Address: P.O. Box 461947 Garland, TX 75046
Phone: 972-494-1566 **Toll Free:** 1-800-889-5478
Website: www.thermosensors.com

Resistance Temperature Detectors (RTDs)

Resistance Temperature Detectors (RTD's). These detectors are frequently used in the plastics industries and many others. Care must be taken to eliminate moisture and vibration effects can be troublesome as well. Thermo Sensors provides the utmost in current state of the art in materials, techniques and research.

Thermo Sensors offers the Reliatemp RTD. This RTD features lifetime moisture free use as well as excellent vibration resistance.

Please refer to our order guide to assist in determining your needs. We can also provide technical design assistance and application suggestions. Give us a call.

Application and Technical Data

Linearity

Linearity is defined as the maximum deviation of the calibration curve (an average of the upscale and downscale readings) from a straight line so positioned as to minimize the maximum deviation.

Platinum resistance elements have a nearly linear output while nickel and nickel-iron (Balco) sensors are quite curved. Copper elements are also nearly linear over their narrow temperature range.

Stability

Stability is the relationship of a sensor's original resistance curve to its curve after being in service. Drift rates published by a manufacturer must be assumed to be applicable to high purity laboratory environment probes. The published drift rates of 0.0°C are to be considered general and not necessarily quantitative.

Several parameters affect stability in a platinum sensor used in industrial processes. Thermal and mechanical treatment cause physical changes in the crystalline structure of the platinum causing different resistances at different temperatures. Chemical reactions involving platinum and impurities as well as migration of internal materials can affect a sensor output. A shunting effect due to insulation resistance deterioration is another influencing occurrence.

The drift caused by these conditions is not normally catastrophic except in rare instances. Attempts to establish a statement of stability in industrial applications would result in an ambiguous approximation at best.

Self-Heating

Since an RTD measures temperature by passing a current through a resistor (the RTD), the error known as self-heating occurs.

Primarily the sensor's mass, its internal construction, the measurement current and to a large degree environmental conditions determine the magnitude of this error. Normally a very small current, usually 1-5 milliamps is used in the excitation circuit to minimize this joule heating of the sensor. Thermo Sensors' internal construction technique maximizes heat transfer quality to further reduce the effect.

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An installation condition requiring large mass hardware such as thermowells or protective tubes coupled with an environment of still or slow moving air is going to experience a great deal more self-heating than the next example. a small diameter (.250" O.D.) direct immersion probe mounted in an environment of flowing water (min. 3 ft./sec) could totally dissipate the error.

Fortunately if a small measuring current (1-2 ma) is used, selfheating errors will be well within acceptable levels for industrial applications.

To approximate the amount of error; consider that normally the dissipation constant will be of the magnitude of 20-100 mw/0°C, and use the following formula.

$$\text{Self-heating error} = \frac{\text{Power}}{\text{Dissipation constant}}$$

Example: Measurement current - 2 ma
Resistance of sensor - 140 ohms
dissipation constant - 50 mw/0°C

Power = 1^2 R
= $(.002)^2$ (140) = 0.56 MW

$$\text{Error} = \frac{.56\text{ mw}}{50\text{ mw/0°C}} \quad .011°C$$

Time Constant

Time constants are values used to indicate the time it takes a sensor to read 63.2% of a step change in temperature. This test is conducted in water flowing at 3 ft/sec or 20 ft/sec in air. Typically this measurement is made by plunging a sensor at room temperature into a bath at 80°C and noting the time required to reach 63.2% of that step change. Generally speaking, it takes approximately five (5) time constants before 100% of the step change is realized.

Several variables affect the response time of sensors. Diameter of the sheath, material of the sheath and internal construction for different temperature ranges are the most variable. It is possible, however, to approximate the time constant for a particular group of sensors based on diameter and assuming the sheath material is a 300 series stainless steel.

These approximations are:

.125"	1.1sec.
.188"	1.7sec.
.250"	2.2sec.

Note: elements capable of a lower range of -250°C (to +600°C) have similar time constants.

These time constants should serve only as a general approximation for direct immersion sensors. Sensors installed in thermowells, protection tubes or that are mounted in conditions allowing appreciable stem losses are not subject to even these general constants.

In the rare instance where the response time absolute needs to be known; response time testing must be conducted to provide a time constant.

Insulation Resistance

To prevent an unacceptable shunting effect between the sensing element and the probe sheath, care must be taken to assure good insulation quality.

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In all sensors and particularly those in industrial service, high temperature operation, contamination and moisture absorption are potential problems.

To eliminate the effects of these occurrences, Thermo Sensors adheres to stringent manufacturing procedures. Reliatemp's Insulation Resistance will always be > 2000 megaHMS at or below 100°C.

Repeatability

By definition repeatability of a sensor is the relationship of the original resistance at 0°C and any different resistance at 0°C after being subjected to the following test.

The sensor shall be brought slowly to the upper limits of its temperature range and then exposed to air at room temperature. It shall then be brought slowly to its lower limit, and exposed to air at room temperature.

This procedure is repeated ten times. The resistance of 0°C is then measured and the difference from the pre-testing resistance is 0°C is noted.

For a typical platinum probe, the resistance should not change more than 0.3°C for a 0.12% sensor or 0.15°C for a 0.06% sensor. The 0.12% and 0.06% are original resistance tolerances at 0°C of the element.

Temperature Coefficient (Alpha)

Temperature coefficient, or Alpha, is the term given to the average resistance/temperature relationship of an RTD over the temperature span of 0-100°C and is expressed as ohm/ohm/0°C. The formula for determining Alpha is:

$$A = \frac{R(100°C) - R(0°C)}{100R\ (0°C)}$$

Typical Temperature Coefficients are:

.003926	(99.999% Pure Plat. - Laboratory Grade)
.00320	(MIL-T-24388)
.00391 .003915 .003902	Sometimes referred to as American standards, although no standards exist.
.003850	Din Standard 43760-widely used in industrial applications. B.S. 1904:1964

Note: SAMA Standard RC21-4-1966, has a temperature coefficient of .003923. The SAMA 100 ohm (Nominal) element only has a resistance of 98.129 ohms at 0°C. This element is in common use and should not be confused with the more commonly used elements having a 100 ohm resistance at 0°C.

Nickel	Copper	Nickel/Iron
.00672	.00427	(Balco)
.00618		.00519

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Platinum is by far the most commonly used material in RTD probes. The other materials are used where the higher resistance change or the non-linearity of their curves are advantageous.

It becomes obvious that since Alpha is a value developed using the variables of R(0°C) & R(100°C) that the Alphas noted above are not absolutes.They do however commonly serve as adequate specifications for the standard elements.

Alpha serves as an integral component in developing resistance versus temperature tables. The R/T table for platinum sensors published at the back of this catalog were developed using the Callendar-Van Dusen equation which corrects for the departure from linearity at temperatures other than 0-100°C which is stated by Alpha.

Callendar-Van Dusen Equation

$$\frac{R}{R_0} = 1+\alpha \left[T-\delta\left(\frac{T}{100}-1\right)\left(\frac{T}{100}\right)-\beta\left(\frac{T}{100}-1\right)\left(\frac{T}{100}\right)^3\right]$$

Where:
T = Temperature (°C)
R = Resistance at temperature T
R_0 = Resistance at 0°C

α = Constant (see formula above)
δ = Constant (typical value 1.5)
β = Constant (typical value 0.11 for temperatures less than 0°C; value is zero for temperatures over 0°C)
a useful form of this equation to calculate the resistance at a given temperature at and above 0°C is:

$R_T = R_O (1 + AT + BT^2)$

$$A=\alpha\left(1+\frac{\delta}{100}\right) \quad B=-\frac{a\delta}{10^4}$$

R_T = Resistance at temperature T
R_O, T, a and d are defined in the first equation.

Accuracy - Interchangeability

The terms accuracy and interchangeability are used jointly when considering the accuracy of an RTD. The factors affecting the accuracy of an RTD measurement excluding the accuracy of the readout instrument, is the relationship of the "as built" sensor to the resistance vs. temperature curve when compared to the assumed curve (the resistance vs. temperature table), and any aging or other environment effects on the sensor.

It is impossible to manufacture on a production basis sensors that will adhere to the calculated value of their resistance vs. temperature tables. There are three terms to be considered to understand why. They are:

Temp	Tolerance	
C	± 0° C	± OHMS
-.200	1.3	0.56
-100	0.8	0.32
0	0.3	0.12

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100	0.8	0.30
200	1.3	0.48
300	1.8	0.64
400	2.3	0.79
500	2.8	0.93
600	3.3	1.06
700	3.8	1.17
100 ohm ± .12% @ 0°C Element		

Proportional Error -
The error caused by the deviation of the sensor's actual temperature coefficient (Alpha) from the reference value. This error exists because of normal manufacturing tolerances in the alloying of the sensor material.

Adjustment Error -
The error caused by deviations of resistance at 0°C from the reference values. For example - a standard tolerance at 0°C for a 100 ohm platinum element is ± 0.12%. a wider tolerance of ±0.5% and tighter tolerance of ± 0.06% and ± 0.03% are available but are somewhat less expensive and appreciably higher in cost respectively.

Intrinsic Error -
Simply the sums of the proportional and adjustment errors. The intrinsic error of an element will influence its relationship to the published resistance/temperature table. Deviations are a function of temperature and accuracy statements cannot be given that will cover the entire useful range of a sensor. Therefore, an "interchangeability factor" is stated for cardinal temperatures throughout the range. The interchangeability tolerance for a 100 ohm platinum element (± 0.12%) is shown in the table below.

Note: Not all sensors are usable at all the temperatures shown. The tolerances are applicable up to the maximum temperature of a given sensor.

Calibration

Occasionally, the interchangeability tolerance listed for a sensor is unacceptable for an application. On those occasions there are three types of calibrations available. Thermo Sensors maintains a laboratory with equipment traceable to the National Bureau of Standards to furnish these calibrations.

1. If there is only one temperature of interest, or the interest is over a narrow range, elements can be selected by calibration to have a closer interchangeability tolerance of no more than .25% of the temperature. This selection calibration makes field adjustment of the measurement instrument unnecessary when elements are changed in critical applications.

2. Elements can be calibrated at a particular temperature of interest. Also if there are temperatures of interest over a narrow range, a two or three point calibration will provide the user with information for interpolation within that range so that the measurement instrument can be adjusted.

3. a complete computer generated resistance/temperature table can be provided for a platinum sensor over the range of 0°C to its maximum useful temperature. These tables can be provided in °F or °C with temperature increments from .01° to 1° as specified by the customer.

Matched Pairs
When using two platinum sensors to measure the differential temperature of chilled water, standard ± 0.12% elements can produce an error as much as 0.6°C. Usually this is unacceptable in critical applications. In those cases, sensors having a differential of down to ± 0.6°C at 0°C or .25% of a selected temperature can be furnished by calibration at additional cost.

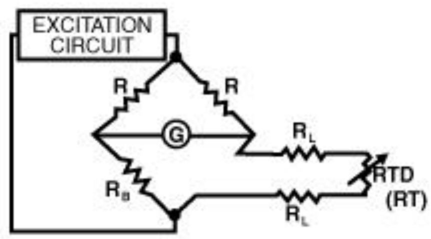
Lead Wire Compensation

Since the readout instrumentation for sensors is normally remoted considerable distances from the sensors themselves, it is important to consider and usually eliminate additional resistance imposed by the connecting wires. It is important that only the resistance change of the sensor be measured. To eliminate any change in lead resistance due to ambient changes, either a three or four wire connection should be used.

Most industrial applications are served well by using a three wire system while the four wire is common in laboratory environments.

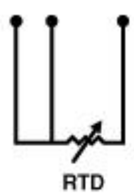
Diagrams and comments relating to the four commonly used wiring systems are shown below.

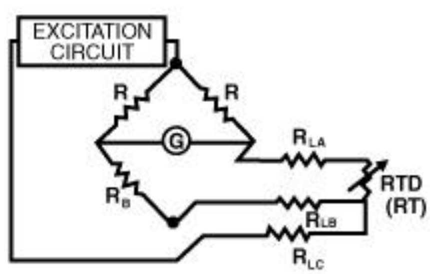
2-Wire System



At balance RB will equal RT + 2RL giving an error equal to the two leads of the sensor connection. Depending on lead length and wire size the error may be negligible or profound.

3-Wire System



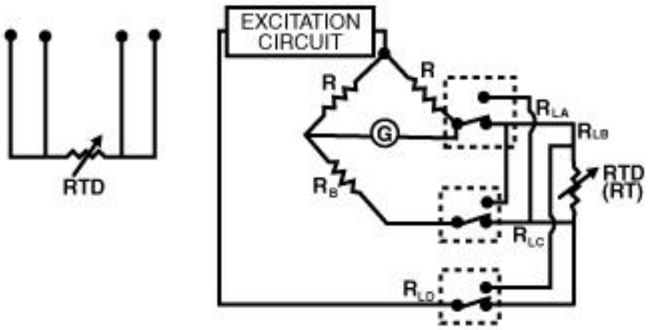


Industrial sensors commonly use this three wire connection system. For this system to be effective, all the leads (R_{LA}, B, C) should be very near the same length and of the same gauge.

At balance:
$R_B = R_{LB} = R_T + R_{LA}$
$R_T = R_B + R_{LB} - R_{LA}$

Any error would be to the magnitude of the difference in resistance of R_{LA} and R_{LB} which should be negligible assuming the leads are the same length and gauge.

4-Wire System



This system provides precision measurements. By switching the pairs of leads and averaging, you arrive at a value from which the lead resistance, thermal emf's in the leads and resistance changes in the leads due to ambient variation has been eliminated.

Switch Position a At balance:
$R_B + R_{LC} = R_T + R_{LA}$
$R_T = R_B + R_{LC} - R_{LA}$

Switch Position B
At balance:
$R_B + R_{LA} = R_T + R_{LC}$
$R_T = R_B + R_{LA} = R_{LC}$