Type N thermocouples give smaller calibration errors than type K thermocouples at high temperatures

Traditionally, type K thermocouples are used and calibrated at high temperatures in such contexts as the steel industry. Previously, the accuracy requirements were so low that calibration errors could be ignored, if they could even be measured at all at that time. However, today's requirements are higher and as a result, calibration errors become significant. This article explores the causes.

The basic rule for all calibration is that the conditions must be identical when doing the calibration and when doing the in-process measuring. [Ref 1]. The thermocouple's output signal depends on the products of sensitivity S [µV/°C] and the temperature differences, which are summed up along the thermocouple's entire length from the measuring junction to the reference junction. See Equation 1. S is also referred to as the Seebeck coefficient. When measuring as shown in Figure 1, the entire signal is generated where the thermocouple passes through the wall. Other temperature differences along the entire thermocouple are to all intents and purposes zero.

$$E = \sum_{0}^{n} [S_n * (T_n - T_{n+1})] \qquad (1)$$

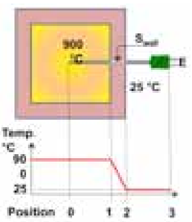

Figure 1. A thermocouple measures the temperature difference between its end points. In accordance with Equation (1) we get: $E = S_{0-1}$ (900-900) + S_{1-2} (900-25) + S_{2-3} (25-25) which gives E = 875 S_{1-2} = 875 S_{wall}. The signal is thus generated where the thermocouple passes through the wall.

The sensitivities S_n and temperatures T_n in Equation (1) are linked to the length divisions (the positions in Figure 1) of the thermocouple. Signals can only be generated for the units of length where $T_n \neq T_{n+1}$. For better adaptation to real temperature distributions, Equation (1) can be altered to an integration function.

Sensitivity seldom homogenous

Figure 2 illustrates the basic problem that calibration and measurement can occur under different conditions. When measuring inside a heat treatment furnace, the output signal E is generated where the almost three-metre-long thermocouple passes through the wall 2.1 to 2.5 m from its probe tip. See the blue curve. When calibrating, e.g. in a calibration furnace, the insertion depth is often limited to 15 to 20 cm from the tip. We apply Equation (1) to the calibration and measuring processes respectively:

$$\Delta E = S_{cal} (900 - 25) - S_{wall} (900 - 25)$$

Other terms become zero given the virtual absence of temperature differences. The difference in output

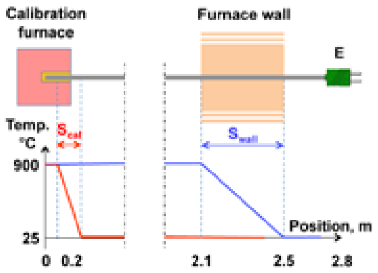

Figure 2. On the left, a thermocouple is under calibration in a 15-cm-deep furnace. On the right, the same thermocouple is being used to measure in a heat treatment furnace. The signal is generated where the temperature changes, which to all intents and purposes only occurs at the positions marked with S_{cal} and S_{wall} for calibration and measuring respectively.

signal should be zero because we are comparing the thermocouple with itself within a short period of time. However, it turns out that difference of several degrees can occur, which means that $S_{cal} \neq S_{wall}$.

There are several reasons for the difference. One is ageing, which can occur differently in the tip and where the thermocouple passes through the wall due to different temperature histories: respectively a constant 900 °C versus all temperatures between 25 and 900 °C. Another property is SRO, which is related to the lattice structure of the thermocouple materials. The structure varies with temperature and time and affects the sensitivity S. See Figure 3. The variation appears as a hysteresis phenomenon. [Ref 2].

SRO negatively affects both types K and N thermocouples but to a differing extent. For type K, the critical zone must be within approx. 250–550 °C and the maximal deviation from the normal output signal can be elevated up to 4–5 °C. For type N thermocouples, the corresponding critical zone is a couple of hundred degrees higher at about 700 °C with a positive deviation of approx. 1–2 °C. This applies to the sheath material Inconel 600®, which is also common in type K thermocouples.

SRO hysteresis

Figure 3 shows how much a type K thermocouple drifts at various temperatures and times. In the ground state the sensitivity is approx. 40 µV/°C. Already after five minutes at 450 °C it has increased by 0.3 µV/°C, which corresponds to 0.75 °C per 100 degrees of temperature difference along the altered zone of the sensor probe.

As long as the thermocouple is kept under 550–600 °C, the achieved change is retained, and this altering process does not stop until after about a month's continual operation. This means that heat treatment to this stage and the subsequent calibration produce a stable sensor but with a shifted scale.

For that part of the sensor which is inserted into a temperature of more than 600 °C the sensitivity reverts to the ground state. Rapid cooling (seconds) leads to the ground state being preserved as long as

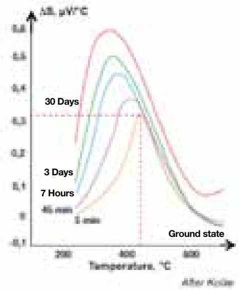

Figure 3. The SRO phenomenon's influence on type K thermocouples at various temperatures and exposure times. Already after five minutes at 450 °C sensitivity S has increased by 0.3 µV/°C.

the temperature does not exceed approx. 200 °C. Figures 4a–d show the hysteresis when measuring at more than 600 °C. In this situation, prior heat treatment is of doubtful benefit. A better way to reduce the SRO hysteresis is to instead use type N thermocouples. These also have a significantly lower long-term drift (ageing) than type K thermocouples at high temperature.

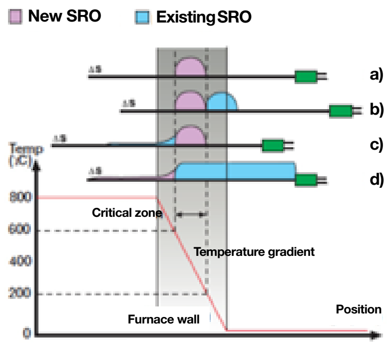

Figure 4.
a). The initial situation of an unused sensor. ΔS increases over time. The reading is immediately affected.
b). The sensor is pulled out quickly by an amount corresponding to the critical zone's width. Previously generated ΔS remains and ends up partly within the gradient. New SRO is generated in the critical zone. The reading increases.
c). The sensor is pushed in by an amount corresponding to two zone widths. Existing SRO is generated backwards above the zone boundary. The reading is reduced and we return to Position a.
d). Prior heat treatment has no beneficial effect because the then-achieved increase in ΔS falls away at temperatures above 600°C. Only an unknown part of the increase lies within the gradient and makes an indefinable contribution to the output signal.

References see www.pentronic.se > News > Pentronic News > Pentronic News Archive
[Ref 1] PentronicNytt 2014-1
[Ref 2] StoPextra 2010-1

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