5.
How to Select and Use the Right Temperature Sensor

Every sensor has its own specification on a particular Temperature range. Now, it is on the user, who will decide that which type of sensor is best suited for his/her application.

The selection of sensor depends on a variety of specifications viz: Application, Tolerance, Accuracy and out of the most temperature ranges.

Now the thing is to differentiate between different type of sensor which will include temperature range, tolerance, accuracy, interchangeability and relative strengths and weakness for each type of sensor.

◈ 5.1 REVIEW OF RTD AND THERMOCOUPLE BASICS

RTD's :

RTD'S contain a sensing element which is an electrical resistor that changes resistance with temperature. This change in resistance is well understood and is repeatable. The sensing element in an RTD usually contains either a coil of wire, or a grid of conductive film which has a conductor pattern cut into it. Extension wires are attached to the sensing element so it's electrical resistance can be measured from some distance away. The sensing element is then packaged so it can be placed into a position in the process where it will reach the same temperature that exists in the process.

Thermocouples :

Thermocouples, on the other hand, contain two electrical conductors made of different materials which are connected at one end. The end of the conductors which will be exposed to the process temperature is called the measurement junction. The point at which the thermocouple conductors end (usually where the conductors connect to the measurement device) is called the reference junction

When the measurement and reference junctions of a thermocouple are at different temperatures, a millivolt potential is formed within the conductors. Knowing the type of thermocouple used, the magnitude of the millivolt potential within the thermocouple, and the temperature of the reference junction allows the user to determine the temperature at the measurement junction.

The millivolt potential that is created in the thermocouple conductors differs depending on the materials used. Some materials make better thermocouples than other because the millivolt potentials created by these materials are more repeatable and well established. These thermocouples have been given specific type designations such as Type E, J, K, N, T, B, R and S.

◈ 5.2 TEMPERATURE LIMITATIONS FOR RTD'S AND THERMOCOUPLES:

The materials used in RTD's and thermocouples have temperature limitations which can be an important consideration in their use.

5.2.1 RTD's

As stated earlier, and RTD consists of a sensing element, wires to connect the sensing element to the measurement instrument and some kind of support to position the sensing element in the process. Each of these materials sets limits on the temperature that the RTD can be exposed to.

Table 1 : Sensing Element Materials And Temperature Limits

Material	Usable Temperature Range
Platinum	-260°C To 650°C
Nickel	-100°C To 300°C
Copper	-70°C To 150°C
Nickel/Iron	0°C To 200°F

The sensing element in an RTD usually contains a platinum wire or film, a ceramic housing and ceramic cement or glass to seal the sensing element and support the element wire. Typically, platinum sensing elements are able to be exposed to temperatures up to approximately 650°C. Other materials such as Nickel, Copper and Nickel/Iron alloy can also be used, however, their useful temperature ranges are quite a bit lower than for platinum. The wires which connect the sensing element to the readout or control instrumentation are usually made of materials such as nickel, nickel alloys, tined copper, silver plated copper or nickel plated copper. The wire insulation used also directly influences the temperature the RTD can be exposed to. Table contains the commonly used wire and insulation materials and their maximum usage temperatures.

Wire/ Insulation Materials	Max Usage Temp.
Tinned Copper/PVC Insulated	105°C
Silver Plated Copper/FEP Teflon Insulated	205°C
Silver Plated Copper/TFE Teflon Insulated	260°C
Nickel Plated Copper/TFE Teflon Insulated	260°C
Nickel Plated Copper/Fiberglass Insulated	480°C
Solid Nickel Wire	650°C

5.2.2 THERMOCOUPLES :

Thermocouple materials are available in Types E, J, K, N, T, R, S and B. These thermocouple types can be separated into two categories: Base Metal and Noble Metal thermocouples.

Type E, J. K, N and T thermocouples are known as Base Metal Thermocouples because they are made of common materials such as copper, nickel, aluminum, iron, chromium and silicon. Each thermocouple type has preferred usage conditions, for example the use of bare Type J thermocouples (Iron/Constantan) are typically limited to a maximum temperature of 540°C and are not recommended for use in oxidizing or sulfurous atmospheres due to deterioration of the Iron conductor. Bare Type T thermocouples (Copper/Constantan) are not used above 370°C due to deterioration of the copper conductor. Temperature ranges for these thermocouple types are included in Table 3.

Type R, S and B thermocouples are known as Noble Metal Thermocouples because they are made of Platinum and Rhodium. These thermocouples are used in applications that exceed the capabilities of Base Metal Thermocouples. Type R and S thermocouples are rated for use at temperatures between 540°C and 1480°C, with Type B rated for use from 540°C to 1700°C. When long term exposure at temperatures above 13700°C is expected, it is prudent to specify Type B thermocouples for improved thermocouple life. Type R & S thermocouples can experience significant grain growth if held near their upper use limit for long periods of time.

Since Thermocouples do not have sensing elements, they do not have many of the temperature limiting materials that RTD's do. Thermocouples are normally constructed using bare conductors which are then insulated in a compacted ceramic compacted ceramic powder or formed ceramic insulators, This construction allows thermocouples to be used at much higher temperatures than RTD's.

Table 3: Thermocouple Types, Temperature Ranges, Limits of Error

Type	Temp. Range	Tolerance Grades	
		Standard	Special
B	800°C - 1700°C	±0.5%	-
R & S	0°C - 1450°C	±1.5°C or ±0.25%	±0.6°C or ±0.1%
N & K	0°C - 1260°C -200°C - 0°C	±2.2°C or ±0.75% ±2.2°C or ±2%	±1.1°C or ±0.4% --
E	-200°C - 0°C 0°C - 870°C	±1.7°C or ±1% ±1.7°C or ±0.5%	-- ±1.0°C or ±0.4%
J	0°C - 760°C	±2.2°C or ±0.75%	±1.1°C or ±0.4%
T	-200°C - 0°C 0°C - 370°C	±1.0°C or ±1.5% ±1.0°C or ±0.75%	-- ±0.5°C or ±0.4%

Thermocouple Application Information

Type	Application Information
E	Recommended for continuously oxidizing or inert atmospheres. Sub Zero limits of error not established. Highest thermoelectric output of the common thermocouples type.
J	Suitable for vacuum, reducing or inert atmosphere, oxidizing atmosphere with reduced life. Iron oxidizes rapidly above 538°C so only heavy gauge wire is recommended for high temperature. Bare element should not be exposed to sulfurous atmospheres above 538°C.
K	Recommended for continuous oxidizing or neutral atmospheres. Mostly used above 538°C. Subject to failure if exposed to sulfur. Preferential oxidization of chromium in positive leg in certain low oxygen concentrations causes “green rot” and large negative calibration drifts most serious in the range of 816- 1038°C . Ventilation or inert sealing of the protection tube can prevent this.
N	Can be used in applications where Type K elements have shorter life and stability problems due to oxidation and the development of “green rot”.
T	Usable in oxidizing, reducing, or inert atmosphere as well as vacuum. Not subject to corrosion in moist atmosphere. Limits of error published for sub zero temperature ranges.
R &S	Recommended for high temperature. Must be protected in a non-metallic protection tube and ceramic insulators. Continued high temperature usage causes grain growth, which can lead to mechanical failure. Negative calibration drift caused by rhodium diffusion to the pure leg of platinum as well as from rhodium volatilization.
B	Same as R & S but has a lower output. Also, has a higher maximum temperature and less susceptible to grain growth.

5.3 TOLERANCE, ACCURACY AND INTERCHANGEABILITY :

Tolerance and Accuracy are the most misunderstood terms in temperature measurement.

The term tolerance refers to a specific requirement, which is usually plus, or minus some amount. Accuracy on the other hand refers to an infinite number of tolerances over a specified range.

For example, RTD's contain a sensing element, which is manufactured to have a specific electrical resistance at a specific temperature. The most common example of this requirement is what's known as the DIN standard. To meet the requirements of the DIN standard, an RTD must have a resistance of 100 Ohms ±0.12 % (or 0.12 Ohms) at 0°C to be considered a Grade B sensor (a Grade A sensor is 100 Ohms ±0.06%. The tolerance of ±0.12 Ohms applies only to the resistance at 32°C and cannot be applied to any other temperature. Many suppliers will provide an interchangeability table for RTD's, which provide the user with a table of tolerances at specific temperatures.

Thermocouples on the other hand are specified differently than RTD's because they are manufactured differently. Unlike the sensing element found in RTD's, the mV potential generated in a thermocouple is a function of the material composition and the metallurgical structure of the conductors. Therefore, thermocouples are not assigned a value at a specific temperature, but given limits of error, which cover an entire temperature range.

These limits assigned to thermocouples are known as standard or special limits of error.

Table 3 contains the standard and special limits of error specifications for each standard thermocouple type. It must be noted that the limits of error values listed in Table 3 are for new thermocouples, prior to use. Once thermocouples are exposed to process conditions, changes in the thermocouple conductors may result in increased errors.

Table 5 : Typical RTD Interchangeability Table

Temp	Tolerance at Temperature			
	Class A		Class B	
	Temp.	Resistance	Temp.	Resistance
-200°C	±0.55°C	±0.24 OHM's	±1.3°C	±0.46 OHM's
-100°C	±0.35°C	±0.14 OHM's	±0.8°C	±0.32 OHM's
0°C	±0.15°C	±0.06 OHM's	±0.3°C	±0.12 OHM's
100°C	±0.35°C	±0.13 OHM's	±0.8°C	±0.30 OHM's
200°C	±0.55°C	±0.20 OHM's	±1.3°C	±0.48 OHM's
300°C	±0.75°C	±0.27 OHM's	±1.8°C	±0.64 OHM's
400°C	±0.95°C	±0.33 OHM's	±2.3°C	±0.79 OHM's
500°C	±1.15°C	±0.38 OHM's	±2.8°C	±0.93 OHM's
600°C	±1.35°C	±0.43 OHM's	±3.3°C	±1.06 OHM's
650°C	±1.45°C	±0.46 OHM's	±3.6°C	±1.13 OHM's

Users are encouraged to perform tests periodically to determine the condition of thermocouples used in high reliability or close accuracy applications.

5.4 COMPARISON OF RESPONSE TIME OF DIFFERENT SENSORS

Specification	Thermocouple mineral insulated	Thermocouple with protection tube and insert	Resistance -element mineral insulated	resistance-element with protection tube and insert
Diameter	0.5-6 mm	9mm	3-6 mm	9mm
Insertion length	100-500 mm	100-400 mm	100-500 mm	100-150 mm
Response Time in water (sec.)	0.06-4.0	7	0.6-4.0	30
Response time in air (sec.)	1.8-60	92	26-55	140

Response time of Temperature sensors: the time it takes to run up to 63% of final measurement value.

5.5 Strengths & Weaknesses

Each type of temperature sensor has particular strengths and weaknesses.

RTD Strengths:

RTD's are commonly used in applications where repeatability and accuracy are important considerations. Properly constructed Platinum RTD's have very repeatable resistance vs. temperature characteristics over time. If a process will be run at a specific temperature, the specific resistance of the RTD at that temperature can be determined in the laboratory and it will not vary significantly over time. RTD's also allow for easier interchangeability since their original variation is much lower than that of thermocouples. For example, a Type K thermocouple used at 400°C has a standard limit of error of ±4°C. A 100-Ohm DIN, Grade B platinum RTD has an interchangeability of ±2.2°C at this same temperature. RTD's also can be used with standard instrumentation cable for connection to display or control equipment where thermocouples must have matching thermocouple wire to obtain an accurate measurement.

RTD Weaknesses:

In the same configuration, you can expect to pay from 2 to 4 times more for an RTD than for a base metal thermocouple. RTD's are more expensive than thermocouples because there is more construction required to make the RTD including manufacture of the sensing element, the hooking up of extension wires and assembly of the sensor. RTD's do not do as well as thermocouples in high vibration and mechanical shock environments due to the construction of the sensing element. RTD's are also limited in temperature to approximately 650°C where thermocouples can be used as high as 1700°C.

Thermocouple Strengths:

Thermocouples can be used to temperatures as high as 1700°C, generally cost less than RTD's and they can be made smaller in size (down to approximately .020" dia) to allow for faster response to temperature. Thermocouples are also more durable than RTD's and can therefore be used in high vibration and shock applications.

Thermocouple Weaknesses:

Thermocouples are less stable than RTD's when exposed to moderate or high temperature conditions. In critical applications, thermocouples should be removed and tested under controlled conditions in order to verify performance. Thermocouple extension wire must be used in hooking up thermocouple sensors to thermocouple instrument or control equipment. Use of instrumentation wire (plated copper) will result in errors when ambient temperatures change.

◈ 5.6 SUMMARY OF SELECTION OF TEMPERATURE SENSOR :

Temperature Sensor Selection Guide

	RTD	Thermocouple
Temperature Range	-200°C to 850°C	-190°C to 1821°C
Response Time	Moderate	Fast
Stability	Stable over long periods < 0.1% error/5 yr.	Not as stable 1% error/yr.
Linearity	Best	Moderate
Sensitivity	High sensitivity	Low sensitivity