

CRITERIA FOR TEMPERATURE SENSOR SELECTION OF T/C AND RTD SENSOR TYPES

*How to Select the Best Temperature Sensor for
Your Process Control Application*

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This is a comprehensive three part series that provides information for choosing an industrial temperature sensor from Thermocouple (T/C) and Resistance Temperature Detector (RTD) sensor types.

Part 1 of this series (8500-911) titled "[The Basics of Temperature Measurement Using Thermocouples](#)", takes a close look at thermocouples, their construction, and how they operate. That document reviewed three important scientific laws that govern the operation of thermocouples: The Law of Homogeneous Material, The Law of Intermediate Materials, and The Law of Successive or Intermediate Temperatures. We saw that choosing between thermocouple types gave consideration to the thermocouple materials, temperature range, sensitivity, and behavior in four primary application atmospheres (i.e. inert atmosphere, reducing atmosphere, oxidizing atmosphere, and operation in a vacuum). Some thermocouple types work better in certain atmospheres than others. Some thermocouples use non-magnetic materials, making them a better choice for temperature sensing near electric motors. Other thermocouple applications will favor T/C materials that are more stable and have better corrosion resistance. We also looked at measures of performance associated with thermocouples including accuracy, non-linearity, sensitivity, sensor drift or de-calibration, and response time. Part 1 also talked about thermocouple connection problems, T/C extension wire, cold junction compensation, lead resistance, thermal shunting, plus noise and common-mode voltage issues.

Part 2 of this series (8500-917), titled "[The Basics of Temperature Measurement Using RTD's](#)" looked similarly at the Resistance Temperature Detector (RTD), its construction, and how it operates. We saw that choosing one RTD type over another gave consideration to its physical construction, sensitivity, material and insulation, and temperature range. We also looked at the RTD Temperature Coefficient of Resistance (TCR) and its relationship to RTD sensitivity. Part 2 summarized two common polynomial expressions used to predict the resistance of an RTD: the Callendar-Van Dusen equation and its IEC751/ITS-90 derivative. Part 2 shows how the input wiring of the RTD is also an important consideration, and how it is used to accomplish lead-wire compensation, improve accuracy and common-mode noise rejection. Part 2 also showed how an RTD's insulation material often limits its useful temperature range to lower application temperatures. It also examined the role of lead resistance and how it can drive measurement error if not considered carefully. Part 2 also looked at RTD performance measures including accuracy, interchangeability, repeatability, stability/drift, and response time. It talked about application issues with RTD's, including corrosion and contamination, shock and vibration, insulation resistance, lead-wire resistance, self-heating error, meter loading, packaging and thermal transfer, and even thermoelectric effects.

This Part 3 will summarize and compare some common aspects of both sensors to help you choose between the two in your quest to find the best sensor for your particular industrial application. Part 3 relies heavily on information provided in Parts 1 and 2 and you should review Parts 1 and 2 before reading this material. You can download any of these documents and more, free of charge from our web site at www.acromag.com.

Thermocouples versus Resistance Temperature Detectors

Many users simply look to fill the basic needs of their application and do not worry much about their choice of temperature sensing technology. That is, they will make a selection based simply on temperature range and their own bias, perhaps based on their familiarity with a particular sensor type.

At a minimum, an informed sensor choice should first consider the following:

- ▶ Measurement range, including the range extensions of shutdown, startup, and process upset.
- ▶ The response time.
- ▶ The sensor stability, accuracy, and sensitivity in the application environment.

When we start to cross the boundaries between choosing one type of sensor over another, the optimum choice between thermocouple and RTD can be difficult. There is a lot of overlap between these sensors at the more popular lower end of the operating temperature range. So for sensors that cover the same operating range, and applications where response time is not a driving issue, plus stability, accuracy, and sensitivity are acceptable, we really have to drill deeper and compare characteristics between sensors to find the best fit for a given application. Table 1 below summarizes many of the comparative differences between thermocouple and RTD sensor types.

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Table 1: Comparison of Salient Features of RTD and T/C Temperature Sensors

Characteristic	Thermocouple (T/C)	Resistance Temperature Detector (RTD)
Measurement Range	Wide, -250°C to +2600°C	Narrower, -200°C to +850°C, often limited to a lower temperature by its insulation.
Output Signal	Voltage wrt difference in end-to-end temperature	Resistance change wrt actual temperature
Accuracy	Less accurate, 2-4°C typical	More accurate, up to 1°C typical
Long Term Stability	Fair, limited to shorter periods	Good, stable over long periods
Stability/Drift	Good, but more subject to drift	Excellent, better long-term stability
Sensitivity	Lower	Higher sensitivity
Interchangeability	Good	Excellent
Linearity	Fair linearity, special linearization generally required.	Better linearity, special linearization still required, but to a lesser degree
Self-Heating Error	No self-heating error	Some self-heating error, but low
Extension Cable	High effect, must match T/C type and is more expensive	Lower effect, can use different material, but ultimately limited by lead wire resistance
Response Time	Fast (≤ 0.1 seconds typical), but CJC has thermal lag	Slower (1 to 7 seconds typical)
Repeatability	Reasonable	Better & greater standardization
Hysteresis	Excellent	Good
Signal Strength	Low, prone to EMI	Higher, more EMI resistant
Vibration/Shock Resistance	Good resistance	Less resistant than T/C
Robustness/Ruggedness	Very good	Good
Sensor Dimensions	Very small to very large	Small to medium
Measurement Area	Small, single point-of-contact	Larger, whole element must contact, 1" typical
Fine Wire Diameter	Small down to 0.25mm diameter	Larger up to 3mm diameter
Reference Junction	Required and a significant source of measurement error. Usually requires a stable ambient at cold junction.	Not required and not a source of error
Excitation Required	Not required, self-powered	Yes, reference voltage or current source
Lead-Wire Resistance	High, but often mitigated by mating technology	Must be considered wrt maximum added resistance and potential resistive imbalance between leads
Cost	Less expensive	More expensive
Complexity	Very simple and less subject to mechanical stress	Physically larger and has a more complex construction making it more subject to mechanical stress
Calibration Ease	More difficult and adds CJC calibration	Less difficult, no CJC to contend with
Noise Immunity	Lower noise immunity but often mitigated by good wiring practice. Small signals and high impedance leads can easily pick up noise.	Better noise immunity than a T/C

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In general, if your application requires the highest accuracy, cost is not a concern, and your operating ambient is less than 800°C, then the choice of an RTD over a thermocouple sensor is probably the right one. The RTD is more accurate, more stable, more repeatable, and offers a more robust output signal with better sensitivity and linearity than a thermocouple. However, the RTD does have a narrower operating range with a lower maximum operating temperature, it is generally more expensive, and it does require excitation which might drive the need for an external power source (a Wheatstone bridge for example). Please review Part 2 of this series for other differentiating features of RTD sensors.

If you instead decide that a thermocouple is best for your application, perhaps because of its lower cost, wider temperature range, faster response time, and simpler construction, plus its many physical sizes and wider range of configurations available, then you might start by picking a Type K thermocouple until you can find a specific reason to choose another type. That is, type K is the most common and least expensive of available T/C types, and it also has a wide operating temperature range with high sensitivity. It is constructed from nickel-based metals which have good resistance to corrosion and are cheaper than the comparable platinum-based metals. So with this in mind, why would you choose anything else? Well, it does have one lead that is magnetic (the Red or negative lead), and this might not work well around electric motors. It is also vulnerable to sulfur attack and should not be used in sulfurous atmospheres. Please consult Part 1 of this series to review other differentiating characteristics between thermocouple types.

Other Points of Contrast Between the Thermocouple and the Resistance Temperature Detector

Although a thermocouple sensor system usually has a generally faster response time to changing temperature at its point of contact, it generally takes longer to reach thermal equilibrium after power is applied. This is largely due to the presence of cold junction compensation, which does not respond to temperature changes at the cold junction as quickly as the T/C junction responds to changes in contact temperature. The thermal lag of cold junction compensation might make a thermocouple a poor choice where its mating amplifier or cold junction is subject to rapid or quickly changing ambient temperatures. Further, the presence of cold junction compensation in the mating amplifier often makes it subject to the self-heating or warm-up of the measuring circuit itself, driving longer warm up periods for the measuring system to reach thermal equilibrium. Thus, applications where temperature measurement is done discontinuously, perhaps only during part of the day and then shut-down overnight, might favor the choice of an RTD sensor over that of a thermocouple.

If you are looking for a temperature sensor that requires the lowest possible current consumption, perhaps in an energy-harvesting application, or for use in a circuit that runs on batteries, then the use of a thermocouple might be a better choice, simply because the RTD sensor requires excitation to operate, typically in the range of about 1mA. While some RTD amplifiers run fine on less than 1mA of excitation current, it still may not be low enough to ensure long battery life.

If the distance between the measuring instrument and the sensor is very long, this might favor the use of a thermocouple over that of an RTD, because minimizing lead-wire resistance can be a big factor in long-distance RTD applications. In general, because you are reading the resistance of the sensor, you try to keep the sensor closer to the instrument such that lead wire resistance is not a negative factor. For long distance runs, some applications will use larger diameter lead wires to minimize lead resistance, but this also has the negative effect of potentially “heat-sinking” the sensor element and artificially reducing the measured temperature.

If reducing wiring or the number of terminal connections is important to your application, then this would again favor the use of thermocouples, which only require two connections to the measuring instrument or transmitter. Although two wire RTD sensors do exist, they are limited to short coupled distances because of the negative effect the uncompensated lead-wire resistance has on the measurement. For comparable or better performance, an RTD will require at least three wired connections per channel versus only two for the thermocouple. This could be a factor for high-density, high channel count installations.

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Whatever the material and construction, an RTD is still relatively bulky by comparison to the thermocouple, and as a result, cannot be used to measure temperature at a single point, like that of a thermocouple. But on the other hand, RTD technology provides an excellent means of measuring the average temperature over a surface by spreading the resistance wire over that surface, and this ability to average temperature over a surface area (or an immersion depth) will be more desirable for some applications.

The use of a platinum RTD sensor may be preferred when a temperature measurement accuracy of better than 1°F or 1°C is required. By comparison, thermocouple accuracy will be on the order of 2°C to 4°C, typical. However, for point-of-contact measurement at temperatures above about 800°C (the maximum temperature at which platinum RTDs can be used), a thermocouple is the better choice due to its higher rated operating temperature.

By now, you should realize that one type of sensor, thermocouple or RTD, is not always a better choice than the other. It really depends on your application and what characteristics you consider important to your application. You must always consider your operating environment and any potentially negative effects it may have on your choice of temperature sensor and measurement system.

About Acromag

Acromag is a leading manufacturer of [temperature transmitters](#) and [signal conditioners](#) for use with thermocouple and RTD sensors. These instruments convert the sensor input to a proportional 4-20mA DC current, DC voltage, [Modbus, Profibus, or Ethernet](#) signal to interface with a PC, PLC, DCS, or other control equipment.

Acromag has designed and manufactured measurement and control products for more than 50 years. They are an AS9100 and ISO 9001-certified international corporation with a world headquarters near Detroit, Michigan and a global network of sales representatives and distributors. Acromag offers a complete line of industrial I/O products including a variety of process instruments, signal conditioners, and distributed fieldbus I/O modules that are available with a 2-year warranty. Industries served include chemical processing, manufacturing, defense, energy, and water services.

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