Keys to achieving high accuracy and reliability in temperature measurement

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The final result of your temperature measurement will depend on the interaction of all the devices and connections between the sensor and control system.

Key concepts

- All devices in your temperature measurement chain will affect the overall accuracy and reliability.
- The accuracy of all devices needs to be similar or you could be wasting money.
- Devices such as transmitters can offer features to make the task easier and more reliable.

Temperature is the most widely measured variable in process industries and is often a critical factor in industrial processing. If you have been following this article series, you know that the very simple concept of measuring a temperature can be surprisingly difficult to implement effectively. If a temperature measurement is not accurate, repeatable, and reliable for any reason, it can have a detrimental effect on such things as process efficiency, energy consumption, product quality, and possibly process safety.

Even a small measurement error can be disruptive or very costly in some processes. Pharmaceutical processing is an example where an inaccurate temperature measurement might ruin a batch of an active ingredient product worth hundreds of thousands of dollars. Another example is in a safety loop where poor performance could be costly, deadly, or both. An example might be a process that can go exothermic and possibly explode if temperature is not measured and controlled accurately.

These examples emphasize that each measurement system needs to be evaluated carefully and engineered to satisfy the requirements of the process.

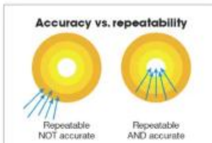

Figure 1: Accuracy of a temperature measurement system is the degree of closeness of the measurement of a temperature to that temperature's actual (true) value. Repeatability is the degree to which repeated measurements under unchanged conditions show the same results. An ideal measurement is both accurate and repeatable. All illustrations courtesy: Emerson Process Management

Finding where weak links hide in the measurement chain

Measurements are typically made using a sensor, usually a TC (thermocouple) or an RTD (resistance temperature detector), and a signal conditioning circuit (either a transmitter or a channel of an input card to a DCS or PLC) to amplify the sensor's low level (ohm or mV) signal to a more robust 4-20 mA current signal or a digital signal such as when using a fieldbus. These components, when combined with a field connection head and thermowell, are referred to as a temperature measurement system or assembly. Articles in this series have considered these individually, but now it's important to consider the larger integration.

Systems are available to meet a variety of measurement accuracy and stability requirements. Some applications just look at trends, and absolute accuracy is not very important. It is enough to know if the temperature is deviating from an ideal value, even though that specific value might not be known precisely.

On the other hand, others may have huge financial impact due to temperature measurement errors. Examples include off-spec production that may require reprocessing, a nuisance process shut down requiring an expensive process restart, reduced production rates, and frequent recalibration costs.

As an insight, the accuracy potential of a high-accuracy system is orders of magnitude more accurate than a loosely designed system. Over- or under-design of your system could be a very expensive oversight. A system that is more accurate than necessary simply adds complexity and cost.

Determine system requirements

To the new or inexperienced engineer it may seem like a daunting task to select the proper temperature measurement system for an application. To design a reliable temperature measurement system, a series of questions needs to be answered to understand the application thoroughly. As a result of this, the best choice of system components can be made including the thermowell, sensor, and signal conditioning device. Performance requirements of the measurement must also be determined. Operating conditions during start-up, steady-state, and potential abnormal conditions must all be considered.

As with any task, a logical and methodical approach usually begins with understanding the performance and physical requirements of the measurement application:

- Review process P&IDs
- Compare diagrams to the actual installation
- Evaluate possible mounting locations
- Consult with process, mechanical, and environmental engineers during the component selection, and
- Plan scope and schedule with project managers.

This kind of method will usually lead to the best path to follow for a well-engineered solution.

Identify measurement performance factors

Temperature measurement system performance is influenced by a number of factors in reporting process temperature measurements. The most significant of these are defined and explained below.

Accuracy of a temperature measurement system is the degree of closeness of the measurement of a temperature to that temperature's actual (true) value.

Repeatability of a measurement system, also called precision, is the degree to which repeated measurements under unchanged conditions show the same results. As an example, an instrument could present the same value for temperature every time (under the same measurement conditions), but the value is offset from the correct value. This is repeatable but not accurate. An ideal measurement is both accurate and repeatable (Figure 1).

Stability refers to the transmitter's ability to avoid drift in order to maintain accuracy over time. It is related to the sensor's measurement signal, which can be influenced by humidity and prolonged exposure to elevated temperatures. Stability is maintained by using reference elements in the transmitter, against which the sensor input is compared. The leading transmitter manufacturers, to improve accuracy and stability, fully characterize every transmitter over its entire temperature range to compensate for the tempera-

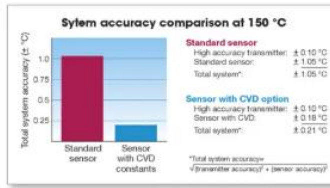

Figure 2: One way to quantify the stack-up of errors is to use a total probable error (TPE) calculation. This analyzes the probable error of the transmitter and sensor system, based on anticipated installation conditions.

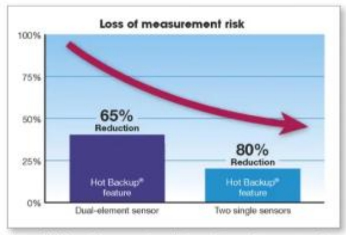

Figure 3: With a dual sensor system, the transmitter can be programmed to switch the transmitter input automatically from the primary sensor to the secondary sensor should the primary sensor fail. This feature allows the assembly to maintain measurement continuity.

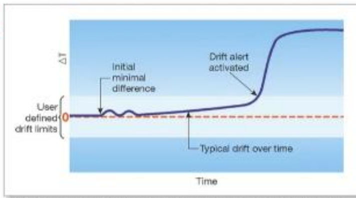

Figure 4: When two sensors are operating in parallel and connected to the same transmitter, the transmitter can be programmed to compare the two sensor readings and notify the control system if the readings begin to diverge due to degradation of one of the sensors that is causing its measurement signal to drift away from the actual value.

ture-dependency of the digital-to-analog converter (D/A) and the analog-to-digital converter (A/D).

Stability of a transmitter is often stated in terms of percent of the reading or the expected maximum change in measured temperature in degrees C or F over a specified amount of time for each sensor type. Data is typically given in year intervals such as one, two, or five years. Typical examples from a high-end transmitter are:

- RTDs: ± 0.25% of reading, or ± 0.25 °C (0.45 °F) for five years, whichever is greater.
- TCs: ± 0.5% of reading, or ± 0.5 °C (0.9 °F) for five years, whichever is greater.

The stability specifications here refer to the transmitter performance and do not include the sensor itself. A well-made RTD is generally considered to be highly stable and will not degrade significantly over time. However, even a well-made TC will degrade measurably over time and much more quickly at high temperatures.

The critical lesson from all this discussion is that your design must recognize the performance of the entire measurement system, not just the transmitter or sensor. One way to quantify the stack-up of errors is to use a total probable error (TPE) calculation. This analyzes the probable error of the transmitter and sensor system, based on anticipated installation conditions. The components of this calculation include the root sum square of the transmitter and sensor accuracy effects (Figure 2).

Durability and reliability create confidence

It is reasonable to assume that a durable device or system will be reliable. You can depend on it to perform its intended function. Just as you would expect a durable battery in your car to reliably start the engine and run the accessories under all reasonable conditions, you would expect a durable temperature measurement system to perform under its specified conditions. Confidence is built upon a history of reliable performance.

In designing a temperature measurement system, each component should be selected to provide the reliability demanded of an application. For example, if dealing with a high-precision measurement requirement, you would not select a sensor that has an excessive drift expectation.

If your environment is electrically noisy, you would not use a transmitter that did not offer intelligent filtering capability. Likewise, in a high-velocity flow application, you would not select a thermowell without performing wake frequency calculations.

The common element is that you must understand the process to know what the most critical requirements are.

Maximizing accuracy and reliability

When selecting transmitters, there are many features and options that can work together to build confidence in your readings:

- **Intelligent filtering**—In most plant environments, electrical surges from lightning or other static discharge are common as are power surges and dips from your local grid. There can be other hostile conditions caused by vibration, high humidity, extreme ambient temperatures, corrosive atmospheres, and so on, that can adversely affect transmitter performance. Fortunately, high-quality manufacturers have design features and configuration options that address these issues and help provide a reliable temperature measurement.

- **Transmitter-sensor matching**—All RTD sensors have inherent inaccuracies or offsets from an ideal theoretical performance curve. Transmitter-sensor matching can create precise compensation for these inaccuracies. Some transmitters offer this as a built-in function using a Callendar-Van Dusen (CVD) equation program.

This equation describes the relationship between resistance and temperature of specific RTDs. The matching process allows the user to enter four sensor-specific CVD constants into the transmitter. The transmitter solves the equation to match the transmitter to that specific sensor, thus providing outstanding accuracy. Accuracy improvement for sensor matching is typically 7:1 and system accuracies of ± 0.025 °F (± 0.014 °C) are possible.

- **Hot device switchover**—With a dual sensor system, the transmitter can be programmed to switch the transmitter input automatically from the primary sensor to the secondary sensor should the primary sensor fail. This feature allows the assembly to maintain measurement continuity (Figure 3).
- **Sensor drift detection**—When two sensors are operating in parallel and connected to the same transmitter, the transmitter can be programmed to compare the two sensor readings and notify the control system if the readings begin to diverge due to degradation of one of the sensors that is causing its measurement signal to drift away from the actual value (Figure 4).

Regardless of the hostile conditions that might exist at the point of measurement, a properly specified temperature measurement system configured with options and features as described above can go a long way to ensure that an accurate and reliable measurement is continually reported to the receiving system. ce

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This is the fourth part of this temperature series. Read the earlier installments at www.controleng.com/archives:

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Taking the mystery out of thermowell selection, Sept. 2013

The long and short of connecting sensors to control rooms, Nov. 2013

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