Install new thermocouples instead of recalibrating

Ever since the ISO 9000 family of standards began to govern the management systems used in industry, the calibration of measurement systems and sensors has been a self-evident aspect of ensuring product quality. However, at high temperatures the calibration of used thermocouples is not always reliable. In this article we will explain why this can happen and how to improve measurement quality.

The problem affects the type K and N base metal thermocouples, which are the most common sensors used in temperatures above about 600 °C. Both types K and N function superbly up to about 200 °C. From there up to 600 °C type N works superbly but type K is affected by the hysteresis effect, which can give a fluctuating measurement error of up to about 4 °C [Ref 1].

Study the installation in Figure 1. A type K thermocouple is located 750 mm inside a furnace that has a constant and even temperature of 900 °C. The output signal (µV) is governed by S (T1–T2) where S is the Seebeck coefficient (µV/°C) of type K. In this example, the temperature gradient between the measuring junction, T1 = 900 °C, and the reference junction at room temperature, T2 = 20 °C, only occurs inside the furnace wall and only affects that part of the thermocouple that is inside the wall. It is only where the slope of the temperature gradient diverges from zero that differences in temperature can occur. At constant temperatures, i.e. where the gradient is horizontal, a thermocouple does not generate any output voltage [Ref 2].

Different gradients

To calibrate the thermocouple shown in this example, dry block furnaces are normally used. These, as well as other types of furnace, often have a limited insertion depth. The electrical connection can also be damaged by heat if it gets too close to the furnace opening from which heat can radiate and convect. For this reason, during calibration the gradient often ends up closer to the sensor's probe tip than is the case for normal installation. See the blue dashed line indicating the gradient 200–250 mm from the tip. In this example S1 determines the sensor's properties. If S1 = S2 the calibration is problem free, but this is rarely the case at temperatures above about 600 °C.

Determined by circumstances

One reason is that the particular circumstances (environment, temperature, etc.) in which the thermocouple has been operating affect the alteration of the Seebeck coefficient along the thermocouple. During operation, the area of S1 is mainly affected at 900 °C whilst S2 senses all temperatures from 900 °C down to room temperature. Temperature is a catalyst that initiates many reactions between the materials in the surroundings, protective tubes, insulation and thermocouple wires. The reactions tend to lead to altered Seebeck coefficients and constant temperatures result in fewer reactions than is the case in a temperature gradient. In other words, it is far from certain that S1 = S2 after a thermocouple has been operating for a while inside a furnace.

Another reason for the difference between S1 and S2 is the natural variation that occurs during the manufacture of thermocouples. Up to about 200 °C this is a matter of ±0.1 to ±0.2 °C, which in the case of thermocouples can be regarded as negligible. At 1000 °C Pentronic's accredited laboratory has measured variations of up to about ±4 °C in thermocouples made from samples from the same roll (batch) of metal-sheathed cable.

Install new thermocouples

So what can be done to avoid the difficulty of having different Seebeck coefficients? The answer is: don't calibrate the thermocouples. Instead, replace them with new, unused sensors at predetermined time intervals. This can actually be less expensive than doing repeated unreliable calibrations.

How, then, should you decide what time intervals to use? One way is to do in situ calibration, which involves calibrating the used sensor against a new reference sensor inside the actual furnace.

If you calibrate at regular time intervals, you can find out when the furnace sensor's signal deviates more from that of the reference sensor than can be tolerated. See Figures 2 and 3. It is a good idea to acquire one or more extra sensors to use as reference sensors when you are ordering new sensors anyway. The extra sensors should then be marked as working standards and stored unused when not being used for in situ calibrations.

References see: www.pentronic.se > Pentronic News > Technical Articles Archive
[Ref 1] Pentronic News 2010-1 page 4
[Ref 2] Pentronic News 2011-2 page 4

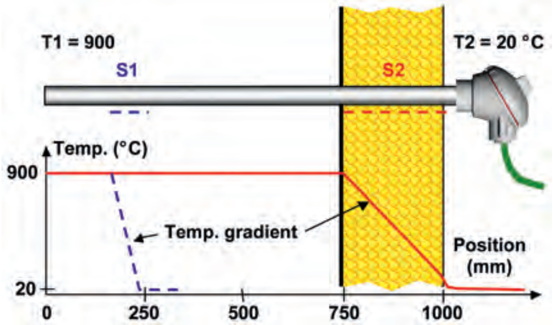

Figure 1
The use of a dry block furnace means that the temperature gradient for the calibration in this example is located at an insertion depth of 20-25 cm. The Seebeck coefficient S1 therefore determines the thermocouple's properties. When measuring inside a furnace the gradient is largely located inside the furnace wall, 750 – 1000 mm from the probe tip, and S2 determines the properties. If S1 = S2 then the calibration is perfect but this is seldom the case at high temperatures.

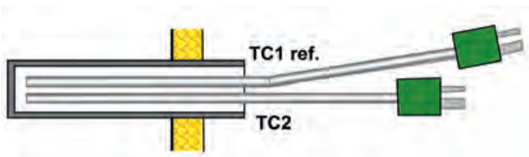

Figure 2
Theoretical diagram of an in situ calibration. An outer protection tube with a closed end functions as an excellent calibration furnace with both sensors having almost identical temperatures if they have the same diameters and insertion depths. If the reference sensor TC1 has been in operation for substantially less time than TC2 then we can see how TC2 has changed over time.

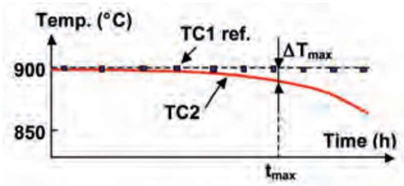

Figure 3
In situ calibration of the sensor TC2 against the reference sensor TC1. At the t_{max} point in time, the operating time of the reference sensor is only a fraction of that of TC2. TC1 has not yet had time to deviate from a normal state. The operational sensors need to be replaced with new ones before the deviation exceeds ΔT_{max}.

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