Temperature Sensor Technology

Types of Sensors

There are three basic types of temperature sensors commonly used today: thermistors, thermocouples, and platinum RTDs. Listed below in tabular format are the important features of each of these device.

In general, thermocouples provide the most economical means of measurement over the widest temperature detectors which include both thermistors and platinum RTDs which will, in general, provide a more accurate means of absolute temperature measurement. This is true, however, over narrow temperature ranges.

Thermocouples

Thermocouples (T/C)are practically the only option available today to measure temperatures in the range from +1200°F to +5000°F.

When using and selecting thermocouples, it is very important to consider the atmosphere, environment, (how corrosive, how much pressure or vacuum, reducing or oxidizing atmosphere), as well as the temperature being measured. These and other factors not only affect the choice of material used for insulation, wire size, wire insulation, and sheaths, but also may determine the construction of the sensor.

Most thermocouples are physically mounted in stainless steel (type 304 or 316) sheaths, approximately 0.25 inch diameter. They are mineral insulated inside and bendable to different shapes. External lead wire insulation includes Teflon™, micatemp, and ceramic beads or cloth. Wire sizes used depend on the sheath diameter and other factors. Larger diameters (from 12-16 gauge) are often used in open or exposed junction configurations. Larger diameter wires are also required to operate at higher temperatures.

The following tables show the maximum operating temperatures for thermocouples and their related components.

Comparison of Temperature Sensors

Specification	*Platinum RTD***	*Thermocouple*	*Thermistor*
Typical Operating Temperature Range	-320°F to +1200°F	-320°F to +2300°F	-150°F to +300°F
Accuracy Interchangeability	-40 to 212°F: ±0.5°F 212 to 932°F: ±3°F 932 to 1200°F: ±3.75°F	32 to 530°F: ±1 $^{1}/_{2}$°F to ±4°F 530 to 2300°F: ±$^{1}/_{2}$ to ±$^{3}/_{4}$%*	-40 to 2121°F: ±0.5°F degrades rapidly over 212°F
Typical Sensitivity at 32°F	0.21 mV/°F with bridge	0.02 mV/°F	2 mV/°F with bridge
Stability	±0.01% for 5 Years	1 to 2°F per year	±0.2 to 0.5°F per year
Repeatability	0.05°F	2 to 4°F	0.2 to 1°F
Linearity	GOOD	AVERAGE	POOR
Size (Min.) Diameter	0.125" diameter	0.015" diameter	0.100"
Time Response	2-5/secs.	2-5/secs.	1-2/secs.
Remarks Stability Over Wide Temp. Range	Best for accuracy and Low signal-level Not best accuracy	Wide range, economical, limited on temp., poor linearity	High sensitivity

* *% of measuring reading.*

** *Industrial grade, 100 ohms, at 0°C, at 0°C, with 1.0 milliampere excitation. Reprinted Courtesy of Analogic Corporation*

In addition, thermocouples require a reference junction. The output voltage of a T/C is approximately proportional to the temperature difference between the measuring (hot) junction and the reference (cold) junction. This constant of proportionality is known as the Seeback Coefficient and ranges from 5 to 50 V/°C for commonly used thermocouples. The best way to know the temperature at the reference junction is to keep this junction in an ice bath resulting in zero output voltage of 0°C (32°F). A more convenient approach used in electronic instruments is known as cold junction compensation. This technique adds a compensating voltage to the thermocouple's output so that the reference junction appears to be at 0°, independent of the actual temperature. If this compensating voltage is proportionality as the thermocouple, changes in ambient temperature will have no effect on output voltage.

Table 1
Sheath and Wire Sizes

Sheath Diameter		*Wire Diameter*		
Fractions	*Inches*	*Inches*	*mm*	*Gauge*
$^{1}/_{16}$	0.062	0.01 to 0.013	0.2 to 0.32	28-32
$^{1}/_{18}$	0.125	0.016 to 0.02	0.4 to 0.8	24-36
$^{3}/_{16}$	0.188	0.032	0.8	20
$^{1}/_{4}$	0.250	0.032 to 0.040	0.8 to 1.0	18-20

Table 2
Thermocouples Max. Operating Temp.

Thermocouples	*Max. Temperature (F°)*
J Iron Constantan	2192°F
*K Chromel Alumel TM	2501°F
T Copper Constantan	752°F
E Chromel Constantan	1832°F
R/S Platinum Rhodium	3214°F
B Platinum Rhodium	3308°F
C Tungsten Rhenium	5000°F

Table 3
Sheaths Max. Operating Temp.

Material	*Max. Temperature (F°)*
Carbon Steel	1000°F
304/316 SS	1800°F
**Monel™	2000°F
***Hastelloy™ C	2000°F
446 Stainless Steel	2000°F
Nickel	2000°F
****Inconel™ 600	2100°F
*****Kanthal™	2200°F
Quartz	2300°F
Cobalt Tungsten	2400°F
Titanium	2700°F
Zirconium	3000°F
Silicon Carbide	3000°F
Platinum Rhodium	3050°F
Silicon Nitride	3150°F
Mullite (Porcelain)	3200°F
99% Alumia (Al203)	3400°F
Moly (molybdenum)	4000°F
Tantium	4500°F
Tungsten	5000°F

Table 4
Interior Insulations
Max. Operating Temp.

Material	*Max. Temperature (F°)*
(1) Al203	2400°F
(2) Mg 0	2500°F
(3) Th O2°	4000°F
(4) Be 0 (toxic)	4200°F

Table 5
Lead Insulations
Max. Operating Temp.

Material	*Max. Temperature (F°)*
Teflon	500°F
Kapton	55/750°F
Glass	1200°F
Asbestos	1200°F
Cefir (R)	2500°F
Ceramic	3000 to 4000°F

Table 6
Temperature Span vs.
Thermistor Resistance

Temperature	*Resistance (Ohms)*
+300 to 600°F	100K–500K @ 25°C
+150 to 300°F	2K–75K @ 25°C
+32 to 212°F	2K–5K @ 25°C
-100 to +150°F	100–1K @ 25°C

** Trademark of Hoskins Mfg. Co.*
*** Trademark of International Nickel Co.*
**** Trademark of Union Carbide Co.*
***** Trademark of International Nickel Co.*
****** Trademark of Kanthal Corp.*

RTDs (Resistance Temperature Detectors)

RTDs are made of copper, nickel, balco (nickel-iron), and platinum, with platinum now becoming the industry standard. These are resistance temperature detectors made of a single high purity wire, usually 0.001" in diameter, space wound onto a ceramic mandrel. Lead wires of nickel plated or ni-clad copper are fusion or resistance welded onto the sensor, usually in a three-wire or four-wire configuration. The sensor itself is then inserted into a thermowell of appropriate material and pressure rated for the intended environment. Most sheathed sensors (RTD or T/C) in industrial applications are brazed or welded onto appropriate fittings and attached through a pipe extension to a connection head.

These intermediate leads are normally glass insulated and are brought out to the end of the sheath through powdered aluminum oxide insulation or a suitable high temperature epoxy. The external lead wires are attached (welded, brazed, soldered, etc.) and potted with a moisture sealing compound (epoxy or ceramic cement). If operation is above 700°F, preoxidized inconel tubing may replace the stainless steel sheath to avoid outgassing contamination.

Standard RTD resistance (at ice point) are 100 and 200 ohms for platinum, 120 or 500 ohms for nickel, and 604 or 2000 ohms for balco. Copper RTDs (and thermistors) are specified at 25°C (77°F) instead of ice point (32°F). Thus a 10 or 100 ohm copper RTD is actually 9.038 or 90.38 ohms @ 32°F.

The RTD “Alpha” used with most instrumentation and the only standard to date, DIN, is 100 ohm platinum with a coefficient of 0.00385Ω/Ω°C (or 3850 ppm), indicating a resistance of 138.50 ohms at boiling point (100°C, 212°F). Tables for the Calendar-Van Dusen Equation have been calculated for both DIN 3850 alphas and higher U.S. Reference Grade (higher purity (99.999%) platinum), alphas, such as 3915 and 3923 ppm.

Theoretically, it is possible to build an RTD above 1200°F. Unfortunately, platinum is easy to contaminate or strain, which shifts the “alpha” or temperature coefficient, rendering the sensor unstable.

Thermistors

As resistance temperature devices (RTD), thermistors provide a direct indication of absolute temperature. They do not need cold junction compensation. They are excellent for low temperature measurements (-450°F) and to a high temperature of about 600°F, above which they decrease in stability. Their sensing area is small and their low mass (unless sheathed) allows a fairly fast response time of measurement.

Thermistors exhibit very high sensitivity and may change resistance 10 million to one over the span of -100 to +400°C where a platinum RTD would only change resistance by a 4:1 ratio over the same span. A thermocouple’s output over its entire temperature range will change only 10 or 15 to 1. Compared with thermocouple accuracies of a few degrees and RTD accuracy of possibly a tenth of a degree, thermistors offer accuracies of ±.01°C over narrow temperature spans.

Efforts have been made recently to overcome their extreme non-linearity by increasing the number of elements in the measuring network. With three thermistor networks, the linearity has been improved and the temperature span widened.

With curve matched and selected units (Fewall), thermistor interchangeably has yielded accuracies of ±0.2°C over wider temperature ranges. Their low cost makes them attractive in volume applications such as the automotive industry and for refrigeration controls. Their upper temperature limit (600°F) effectively precludes them from use in the power, chemical, and metal process industries. They are widely used in temperature controllers for copiers, air conditioning, photography, and other limited applications.