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Selecting the Right Temperature Sensor:

Imagine that you are an Instrumentation Engineer. You are looking at the prints for a new plant, and you see the many locations marked out for temperature transducers. You ask yourself: What has been specified to fill each space? RTD's for their high accuracy and linearity? Or thermocouples because of their lower cost and familiarity? ***Has anything*** been specified to fill the requirements?

The selection of what type of temperature transducer is used affects other aspects of the design and installation of the equipment in the plant such as:
- What type of wire needs to be run?
- What type of instrument will be in the control room on the other end of the wire?
- Will there be local junction boxes with terminal strips or transmitters and if so, what type of transmitter is required?

These are important considerations, and we have not even touched on the actual selection and design of the sensor itself. We have all read articles on this subject before, but as long as there are temperatures to be measured, there will be discussions on how best to do it. Let's look at the big picture and try to narrow down the choices in a logical way. First, we'll look at survival of the sensor. Only then can we discuss the finer points; such as meeting the design parameters.

Temperature Range:

The International Temperature Scale (ITS-90) defines temperatures between 13.8033°K and 961.78°C by use of Platinum Resistance Thermometers (PRT's) calibrated at specified sets of fixed points. While this is fine in a laboratory, you are not likely to find an industrial grade RTD that will cover this entire range adequately. And please note that the standard says PRT's- plural; one PRT will not cover the entire range adequately in a laboratory situation either. ASTM defines the platinum RTD for use over the range of -200°C to 650°C. This is a good guideline to follow for commercial purposes even though IEC extends the upper limit to 850°C. Industrial grade Platinum RTD's can be manufactured for use to 850°C, but it is not an easy task that can be undertaken by just anyone. Some manufacturers even claim to produce RTD's for temperatures higher than that, but results may vary. Also, you may find that standard warranties are not valid for this type of service. Fortunately, over 90% of all contact temperature measurements made in industry are below 650°C.
For Temperatures above 800°C or so, Type K or N, Platinum/Rhodium, or Tungsten/Rhenium Thermocouples should be considered.

Vibration:

This is one area where Thermocouples may have a slight advantage. Due to the sheer size of the wires used in the construction of industrial Thermocouples, they tend to stand up to high vibration better than most RTD's. A 1/4" OD Mineral Insulated thermocouple has 16 AWG conductors within it, and these conductors are used to form the thermocouple junction. On the other hand, a wire-wound RTD element may have lead wires of approximately 26-30 AWG which are attached to a very fine Platinum wire used to wind the sensor itself. The wire in these windings is generally in the range of 15 to 35 microns (that's about 0.00059 - 0.00138 inches) in diameter, and is consequently very fragile. High vibration has been known to cause problems in some wire-wound resistance elements which are not of fully supported construction. Failures may be in the form of open circuits, noisy signals, or intermittent high readings.
Fully supported Wire-wound, as well as Thin-film RTDs tend to fare better than the semi-supported Wire-wound units. But keep in mind that the element leads are still only 26-30AWG and therefore relatively susceptible to breakage induced by continued high vibration. Also, special care must be exerted by the RTD manufacturer to properly package these elements for the rugged environment that they will see.

Accuracy:

After temperature range and vibration, which essentially helps us choose whether or not we can even consider a particular sensor for our application, we may evaluate the accuracy of various types. A standard, ASTM Grade B RTD will provide true accuracy (as compared to the published R vs. T Tables) of +/-0.25°C at 0°C. Due to variations in temperature coefficient this same grade B thermometer may only provide temperature readings within 3.0°C at 650°C. More accurate, grade A RTDs are available which will perform within 1.24°C at 650°C, and some RTD's can be calibrated and selected with even greater accuracy at specified points.
By comparison, the most common base metal Thermocouples, types J and K, will provide accuracy of 2.2°C or 0.75% (whichever is greater) when supplied in 'standard accuracy'. That could be as much as +/- 4.875°C at 650°C, considerably larger than even the grade B RTD. This is true across the range, up to the RTD's upper limit of 650°C for grade B RTD's vs standard tolerance Thermocouples, as well as grade A RTD's vs Thermocouples selected to special tolerance limits. Simply stated; **if accuracy is important to you, and all other conditions permit it, select an RTD over a Thermocouple**.

Repeatability / Stability:

This is not as easy to quantify for RTD's or Thermocouples due to the tremendous effect that the application has on the results. For instance; ASTM E-230 Part 6, Table 1, Note 3 states: "Caution: Users should be aware that certain characteristics of Thermocouple materials, including the emf versus temperature relationship may change with time in use; consequently, test results and performance obtained at time of manufacture may not necessarily apply throughout an extended period of use. Tolerances given in this table apply only to new wire as delivered to the user and do not allow for changes in characteristics with use. The magnitude of such changes will depend on such factors as wire size, temperature, time of exposure, and environment."

For Platinum RTD'S, ASTM-1137 Part 9 requires the stability of the unit to remain within the specific accuracy grade (i.e.: Grade B) for a four week test. IEC60751 goes farther as section 6.4.2 requires that Class B RTD's cannot drift more than 0.3°C after exposure to their maximum temperature limit for 1,000 hours. Section 6.5.5 imposes the same requirement for 10 min/max temperature cycles. Thermocouples are typically not expected to perform within stability/repeatability limits as strict as these.

Response Time:

This is another area where Thermocouples can excel over RTD'S, and it's a simple matter of physics to understand why. Contact temperature sensors do not indicate the temperature of the area around them, they indicate their own temperature along their own sensitive area. In order for any contact temperature sensor to indicate the temperature it is in contact with, the sensor must first come to thermal equilibrium with that environment. Let's not discuss the theoretical aspect that the two never actually attain the same temperature, just the fact that after some time the two are approximately at thermal equilibrium.
The most basic of Thermocouples is merely a junction of the two dissimilar metal wires. This could be a beaded junction, or a butt-welded junction which turns out to be nearly the same diameter as the Thermocouple wire itself. In order to indicate the surrounding temperature, the junction must be at that temperature. That junction might only be .010" in diameter (for a 30 AWG wire thermocouple), or smaller if finer wires are used. RTD's require either a length of fine Platinum wire wound around or within a former (typically ceramic or glass), or a layer of platinum deposited upon a substrate. In all cases, there is an area of Platinum (which is the temperature-sensitive portion of the RTD) in contact with this inert, insulating material, and both are physically larger than a weld junction (generally speaking). Both the Platinum and the insulator have thermal mass that must come to equilibrium with the surroundings before the sensor can provide an accurate temperature reading. Since there is generally more thermal mass involved here than with a bare thermocouple junction, the thermocouple will respond faster when put in a similar environment.
The aforementioned statement is true primarily when reaching for the extremely fast response times of each type and working with bare resistance elements and exposed thermocouple junctions. If both sensors are encapsulated within metal sheaths, or installed into Thermowells, and the thermocouple junction is isolated from the sheath (as an RTD circuit always is), then response times will be quite similar.

Sensitivity:

In this situation, the RTDs are simply superior to Thermocouples. Take if you will, a platinum 100 ohm RTD with .00385 temperature coefficient. From 0°C to +100°C its resistance changes from 100.00 to 138.50 ohms, a difference in 38.50 ohms. If we had been using 1mA sensing current, Ohms law ($V = i R$) tells us that we would see a difference of 38.5mV over this range. By comparison, a Type E thermocouple, which provides the highest sensitivity of all recognized Thermocouples, will show only a change of 6.317 mV. This is only about one sixth of the sensitivity of the RTD. If your environment might provide electrical interference, the Thermocouple will be at least 6 times more susceptible to it. And this is when using a Type E. Other Thermocouple types have sensitivity as low as .33 micro volts per degrees Celsius. If you need even higher sensitivity, you may opt for a Pt 500 ohm RTD to provide 5 times the sensitivity of the Pt 100, or a Pt 1000 ohm to give you a change of 385 ohms over that 100 degree range.

Life Expectancy / Replacement Cost:

This again goes back to what we've said about application parameters in the areas of temperature range and stability: it all depends on the specific application. A few generalizations can be made, however. It is widely accepted that Thermocouples are in a constant state of degradation and need to be checked and replaced periodically, while Platinum RTD's may last indefinitely, if adverse environmental conditions do not deteriorate them.

Cost:

As much as we might hate to admit it, the final factor in most decisions is cost. For many years, Thermocouples have been the most widely used form of electrical temperature sensor mainly because they are cheap. While this is still true, it must be pointed out that the cost for a platinum RTD has come down to a very competitive range, due to the increased use of Thin-film sensors. Thin-film RTD sensors are certainly not new technology anymore; they were developed in Germany in the 1970's. These RTDs are now being used in ever increasing numbers; in applications from -50 to 600°C, for use in industrial environments, the food and beverage industry, as well as laboratory equipment and some automotive uses. Whether or not an RTD can actually be used in place of a Thermocouple will depend on the specific design and application as outlined above. But if it is feasible, the actual price difference from Thermocouple to RTD may be less than $10. If this is part of a large assembly, particularly one involving a Thermowell and Transmitter, that will amount to a very small part of the total cost. It should be pointed out that there might be additional savings on the installation of the RTD if no Transmitter is required, since standard instrument wire can be used, as no specially compensated cables are required.

OEM / Automotive Applications

Up until now, we have been discussing primarily Industrial applications as might be seen in a chemical or petroleum processing plant. But what about equipment manufacturers, automotive Engineers and others who need to include some form of Temperature measurement right in their products. Most of the above principles still apply, with the exception of Temperature Transmitters which should not be necessary when long runs of cable are not required. Even the additional cost of compensating Thermocouple extension wire is minimized by the small amount of wire typically required. But these applications also open themselves up to two more types of Temperature sensors: Thermistors, and Digital sensors.

Thermistors are commonly used to sense Temperatures from about -50 to +100°C. Beyond that they tend to degrade and drift more quickly, but some specialty units can been used for higher temperatures. The engine temperature sensor in your car is most likely a Thermistor, as is the sensor in most digital oral thermometers sold for home use. Note that in both cases the temperature range is fairly limited and known in advance. Advantages are they are inexpensive, have high sensitivity, and fast response due to their small size. Disadvantages are their limited temperature range, nonlinear output, high susceptibility to self-heating, and poor interchangeability.

Some luxury automobiles actually use Platinum RTD's for the ambient air temperature display on the dashboard. In this application, RTD's are chosen because their nominal resistance is targeted at 0°C – the freezing point of water – where a wet road will turn to ice. This gives the driver a more precise reading at a critical temperature where safety is paramount.

Digital Temperature Sensors are useful over about the same Temperature Range as Thermistors, and directly provide a digital output so sensitivity is fixed and linearity is a non-issue. But because so much is packed onto that semiconductor chip, they are physically larger than most Thermistor Beads or RTD Elements and their Response-time is generally slower. However, if they are packaged in a ¼" OD tube their response-times will be quite similar to other sensors in a similar package. Advantages of Digital Temperature Sensors are their low cost and ease of signal processing.

Summary:

Temperatures below -50°C – Use a Wire-Wound Platinum RTD or Type K, T, E or N Thermocouple.

-50°C and above, the above are useful, plus Thin-Film RTD's, Type J T/C's, Thermistors and Digital Sensors.

Thermistors and Digital Sensors are limited to Maximum Temperatures starting around +70°C, +100°C, or similar. Check manufacturer’s specifications for specific limitations.

For Temperatures Exceeding 850°C, Thermocouples are your best choice.

For High Accuracy/High Repeatability, Platinum RTD’s are best.

For Fast Response, Small Thermocouples and Thermistors are preferred.

So, as in most situations, we cannot make any generalizations: each application must be judged on its own. But if you have a new requirement for a Temperature Sensor and you are not quite sure how to fill the space, run down the criteria discussed here. Maybe a Thermocouple or Thermistor will serve your needs, or maybe you will find that a Platinum RTD is much better suited for the situation and really won't cost you any more in the long run.