# <u>Selecting the Right Temperature Sensor</u>

**Imagine that you are an Instrumentation Engineer. You are looking at the prints for a new plant, and see the many locations marked out for Temperature Transducers (TT).**

- *But 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 those spaces?*
- *Or has this been left to chance at the last minute?*

**The selection of what type of Temperature Transducer to be used affects many 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 that wire?*
- *Will there be local junction boxes with terminal strips or transmitters, and if so, what type of transmitters are required?*
- *Do any special piping considerations need to be made to protect the sensor or provide the required response time?*

These are just some of the details, 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 questions out there, more information will be provided to help make wise and informed decisions regarding each specific application.

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 specified requirements.

## TEMPERATURE RANGE

The International Temperature Scale (ITS-90) defines temperatures between 13.8003 K and 1234.93 K (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. Please note that the standard says PRT's - plural; one PRT will not cover the entire range adequately in a laboratory situation either: several are used,

ASTM defines the Platinum RTD for use over the range -200°C to 650°C. This is a good guideline to follow, 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 taken on by just anyone. 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.

Thermocouples also have temperature limitations based on what type is specified, and what gage wire it is constructed of. A typical 1/4" OD, single, mineral insulated Thermocouple has 16 AWG wire within it. ASTM E-608 recommends the following temperature limits for such base metal thermocouples;

Type T 370°C, Type J 720°C Type E 820°C, Type K 1150°. Now just because ASTM says these thermocouples can be used at these temperatures doesn't mean that they are going to last forever. The higher the application temperature, the sooner they will begin to drift, and the shorter the life. ASTM does not publish any guidelines on drift or life expectancy, due to the many variables involved which affect thermocouple performance.

Above these temperatures, we must step up to precious metal Thermocouples: either Platinum-Rhodium Alloys, or Tungsten- Rhenium Alloys. These do tend to get expensive, but when you've got to measure temperature above about 1000°C, it really is the way to go. The life expectancy is much longer, and they are not as prone to drift.

ASTM E-230 lists suggested upper temperature limits for Types R and S Platinum- Rhodium Thermocouples as 1480°C (2700°F), and for Type B as 1700°C (3100°F). These values are for protected 24 AWG construction.

# ACCURACY

After temperature range, 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 RTD's are available which will perform within 1.24°C at 650°C, at additional cost.

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 (ie: Grade B) for a four week test. IEC-751 goes a step further and requires that Class B RTD's must withstand 250 hours at maximum temperature and 250 hours at minimum temperature with a change in resistance of no more than 0.3°C. The same requirement must be maintained for 10 min/max cycles. That's a total of 5000 hours, or more than 208 days at the extremes. Thermocouples are typically not expected to perform within stability/repeatability limits as strict as these.

# VIBRATION

This is one area where Thermocouples may have a slight advantage. Due to the sheer size of the wires used in Thermocouple construction, they tend to stand up to high vibration better than most RTD'S. Remember that the 1/4" OD Mineral Insulated Thermocouple previously mentioned had 16 AWG conductors within it, and these conductors are used to form the Thermocouple Junction. On the other hand, a Wire-Wound RTD element mav 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 RTD's tend to fare somewhat better than the semi-supported types. But keep in mind that the element leads are still only 26-30 AWG and there-fore 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 environ-ment that they will see.

## RESPONSE TIME

This is another area where Thermocouples 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, but 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, or a layer of platinum deposited upon a substrate. In all cases, there is an area of Platinum (which is the sensitive portion of the RTD) in contact with this inert, insulating former, 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 give an accurate reading. Since there is generally more thermal mass involved here than with the thermocouple junction, the thermocouple will respond faster when put in a similar environment.

The aforementioned statement is true only 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, and the thermocouple junction is isolated from the sheath (as an RTD circuit always is), then response times will be quite similar.

## SENSITIVITY

Here the RTD's are very simply; Superior. 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 of 38.5 ohms. If we had been using 1 mA sensing current (which is quite typical to avoid self-heating effects), Ohm's Law (V=iR) tells us that we would see a difference of 38.5 mV 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 envi-ronment might provide electrical interference, the thermocouple will be at least 6 times more sus-ceptible to it. And this is when using a type E, other types have sensitivity as low as .33 micro-volts per degree Celsius. If you want 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 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 details. 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 the environment does not deteriorate them.

## COST

As much as we 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 usage of thin-film sensors. Thin-film RTD sensors are certainly not new technology anymore; they were developed in Germany in the early 1970's. But they are 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's 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 unit cost.

It should be pointed out that there will be hidden savings on the installation of the RTD since standard instrument wire can be used, as no specially compensated cables are required.

## IN SUMMARY

We cannot make any generalizations, each application must be judged on its own. But if you have a new requirement for a temperature transducer, and you are not quite sure how to fill the space, run down the requirements and apply the concepts listed above. Maybe a thermocouple will provide what you need, or maybe you will find that an RTD is much better suited for the situation and really won't cost you any more in the long run. Reprinted from

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