Tips for temperature testing

Dale Cigoy, Keithley Instruments, Inc.

ENGINEERS have a wide choice of ways to measure temperature, including thermocouples (T/Cs), resistance temperature detectors (RTDs), thermistors, solid state monolithic (IC) temperature sensors, and infrared (IR) sensors, plus a few specialized methods like temperature-sensitive paint. Used appropriately, any of them will give useful results, but they must be chosen with care. This article will discuss ways to improve results when using T/Cs, RTDs, and thermistors.

The first thing to consider when selecting a temperature sensor is the range of temperatures to be measured. Other considerations include the accuracy desired, the need to replace sensors without recalibrating, the types of instruments required to interface to them, and the physical environment (for example, some RTDs are fragile and cannot withstand much shock or vibration). Let's look at some common sensors.

Thermocouples (T/Cs)

A thermocouple generates a small voltage that varies in a known way with the difference in temperature between its two junctions. While T/Cs are rugged and can cover a very wide temperature range (they are available to measure from –268°C to 2316°C (–450°F to 4200°F), they produce very small output voltages, so appropriate instrumentation must be used with them. T/Cs are nonlinear, and require specialized instrumentation, although many digital multimeters (DMMs) are now available to work with them.

T/C errors:

CJC (Cold Junction Compensation) is not configured or compensated—Thermocouples measure the difference in temperature between the hot junction (used for the actual measurement) and the cold or reference junction (at the instrument). If the temperature of the cold junction is not known or not compensated for (cold junction compensation) the temperature readings will be wrong.

Use of copper wire from T/C connection to measurement device—Connections between the T/C and the instrument should be made with the same kind of wire used for the T/C. In theory, you could use copper wire, but it would require controlling the temperature of all the wire, which is generally impractical.

Voltmeter is not sensitive or accurate enough to T/C measurements—Thermocouples produce outputs measured in microvolts, so the instrument used must be able to measure those low voltages. Some DMMs are designed to work with T/Cs.

Resistance temperature detectors (RTDs)

RTDs measure temperature by monitoring changes in the electrical resistance of metal wires or films. The wire used is usually platinum, although other metals, including nickel, a nickel/iron alloy, and copper are also available. Like T/Cs, RTDs are nonlinear, and must be compensated.

RTD errors

Self-heating not accounted for—An RTD must conduct a current in order to read temperature, and this current will heat up the sensor or RTD. The current through a Pt100 RTD, for example, must be kept below 1mA to avoid problems with self-heating, and the current must be even smaller for nickel or nickel/iron alloy RTDs.

Test lead compensation—The resistance of the test leads can have a great effect on the accuracy of an RTD temperature measurement, and when leads are longer than a few inches it is usually better to use a three-wire or four-wire (Kelvin) connection.

Using the wrong type of RTD for the temperature range—While a platinum wire RTD can be used from –240°C to 649°C (–400°F to 1200°F), and a platinum thin-film RTD from –196°C to 538°C (–320°F to 1000°F), a nickel RTD, with a larger output than a Pt unit, is limited to –350°C to 316°C (–212°F to 600°F). A nickel/iron alloy RTD, while it has a much larger output than a platinum RTD, is limited to –73°C to 204°C (–100°F to 400°F).

Using the wrong instrument—While an RTD can be exceedingly accurate, its output is small: for example, a 1°C temperature change will cause a resistance change of only 0.385Ω in a standard Pt100 RTD, so the measuring instrument must be able to measure small resistances with great accuracy.

Thermistors

Thermistors have larger outputs than RTDs, but their temperature range is more limited, their accuracy is less than that of RTDs, their interchangeability is poor to fair, and their long-term stability is poor. Thermistors are also nonlinear, so the instrumentation used with them must provide compensation.

Comparison of Common Temperature Sensor Types

Characteristic	Thermocouples	Resistive Temperature Detectors	Thermistors	Solid State Monolithic Temperature Sensors
General	Broad range; moderate accuracy	High accuracy and repeatability	High resolution	Easy to use. Digital or linear analog output
Range	–268°C to 2316°C (-450°F to 4200°F)	–240°C to 649°C (–400°F to 1200°F)	–73°C to 260°C (-100°F to 500°F)	–49°C to 150°C (-57°F to 300°F)
Accuracy	±1°C – 2°C	± 0.1°C – 0.2°C	±0.1°C – 0.2°C	±1°C – 3°C
Output Signal	Very low V	Slight R change	Wide R change	Low V or low I
Typical Applications	• Industrial • Food processing	• Burn-in • Aerospace • Laboratory monitoring • Pharmaceuticals • Automotive • Food processing	• Biological applications • Control systems • Measurement of environmental temps • Consumer devices	See thermistor applications
Notes	• Several types, each with specific useful temperature range • Non-linear output • Require cold junction compensation	• Relatively fragile • Non-linear ΔR vs. Δt • Require a resistive bridge circuit or 4-wire low ohms	• Relatively fragile • Non-linear ΔR vs. Δt • Require high-resolution ohms measurement	• Low level V or I output • Linear ΔV or ΔI vs. Δt • Digital output available • Require excitation

Thermistor errors

Self-heating not accounted for—A thermistor, like an RTD, must conduct a current in order to read temperature, and this current will increase its temperature. It's important to limit the excitation current to the smallest amount that will give a satisfactory output.

Inadequate temperature range—While a thermistor has a much larger output than an RTD or T/C, its operating temperature is generally limited to –73°C to 260°C (–100°F to 500°F).

Other common errors

Neglecting the thermal effect of leads—If a temperature sensor is connected with fairly thick wires, enough heat may be conducted along those wires to change the temperature reading. It's generally a good idea to make sure the leads near the sensor are close to the temperature being measured.

Inadequate thermal contact between sensor and surface—If the sensor makes poor thermal contact with the object to be measured, it is likely to be at a different temperature. When measuring the temperature of a surface, fasten the sensor solidly to it. If the temperature is moderate, some thermal (heat sink) compound can also be used to improve thermal contact.

Locating sensor in a stagnant area when measuring fluid temperature—When measuring fluids, make sure the temperature sensor is reading the temperature of the main body of the fluid, not the temperature in a spot where the fluid is not circulating.

Conclusion

Accurate temperature measurements are not difficult to obtain if the correct sensors are used and they are applied properly. However, using sensors incorrectly will lead to inaccurate results. KEITHLEY

About the Author

Dale Cigoy is a senior application engineer at Keithley Instruments. His major responsibility is helping customers with measurement applications that include Keithley equipment. Cigoy joined Keithley in 1976 after earning a Bachelor of Science degree in Electronic Technology from Capitol College in Laurel, MD. He can be reached by at dcigoy@keithley.com, or at 440-248-0400.

KEITHLEY

Keithley Instruments, Inc. 28775 Aurora Road • Cleveland, Ohio 44139 • 440-248-0400 • Fax: 440-248-6168
1-888-KEITHLEY (534-8453) • www.keithley.com

No. 2511
0304