Sharpen your temperature measurement chain

An ordinary temperature measurement chain of Pt100 sensors can have a measurement uncertainty of ± 0.8 °C under given conditions. In this article we will examine how we can reduce this measurement uncertainty at least down to ± 0.2 °C by taking various steps.

A normal measurement chain for lower process temperatures up to e.g. 160 °C is often composed of Pt100 sensors that are connected to a transmitter in an adjoining electrical cabinet. See Figure 1, Measurement Chains 1 and 2. The electronics transform the signal to 4-20 mA current for onward transport to an analogue/digital transformer (A/D) and connection to a superior control system.

The sensor is three-wire connected to the transmitter. Calibration has not been done; instead, the sensor is presumed to be Class A in accordance with the IEC 60751 standard, that is, ± 0.15 at 0 °C. At the interval's upper limit of 160 °C the tolerance is then ± 0.47 °C. Due to temperature drift when the cabinet temperature is increased, the uncertainty in the transmitter can be ± 0.5 °C across the entire measuring interval.

As a result of the A/D transformation during the next stage, the measurement uncertainty becomes approximately ± 0.2 °C, which applies to all the A/D transformations in Figure 1. Once the signal is in digital form, no more errors arise in the measurement value.

Pt100 three-wire connections are uncertain

However, we have an uncertainty remaining in the analogue chain that we cannot disregard: the weakness in the three-wire connection. This consists of the difference between the resistances in the cable's three wires en route from the Pt100 resistor to the transmitter. Wire resistance includes all contact resistances such as in the screw connectors and other connection points.

The cable resistance can be calibrated away but slow oxidation of the contact points changes the conditions over time, especially in difficult process environments. A three-wire connection requires that all three links must have equal resistance. Every difference becomes incorporated in to the measurement error. In fact, this applies only to the white wire and one of the red ones, but because there are two red ones we cannot determine which one is the critical one. In order to be certain, we must ensure that all of them have the same resistance. We have based this analysis on a measurement error of 0.1 °C but in a bad environment this error can increase over time up to at least a couple of degrees.

By adding up the partial uncertainties (u_i) according to the rules for calculating measurement uncertainty (see Figure 2) we get the following uncertainties in the interval limits: 0 °C gives ± 0.7 °C and 160 °C gives ± 0.8 °C respectively. There is an additional uncertainty due to the probe tip's design because that can vary according to the measurement task.

Measurement Chain 2 is composed of an uncalibrated four-wire-connected Pt100 and a Pentronic PAT1201 analogue transmitter for a DIN rail with improved properties: ± 0.25 °C uncertainty in both the interval limits. Thus the total uncertainty will be ± 0.4 and ± 0.7 °C respectively at the limits. The four-wire connection totally eliminates the three-wire cable's long-term drift.

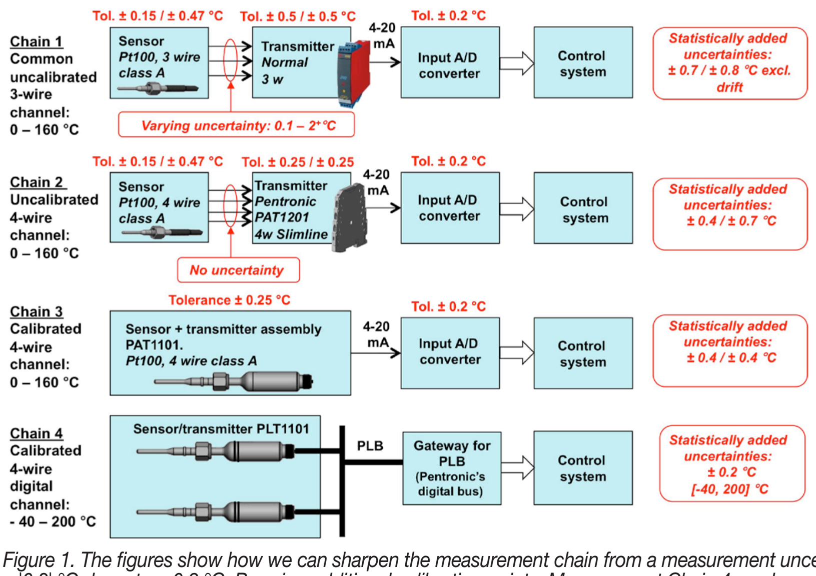

Figure 1. The figures show how we can sharpen the measurement chain from a measurement uncertainty ≥ |0.8| °C down to ± 0.2 °C. By using additional calibration points, Measurement Chain 4 can be pushed down to ± 0.05 °C. In all cases there will be additional uncertainties due to the probe tip's design and installation.

System calibration minimises errors

Measurement Chain 3 is composed of an integrated sensor and transmitter with an analogue output signal that was system calibrated upon delivery. This method allows us to really tighten up the tolerance limits used in measurement chains 1 and 2. The transmitter contains both an A/D and a D/A transformer. In this case the uncertainty is ± 0.25 °C. The system calibration also eliminates the measurement error. The total uncertainty not counting the probe tip is reduced to ± 0.4 °C.

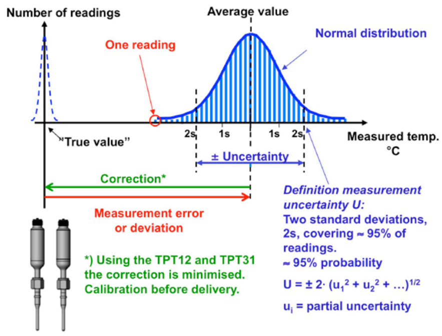

Figure 2. Definition of measurement error (deviation) and measurement uncertainty. The measurement error can be minimised by system calibrating an integrated sensor and transmitter.

Measurement Chain 4 in Figure 2 is based on the sensor and transmitter from the analogue Measurement Chain 3, whose A/D transformer was connected to a PLB digital measuring sub bus (PLB = Pentronic Low-power Bus). This bus can be linked via a gateway to most bus systems on the market. By system calibrating the sensor and transmitter and by transmitting digitally directly to the superior control system, we reduce the uncertainty to ± 0.2 °C at both interval limits, which in this case can be extended to - 40 and 200 °C.

Push down towards ± 0.05 °C

As before, the uncertainty level does not take account of the probe tip's properties. The system calibration is done at two temperatures. The Pt100 resistor is not totally linear. A small quadratic term, i.e. the equation "resistance as a function of temperature", creates a curve, which can be compensated for by doing a three-point calibration. The uncertainty can then be pushed down to ± 0.05 °C across the entire interval. The three-point calibration does require additional manual calibration work but this can be automated when more users demand greater measurement accuracy.

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