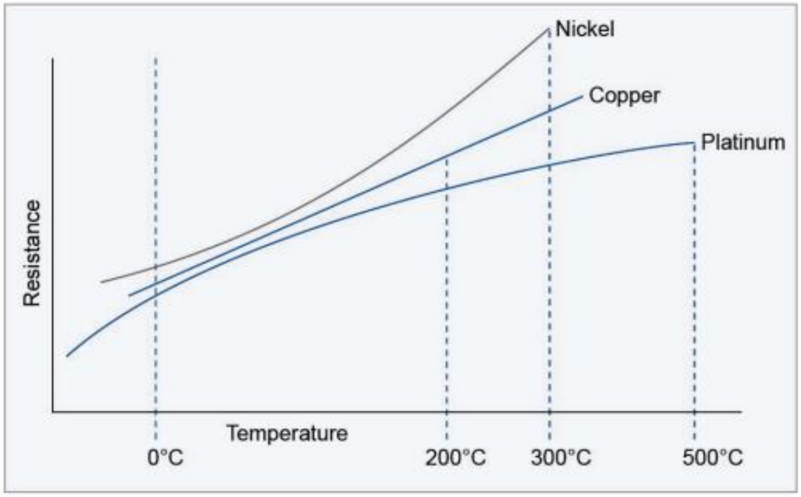
4. **Protective Sheath:** The RTD sensor typically has a protective sheath made of materials like stainless steel or Inconel. This sheath shields the sensing element from the surrounding environment and mechanical damage. It allows the measuring end of the sensor to be inserted directly into the area where temperature measurement is required.

5. **Termination Wires:** The RTD sensor is connected to a measuring and recording device via termination wires. These wires transmit the electrical resistance measurements to the recording instrument.

6. **Temperature Measurement:** As the RTD sensor is exposed to the temperature in the process, the electrical resistance of the metal sensing element changes accordingly. This change in resistance is recorded by the measuring device. By knowing the material's resistance-temperature relationship and measuring the resistance, the device can accurately determine the temperature.

Example: Consider a platinum RTD sensor, which is a common type of RTD. Platinum has a highly linear resistance-temperature relationship. At a certain reference temperature (usually 0°C), the resistance of the platinum is known. As the temperature changes, the resistance of the platinum element in the sensor changes proportionally.

Let's say at 0°C, the platinum resistance is 100 ohms. If the resistance is measured as 120 ohms at a particular temperature, the RTD sensor and the measuring device can deduce that the temperature is, for example, 100°C. This relationship is well-defined and allows for precise temperature measurement, making RTD sensors a preferred choice in various industries where accuracy and stability are critical.

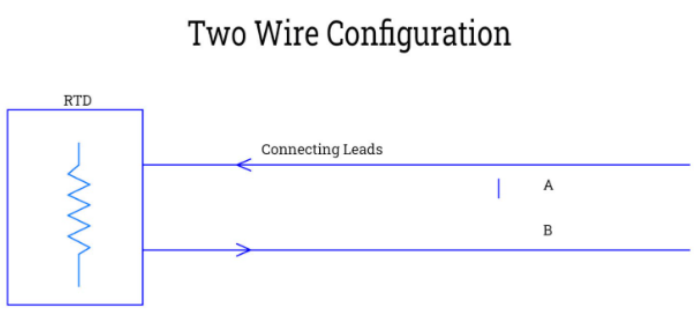


RTD Resistance versus Temperature

RTD Connections

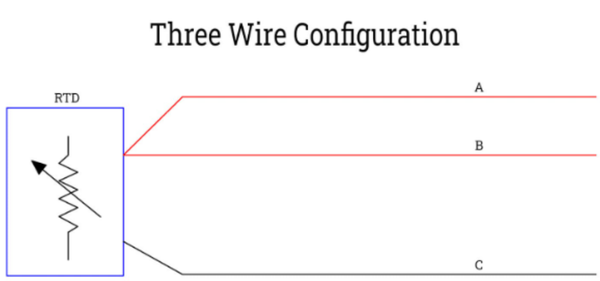
Two Wire RTD Sensors

The two wire type of RTD is the simplest circuit design. A single lead wire connects to each end of the element. The resistance in the circuit is calculated by measuring the resistance in the lead wires and connectors. This results in some degree error or readout that is higher than the actual measured temperature. This can be eliminated with calibration.



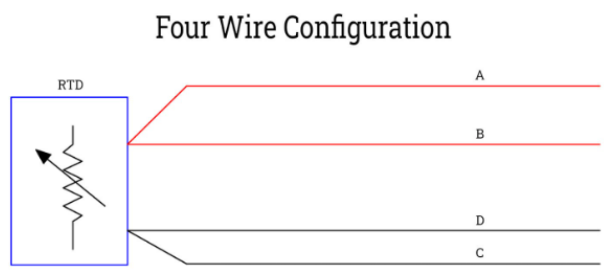
Three Wire RTD Sensors

The three wire configuration is the most used in industrial applications. Two wires are connected to one end of the sensor, A and B, and to the monitoring device. The third wire, C, is connected to the element. The three wires are of equal length, so their resistance is equal. The three wire configuration also has errors that have to be adjusted by calibration.



Four Wire RTD Sensors

The four wire configuration is the most complex, time consuming, and expensive to install but produces the most accurate and precise readings. DC current is provided through two leads, A and C. The voltage drop is measured by the other two leads, B and D. The voltage drop and current are known, making the resistance easy to read as well as the temperature across the system.



A variation of the four wire design has two red wires connected to the element with a white configuration that is looped. This design is a combination of the three and four wire methods.