

What Is an RTD?

(Submitted by Randall Gauthier,
RdF Corporation, <http://www.rdfcorp.com/>)

An RTD (Resistance Temperature Detector) is basically a temperature sensitive resistor. It is a positive temperature coefficient device, which means that the resistance increases with temperature. The resistance of the metal increases with temperature. The resistive property of the metal is called its resistivity. The resistive property defines length and cross sectional area required to fabricate an RTD of a given value. The resistance is proportional to length and inversely proportional to the cross sectional area :

$$R = \frac{r \times L}{A}$$

Where

R = Resistance (ohms)

r = Resistivity (ohms)

L = Length

A = Cross sectional area

RTD Materials

The criterion for selecting a material to make an RTD is:

- the material must be malleable so that it can be formed into small wires.
- it must have a repeatable and stable slope or curve.
- the material should also be resistant to corrosion.
- the material should be low cost
- it is preferred that the material have a linear resistance versus temperature slope

Some of the common RTD materials are:

Platinum with a temperature coefficient of 0.00385 - 0.003923 $\Omega/\Omega/^\circ\text{C}$ and practical temperature range of -452 to +1100°F (-269 to +593°C).

The platinum RTD has the best accuracy and stability among the

common RTD materials. The resistance versus temperature curve is fairly linear and the temperature range is the widest of the common RTD materials. Platinum has a very high resistivity, which means that only a small quantity of platinum is required to fabricate a sensor and making platinum cost competitive with other RTD materials. Platinum is the only RTD commonly available with a thin film element style.

Primary uses: Platinum is the primary choice for most industrial, commercial, laboratory and other critical RTD temperature measurements.

Copper, nickel and nickel iron are also commonly used RTD materials. They are mostly used in lower cost non-critical applications and will not be detailed in this article.

Platinum RTD Performance Specifications :

Temperature Coefficient (α):

Platinum RTDs are manufactured with two distinct types or temperature coefficients (α). The temperature coefficient (α) is the slope of the platinum RTD between 0°C to 100°C. It is calculated as follows:

$$\alpha = \frac{R_{100} - R_0}{100 \times R_0}$$

α = Temperature Coefficient ($\Omega/\Omega/^\circ\text{C}$)

R_{100} = RTD resistance at 100°C

R_0 = RTD resistance at 0°C

DIN Grade Platinum:

The DIN grade, sometimes referred to as the European standard, has a temperature coefficient of 0.00385 $\Omega/\Omega/^\circ\text{C}$ (+/- 0.000012). A consortium of European standards committees developed the curve that all manufacturers of platinum RTDs could conform to. The platinum that is used to

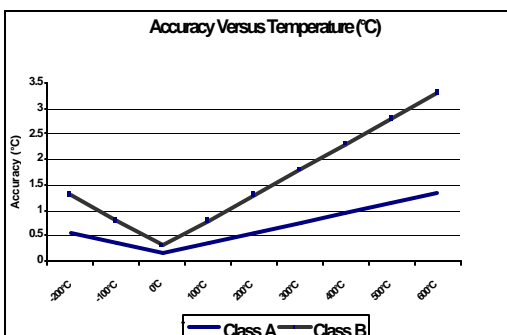
achieve the DIN standard is pure platinum that is alloyed with a controlled small amount of platinum group metals to reproduce the curve. The DIN curve has captured a majority of the market for industrial RTDs worldwide. Thin film sensors are only manufactured with DIN platinum.

Reference Grade Platinum:

Reference grade platinum is made from 99.999% pure platinum. It will produce a maximum temperature coefficient of $0.003926\Omega/\Omega/^{\circ}\text{C}$. The maximum temperature coefficient can only be achieved in Standard Platinum Resistance Thermometers (SPRT) for laboratory use. The practical range of temperature coefficients for industrial use is 0.003902 to $0.003923\Omega/\Omega/^{\circ}\text{C}$. Reference grade platinum is still the choice for critical applications including aerospace and nuclear.

Accuracy: Platinum RTDs typically are provided in two classes, class A and Class B. Class A is considered high accuracy and has an ice point tolerance of ± 0.06 ohms. Class B is standard accuracy and has an ice point tolerance of ± 0.12 ohms. Class B is widely used by most industries.

The accuracy will decrease with temperature. Class A will have an accuracy of ± 0.43 ohms ($\pm 1.45^{\circ}\text{C}$) at 600°C and class B will be ± 1.06 ohms ($\pm 3.3^{\circ}\text{C}$) at 600°C . The chart below shows the tolerance versus temperature (IEC 751).



Other looser accuracies are available, but are generally only used in very low cost and high volume applications.

The accuracies stated here are based on International Standard IEC Publication 751 for DIN RTDs. There are many standards that define accuracy and they have slight variations on accuracy values, but generally fall within the class A and B definitions.

Some of the commonly used standards are:

- ASTM E 1137 American Society for Testing and Materials
- B.S. 1904 British Standards Institution
- IEC 751 International Electrotechnical Commission
- DIN 43760 German Electrotechnical Commission
- JIS C 1604 Japanese Industrial Standard
- Mil-T-24388 Thermocouple and Resistance Temperature Element Assemblies (Naval Shipboard)

Stability: This is a measurement of drift over time. This is often referred to as long term stability. Most manufacturers specify stability at less than 0.05°C per year. Stability is affected by the sensor design. A well designed, high quality sensor will have less drift. Stability is also affected by the sensor's service environment. High vibration, mechanical abuse and thermal shock will affect stability.

Interchangeability : Interchangeability is the measure of variability of base tolerance and temperature coefficient from sensor to sensor. This is important when replacing a sensor, to insure that the system retains its rated performance characteristics without re-calibration. System designers should know what sensor tolerances will support their

performance expectations when specifying the sensor.

Response Time: Response time is the sensor's ability to react to temperature changes in the process. The ability to track process changes depends on the sensor's thermal mass and proximity to the process. Direct immersion sensors generally are the fastest responding, but in many applications a thermowell is used so that the process does not have to be drained to change a sensor.

Sensor Description	Approximate Time Response
Direct immersion Aerospace/nuclear style sensor	0.3 to 3 seconds
1/8 inch diameter 300 series SST sheath	2 to 3 seconds
3/16 inch diameter 300 series SST sheath	4 to 5 seconds
¼ inch diameter 300 series SST sheath	5 to 7 seconds
¼ inch diameter sheath spring loaded into a thermowell	15 to 20 seconds

Sensors in thermowells are slower due to the additional thermal mass and the radial clearance between the sensor and thermowell. Sensor/thermowell assemblies can be made faster by making the sensor to bore fit more precise or by using a filler material, such as a thermal grease.

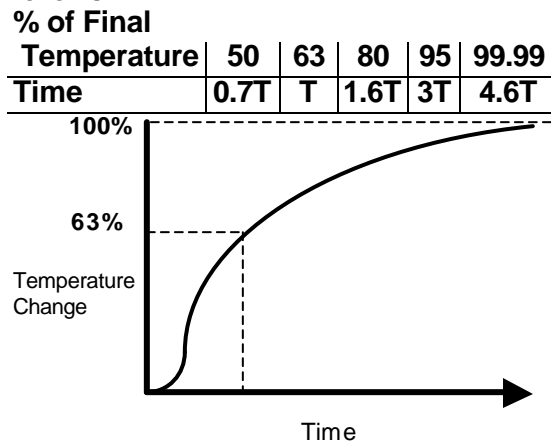
There are a number of other factors in the system that will influence the sensor's response, such as:

- the thermal lag of the sensor combined with the thermowell
- immersion depth (the rule of thumb is that the sensor should be immersed at least 1.5 times the sensing element's length.
- flow velocity of the process fluid
- process fluid transients

- fluid boundary or film on sensing surface
- influences from wall or vessel
- thermal lag on wall or vessel
- other outside environmental influences (convective and conductive)

Industrial specifications define response time as 63.2% of a step change in temperature. This is usually tested in water flowing at three feet per second. This is a direct plunge test from ambient to water at approximately 70 to 90°C.

The approximate relationship of % of temperature change versus time is as follows:



Insulation Resistance: RTD

assemblies are usually filled with inorganic fillers such as aluminum or magnesium oxide. These materials are hygroscopic and any moisture absorbed will cause a shunting effect across the sensing element. This shunting is usually high compared to the resistance of the sensing element so that the shunting effect is not detectable. When the insulation resistance falls a shunting error will occur. An estimate of this error can be calculated as follows:

$$\Delta T = \frac{R_r^2}{(R_s + R_r) \left[\Delta R / \Delta T \right]}$$

Where:

ΔT = measurement error (°C)

R_r = resistance of the RTD (ohms)

R_s = Resistance between element leads and case (ohms)
 $\Delta R/\Delta T$ = slope of the RTD ($\Omega/^\circ\text{C}$)

This is only an estimate because there is no direct measurement of insulation resistance across the sensing element. The standard test method for the measurement of insulation resistance takes the measurement from the commoned leadwires to the sensor case. The test is usually performed using 50 or 100Volts DC and an insulation resistance of greater than 100 megohms is considered acceptable. Insulation resistance is the largest cause of error and failure in an RTD. The causes can be an inadequate seal, high humidity environment, or a failed seal. In some cases baking the RTD assembly will increase the insulation resistance and recover the RTD.

Self-Heating : RTDs are constructed of very fine wires or very thin coatings. The very small cross-sectional areas in the sensing elements will tend to heat when electrical current is applied. Most RTDs are specified to be operated with a current of 1 milliamp or less. The test for self-heating involves placing the sensor in a controlled temperature bath at approximately 25°C , with a liquid flow of 3 feet per second. The sensor's resistance is measured with the minimum current and then measured with current increased in steps. The self-heating can be calculated as follows:

$$\text{MW}/^\circ\text{C} = \frac{S(P_2 - P_1)}{R_2 - R_1}$$

Where:

R_1 = resistance at the lower power dissipation (Ohms).

R_2 = resistance at the higher power dissipation (Ohms).

S = RTD slope at test temperature (ohms/ $^\circ\text{C}$).

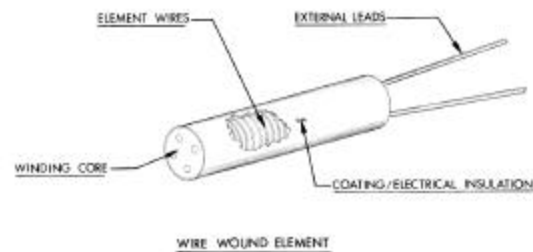
P_1 = Lower power dissipation ($R_1 I_1^2$)

P_2 = Lower power dissipation ($R_2 I_2^2$)

A typical range for self-heating in an industrial RTD is 30 to 60mW/ $^\circ\text{C}$.

RTD Types : There are basically three styles of platinum sensing elements. Each style has unique characteristics and advantages.

Wire wound Element : The wire wound sensor is the simplest sensor design. The sensing wire is wrapped around an insulating mandrel or core. The winding core can be round or flat, but must be an electrical insulator. Matching the coefficient of thermal expansion of the sensing wire and winding core materials will minimize any mechanical strain.



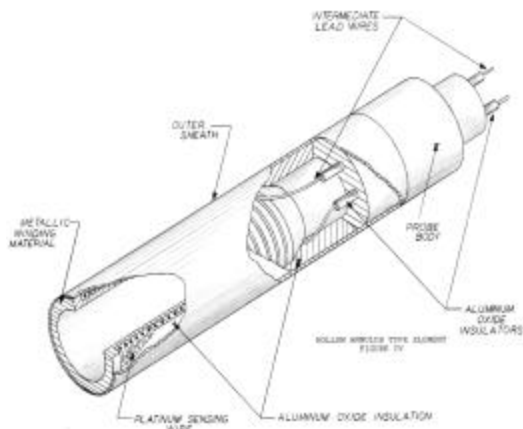
Strain on the element wire will result in an error in the measurement. The winding core must also be selected to match the intended service temperature and environment.

The sensing wire is connected to a larger wire, usually referred to as the element lead or wire. This wire is selected to be compatible with sensing wire so that the combination does not generate an emf that would distort the measurement. The wire also has to be able to withstand any annealing during the process.

The wire wound sensor is the only configuration that can be made with all

of the sensing materials mentioned earlier.

A unique version of the wire wound sensor is the hollow annulus design. This design is intended for Aerospace or Nuclear applications, where response time is important or the application is of a critical nature.



The sensing element is wound on a hollow stainless steel winding core that is insulated with a flame sprayed coating aluminum oxide. A specific stainless steel is chosen for its close match of thermal expansion with the platinum sensing wire. After the usual processing, annealing and coating, the sensing element is enclosed incased with a thin stainless steel sheath. This provides a completely sealed sensing element that can be directly immersed into a process fluid.

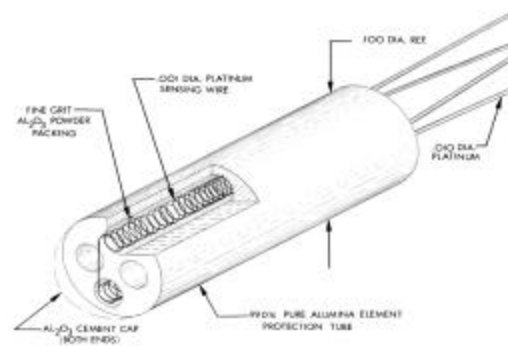
Response time for this sensor ranges from 350 milli-seconds for a directly immersed sensor to approximately 11 seconds in an appropriately fitted thermowell.

The disadvantage of this style sensing element is the high cost.

Coiled Element : The coiled sensor is a method to produce a "strain free" design. A strain free design allows the sensing wire to expand and contract free of influences from other materials in

the assembly. Techniques similar to those used in this design are used in Standard Platinum Resistance Thermometers (SPRT), which are used as laboratory standards.

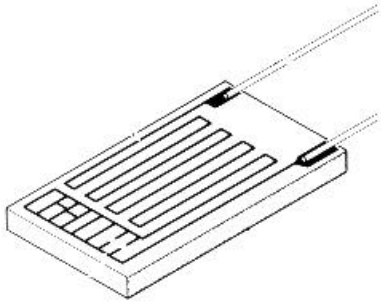
There are variations to this style sensor depending on the manufacturer. The basis of the sensing element is a small coil of platinum sensing wire. This coil resembles a filament in an incandescent light bulb. The housing or mandrel is a hard fired aluminum oxide tube with four equally spaced bores that run transverse to the axes. The coil is inserted in the bores of the mandrel and the bores are packed with a very fine grit ceramic powder. This permits the sensing wire to move while still remaining in good thermal contact with the process being measured.



Thin Film Element: The thin film sensing element is manufactured by depositing a very thin layer of platinum on a ceramic substrate. This layer is usually just a 10 to 100 angstroms (10^{-8} centimeters) thick. The platinum film is coated with epoxy or glass. This coating helps protect deposited platinum film and acts as a strain relief for the external leadwires.

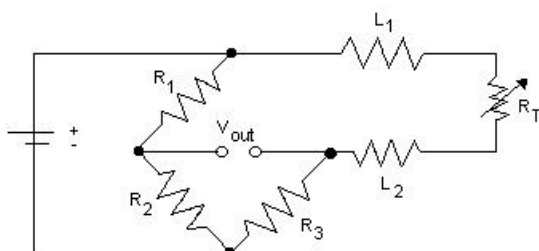
When thin film sensors were introduced many years ago, they had a reputation for being unreliable. They were unstable and were susceptible to mechanical failure, such as breakage of leadwires. The thin films today are much better. They are more rugged and reliable.

The advantage of the thin film Platinum RTD is low cost and low thermal mass. The low thermal mass makes them respond faster and they are easier to assemble into small packages. Disadvantages are that they are not as stable as wire wound RTDs and they are only available in DIN (0.00385 $\Omega/\Omega/^{\circ}\text{C}$) platinum.



Leadwire Configurations: RTDs are available with four different leadwire configurations. The selection of leadwire configuration is based on desired accuracy and instrumentation to be used for the measurement.

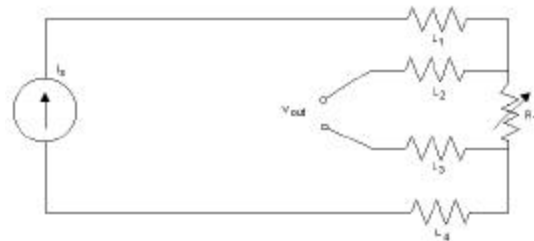
Two wire RTD: The two wire RTD is the simplest wire configuration. One wire is attached to each side of the element. A measure can be taken by any device equipped to measure resistance, including basic Volt Ohm Meters (VOM). This is the least accurate way of measuring temperature, due to the fact that the leadwire resistance is in series with the sensing element. The leadwire is at a different temperature than the sensing element and also has different resistance versus temperature characteristics. The longer the leadwire the greater the effect on the measurement. A typical two wire bridge looks like the following:



Three Wire RTD: The three wire RTD is the most popular configuration for use in industrial applications. When used correctly, the three wire configuration eliminates the series resistance. This permits an accurate measurement of the sensing element. Two of the leads are connected to one side of the sensing element and the single lead to the other side.

The resistance in L_1 and L_3 should be matched as close as possible, this will cause the lead resistance to cancel themselves.

The color code for a three wire RTD is two red wires and one white. A typical three wire RTD is shown below:



Four Wire RTD: A four wire RTD is the most accurate method to measure an RTD. It is primarily used in laboratories and is seldom seen in an industrial application. A four wire RTD circuit removes the effect of mismatched resistances on the lead wires. A constant current is passed through L_1 and L_4 . L_2 and L_3 measure the voltage drop across the RTD element. The color code for a four wire RTD is usually two red wires and two white wires.

The following diagram illustrates a typical four wire measurement:

