Challenges of Temperature Sensing

Measuring each of the "big four" process variables has its specific peculiarities, but temperature seems particularly controversial. In fact, this apparently simple task often gets complicated. This tutorial explains why.

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Almost ten years ago, I was saddled with the task of overseeing startup of a pollution control system our company had provided for a lime producer. It involved measuring the temperature of flue gas which seemed simple enough. However, between my group, our system integrator, our parent company, the local operators, the customer's engineering contractor, and the customer's parent company, we had many differences of opinion as to what type of sensor was best. The discussions created almost as much heat as the kiln. Before the commissioning was over, we installed two types of thermocouples and at least one RTD (resistance temperature device), including pulling appropriate cables for each. It was an expensive lesson.

Choosing can be difficult, even though there are only three main technologies for measuring temperature electronically:

- Thermocouple;
- RTD; and
- Thermistor.

It is easy to make generalizations about the characteristics of the three device types, and that information would likely serve you in the majority of applications. Many articles have been written with this assumption. However, these generalizations don't always apply, and technologies are evolving in a way that changes their relevance. We need to examine some of those points and see what we can draw from them. In preparing this article, I consulted with a variety of people, generally representing smaller companies for whom temperature measurement is a major, if not the largest part, of their business activity.

Conventional wisdom?

When choosing a sensor, there are several basic questions you have to ask about the application to guide a selection:

- Measuring range—Not just the specific operating temperature expected, but the full potential range that could be experienced during

A typical temperature sensor installation uses a thermowell or other probe to reach into the process where it can sense the required temperature. Having a transmitter at the device minimizes the amount of specialized wiring required, and reduces the likelihood of signal contamination from electromagnetic interference.
Source: Moore Industries

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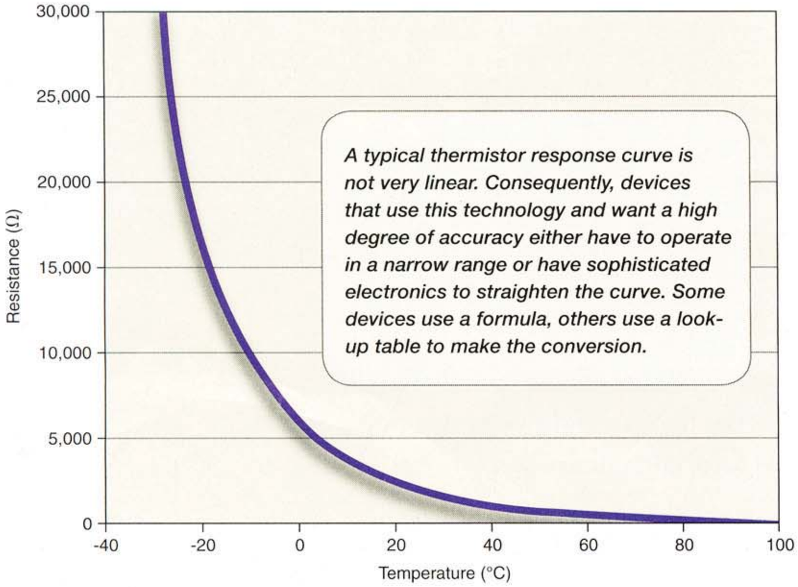
Typical thermistor curve



Source: Control Engineering *with data from Omega.*

shutdown, startup, and process upsets.

■ Stability, accuracy, and sensitivity—These are all related, and determining the mix of these requirements is hugely dependent on the needs of the process. A bio-reactor in a pharmaceutical application may demand a very accurate and repeatable reading. This calls for a much different strategy than a simple storage-tank-monitoring situation.

■ Response time—Some processes change temperature very rapidly. A sensor can be configured in a way that allows it to capture minute changes in a process stream very quickly if that's necessary, but often at the cost of durability and stability.

Sensors have some general characteristics that apply most of the time. For example, thermocouples indicate temperature by providing a very small voltage signal generated by a junction of dissimilar metals. The measurement is actually a temperature differential between the process and a reference point. The reference point has to provide a temperature of its own as a basis of comparison, so a thermocouple installation actually involves two temperature sensors.

Thermocouples also have a number of key strengths:

■ Wide variety of measuring ranges, including the highest limits of the group;

■ Many physical sizes and configurations;

■ Can have very fast response times;

■ Moderate price and simple configuration;

■ Medium accuracy and sensitivity;

■ Specific types have to have matching cable (e.g., type K thermocouple has to have type K cable.); and

■ Signal strength is very low and prone to EMI problems.

RTDs use the fact that some metals (usually platinum) increase electrical resistance as they get hotter. To measure the change, the sensor output is fed into a Wheatstone bridge with a reference voltage. RTDs have characteristics that compare well against thermocouples:

■ More accurate, stable, and repeatable;

■ Better sensitivity and linearity;

■ More robust signal;

■ Narrower measuring range, particularly at the high end;

■ More expensive; and

■ Require an external power source.

Thermistors act in much the same way as RTDs, but use a different type of element. Most types have an inverse relationship between temperature and resistance, or NTC (negative temperature coefficient), meaning that resistance drops as the temperature rises.

■ Narrowest measuring range of the group;

■ Lowest linearity;

■ Accuracy and response time comparable to thermocouples;

■ High resolution possible due to wide resistance range; and

■ Least expensive.

"Generalizations are misleading," warns Jerry Gaffney, chief engineer, GEC Instruments. "People don't take it as general, and they form lifelong opinions that are not always correct. If people are buying something and are serious about it, they should look into all the different factors that they're looking for and consider cost, accuracy, sensor size, and all these things, and then decide what they need. They shouldn't decide that they shouldn't use thermocouples because they read an article that says thermocouples aren't accurate."

There are, of course, exceptions to every rule. Instrumentation manufacturers can create devices with characteristics contrary to the norm. However these are often designed for specialized applications or laboratory use. Devices common to process manufacturing plants are typically more mundane and tend to follow these characterizations more closely.

Still, if generalizations can be misleading, what are some of the more specific considerations? Let's take another look at each sensor technology.

Thermocouples

"Most companies in industrial markets want to use thermocouples," says Fred Molinari, president, Data Translation. "They have a lot of experience

RTDs can be very small. This one uses ceramic encapsulation to protect the delicate platinum wires. If the mass is not too great, response time can still be kept short. Source: Heraeus Sensor Technology

with them and you don't need any stimulus voltage of any kind—it's just two wires."

While thermocouples are self exciting, the amount of current they produce is very low, which means the signal can be delicate and must be handled carefully. "When you have typically 41 µV per degree Celsius on a K type thermocouple, that's really not much signal," says Steve Conners, design engineer, Data Translation. "But by using modern technology, for example a sigma-delta A/D converter per point with 50 and 60 Hz notch filters to remove noise, we can do a pretty good job of getting accurate readings with thermocouples."

Given the signal characteristics, how you process a thermocouple's output is critical. At the same time, that won't solve one problematic tendency for them to drift due to changing sensor characteristics. "There's an entire industry out there of thermocouple calibration equipment, because they drift so badly," says Alan Clark, distribution manager, Palmer Wahl Instruments. "Thermocouple wire changes properties over time.

"For example, with a type J thermocouple, one of the wires is iron. Because iron rusts, its thermal conductivity changes, causing it to drift. Thermocouple calibration is kind of a misnomer since you aren't actually changing the thermocouple. What you're doing is reading how much it's drifted, and you're putting in a correction factor for your meter to correct for that error. You have to do that periodically, probably every three months or so."

Moreover, since a thermocouple produces a differential reading, there has to be the other point for comparison. If the reference point changes, the reading will change with it even though the process is the same. "One of the inherent disadvantages of thermocouples is they need the cold junction compensation," says Bob Gliniecki, product manager, DWM & Associates. "That's now done electronically, but it adds some expense. The thing I always found kind of funny is that this electronic cold junction circuitry usually contains a thermistor."

RTDs

RTDs are generally regarded as the most sophisticated technology, provided the temperature range is not past their maximum. This comes at a higher cost usually, both from the literal expense and the need for more elaborate signal processing. "RTDs require more signal conditioning, but you can get 1/100 of a degree accuracy," says Conners.

RTDs also have extensive standardization which provides predictability for performance. "With a platinum element RTD, there is an international standard, IEC 60751," says Gliniecki. "For example, it defines class B accuracy, which is ±0.3 °C at 0 °C, and there's a formula that will describe what it's going to be at other temperatures. If you buy a class B element from one manufacturer, it will be the same as a class B element from another manufacturer."

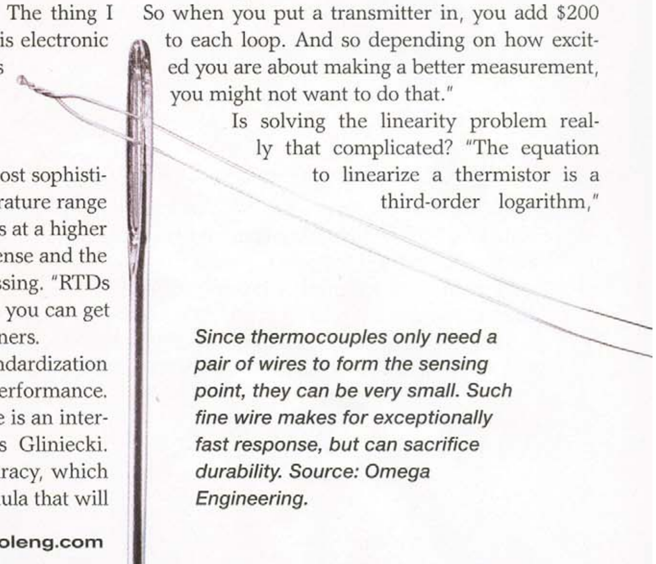
The precision and stability of RTDs can be combined with a specific transmitter and fine tuned to offer very high accuracy. Gary Mathur, applications engineer for Moore Industries International, offers this advice: "Since an RTD is a resistance, you can calibrate it at a number of points by putting it in a bath, capturing those readings, and putting them in the transmitter's memory. If you do a bath calibration in the range where your reading is most critical with a series of readings around that value, you can put those ohm values into the transmitter's memory, and the transmitter becomes matched with that RTD. Then you have a highly accurate assembly, which you can't do with a thermocouple."

Thermistors

"For room temperature applications, and by that I mean -40 to 100 °C, a thermistor tends to be the sensor of choice," advises Gliniecki. "They are typically very inexpensive, and with that large resistance change per degree, it's easy to get good resolution."

Thermistors are usually considered the low end of the market, with the narrowest measuring range. While stable, their non-linearity (see graphic) can make them more difficult to work with. "Thermistors get a bad rap" says David L. Neal, P.E., consulting engineer, Advanced Industrial Systems Inc. "That's mostly because they're non-linear, and so they're hard to use. But with the new transmitters that are now available, you can get a 4-20 mA linear signal. But that's if you use transmitters. Lots of I/O modules are set up to work directly with thermocouples and RTDs without a transmitter. So when you put a transmitter in, you add $200 to each loop. And so depending on how excited you are about making a better measurement, you might not want to do that."

Is solving the linearity problem really that complicated? "The equation to linearize a thermistor is a third-order logarithm,"



Since thermocouples only need a pair of wires to form the sensing point, they can be very small. Such fine wire makes for exceptionally fast response, but can sacrifice durability. Source: Omega Engineering.

Neal adds. "I'm pretty good at math, but I would have a hard time deriving that equation if I had to sit down and do it. But if you have the capability of scaling the thermistor in your computer, and you're in the neighborhood of 0 to 70 °C, a thermistor is a really good solution."

Why is it so hard?

Why does temperature measurement seem to be so difficult? Dave King, sales engineer, Thermometrics, offers his assessment: "The thing where most people get into trouble is viewing temperature measurement as an afterthought. It happens in process industries, but not nearly so often because you have people in that field who are more seasoned, but every once-in-a-while you'll see somebody who tries to put a flanged thermowell on a line that's really not big enough for it. If you think ahead a little bit, you can incorporate it into an elbow or bend and make it work. Otherwise, it's adequate, maybe."

In many situations, the problem relates to sensor placement as much as selection. The enclosure can serve as a barrier or heat sink, keeping the sensor from seeing the true process temperature. Even your lead wire can wick away heat from the sensor if it is large enough.

While temperature measurement has a relatively small group of potential sensor technologies, the differences are often subtle and easily misunderstood. This can lead to poorly applied devices. "A lot of people tell us they know what they want," says Joe Cheatham, vice president, sales and marketing, Weed Instruments. "They want a thermocouple. They want an RTD. I don't know if they're looking at some engineering spec or it's just habit, or they're using a generic term like thermocouple for all temperature sensors. They may not actually want a thermocouple, but simply need some type of contact measurement device and that's just what they call it.

"Customers need to communicate very clearly with potential suppliers. They need to understand how the sensor is going to be applied, what the physical environment is around it. Is it a stable temperature measurement, or is it spiking and cycling up and down? What's the electrical environment around it? How far is the sensor from where they want to take the measurement?" Cheatham says.

Ron Desmarais, project engineer for Omega Engineering, sums up the problem as one of declining understanding in the face of more sophisticated deployments. "I think we are seeing a number of conditions occurring simultaneously in the industry," he observes. "There is a widening implementation of increasingly sophisticated process control systems focused on improving quality, reducing costs, and improving process efficiency. This is resulting in a significant increase in the use of temperature and other sensors."

Many of these sensors are placed in fairly harsh environments where it may not be readily apparent as to whether the sensor is working correctly, Desmarais says. It is important to have a means of verifying the sensor performance at installation, as well as periodically during use, depending on the conditions experienced, he adds. This requires that the personnel designing, using, and maintaining the systems understand the limits of the system and how to pick up on any changes that may occur. The level of criticality of the process condition measured dictates the level of surveillance and understanding needed.

Desmarais says, "This is all happening at a time when the understanding of the nuances associated with the varying types of temperature sensors is decreasing. In the past, organizations that used sensors on a regular basis had people who became in-house specialists on the different types of sensors and how to apply them. Unfortunately with the retirement of a number of more experienced instrumentation engineers, increasing workloads and leaner organizations, that level of specialization and understanding is being lost at an alarming rate. Today it seems like many engineers are developing more of a plug-and-play approach to the selection and use of temperature sensors. This requires that the industry step up to fill that knowledge gap and help guide the customer into making the right choices."

Those last thoughts are probably the most telling. Much about instrumentation and process control requires nuance and finesse. While more sophisticated devices and electronics have eliminated a great deal of the need for specialization, it's difficult to replace skill, ingenuity, and intimate knowledge of a process. **ce**

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