Callendar-Van Dusen equations for the calibration of platinum resistance thermometers

The accuracy of a platinum resistance thermometer (PRT) can be improved by the calculation of coefficients.

PRTs are usually calibrated at several temperature points in a temperature range requested by the user. Generally, the thermometer is not used at the exact calibration points, but also in between. This is why the user ofter requests a continuous description of the correlation between temperature and resistance over the complete temperature range used.

In most cases, this is achieved by the specification of a mathematical equation that describes the measured temperature points as an approximation.

Also widely used is the Callendar-van Dusen equation (CvD) which is used in DIN EN IEC 60751 as well in order to illustrate the so-called DIN characteristic curve.

In case of moderate requirements for measurement uncertainty, it is suitable for common Pt100 models across a wide temperature range.

The coefficients A, B, C and the conversion into α, δ, β

The relationship between resistance and temperature for platinum RTDs can be described by a polynomial.

In the early days of thermometry, Hugh Longbourne Callendar (1863 - 1930), British physicist, used a simple quadratic equation. Milton S. van Dusen, American chemist, later found that a third order term was required to adequately describe the relationship for temperatures below 0 °C. This gave rise to the Callendar-van Dusen equations still valid today:

For t > 0 °C:

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

For t < 0 °C:

$$R_t = R_0 \, (1 + At + Bt^2 + C\,(t - 100)\,t^3)$$

Legend:
t = temperature in °C
R_t = resistance at temperature t
R_0 = resistance at 0 °C

These equations were used to establish the international temperature scale of 1927 (ITS-27) between 1927 and 1990. Since 1990 a more sophisticated equation has been used at national standards level (as described in the international temperature scale of 1990 (ITS-90)), but the Callendar-van Dusen equations are still widely used with industrial PRTs.

Historically, the equations were written in an alternative but equivalent form:

For t > 0 °C:

$$R_t = R_0 \left\{ 1 + \alpha \left[t + \delta \frac{t}{100} \left(1 - \frac{t}{100} \right) \right] \right\}$$

For t < 0 °C:

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

Although this looks more complex than the version using A, B and C coefficients, it is easier to derive the coefficients from calibration data. This form was therefore favoured before calculators and computers were available. It is still often used today, especially in the USA.

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Usage limitations and accuracies of platinum resistance thermometers per EN 60751: 2008; see IN 00.17

These forms of the equation are equivalent and it is a simple matter to convert the coefficients from one form into the other:

$$A = \alpha \left\{ 1 + \frac{\delta}{100} \right\}$$

$$B = \frac{-\alpha\delta}{10^4}$$

$$C = \frac{-\alpha\beta}{10^8}$$

$$\alpha = A + 100B$$

$$\delta = \frac{-10^4 \cdot B}{(A + 100B)} = \frac{-10^4 \cdot B}{\alpha}$$

$$\beta = \frac{-10^8 \cdot C}{(A + 100B)} = \frac{-10^8 \cdot C}{\alpha}$$

For best accuracy, a PRT should be individually calibrated to generate the A, B, C or α, δ, β coefficients.

Alternatively, for less accurate temperature measurement generic values can be used. With generic coefficients, the accuracy of the temperature measurement depends on a number of factors, the most important being the purity of the platinum.

The purity of the platinum is indicated by the α value, which is easily determined as the average slope of the line between the ice and steam points on the resistance-temperature curve:

$$\alpha = \frac{R_{100\,°C} - R_{0\,°C}}{100 \cdot R_{0\,°C}}$$

Typically, industrial PRTs have a nominal alpha value of $\alpha = 3.85 \cdot 10^{-3}$ per °C.
For this grade of PRT, standard EN 60751:1995 provides values for the coefficients of:

A = $3.9083 \cdot 10^{-3}$ °C^{-1}
B = $-5.775 \cdot 10^{-7}$ °C^{-2}
C = $-4.183 \cdot 10^{-12}$ °C^{-4}

The converted values are as follows:
$\alpha = 3.85 \cdot 10^{-3}$ °C^{-1}
$\delta = 1.500$ °C
$\beta = 0.1086$

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