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SEPTEMBER 2005
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Instrumentation/Control

SECOND OF A TWO-PART SERIES

It's Not All About The Sensor

Strategies for Identifying and Reducing Sources of Temperature Measurement Uncertainty

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A basic awareness of the inherent accuracy of particular sensor types is important, but goes only a short way toward the goal of achieving optimally accurate temperature measurement. It is the broader knowledge of how sensor choice, sensor placement and a wide variety of environmental factors can contribute to sensor error, as well as having a familiarity with calibration techniques that will ultimately lead to optimum sensor selection and measurement accuracy.

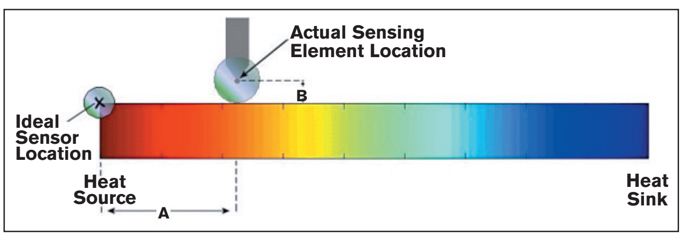

Figure 1. Improper sensor location can cause errors that will affect temperature measurement accuracy.

Location and transient errors

It is nearly impossible to sense temperature exactly where you need it. At the very least, the sensor itself has a finite size that displaces the sensing element from its attachment — resulting in the sensor being at a different location than the desired measurement location. Thermistors and RTD's are at greater risk for location error than an equivalently placed thermocouple — simply because of their size.

If surrounding heat sources and sinks are known, compensation can be made for location errors. However, this can be difficult in many systems and will result in location errors resisting calibration. The simplest solution, which avoids complex calibration techniques, is to utilize a small sensor and place it as close to the temperature source as possible.

Figure 1 illustrates how errors in sensor location can affect temperature measurement accuracy. Location error 'A' is a direct result of the entire sensor being displaced from its desired location, typically because of interference. Location error 'B' is a direct result of the sensor element being displaced from the intended surface by its encasement.

Transient errors are dynamic thermal errors for which compensation is typically very difficult because every material within the thermal system has its own unique thermal conductivity and capacity. Of the three most popular sensor types, it is the thermocouple that best minimizes transient errors because it corresponds to the smallest time constant.

Heat transfer errors

Sensors receive conductive, convective and/or radiative inputs that contribute to measurement inaccuracy. In **Figure 1**, these types of errors can be represented by ambient conditions that heat up or cool down the sensor — often along specific pathways such as along the thermally conductive electrical wires used in thermistors, RTD's and some thermocouples, from a nearby heating element. In this instance, heat from a local source travels up the copper wire to the sensing element and distorts the measurement. E and J thermocouples use alloys that are less conductive, which makes them ideal for mitigating this kind of error.

Self-heating errors

Self-heating errors apply to thermistors and RTDs, and result from heat dissipating inside the sensing element itself. This causes the temperature inside the sensor to rise, making the measured temperature less indicative of the environment. Strategies for minimizing this include keeping the current low or pulsing the sensor with a low duty cycle to keep low the average power dissipated in the sensor.

Environmental influences

For all three sensor types, operating or cycling them near their temperature limits can cause deterioration, which then results in a drift from the initial profile. Thermistors and RTDs are usually well sealed from the environment, which makes them less susceptible to internal corrosion. However, these sensors are usually connected to copper wires, which increase the risk of lead wire deterioration.

For RTDs, this lead-wire corrosion problem is mitigated by using 3-wire or 4-wire units that effectively measure the resistance of the sensing element, versus the connection wire. This helps give RTDs the greatest overall stability of the three sensor types. Thermistors usually exhibit some initial drift, but are generally stable after initial aging.

Thermocouples exhibit more complex behavior because the voltages produced are a direct result of the dissimilar metals used, as well as their alloy formulation, which both change as the metal ages and deteriorates.

Motion and noise

Small wire gages and fragile sensors should be avoided in applications that subject them to extreme mechanical motion, vibration or high intensity acoustics. The most common wire failures occur near connection points, where there is the greatest amount of flexure. However, mechanical motion or vibration can also stimulate internal resonances inside the sensor — leading to early failure. Thermocouples are generally the most durable of the three sensor types because many of the alloys used in the wires are more ductile — allowing them to handle additional motion.

Besides fatigue, cables in motion can also generate low voltage triboelectric effects. For microvolt sensors — such as thermocouples or RTD's — these effects could become another contributor to measurement uncertainty if the motion stimulating the effect is of the same order as the thermal responsiveness you intend to measure.

Magnetic and grounding effects

Thermocouples and RTDs generally have the lowest noise immunity. By shielding and properly grounding these sensors, their immunity from potential noise offsets can be further improved. This is true for offsets caused by capacitive, radio frequency (RF) and offset currents, but immunity from magnetic sources is not so easily achieved.

The environment in which sensors operate can often contain large motors and solenoids, or high current devices that can cause transient currents or magnetic surges. For sensor types that require stimulating electronics (thermistors and RTDs), these power droops could potentially affect the power supplies and sensing circuits inside the sensor electronics, which subsequently affects temperature readings.

Additionally, large inductive spikes can create circulating currents that alter ground potentials near the sensors. This effect then biases the voltage read from the sensor and creates a false reading.

The best method to protect from outside electrical and magnetic sources is to keep the sensor and lead wires away from them, shield them and pay close attention to electronics isolation and grounding. Keeping sensor lead wires short and converting the signals into digital form, as close to the measurement point as possible, also helps minimize noise.

Sensor calibration techniques

A common way to correct for inherent accuracy errors is to calibrate the sensor in a controlled isothermal liquid bath and compare temperature readings against a standard reference. Point calibration — immerging sensors in an ice bath or other standardized freeze point — is an alternative way to characterize accuracy.

If only relative accuracy is important, an array of sensors can be calibrated to each other by immersing them in a common bath at a known temperature. The temperature in the bath can then be slowly raised, while tracking all sensor responses. The calibration bath should span the same temperature range as the intended measurement. Additionally, the rate of temperature increase should be slow to reduce time-transient errors.

The limiting factor for minimizing inherent sensor error is the uncertainty of the calibration process. Generally, thermistors and RTD's have better inherent accuracy than thermocouples, but all three types of sensors will require calibration to achieve accuracies down to 0.1 deg. C.

Putting it all together

Sensor selection goes beyond having a sound knowledge of the inherent accuracy of particular sensor types. In selecting the best sensor for an application, environmental factors must also be considered for potential sources of error. It is also equally important to be familiar with the strategies that can be used to minimize environmental influences and maintain the best level of temperature accuracy.

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