So, what is a Platinum RTD?

– **Doris Garvey**,
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Temperature measurement can be very simple or very complex, depending on your application and requirements. Understanding these platinumn RTD specifications is an important first step toward finding the right device. International industrial RTD standards exist only for platinum RTDs.

Resistance temperature detectors (RTDs) operate on the inherent propensity of metal to exhibit a change in electrical resistance as a result of a change in temperature. We are all aware that metals are conductive materials. It is actually the inverse of a metal's conductivity, or its resistivity, that brought about the development of RTDs. Each metal has a specific and unique resistivity that can be determined experimentally. This resistance, "R", is directly proportional to a metal wire's length, "L", and inversely proportional to the cross-sectional area, "A":

$$R = \rho L \, / \, A \qquad\qquad (1)$$

where: ρ = the constant of proportionality, or the resistivity of the material.

Principle of Operation

RTDs are manufactured from metals whose resistance increases with temperature. Within a limited temperature range, this resistivity increases linearly with temperature:

$$R_t = R_0\big[1 + \alpha(t - t_0)\big] \qquad\qquad (2)$$

where:

R_t = resistance at temperature t

R_0 = resistance at a standard temperature t_0

α = temperature coefficient of resistance (°C^{-1})

Temperature measurement is essential to a wide variety of industries. This task can be handled by resistance temperature detectors, or RTDs, which are available in a variety of configurations and ratings, such as sanitary and explosion proof, to satisfy the particular application.

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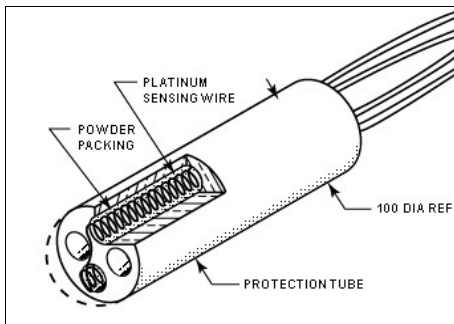AS9100
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Figure 1. The coiled element sensor, made by inserting the helical sensing wires into a packed powder-filled insulating mandrel, provides a strain-free sensing element.

Combining Equations **(1)** and **(2)**, setting t_0 to 0°C, and rearranging to the standard linear $y=mx+b$ form, it is clear that resistance vs. temperature is linear with a slope equal to ɑ:

$$R / R_0 = \alpha t + 1 \qquad (3)$$

In theory, any metal could be used to measure temperature. The metal selected should have a high melting point and an ability to withstand the effects of corrosion. Platinum has therefore become the metal of choice for RTDs. Its desirable characteristics include chemical stability, availability in a pure form, and electrical properties that are highly reproducible.

Platinum RTDs are made of either IEC/DIN grade platinum or reference grade platinum. The difference lies in the purity of the platinum. The IEC/DIN standard is pure platinum that is intentionally contaminated with other platinum group metals. The reference grade platinum is made from 99.999+% pure platinum. Both probes will read 100Ω at 0°C, but at 100°C the DIN grade platinum RTD will read 138.5Ω and the reference grade will read 139.24Ω in RdF's maxiumum performance strain-free assemblies. International committees have been established to develop standard curves for RTDs. *Only platinum RTDs have an international standard.* Standards for any other metal are local. The committees have adopted a mean temperature coefficient between the 0°C and 100°C resistance values as the ("alpha") for industrial platinum RTDs conforming to the relationships below.

Solving equation **(3)** for ɑ:

$$\alpha = \left(R_{100} - R_0 \right) / R_0 \cdot \Delta t \qquad (4)$$

IEC/DIN grade platinum:
ɑ = 0.00385 Ω/Ω/°C

Reference grade platinum:
ɑ = 0.003926 Ω/Ω/°C (max.)

The relationship between resistance and temperature can be approximated by the Callendar-Van Dusen equation:

$$\frac{R_t}{R_0} = 1 + \alpha \left[t - \delta \left(\frac{t}{100} - 1 \right) \left(\frac{t}{100} \right) - \beta \cdot \left(\frac{t}{100} - 1 \right) \left(\frac{t}{100} \right)^3 \right] \qquad (5)$$

where:

t = temperature (°C)

R_t = Resistance at temperature t

R_0 = Resistance at the ice point

ɑ = Constant "alpha", equation **(4)**, (gives the linear approximation to the R vs. t curve)

d = Constant "delta" (for small 2nd order nonlinearity) (~1.5)

b = Constant "beta" (b = 0 when t > 0°C) (opposes d < 0°C, negligible above −40°C) (~0.11)

The actual values for the coefficients ɑ, d, and b are determined by testing the RTD at four temperatures and solving the equations.

The Callendar-Van Dusen equation was constructed to directly use laboratory data fixing alpha from 0°C and 100°C resistances. It is arranged from the prefered computation form used in the IEC/DIN International curve defining equation:

$$R_t = R_0 \left[1 + At + Bt^2 + C \left(t - 100°C \right) t^3 \right] \qquad (6)$$

In the positive quadrant, temperatures over 0°C, **C** is zero so the behavior of a platinum RTD simplifies to equation **(7)** which is also adequate for extrapolation to −40°C.

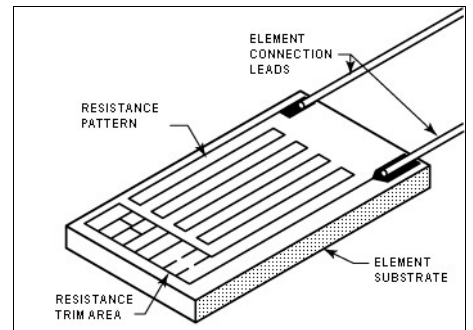$$R_t = R_0 \left(1 + At + Bt^2 \right) \qquad (7)$$

Figure 2. The thin film sensing element is made by depositing a thin layer of platinum in a resistance pattern on a ceramic substrate. A glassy layer is applied for seal and protection.

As written, the above implies that valid equations for positive temperatures may be generated from empirical data taken using 0°C plus two arbitrarily selected positive temperatures. For a single PRT, the constants **A** and **B** could be slightly different, depending on the temperatures selected.

Callendar resolved the issue by defining two additional fixed points:

• The boiling point of water, 100°C (As embedded in equations **(5)** and **(6)**)
• The freezing point of zinc, 419.53°C (Practical calibrations use >200°C)

The coefficients **A**, **B**, and **C** depend on the platinum wire material, purity, form (film or wire) and method of support. International standard IEC 751 defines them to permit universal interchangeability among international grade platinum RTDs.

The coefficients and their relationship to constants in equation **(5)** are:

$$A = \alpha (1 + \delta / 100) = 3.9083 \times 10^{-3} \text{ °C}^{-1}$$
$$B = -10^{-4} \alpha \delta = -5.775 \times 10^{-7} \text{ °C}^{-2}$$
$$C = -10^{-8} \delta \beta = -4.183 \times 10^{-12} \text{ °C}^{-4}$$

(**C**=0 when t is >0°C)

*Only the ɑ or **A** constants from 0°C and 100°C calibrations are needed to define individual probe curves in most applications where precision better than standard interchangeablitiy is desired.* The other constants usually can be considered invarient in the range −100°C to 250°C. Only outside this range can differences exceed ordinary test precision on RTDs of the same type, requiring additional high and/or low test points.

Fabrication

Platinum RTD elements take either of two forms: wire-wound (see **Fig. 1**) or thin film. RdF wire-wound elements are made primarily by winding a very fine strand of platinum wire into a coil until there is enough material to equal 100Ω of resistance. The coil is then inserted into a mandrel and powder is packed around it to prevent the sensor from shorting and to provide vibration resistance. This is a time consuming method and all work is done manually under a microscope, but the result is a strain-free design. Strain-free elements are required for industrial measurements below –200°C. They also insure superior interchangeablity and stability to the highest temperatures.

Thin film elements (see **Fig. 2**) are manufactured by depositing a thin layer of platinum or its alloys on a ceramic substrate. The metal is deposited in a specific pattern and trimmed to the final resistance. The elements are coated with a glass-like material for mechanical and moisture protection. An advantage of the thin film sensor is that a greater resistance can be placed in a smaller area; 1000Ω RTD sensors are readily available. Thin film sensors are susceptible to a small thermal expansion mismatch strain that limits maximum temperature coefficient to the 0.00385 Ω/Ω/°C International grade. On the plus side, 1000Ω elements offer the advantage of increased resolution per degree of temperature, and errors due to lead wire resistance are minimized. Although 1000Ω thin film elements would appear preferable, most of the older electronics are designed to accept only the 100Ω sensor. 100, 500 and 1000 Ω thin-films, now produced world-wide, incorporate platinum advantages so efficiently no other metal can compete.
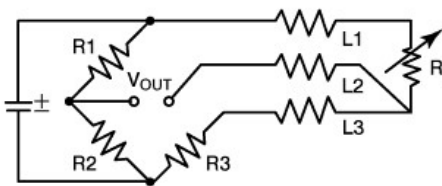
Specifications

When discussing RTDs, several spec-ifications must be considered:

• Wiring configuration (2, 3, or 4-wire)
• Self-heating
• Accuracy
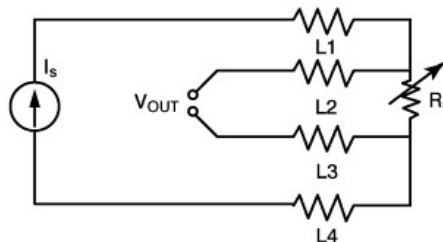• Stability
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• Response time
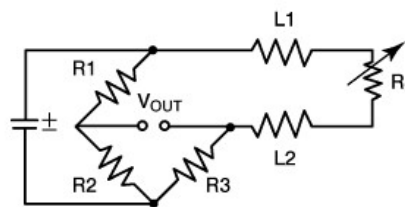
Figure 3. Lead wires have resistance that is a function of the material used, wire size, and lead length. This resistance can add to the measured RTD resistance, and improper wire compensation can result in significant errors. The common configurations of RTDs are two (A), three (B) or four wires (C).

Wiring Configuration

Serious lead-wire resistance errors can occur when using a two-wire RTD **(see Fig. 3A)**, especially in a 100Ω sensor. In a two-wire circuit, a current is passed through the sensor. As the temperature of the sensor increases, the resistance increases. This increase in resistance will be detected by an increase in the voltage ($V = I•R$). The actual resistance causing the voltage increase is the total resistance of the sensor and the resistance introduced by the lead wires. As long as the lead wire resistance remains constant, it can be offset and not affect the temperature measurement. The wire resistance will change with temperature, however, so as the ambient conditions change, the wire resistance will also change, introducing errors. If the wire is very long, this source of error could be significant. Two-wire RTDs are typically used only with very short lead wires, or with a 1000Ω element.

In a 3-wire RTD (see **Fig. 3B**), there are three leads coming from the RTD instead of two. L1 and L3 carry the measuring current, while L2 acts only as a potential lead. Ideally, the resistances of L1 and L3 are perfectly matched and therefore canceled. The resistance in R3 is equal to the resistance of the sensor Rt at a given temperature—usually the begining of the temperature range. At this point, V out = zero. As the temperature of the sensor increases, the resistance of the sensor increases, causing the resistance to be out of balance and indicated at V out. *Resistances L1 and L3 in leads up to tens of feet long usually match well enough for 100 Ω three-wire RTDs. The worst case is resistance offset equal to 10% of single-lead resistance.*

The optimum form of connection for RTDs is a four-wire circuit (see **Fig. 3C**). It removes the error caused by mismatched resistance of the lead wires. A constant current is passed through L1 and L4; L2 and L3 measure the voltage drop across the RTD. With a constant current, the voltage is strictly a function of the resistance and a true measurement is achieved. This design is slightly more expensive than two or three-wire configurations, but is the best choice when a high degree of accuracy is required.

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Self-Heating

To measure resistance, it is necessary to pass a current through the RTD. The resultant voltage drop across the resistor heats the device in an effect known as the I^2R, or Joule heating. The sensor's indicated temperature is therefore slightly higher than the actual temperature. The amount of self-heating also depends heavily on the medium in which the RTD is immersed. An RTD can self-heat up to 100x higher in still air than in moving water, so self-heating specifications are just a conservative guide.

Accuracy / Interchangeability, Stability & Repeatability

These terms are often confused, but it is important to understand the difference.

• Accuracy/Interchangeability

IEC standard 751 sets two tolerance classes for the interchangeability of platinum RTDs:

Class A and Class B:

Class A: Dt °C= ± (0.15 + 0.002 • | t |)

Class B: Dt °C= ± (0.30 + 0.005 • | t |)

where:
| t | = absolute value of temperature in °C

Class A applies to temperatures from –200°C to 650°C, and only for RTDs with three or four-wire configurations.

Class B covers the entire range from –200°C to 850°C.

A major advantage of platinum RTDs is that calibration at as few as two temperatures offers accuracy, preserved by high stability, much tighter than even Class A interchangeability. No other temperature sensor offers specifications for stability (see following) that will preserve laboratory accuracy embedded in calibrations over long time periods and wide temperature ranges and every configuration. Primary Standard Resistance Temperature Sensors (SPRTS) are platinum for good reason.

• Stability

This is the sensor's ability to maintain a consistent output when a constant input is applied. Unintended physical or thermal shocks can cause small, one-time shifts. The material that the platinum is adhered to, when wound on a mandrel or deposited on a substrate, can expand and contract differentially to cause strain incorporated in normal performance but not cause shifts. Stability limits conservatively specified by RdF are typically 0.05°C/yr in wide temperature ranges or 0.05°C/5 yrs in medium ranges.

• Repeatability

Repeatability is the sensor's ability to give the same output or reading under repeated identical conditions. *In platinum RTDs, cycle to cycle differences normally can't be measured and are considered lumped into stability specifications.*

Absolute accuracy is not necessary in most applications. The focus should be on the stability and repeatability of the sensor. If an RTD in a 100.00°C bath consistently reads 100.06°C, the electronics can easily compensate for this error. The stability of platinum RTDs is exceptional, with most experiencing drift rates < 0.05°C over five years.

Response Time

Response time is the sensor's ability to react to a change in temperature, and depends on the sensor's thermal mass and heat transfer from the material being tested. For instance, an RTD probe in a thermowell will react much more slowly than the same sensor immersed directly into a fluid. The sensor in a solidly bonded internal assembly responds twice as fast as one with a single loose interface in the same assembly. Surface RTDs respond quickly to surface temperature change. RTD specifications will list the sensor's time constant, which is the time it takes for an RTD to respond to a step change in temperature and come to 63% of its final equilibrium value.

Probe response times are measured in water flowing at 3ft/sec (1m/s) and in air flowing at 10ft/sec (3m/s). This gives a useful comparison of RTD probe configurations.

Relationships useful for extrapolating response times, t, within the same probe construction and the same flow characteristics are as follows. If cylindrical probe diameter, d, is changed for the same fluid mass flow across the probe:

$$t \; \mu \; d^{1.5} \text{ or } t_2/t_1 = (d_2/d_1)^{1.5} \qquad (8)$$

If fluid mass flow, m, is changed for the same probe diameter:

$$t \; \mu \; 1/m^{0.5} \text{ or } t_2/t_1 = (m_1/m_2)^{0.5} \qquad (9)$$

Summary

The operating principle, operating equations, fabrication, calibration recomendations and specifications are given for platinum RTDs. International industrial RTD standards exist only for platinum RTDs. Platinum RTDs are more efficient to produce, cover the widest temperature range by 2x or more and overwhelmingly outperform obsolete base-metal RTDs.
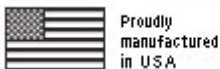
100 Ω platinum RTD 3-wire connections common in industry normally provide adequate cancelation of lead resistance up to tens of feet. 1000 Ω platinum thin film RTDs provide comparable performance with 2-wire connections because series lead resisitance offsets are 10x smaller.

A major advantage of platinum RTDs is that calibration at as few as two temperatures offers accuracy, preserved by high stability, much tighter than defined classes of interchangeability. No other temperature sensor offers specifications for stability that will preserve laboratory accuracies embedded in calibrations over long periods and wide temperature ranges in every configuration. ∎

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