Calibration basics

(1) MEASUREMENT ERROR AND MEASUREMENT UNCERTAINTY

Pentronic has been teaching regular courses in temperature measurement and control since 1991. We have noticed that many more people could benefit from knowledge about what is really involved in calibration and how they should interpret calibration measurements. We are now offering our readers the opportunity to learn more about this topic.

Calibration involves comparing a test device (also called the unit under test) with a known standard, and is a measurement of the test device's deviation from that standard at a specific point in time and under specific conditions. If the calibration is done correctly, anyone who requires measured values from an industrial process can rely on them within the limits of actual measurement uncertainty. The ISO 9000 quality standard requires traceability to national standards, which in practice is achieved by using accredited calibration laboratories to perform the required calibration services.

THE READINGS SCATTER

The histogram in Diagram 1 shows a calibration result in which various measured values were recorded with the degree of resolution possessed by the test device and indicated by the distance between the columns. Statistical theory states that even when we measure only from between 10 to 20 values, we achieve a distribution of the measured values that agrees closely with normal probability distribution. The difference between the mean value and the reference value is the measurement error or deviation from the true value, which the reference value represents due to its traceability to an earlier calibration at an accredited laboratory. When used with the opposite sign, the deviation functions as a correction term. By adding the correction term to the test device's mean value, we can adjust the mean value to show the true value. We must not forget that the correction term includes a measurement uncertainty based on our inability to measure perfectly due to drift, digital resolution, the scattering of the measured values, et cetera.

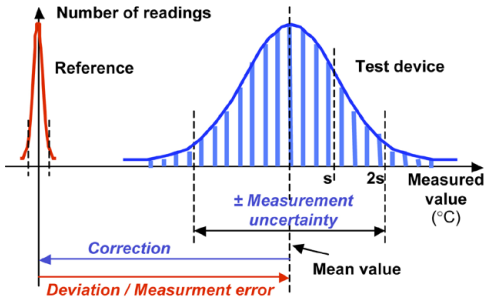

Diagram 1. A theoretical histogram of a calibration in which the columns represent the number of times that the same measured value has occurred. The correction term and measurement uncertainty must be stated in order for the calibration to be complete and meet the requirements of quality standards such as ISO 9000.

TOTAL MEASUREMENT UNCERTAINTY

In simple terms, total measurement uncertainty (U) consists of a number of partial deviations (u_i), which are expressed as standard deviations and which we add together quadratically and then extract the root and multiply by a coverage factor (k). See equation (1).

$$U = \pm k\,(u_1^2 + u_2^2 + u_3^2 + \ldots)^{1/2} \qquad (1)$$

The result of the equation is normally distributed with the standard deviation (s) as shown in Diagram 1. The rules state to use the coverage factor k=2, which gives the total measurement uncertainty 2s, that is, including approximately 95% of the measured values. 1s represents approximately 68% of all the values, while 3s represents approximately 99%. 1s is too little and 3s is too much – a worst case that exceeds the measurement uncertainty. We can say that because all the partial deviations have been assessed in a slightly pessimistic way, that is, they have been rounded up, then we have achieved a sufficient safety margin. This means the actual error will be within 2 standard deviations with 95% probability.

CALIBRATE AT CRITICAL POINTS

Calibrating at a single temperature point only provides information about the correction and measurement uncertainty in the immediate vicinity of that point. To ensure an interval it may be enough to use two points. Calibrating at several points between the extreme values increases the accuracy but costs time and money, which must be balanced against the need for accuracy. Extrapolation is not permitted – that is, you may not use calibration points within an interval to achieve traceability outside the interval. Accordingly, in Diagram 2 we are not permitted to draw conclusions about deviations below point T1 or above point T5. The aim should be to calibrate at the temperatures that are most critical for the test device/measuring system in question, and where it is straightforward to calculate corrections and uncertainties from calibration data.

In practice, good quality Pt100 sensors can achieve really small measurement uncertainties at temperatures up to 600 °C while thermocouples are more unstable.

INCLUDE MEASUREMENT UNCERTAINTY

Sometimes companies' in-house laboratories and maintenance departments do not calculate measurement uncertainties, but are content to note that the measuring device gives a reading that lies within a prescribed interval. It is only possible to do this if you use measurement uncertainty calculations to determine the size of the interval. In Diagram 1 the interval between the reference point and point 2s equals two standard deviations. The importance of the measurement uncertainty naturally increases as the size of the deviation decreases.

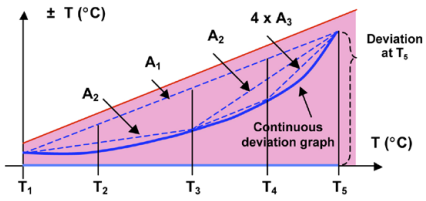

Diagram 2. The positive tolerance of an imaginary sensor type is shown by the pink area. The continuous deviations of an individual sensor are related to the norm curve (the "x" axis). Calibration at points T1 and T5 gives the approximate deviation A1 and large deviations at T3 when we apply linear interpolation. If we also calibrate at T3 the deviation is reduced by interpolations according to the A2 lines. Further calibration at T2 and T4 gives the four A3 approximations that provide the best fit. Remember that all deviations suffer from measurement uncertainty (see Diagram 1).

Opinions and questions are welcome at: hans.wenegard@pentronic.se