# Temperature Sensing & Control

COMPONENTS

Application & Technical Guide

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# RTD, Thermocouple, or Thermistor?

## Resistance temperature detectors (RTDs)

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. Their advantages include:

- **Temperature range:** Minco models cover temperatures 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-linearities 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 PM).

## 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:

**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. Some manufacturers offer thermistors with positive 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.

| | RTD | Thermocouple | Thermistor |
|---|---|---|---|
| Temp. range | -260 to 850°C (-436 to 1562°F) | -270 to 1800°C (-454 to 3272°F) | -80 to 150°C (-112 to 302°F) (typical) |
| Sensor cost | Moderate | Low | Low |
| System cost | Moderate | High | Moderate |
| Stability | Best | Low | Moderate |
| Sensitivity | Moderate | Low | Best |
| Linearity | Best | Moderate | Poor |
| Specify for | General purpose sensing<br>Highest accuracy<br>Temperature averaging | Highest temperatures | Best sensitivity<br>Narrow ranges (e.g. medical)<br>Point sensing |

# Choosing Sensor Elements

## RTD element types

Platinum is the most widely specified RTD element type due to its wide temperature range, stability, and standardization between manufacturers. Copper, nickel, and nickel-iron can offer comparable accuracy at lower cost in many applications.

| Element material | Temperature range | Benefits | Typical base resistance | Sensitivity (Avg. Ω/°C, 0 to 100°C) | TCR Ω/Ω/°C |
|---|---|---|---|---|---|
| Platinum | -260 to 650°C (-436 to 1202°F) | Greatest range<br>Best stability<br>Good linearity | 100 Ω at 0°C<br>1000 Ω at 0°C | 0.39<br>3.90 | 0.00375 to 0.003927 |
| Copper | -100 to 260°C (-148 to 500°F) | Best linearity | 10 Ω at 25°C | 0.04 | 0.00427 |
| Nickel | -100 to 260°C (-148 to 500°F) | Low cost<br>High sensitivity | 100 Ω at 0°C<br>120 Ω at 0°C | 0.62<br>0.81 | 0.00618 0.00672 |
| Nickel-iron | -100 to 204°C (-148 to 400°F) | Low cost<br>Highest sensitivity | 604 Ω at 0°C<br>1000 Ω at 70°F<br>2000 Ω at 70°F | 3.13<br>4.79<br>9.58 | 0.00518 to 0.00527 |

## Temperature Coefficient of Resistance (TCR)

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:

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

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:

$$\text{TCR} = \frac{139.11\Omega - 100\Omega}{100\Omega \times 100°C}$$

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

$$\text{TCR} = \frac{12.897\Omega - 9.035\Omega}{9.035\Omega \times 100°C} = 0.00427$$

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 and thermistor interchangeability

The tables below show temperature tolerance — the allowable deviation from nominal curves — for RTDs and thermistors in this guide. Minco can supply sensors with tighter overall tolerance, or with the narrowest tolerance at a point other than 0°C.

| Temperature °C | Interchangeability | | | | | | |
|---|---|---|---|---|---|---|---|
| | Platinum RTD | | | | | | |
| | 0.06% at 0°C (Class A) | 0.1% at 0°C (Class B) | 0.22% at 0°C | 0.36% at 0°C | 0.5% at 0°C | 0.1% at 70°F | 0.24% at 70°F |
| -200 | ±0.55°C | ±1.3°C | | | ±2.1°C | | |
| -100 | ±0.35°C | ±0.8°C | ±1.3°C | | ±1.7°C | | |
| 0 | ±0.15°C | ±0.3°C | ±0.5°C | ±0.9°C | ±1.3°C | ±0.3°C | ±0.7°C |
| 20 | ±0.19°C | ±0.4°C | ±0.7°C | ±1.3°C | ±1.6°C | ±0.3°C | ±0.6°C |
| 100 | ±0.35°C | ±0.8°C | ±1.8°C | ±2.3°C | ±2.9°C | ±0.7°C | ±1.1°C |
| 200 | ±0.55°C | ±1.3°C | ±3.1°C | ±3.7°C | ±4.4°C | ±1.3°C | ±1.8°C |
| 260 | ±0.67°C | ±1.6°C | ±3.7°C | ±4.6°C | ±5.5°C | | |
| 300 | ±0.75°C | ±1.8°C | | | | | |
| 400 | ±0.95°C | ±2.3°C | | | | | |
| 500 | ±1.15°C | ±2.8°C | | | | | |
| 600 | ±1.35°C | ±3.3°C | | | | | |
| 700 | | ±3.8°C | | | | | |
| 800 | | ±4.3°C | | | | | |
| 850 | | ±4.6°C | | | | | |

| Temperature °C | Interchangeability | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Copper RTD | | Nickel RTD | | Nickel-iron RTD | | | | | Thermistor |
| | ±0.2% at 25°C | ±0.5% at 25°C | ±0.3% at 25°C | ±0.5% at 0°C | ±0.26% at 0°C | ±0.5% at 0°C | ±0.5% at 25°C | ±0.12% at 70°F | ±0.25% at 70°F | ±0.1% at 0°C |
| -100 | ±1.5°C | ±2.2°C | | | | ±2.5°C | ±2.9°C | | | |
| 0 | ±0.7°C | ±1.5°C | ±0.5°C | ±0.8°C | ±0.6°C | ±1.1°C | ±1.4°C | ±0.5°C | ±1.4°C | ±0.2°C |
| 20 | ±0.5°C | ±1.3°C | ±0.8°C | ±1.2°C | ±0.8°C | ±1.4°C | ±1.2°C | ±0.3°C | ±0.7°C | ±0.2°C |
| 100 | ±1.5°C | ±2.5°C | ±1.8°C | ±2.2°C | ±1.7°C | ±2.4°C | ±2.2°C | ±1.1°C | ±2.0°C | ±0.3°C |
| 150 | ±2.2°C | ±3.3°C | ±2.5°C | ±3.0°C | ±2.3°C | ±3.1°C | ±2.9°C | ±1.6°C | ±2.9°C | ±1.0°C |
| 200 | ±2.8°C | ±4.1°C | ±3.1°C | ±3.7°C | ±2.9°C | ±3.8°C | ±3.6°C | ±2.1°C | ±3.8°C | |
| 260 | ±3.6°C | ±5.1°C | ±3.4°C | ±4.0°C | | | | | | |

## Thermocouple limits of error per NBS (NIST) Monograph 175, based on ITS-90

| Junction type: | E (Chromel-Constantan) | J (Iron-Constantan) | K (Chromel-Alumel) | T (Copper-Constantan) |
|---|---|---|---|---|
| Limits of error: | ±1.7°C or ±0.5%<br>0 to 900°C | ±2.2°C or ±0.75%<br>0 to 750°C | ±2.2°C or ±0.75%<br>0 to 1250°C | ±1.0°C or ±0.75%<br>0 to 350°C |

## 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 on page 3, 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.) x (0.0165 Ω / ft.) = 3.3 Ω

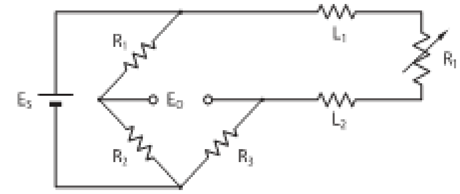
Approximate error is:

$$E = \frac{3.3\,\Omega}{0.39\,\Omega/°C} = 8.5°C$$

| 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 |

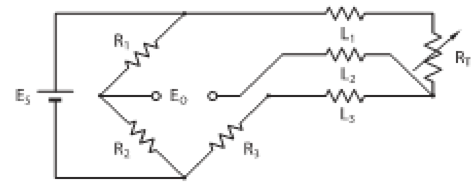
You can reduce leadwire error by:

- 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.



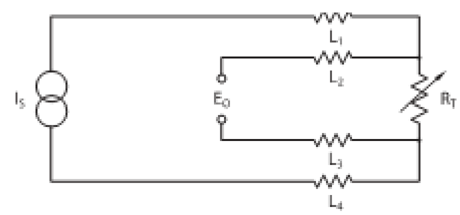

### 2-wire circuit

Shown above is a 2-wire RTD connected to a typical Wheatstone bridge circuit. ES is the supply voltage; EO is the output voltage; R1, R2, and R3 are fixed resistors; and RT is the RTD. In this uncompensated circuit, lead resistances L1 and L2 add directly to RT.




### 3-wire circuit

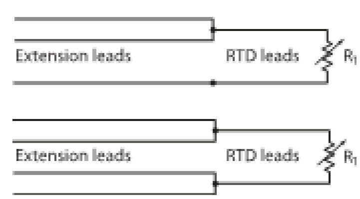
In this circuit there are three leads coming from the RTD instead of two. L1 and L3 carry the measuring current while L2 acts only as a potential lead. No current flows through it while the bridge is in balance. Since L1 and L3 are in separate arms of the bridge, resistance is canceled. This circuit assumes high impedance at EO and close matching of resistance between wires L1 and L3. 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. IS drives a precise measuring current through L1 and L4. L2 and L3 measure the voltage drop across the RTD element. EO 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 right. As long as the junctions are near the RTD, as in a connection head, errors are negligible.



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# Custom and Integrated Solutions

Minco designs and manufactures three different product lines, all coordinated in the same facility for faster, seamless integration that can decrease your time-to-market. This makes us unique in our ability to customize and integrate components into turnkey assemblies and complete solutions. All of our components can be designed, manufactured, and integrated to perfectly fit your application while providing matched system accuracy.

## Custom Solutions

Minco's customized products provide an affordable solution to meet your exact specifications. We work diligently to build our products with the greatest efficiency, quality, and accuracy to meet your critical standards and ensure ROI.

### Temperature Sensing & Control Solutions

- RTD and thermistor elements to match any TCR (temperature coefficient of resistance) curve
- Unlimited packaging options available to provide critical thermal response and perfectly fit your application
- Leadwire and cable options to meet your application parameters
- Custom transmitters, controllers, and monitors for accurate sensing solutions

### Thermal Solutions

- Thin and flexible, Thermofoil heaters provide critical temperature uniformity and rapid thermal response
- Profiled and multi-zone heaters put the heat exactly where you need it
- Limitless shape and size possibilities offer a precise fit in virtually any application
- Leadwire, flex circuit or solder pad terminations offer easy integration into your assembly

### Flex Circuit Solutions

- Single sided, double sided, multilayer and rigid-flex circuits with high layer counts meet your interconnection needs
- Fine lines, circuit forming and selective bonding add to space and weight savings
- Stiffeners, pins, connectors and full turnkey electronics packaging offer efficient integration into your application
- Inductive communication coils can be integrated with flex circuits to provide critical communication assemblies

## Integrated Solutions

All of Minco's products - Thermofoil Heaters, Flex Circuits, Sensors, Instruments - can be integrated into a single component for greater efficiency. Whether it is a complete thermal optimization system or interconnection application, Minco's design engineers will partner with you to ensure success.

With integrated solutions there is less work on your end, and less that can go wrong. Our integrated assemblies truly lower your total cost of ownership (TCO) because of less front end assembly, easy installation, and unparalleled quality and reliability.