# Calibration

Temperature calibration provides a means of quantifying uncertainties in temperature measurement in order to optimise sensor and/or system accuracies.

Uncertainties result from various factors including:

a) Sensor tolerances which are usually specified according to published standards and manufacturers specifications.

b) Instrumentation (measurement) inaccuracies, again specified in manufacturers specifications.

c) Drift in the characteristics of the sensor due to temperature cycling and ageing.

d) Possible thermal effects resulting from the installation, for example thermal voltages created at interconnection junctions.

A combination of such factors will constitute overall system uncertainty. Calibration procedures can be applied to sensors and instruments separately or in combination. Calibration can be performed to approved recognised standards (National and International) or may simply constitute checking procedures on an “in-house” basis. Temperature calibration has many facets, it can be carried out thermally in the case of probes or electrically (simulated) in the case of instruments and it can be performed directly with certified equipment or indirectly with traceable standards.

Thermal (temperature) calibration is achieved by elevating (or depressing) the temperature sensor to a known, controlled temperature and measuring the corresponding change in its associated electrical parameter (voltage or resistance). The accurately measured parameter is compared with that of a certified reference probe; the absolute difference represents a calibration error. This is a comparison process. If the sensor is connected to a measuring instrument, the sensor and instrument combination can be effectively calibrated by this technique. Absolute temperatures are provided by fixed point apparatus and comparison measurements are not used in that case. Electrical Calibration is used for measuring and control instruments which are scaled for temperature or other parameters. An electrical signal, precisely generated to match that produced by the appropriate sensor at various temperatures is applied to the instrument which is then calibrated accordingly. The sensor is effectively simulated by this means which offers a fairly convenient method of checking or calibration. A wide range of calibration “simulators” is available for this purpose; in many cases, the operator simply sets the desired temperature and the equivalent electrical signal is generated automatically without the need for computation. However this approach is not applicable to sensor calibration for which various thermal techniques are used.

## The International Temperature Scale of 1990

The International Temperature Scale of 1990 was adopted by the International Committee of Weights and Measures at its meeting in 1989, in accordance with the request embodied in Resolution 7 of the 18th General Conference of Weights and Measures of 1987. This scale supersedes the International Practical Temperature Scale of 1968 (amended edition of 1975) and the 1976 Provisional 0.5 K to 30 K Temperature Scale.

### 1. Units of Temperature

The unit of the fundamental physical quantity known as thermodynamic temperature, symbol T, is the kelvin, symbol K, defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water[1].

Because of the way earlier temperature scales were defined, it remains common practice to express a temperature in terms of its difference from 273.15 K, the ice point. A thermodynamic temperature, T, expressed in this way is known as a Celsius temperature, symbol t, defined by:

$$t / {}^\circ C = T/K - 273.15 \;. \quad (1)$$

The unit of Celsius temperature is the degree Celsius, symbol °C, which is by definition equal in magnitude to the kelvin. A difference of temperature may be expressed in kelvins or degrees Celsius.

The International Temperature Scale of 1990 (ITS-90) defines both International Kelvin Temperatures, symbol T90, and International Celsius Temperatures, symbol t90. The relation between T90 and t90, is the same as that between T and t, i.e.:

$$t_{90} / {}^\circ C = T_{90}/K - 273.15 \;. \quad (2)$$

The unit of the physical quantity T90 is the kelvin, symbol K, and the unit of the physical quantity t90, is the degree Celsius, symbol °C, as is the case for the thermodynamic temperature T and the Celsius temperature t.

### ITS 90 Fixed points include:

Boiling point of Nitrogen -195.798°C
Mercury triple point -38.8344°C
Triple point of water 0.01°C
Melting point of Gallium 29.7646°C
Freezing point of Indium 156.5985°C
Freezing point of Tin 231.928°C
Freezing point of Lead 327.462°C
Freezing point of Zinc 419.527°C
Freezing point of Antimony 630.63°C
Freezing point of Aluminium 660.323°C
Freezing point of Silver 961.78°C

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:

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

where:

$\rho$ = 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:

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

where:

$\rho_t$ = resistivity at temperature, t

$\rho_0$ = 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:

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

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 99.99% 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:

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

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:

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

where:

T = temperature (°C)

R = resistance at temperature T

$R_0$ = resistance at the ice point

$\alpha$ = constant (gives the linear approximation to the R vs. T curve)

$\delta$= constant

$\beta$= 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:

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

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

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