Too shallow an immersion depth causes measurement error

The new IEC60751:2008 standard proposes a number of type tests for Pt100 sensors. One test establishes the minimum immersion depth. Another establishes the response times. Let us examine what lies behind these tests.

According to IEC60751:2008 [Ref 1], the definition of the minimum immersion depth for a sensor is the depth at which the signal has decreased by 0.1 °C compared with the immersion depth used during the tolerance acceptance test. Further, the standard specifies that the measuring medium shall be water with a temperature of at least 85 °C. No flow velocity is stated but at temperatures above 85 degrees water has a strong self-circulation. The sensor's terminals are located at room temperature, which temperature laboratories set at 23 °C. From this starting point, the sensor is then raised step by step out of the water. The immersion depth at which the temperature has dropped by 0.1 °C shall then be stated as the minimum immersion depth.

The basic cause of falling temperature readings taken by a sensor at shallower and shallower immersion depths is the temperature difference between the sensor's two end points. This difference creates a heat flow from the warmer end point to the colder one. Heat is transported along the tube via conduction and is emitted to the surroundings via radiation and convection. The shallower the immersion depth, the greater the temperature difference per unit of length in the tube. (See diagram 1.)

Where the sensor exits the process, or the water bath in the test, the temperature gradient (degrees per unit of length) is steepest. This is where the biggest drop in temperature occurs.

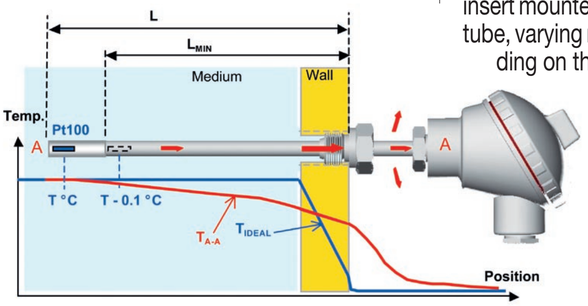

Diagram 1. IEC defines the minimum immersion depth L_{MIN} for a sensor whose reading has decreased by 0.1 °C compared with the tolerance acceptance test reading taken at insertion point L. The diagram shows both alternatives. The cause of measurement error in shallow immersion depths is the greater temperature gradient in the protective inner and outer tubes.

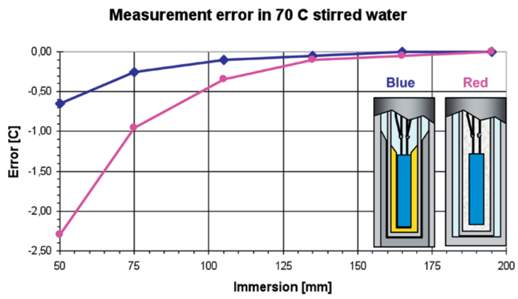

Diagram 2. The ability to transfer heat between the probe tip and the Pt100 resistor is important at shallow immersion depths. For example, at a 75 mm immersion depth the blue design decreases by 0.25 °C and the red one by 1 °C. The explanation is the use of a metal filling in the blue probe instead of the air gap plus a powder filling in the red probe.

You can avoid significant measurement errors by first trying to establish a greater immersion depth, that is, by placing the sensor in a zone that has little difference in temperature. (Cf. diagram one.)

APPLIES TO ALL SENSORS

It must be emphasised that all temperature sensors have a minimum immersion depth at which the temperature reading has changed by 0.1 °C. What distinguishes temperature sensors from each other is factors like their physical design and dimensions, the properties of the medium, and the flow velocity. A thin thermocouple wire in water has a very shallow minimum immersion depth.

Diagram 2 shows a practical experiment that was conducted in Pentronic's temperature laboratory using DIN Form B-type process sensors. Different versions of the sensors were immersed to varying depths in a stirred calibration bath. Using a Ø 6 mm measuring insert mounted in a Ø 10 mm outer protective tube, varying readings were achieved depending on the different probe tip designs.

It was clear that the air gap between the sensor and the outer protective tube exerted a serious negative effect at shallow immersion depths. The sensor model which had a metal filling had a very small drop in temperature up to the Pt100 resistor. The other model showed a greater temperature drop in the air gap and thereby a lower temperature in the resistor.

In both cases, the measuring equipment showed stable readings. This situation can make an operator believe that the stationary values are the true ones.

The response time is also affected by the probe tip design and the sensor's heat conduction ability. Diagrams 3A and B show the measured response time curves for both sensor designs. Not unexpectedly, the sensor with the air gap responded significantly more slowly than the sensor with the metal filling to an instantaneous temperature step (immersion). The reason is of course the limited ability of the former to conduct heat.

AFFECTS THE RESPONSE TIME

IEC60751:2008 recommends the following conditions for testing response times. The medium is water or air with a flow velocity of > 0.2 m/s and (3 ± 0.3) m/s respectively. Normally, the time it takes to achieve half the final value is stated as the response time. Note that the measuring system within which the sensor is to be used has its own response time (the system response time). The sensor forms only part of this system.

The design of the temperature sensor influences all its properties with regard to the minimum immersion depth and possible response time. For this reason, in critical situations it is important to study and compare the properties of different sensor designs under the same conditions, or to clearly specify the desired properties and have a sensor custom made for the purpose.

[Ref 1] See www.pentronic.se > Pentronic News > Pentronic News Archive > Pentronic News 2009-4

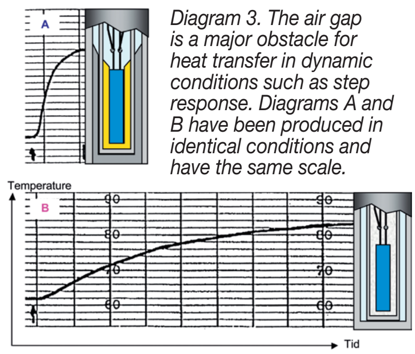

Diagram 3. The air gap is a major obstacle for heat transfer in dynamic conditions such as step response. Diagrams A and B have been produced in identical conditions and have the same scale.

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