System calibration of sensors and transmitters

There is a growing demand for increasingly precise temperature readings. It is no longer enough to rely on tolerance specifications listed in standards and data sheets. Calibration is essential – but even that can be done in different ways. In this article we estimate the difference in measurement uncertainty between calibrating sensors and transmitters separately, and calibrating them together, compared with relying on stated tolerances.

Calibrating a temperature sensor involves mapping a deviation against a reference object. Readings of that deviation will vary over time, due to unavoidable imperfections in both the calibration set-up as a whole and in our ability to take the readings.

All uncertainties that affect the measurement process must be summarised according to a formula. If we repeat a measurement often enough, our readings will create a normal distribution pattern (see Figure 1). Two standard deviations (2s) in this normal distribution pattern will with 95% probability include the remaining measurement uncertainty of the measurement object. This is after we have corrected for the deviations in the reference object and measurement object respectively. [Ref 1]

We do this correction by adding, with the opposite sign, the deviation from the reference object to the mean value. The reference object must also have been corrected in the corresponding way, as shown on its calibration certificate.

No calibration

There are three levels of "accuracy" and they all depend on the calibration method or the lack of one, i.e. no calibration at all. In the last case, we must use standards and data sheets to determine deviations and measurement uncertainties. For Pt100 sensors there is the IEC 60751 standard and Class A, which is a common tolerance requirement. At 150 °C a tolerance of ± 0.45 °C is given for complete sensor in an installation that has favourable conditions. We can assume that the transmitter gives a tolerance of ± 0.2 °C, at least when its surroundings are at room temperature. In this case, the estimated measurement uncertainty according to standardised methods is about ± 0.5 °C (see Figure 4), because we must regard the tolerances as being included in the measurement uncertainty. In all cases we use indicators with a resolution of 0.01 °C or the equivalent units.

Method A – two or more instruments

Calibration done in accordance with Method A

in Figure 2 involves calibrating the sensor and transmitter separately. We can calculate the correction term and measurement uncertainty for both objects. More instruments are used in Method A than in Method B (figure 3). As a result, the measurement uncertainty is also somewhat greater in Case A than in Case B.

The correction terms for the components must be used to cancel the respective deviations in the connected data acquisition system. This requires that we keep track of the individual components so that we can identify the corrections for each measuring channel. If we instead combine the sensors and transmitters in an arbitrary way, we must accept that the uncertainty interval will be larger than that indicated by the white column in Figure 4. However, the uncertainty will still be significantly less than if we do no calibration at all.

Method B – system calibration

System calibration done in accordance with Method B in Figure 3 involves a one-step calibration of the measurement chain, which is comprised of the sensor plus the transmitter. The individual deviations of both components can partly cancel out each other. It is important that the calibrated components are kept together during warehousing and installation; otherwise you will lose the low measurement uncertainty. An excellent way to automatically match up a sensor and transmitter is to integrate them as shown in Figure 5.

Remember that the measurement uncertainties given in this article are based on specific conditions that may not apply to your situation. The calibration is considered done in an in-house laboratory. This means that some additional common uncertainties occur within the process installation itself, for example stem losses, resolution, temperature drift, uncertainties at 3-wire connected Pt100s, etc. [Ref 2]

Figure 2 – A1

Figure 2 – A2

Figure 2. Method A. A temperature sensor and a transmitter are calibrated separately. The sensor is calibrated in a temperature-stable heat source and the transmitter's input signal is simulated with a process calibrator. The resolution corresponds to ± 0.01 °C for all the instruments.

Figure 3 – B

Figure 3. Method B. System calibration of the sensor and transmitter requires that both objects be linked together. Otherwise the low measurement uncertainty will be lost. An integrated sensor/transmitter like that shown in Figure 5 automatically ensures such a link is present.

Figure 4

Figure 4. Estimated measurement uncertainties for calibrations done in an in-house laboratory under favourable conditions. Calibration temperature 150 °C, indicator resolution 0.01 °C. Calibration methods: W/O = Without calibration; for A and B see Figures 2 and 3 respectively and the main text.

Figure 5

Figure 5. A temperature sensor with an integrated transmitter, in this case designed for the food industry. The sensor is a Pt100 and has an analog output, 4-20 mA. One advantage is that it can be used to trim deviations at one or more temperature points.
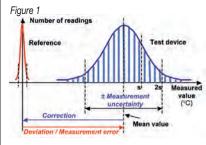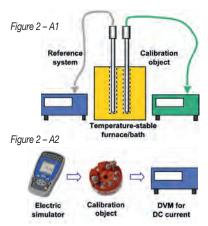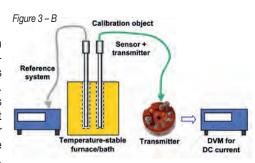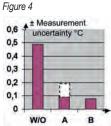
Figure 1

Figure 1. Definition of the terms used in calibration. Many repeated measurements will produce a result curve with normal distribution. See further [Ref 1].

See www.pentronic.se and *Pentronic News archive:*
[Ref 1] Pentronic News 2009-3 p 4 (measurement uncertainty)
[Ref 2] Pentronic News 2009-6 p 4 (calibration certificates)