Proven strategies for reliable temperature measurement

Technical Note and Case Study

How to prevent downtime

Instrument technicians are responsible for testing and maintaining systems that keep industry up and running. They have to be ready to troubleshoot and repair when a process is interrupted, but the goal is to prevent rather than react to equipment downtime. This requires effective scheduled maintenance and is a result of using proven strategies.

Use proven strategies

Temperature calibration is an important strategy for preventing downtime when temperature control is a critical process parameter. The temperature sensor usually contributes the most to inaccuracy in a control loop because they drift with exposure to extreme temperatures, thermal cycling, and vibration. Temperature calibration compares one thermometer against a standard thermometer of higher accuracy to detect, adjust, or characterize the accuracy of the thermometer under test. These comparisons should be traceable to the ITS-90 (International Temperature Scale of 1990) through a national standards organization such as NIST.

Instrument technicians perform calibrations to a specified tolerance. As a result a tolerance status of pass or fail is assigned. There is a chance that an instrument found in tolerance is actually out of tolerance. The risk may be increased down time, lost revenue, excessive energy costs, poor product yields, excessive product defect rates, safety hazards, or legal exposure.

However there is a much larger chance that an instrument found out of tolerance is really in tolerance. The risk is the cost of adjusting instruments found out of tolerance and taking as left data. This cost can be substantial.

To minimize these problems, a good strategy is to keep the collective uncertainty of the calibration standards to a low percentage of the acceptable tolerance. For example a test uncertainty ratio (TUR) of 4:1 means that the collective uncertainty of the calibration standards is 25% of the acceptable tolerance.

This is generally considered a good TUR. A TUR of 2:1 means that the collective uncertainty of the calibration standards is 50% of the acceptable tolerance. Calibrations with a TUR of 1:1 don't meet the requirement to compare against a standard of higher accuracy and the table below demonstrates that tolerance status will be assigned incorrectly at a very high rate when the TUR is 1:1.

As an example, imagine 950 of 1,000 instruments are truly in tolerance. See the table below. If all 1,000 are calibrated with a 2:1 TUR then we expect that 926 will be found in tolerance (accepted), 12 of which are truly out of tolerance (false accept). Of the 74 expected to be rejected, 41 are expected to be truly in tolerance (false reject). The cost incurred for each of those falsely rejected instruments could range from $50/each for a calibration house to $10,000/each in down time in the chemical process industry.

TUR	Accepted	False Accept	Rejected	False Reject
1:1	843	17	157	128
2:1	925	12	75	41
3:1	941	9	59	22
4:1	947	8	53	15

Table 1. What-if table summarizing false accept and false reject risk for a hypothetical scenario of 1000 instruments that are truly 95% in tolerance. A normal distribution is assumed.

Work smart

Working smarter means: following best practices to choose the right tools and techniques for a given situation. Instead of re-inventing the wheel, we can learn and benefit from the experience of people who have already found solutions.

Choose the right tools

There are a lot of choices out there when it comes to temperature measurement. The wrong choice may give invalid results. The right choice depends on temperature range and accuracy.

There are many types of temperature sensors available for temperature measurement each with their own limits in temperature range and accuracy. Electronic thermometers usually read thermocouples, PRTs or thermistors. Thermocouples tend to be the least expensive, have the widest range, but they are often the least accurate. PRTs have a wide temperature range and good accuracy, but they are more expensive than thermocouples. Thermistors are less expensive and more accurate than most PRTs, but they have the smallest temperature range. The right tool for the job is going to depend on the application. The

Electronic thermometers require a digital readout. The best digital readout for an electronic thermometer is going to be one designed specifically for temperature. Its circuit will be designed for linearity over the range of the sensor and have circuitry to reduce electrical noise and remove the effects of thermal EMFs. Instruments that measure PRTs and thermistors should be able to make four-wire measurements, use recommended current levels to reduce the effects of self-heating. Instruments that measure thermocouples will have low noise floors and good reference junction compensation capability for accurate temperature measurement.

Remember that environmental conditions will affect the accuracy of measurement instruments. A good temperature coefficient means that the accuracy of the measuring device will be less affected by deviations from specified environmental temperature conditions.

Use the right techniques

The right time to take data is when the temperature is stabilized. This usually takes time after inserting the probe into the area to be measured. For the thermometer to come to the same temperature as the area to be measured it must be sufficiently immersed. Some thermometers require more immersion than others. Most require 4 to 6 inches when inserted into a liquid or snug fitting well, depending on the diameter of the probe. Best results in terms of accuracy and stabilization time occur when the probe can be inserted into a stirred liquid. Air pockets between probes and solid surfaces lead to longer stabilization times and require more immersion than would be required in a liquid.

Often devices that measure and display temperature need to be verified or calibrated against a reference thermometer. Accuracy is improved when the distance between the two thermometers is reduced. A best practice is to align the centers of the sensing elements of the reference thermometer and the device under test. Be aware that the location of the center of the sensor depends on the sensor type and model (i.e. PRT, thermocouple, bimetallic etc...).

A common method of calibrating temperature sensors is to remove them from where they are installed and place them in a dry-well calibrator or a Micro-Bath. These calibrators provide a stable temperature environment over a range of temperatures to compare the device under test to a reference thermometer or to the calibrator display. Alternatively temperature sensors may be calibrated without removing them from their installed location. Usually this is done by inserting a reference thermometer into a thermowell, immersion well, or thermometer pocket installed next to the thermometer to be tested.

In other cases the sensing element of the reference thermometer must be placed inside of the freezer, oven, or environmental chamber being verified, calibrated or adjusted. In these cases it is often necessary to record data over a period of time such as a few hours to verify performance. Statistics such as average value, maximum and minimum, or standard deviation may need to be recorded as well.

Testing the energy performance of steam systems, cooling towers, heat exchangers, and refrigeration systems, turbines, and internal and external combustion engines requires measuring differences between inlet and outlet temperatures. Therefore, another important measurement that needs to be included in our tool box is differential temperature measurement.

The role of calibration

Temperature measurement with an electronic temperature sensor requires a relationship between a known electronic quantity and an unknown temperature. This relationship may be specified for a class of thermometers or characterized (calibrated) for each individual sensor. ASTM E 1137 and IEC 60751 specify a resistance versus temperature relation and tolerance for a class of platinum resistance thermometers and ASTM E 230-03 (based on NIST monograph 175) specifies the electromotive-force versus temperature relationship and tolerance for letter-designated thermocouples. Instrument technicians use calibrated thermometers to check these sensors for compliance with their tolerances. The calibrated thermometer is usually required to be traceable to national standards (i.e. traceable to NIST).

Traceability requires comparison to a calibrated thermometer of higher accuracy that is also traceable to national standards. The adjustments made to electronic thermometers during calibration are called the calibration coefficients. These coefficients define the resistance versus temperature relationship for calibrated PRTs, RTDs and thermistors, and define the electromotive-force versus temperature relationship for calibrated thermocouples. Without these coefficients, measurements with these thermometers will not be traceable or as accurate.

Sometimes there is an additional requirement for accreditation. Accreditation provides assurance that an appropriate quality program is in place and that training and procedures meet the technical requirements for the service provided.

Maintain your standards

Maintenance of calibrated equipment is an important part of quality assurance. There is no guarantee that a calibrated thermometer will remain calibrated over time. Changes in the temperature relationship of used thermometers over time need to be corrected by calibration at regular intervals. When thermometers are found repeatedly out of tolerance remedial actions need to take place, such as shortening the calibration interval or replacing the thermometer. It is a good idea to keep records and monitor certified thermometers between calibrations using an appropriate method such as an ice bath, or triple point of water cell. This will limit and prevent large-scale consequences should a certified thermometer be found significantly out of tolerance.

Case study: New Reference Thermometer from Fluke's Hart Scientific division

Fluke is known for tools that engineers and technicians can rely on to keep industry up and running. An example of one of these tools is the new 1523 and 1524 Reference Thermometers from Fluke's Hart Scientific division. They measure, graph, and record detachable PRTs, thermocouples, and thermistors for precision applications. Features include trending, logging and two-channel measurement all in a traceable, calibrated, take-anywhere tool.

Temperature is critical in many industries, and accuracy requirements may vary. Assuming a temperature accuracy requirement of ± 0.1 °F (± 0.06 °C) for field instrumentation, the accuracy required in a handheld thermometer used to calibration the instrumentation would depend on the required test uncertainty ratio (TUR). Going back to table 1 we can see that we would probably need a minimum 2:1 TUR (i.e. ± 0.05 °C accuracy thermometer). A 2:1 TUR would minimize the thermometer cost but increase maintenance time, because the number of calibrations incorrectly assigned an out of tolerance condition (false rejects) would still be high. This may mean an extra couple hours of work adjusting and taking as left data unnecessarily. For a better TUR a more accurate instrument is required. To maximize accuracy, the 1523/1524 Reference Thermometers use current reversal to eliminate thermal EMFs and provide superior measurement quality. To eliminate lead resistance errors the Reference Thermometers are configured for four-wire measurement of PRTs, RTDs, and thermistors.

Many probe options are available for a wide range of applications, including probes with traceable calibrations and accredited calibrations. Probes are available with some of the lowest uncertainties in the industry making on-site calibration work more reliable. Achievable accuracies with the readout depend on the type of probe and the temperature range, but are as good as ±0.009 ° C with a precision thermistor or ±0.014 ° C in combination with a PRT (including calibration and drift).

Connecting a detachable probe option (temperature sensor) to the Reference Thermometer is a snap, literally. The 1523 takes one probe at a time and the 1524 can take two probes to measure two temperatures or the difference between two temperatures (i.e. inlet and outlet).

Each probe has an INFO-CON connector with an on-board memory chip to keep calibration information for the attached probe. Simply plugging in the probe uploads the information to the readout. The connector transfers this information to the 1523/24 automatically, ensuring the correct temperature conversion for accurate, traceable, hassle-free measurements.

Plug any thermocouple with mini-thermocouple jacks into an optional universal thermocouple adapter for convenient measurement. Each thermocouple adapter or standard connector supports reference junction compensation (RJC) with its own internal precision thermistor that is individually tested for accuracy.

You may have to do calibration work in temperatures outside the thermometers standard environmental conditions of 13 °C to 33 °C ambient. Extended specifications are still very accurate from

–10 °C to 60 °C, because the 1523/24 uses a highly stable reference voltage source and precision resistors with very low sensitivity to temperature. Like all Fluke handheld tools, the 1523/24 Reference Thermometers are built to last, enduring rigorous testing in both temperature extremes and harsh conditions of vibration.

The two Reference Thermometers display trends graphically and the resolution adjusts at the touch of a button. This helps technicians see when temperature is stable, without statistics or long delays. However the thermometer readouts also document up to 25 readings and their associated statistics for easy retrieval when needed. View the data through the display or by uploading it to a PC via RS-232 connection and 9940 I/O ToolKit software, included free.

Sometimes a reference thermometer is needed as a reference to track behavior over time. The 1524 works well as a logger. With a real-time clock and memory for 15,000 time-and-date stamped measurements. It can log up to 3 times per second, or once every hour with other options in between. Use the free 9940 software to download the data to a PC for analysis when you need it. This is useful for testing environmental chambers, freezers, and ovens that often need to be monitored over the space of several hours. To monitor and log even more data with either model, a PC and optional Log*Ware* II software are all that is needed.

Conclusion

Temperature calibration is a proven strategy for preventing downtime. Calibrating the sensor is the most important part of temperature calibration. Using the right tools can help make temperature calibration more effective. An important tool that every instrument technician should have in their toolbox is a Reference Thermometer. Since productivity is more and more important in today's competitive environment, we suggest using a measuring tool that is versatile and accurate will keep you better prepared and working smart.