TECHNICAL INFORMATION FOR SENSORS

Temperature Sensor Element Types

Minco supplies temperature sensors using the four main sensing element technologies: RTDs, Thermocouples, Thermistors, and Integrated Circuits. Each have their advantages, but all technologies can be incorporated into our varied sensor designs.

Resistance temperature detectors (RTDs)

A Resistance Temperature Detector (RTD) is a type of temperature sensor that measures temperature by correlating the resistance of the RTD element with temperature. RTDs are commonly used in industrial and laboratory temperature measurement applications due to their accuracy and stability.

An RTD sensing element consists of a wire coil or deposited film of pure metal. The element's resistance increases with temperature in a known and repeatable manner. RTDs exhibit excellent accuracy over a wide temperature range and represent the fastest growing segment among industrial temperature sensors.

Minco supplies RTDs to work with nearly any type of instrument option.

- Platinum RTDs with wide range of TCR (temperature coefficient of resistance)
    - Range from 0.00375 to 0.003927
    - 0.00385 (Minco element "PD") is most popular
- Nickel, copper, and nickel-iron RTD elements
- Non-standard resistance-temperature curves
- Base resistances from 10 to 10,000 ohms
- Thin film or wire wound constructions

RTD advantages include:

- Temperature ranges from -260 to 650°C (-436 to 1202°F).
- Repeatability and stability: The platinum resistance thermometer is the primary interpolation instrument used by the National Institute of Standards and Technology from -260 to 962°C. Ordinary industrial RTDs typically drift less than 0.1°C/year.
- Sensitivity: The voltage drop across an RTD provides a much larger output than a thermocouple.
- Linearity: Platinum and copper RTDs produce a more linear response than thermocouples or thermistors. RTD non-linearity can be corrected through proper design of resistive bridge networks.
- Low system cost: RTDs use ordinary copper extension leads and require no cold junction compensation.
- Standardization: Manufacturers offer RTDs to industry standard curves, most commonly 100 Ω platinum to EN60751 (Minco element code PD or PE).

Thermocouples

A thermocouple consists of two wires of dissimilar metals welded together into a junction. At the other end of the signal wires, usually as part of the input instrument, is another junction called the reference junction, which is electronically compensated for its ambient temperature.

Heating the sensing junction generates a thermoelectric potential (emf) proportional to the temperature difference between the two junctions. This millivolt-level emf, when compensated for the known temperature of the reference junction, indicates the temperature at the sensing tip.

Thermocouples are simple and familiar. Designing them into systems, however, is complicated by the need for special extension wires and reference junction compensation. Thermocouple advantages include:

Thermocouple advantages include:

- Extremely high temperature capability: Thermocouples with precious metal junctions may be rated as high as 1800°C (3272°F).
- Ruggedness: The inherent simplicity of thermocouples makes them resistant to shock and vibration.
- Small size/fast response: A fine-wire thermocouple junction takes up little space and has low mass, making it suitable for point sensing and fast response. Note, however, that many Minco RTDs have time constants faster than equivalent thermocouples.

Thermistors

A thermistor is a resistive device composed of metal oxides formed into a bead and encapsulated in epoxy or glass. A typical thermistor shows a large negative temperature coefficient. Resistance drops dramatically and non-linearly with temperature. Sensitivity is many times that of RTDs but useful temperature range is limited. Although rare, thermistors are also available with positive temperature coefficients. Linearized models are also available.

There are wide variations of performance and price between thermistors from different sources. Typical benefits are:

- Low sensor cost: Basic thermistors are quite inexpensive. However, models with tighter interchangeability or extended temperature ranges often cost more than RTDs.
- High sensitivity: A thermistor may change resistance by tens of ohms per degree temperature change, versus a fraction of an ohm for RTDs.
- Point sensing: A thermistor bead can be made the size of a pin head for small area sensing.

Integrated Circuits (IC)

An IC chip is a silicon-based temperature sensor that produces an output current proportional to absolute temperature. Due to the reduced temperature range, when compared to RTDs and Thermocouples, IC sensors are traditionally used on circuit boards and other electronics. These sensors offer analog or digital outputs with modest accuracy at a low cost.

Typical benefits are:

- Low sensor cost: Integrated Circuit sensors can be inexpensive if temperature range and accuracy requirements are not severe.
- Linear output: The sensor signal is adjusted on the Integrated Circuit itself. This can simplify electronic design.

TCR (Temperature Coefficient of Resistance)

TCR differentiates RTDs by their resistance/temperature curves. Sometimes called alpha (α), it is specified in various ways by different manufacturers. In this guide TCR is the RTD's resistance change from 0 to 100°C, divided by the resistance at 0°C, divided by 100°C:

$$TCR(\Omega/\Omega/^{\circ}C) = \frac{R_{100^{\circ}C} - R_{0^{\circ}C}}{R_{0^{\circ}C} \times 100^{\circ}C}$$

For example, a platinum thermometer measuring 100 Ω at 0°C and 139.11 Ω at 100°C has TCR 0.00391 Ω/Ω/°C:

$$TCR = \frac{139.11\Omega - 100\,\Omega}{100\,\Omega \times 100^{\circ}C}$$

For a copper RTD, 10 Ω at 25°C, TCR is:

$$TCR = \frac{12.897\,\Omega - 9.035\,\Omega}{9.035\,\Omega \times 100^{\circ}C} = 0.00427$$

Stated another way, TCR is the average resistance increase per degree of a hypothetical RTD measuring 1 Ω at 0°C. The most common use of TCR is to distinguish between curves for platinum, which is available with TCRs ranging from 0.00375 to 0.003927. The highest TCR indicates the highest purity platinum and is mandated by ITS 90 for standard platinum thermometers. There are no technical advantages of one TCR versus another in practical industrial applications. 0.00385 platinum is the most popular worldwide standard and is available in both wire-wound and thin-film elements. In most cases, all you need to know about TCR is that it must be properly matched when replacing RTDs or connecting them to instruments.

RTD Connections: 2 Wire, 3 Wire, 4 Wire?

Because an RTD is a resistance type sensor, resistance introduced by connecting copper extension wires between the RTD and control instrument will add to readings. Furthermore, this additional resistance is not constant but increases with ambient temperature. To estimate leadwire error in 2-wire circuits, multiply the total length of the extension leads times the resistance per foot in the table below. Then divide by the sensitivity of the RTD, given in the next two pages, to obtain an error figure in °C. For example, assume you have connected 100 feet of AWG 22 wires to a 100 Ω platinum RTD (PD element).

Lead resistance is:

$$R = (200\ ft.) \times (0.0165\ \Omega / ft.) = 3.3\ \Omega$$

Approximate error is:

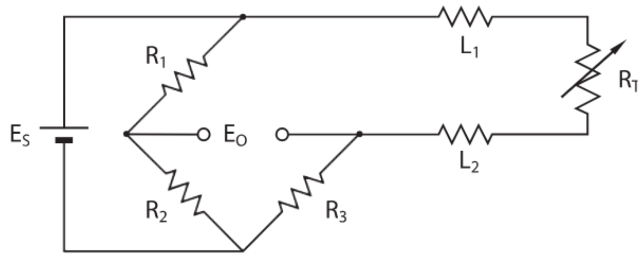
$$E = \frac{3.3\,\Omega}{0.385\,\Omega / {}^\circ C} = 8.6\,{}^\circ C$$

Copper Leadwire AWG	Ohms/ft. at 25°C
12	0.0016
14	0.0026
16	0.0041
18	0.0065
20	0.0103
22	0.0165
24	0.0262
26	0.0418
28	0.0666
30	0.1058

You can reduce leadwire error by:

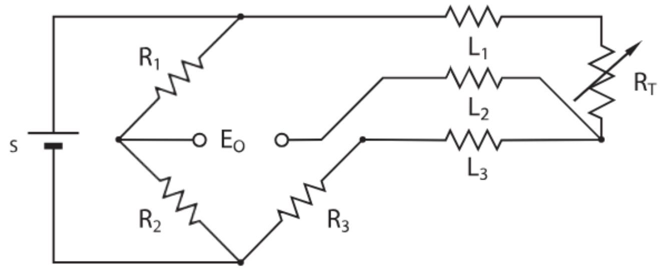
- Using larger gauge extension wires.
- Specifying an RTD with greater sensitivity; 1000 Ω instead of 100 Ω, for example.
- Employing a 3 or 4-wire resistance canceling circuit as shown at right. Common leads, connected to the same end of the sensing element, are the same color.
- Using a 2-wire current transmitter. Its linearized signal is immune to electrical noise as well as resistance and can maintain accuracy over runs of several thousand feet.

2-wire circuit



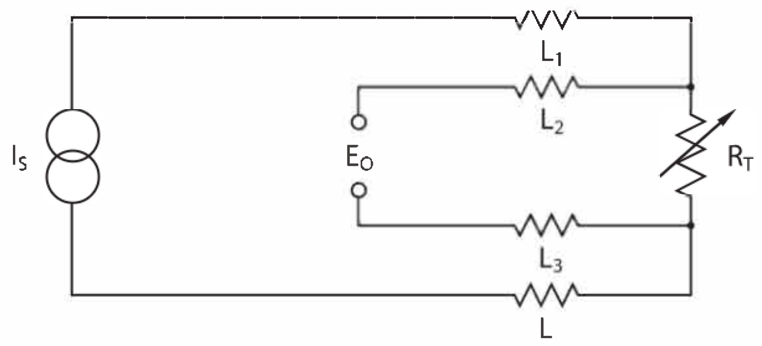
Shown above is a 2-wire RTD connected to a typical Wheatstone bridge circuit. ES is the supply voltage; EO is the output voltage; R_1, R_2, and R_3 are fixed resistors; and R_T is the RTD. In this uncompensated circuit, lead resistances L_1 and L_2 add directly to R_T.

3-wire circuit

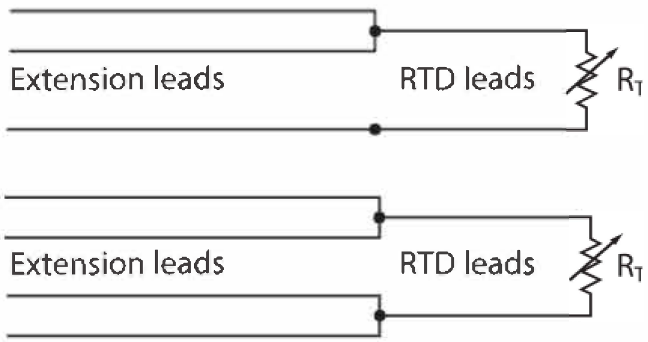


In this circuit there are three leads coming from the RTD instead of two. L_1 and L_3 carry the measuring current while L_2 acts only as a potential lead. No current flows through it while the bridge is in balance. Since L_1 and L_3 are in separate arms of the bridge, resistance is canceled. This circuit assumes high impedance at EO and close matching of resistance between wires L_1 and L_3. Minco matches RTD leads within 5%.

4-wire circuit



4-wire RTD circuits not only cancel leadwires but remove the effects of mismatched resistances such as contact points. A common version is the constant current circuit shown above. I_S drives a precise measuring current through L_1 and L_4. L_2 and L_3 measure the voltage drop across the RTD element. E_O must have high impedance to prevent current flow in the potential leads. 4-wire circuits may be usable over longer distances than 3-wire, but you should consider using a transmitter in electrically noisy environments.



If necessary you can connect a 2-wire RTD to a 3-wire circuit or 4-wire circuit, as shown to the above. As long as the junctions are near the RTD, as in a connection head, errors are negligible.