Resistance temperature detectors (RTDs) operate on the inherent propensity of metals 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:

$$R = \rho L/A \quad (1)$$

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:

$$\rho_t = \rho_0 [1 + a (t - t_0)] \quad (2)$$

where:

ρ_t = resistivity at temperature, t

ρ_0 = resistivity at a standard temperature, t_0

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

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 a:

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

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 99.99% pure platinum. Both probes will read 100 Ω at 0°C, but at 100°C the DIN grade platinum RTD will read 138.5 Ω and the reference grade will read 139.02 Ω. International committees have been established to develop standard curves for RTDs. The committees have defined a mean temperature coefficient to be between 0°C and 100°C. Solving Equation (3) for a:

$$\alpha = (R_{100} - R_0) / R_0 t \quad (4)$$

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

reference grade platinum: a = 0.003926 Ω/Ω/°C (max.)

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

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

where:

T = temperature (°C)

R = resistance at temperature T

R_0 = resistance at the ice point

α = constant (gives the linear approximation to the R vs. T curve)

δ= constant

β= constant (b = 0 when T is >0°C)

The actual values for the coefficients,α, δ, and β are determined by testing the RTD at four temperatures and solving the equations. The Callendar-Van Dusen equation can be simplified to:

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

In the positive quadrant, temperatures over 0°C, the behavior of a PRT may be described by a quadratic equation in the form:

$$R_t = R_0 (1 + At + Bt^2) \quad (7)$$

As written, the above implies that valid equations 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
- The triple point of zinc, 419.58°

The coefficients A, B, and C depend on the wire material (i.e., platinum) and its purity. International standard IEC 751 describes the specifications that permit universal interchangeability among platinum RTDs.

The coefficients for platinum RTDs according to the IEC 751-2 (ITS90) Standard are:

$A = 3.9083 \times 10^{-3}\, C^{-1}$

$B = -5.775 \times 10^{-7}\, C^{-2}$

$C = -4.183 \times 10^{-12}\, C^{-3}$