CALIBRATING SHORT AND SANITARY SENSORS USING STATE-OF-THE-ART DRY-BLOCK TECHNOLOGY

By Laboratory Manager Tom M. Hansen, AMETEK Denmark A/S

ABSTRACT & THESIS

In many processing plants, particularly within the pharmaceutical and food industries, there is a wide range of sensors geared to a company's individual needs. Often however, these sensors are short and manufactured with a geometrical design that can cause problems during calibration. In general, it is assumed that a sensor must be immersed in a calibration instrument (whether it is a dry block or bath unit) at least 15 times the diameter of the sensor to get an accurate measurement. This means that the sensor's active part must be located in a temperature-homogeneous zone. If this is not possible, other ways must be found to successfully complete the calibration.

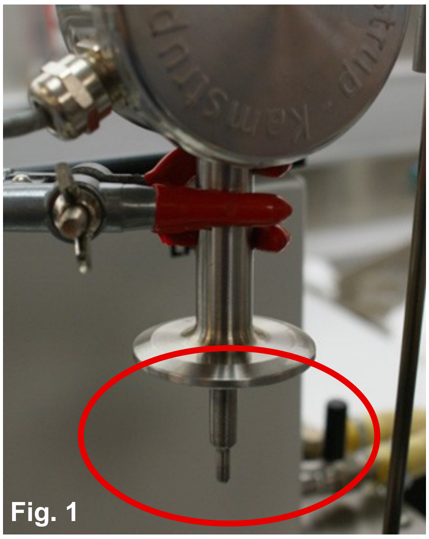


Fig. 1

One way to get around the issue is to calibrate the sensors using a liquid bath, but this requires a bath type where the liquid is pumped around axially to ensure temperature homogeneity all the way to the surface. Additionally, there is often a need for "pure" calibration, which means the sensor must not be contaminated with silicone oil or anything else that might be located in the bath. Due to these challenges, liquid-bath calibration often does not work for short sensors and sanitary sensors.

An alternative is to calibrate these sensors in a dry block unit. This document will deal with the calibration of a typical sanitary sensor (the unit under test or UUT) manufactured by KAMSTRUP - today Baumer (fig. 1) using an AMETEK JOFRA RTC-156 B (fig. 2). In this matter a clean calibration is ensured.

The UUT is connected as a direct 4-wire to prevent uncertainty contribution from any transmitter or similar.

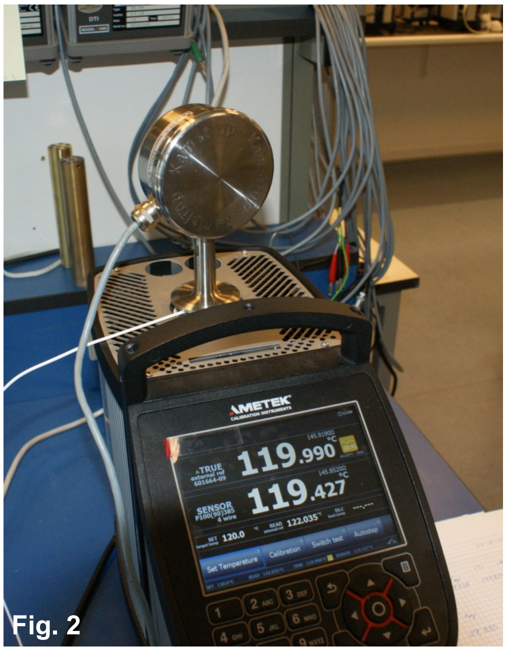


Fig. 2

The following will be addressed further along in the paper:

- Practical calibration results
- Achievable measurement uncertainty
- Error sources
- Conclusion

CALIBRATION OF THE UUT IN THE LIQUID BATH

The sanitary sensor will be calibrated in a liquid bath at two temperatures, which represent some outlying areas of application - in this case -10 and 120°C. Since liquid bath calibration is deemed to be almost perfect, the results from this calibration will form the "standard" when the calibration is subsequently repeated using the RTC-156 B dry block calibrator. In broad terms, a direct comparison will be made between the UUT (dry block) minus the UUT (liquid bath).

The UUT was immersed until the underside of the flange just touched the liquid surface (fig. 3). Silicone oil (high temperature) and ethanol (low temperature) were used during the calibration. All measurements were repeated three times to assess repeatability, which is a parameter of the total uncertainty.

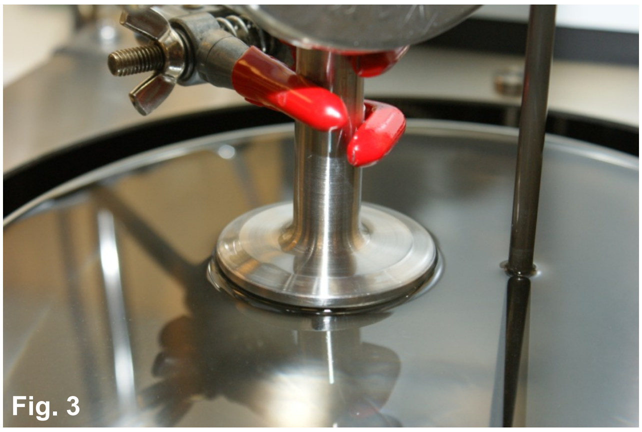


Fig. 3

It should be noted that there was long stability times before the measurements were performed, since it takes a relatively long time before the large thermal mass in the liquid bath has found its equilibrium. The following measurements were made after approximately 45 minutes.

Results at nominal temperature 120°C

Kamstrup Model 8142 B Class

Sensor immersed to liquid surface

t(ref) bath [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
119,838	145,8243	119,356	-0,482	0,899

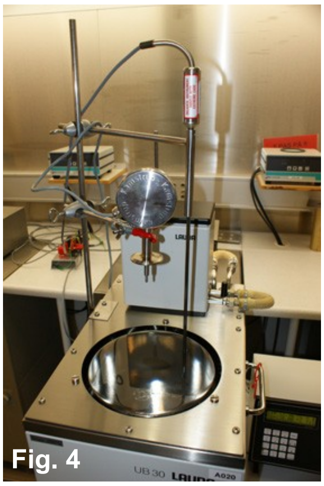


Fig. 4

Results at nominal temperature -10°C

Kamstrup Model 8142 B Class

Sensor immersed to liquid surface

t(ref) bath [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
-9,966	96,0885	-9,993	-0,027	0,350

The liquid calibration results initially appeared to be at the same level and within the Class B specifications. More on this topic will be provided later in the paper.

CALIBRATION OF THE UUT IN DRY BLOCK MODEL RTC-156 B

In this case, the dry block calibration insert (fig. 5) used is "Application kit for sanitary sensors", which can be seen in fig. 5. Similarly, the reference sensor type used is a cable model of the STS-030 with the short-sensing element, so that reference can be located at the same level as the UUT (fig. 6 -8).


Fig. 5

The UUT was connected directly with a 4-wire to the calibrator UUT measurement input, and the reference sensor was connected to the reference entrance on the front. Just as during the liquid bath calibration, all of the measurements were also again repeated three times.

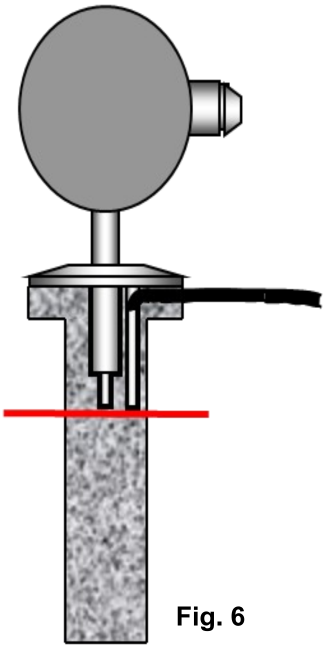


Fig. 6

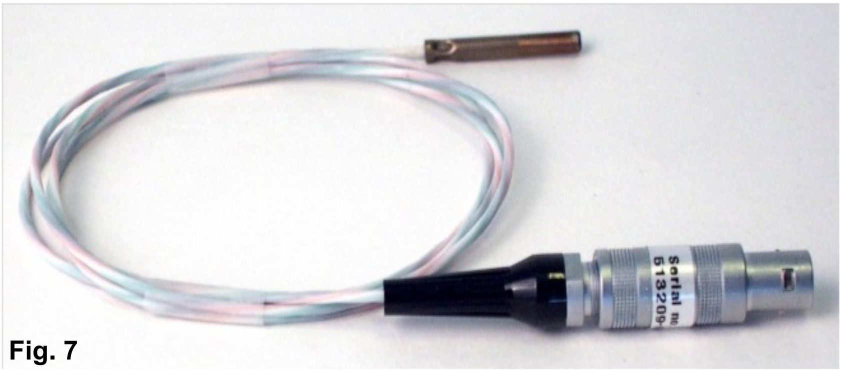


Fig. 7

Results at nominal temperature 120°C:

Kamstrup Model 8142 B Class

Sensor without insulation

t(ref) bath [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
119,996	145,421	119,421	-0,575	0,900

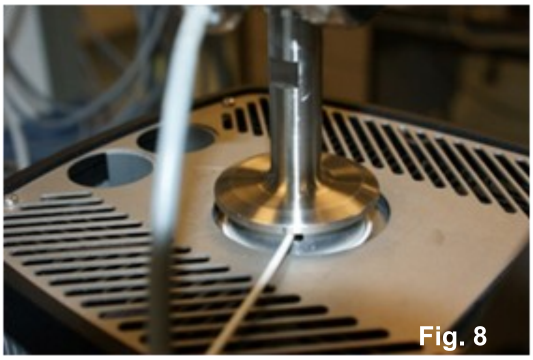
Results at nominal temperature -10°C:

Kamstrup Model 8142 B Class

Sensor without insulation

t(ref) bath [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
-10,003	96,0993	-9,966	0,037	0,350

As with the liquid bath calibration, these results initially appeared to be at the same level and within the Class B specifications. More on this topic will be provided later in the paper.



DRY BLOCK VERSUS LIQUID BATH CALIBRATION RESULTS

The following results were determined as the difference between dry block and liquid bath calibration, under the conditions described earlier. Moreover, the reference temperatures have been corrected to 120 and -10°C purely for the sake of fair comparison.

Temperature adjusted to reference temperature 120°C

t(ref) bath [°C]	UUT bath [°C]	t(ref) dry block [°C]	UUT dry block [°C]	Variance dry block [°C]
120,000	119,518	120,000	119,433	-0,085

Temperature adjusted to reference temperature -10°C

t(ref) bath [°C]	UUT bath [°C]	t(ref) dry block [°C]	UUT dry block [°C]	Variance dry block [°C]
-10,000	-10,027	-10,000	-9,993	0,034

MEASUREMENT UNCERTAINTIES

The following measurement uncertainty was calculated for 120°C on a simple basis and only includes essential contributions. Thus standard deviations are not included, since the scattering scheme for both types of calibrations were so small that in this case it does not influence the final result.

Liquid bath calibration uncertainty at 120°C (-10°C)				
Influence parameter	**k=2 specification [°C]**	**Distribution**	**k=1**	**u*u**
SPRT reference sensor	0.014	Normal	0.00700	0.000049
Stability 0.5 h	0.006	Square	0.00346	0.000012
Axial gradients*	-0.025	Square	-0.01443	0.000208
UUT 4-wire measurement	0.010	Normal	0.00500	0.000025
Geometric sum				0.017156
k=2				0.034

Result 120 ± 0.04°C

Dry block calibration uncertainty at 120°C (-10°C)				
Influence parameter	**k=2 specification [°C]**	**Distribution**	**k=1**	**u*u**
Reference entrance includ-ing STS-102 sensor	0.04	Normal	0.020000	0.000400
Stability 0.5 h	0.02	Square	0.011547	0.000133
Axial gradients	0.01	Square	0.005774	0.000033
UUT 4-wire measurement	0.01	Normal	0.005000	0.000025
Geometric sum				0.024324
k=2				0.049
k=2				0,049

Result 120 +/- 0,05 °C

*)The axial gradients of the applied LAUDA bath are measured with a special temperature sensor, which is bent into a U so that the sensor can measure at the surface of the bath (fig. 9). To perform this measurement two sensors were used. One is located next to the fully immersed sensor, in this case at 100 mm, while the U sensor is immersed until the measuring head is just touching the liquid surface. The measurements were taken between the two sensors in small steps of 20 mm each. The following table shows the results of the measurements.

Fig. 9

Lauda Bath		Reg A020		
4 mm sensor:	STS-100-500 A			
4 mm sensor:	Special U-sensor			
Set temp	120°C			
Position	T-1 [°C]	T-2. [°C]	dT [°C	dTkor.[°C]
0	117,601	117,545	117,601	**0**
20	117,599	117,624	117,599	**0,025**
40	117,595	117,619	117,595	**0,024**
60	117,590	117,614	117,590	**0,024**
80	117,596	117,619	117,596	**0,023**
100	117,590	117,614	117,590	**0,024**

ERROR SOURCES

Influence of axial temperature gradients:
The observant reader will notice that there are no documented axial gradients in the RTC dry block. This is not an oversight, but it is not directly possible to measure these gradients in the upper part of calibration insert.

In the uncertainty budget for the LAUDA bath, the maximum measured gradient is conservatively used, although the curve is flat just below the surface and exhibits almost no temperature variations down to the measured 100 mm.

The measured difference between the bath and dry block are an expression of the relatively large gradient transparencies that need to be in the top of calibration insert. It is therefore important that the reference sensor is placed at the same level as the UUT to eliminate some of gradient influence.

In principle, gradients would have no influence on measurement results if both the UUT and reference sensor possessed exactly the same thermal properties.

Influence of calibrator stability:
Generally, the RTC calibrator complied with the specified stability of ± 0.005°C within a good margin. However, the sanitary sensor with flange and the large protruding mass affects stability negatively. Therefore, the stability requirement was set to ±0.02°C, which was easy to comply with.

Influence of ambient temperature:
It is important for the UUT to either copy the installation process during calibration as best possible, or at least clearly document the conditions. This applies to both dry block and bath calibration.

This effect is measured both at -10°C and at 120°C, because these temperatures are farthest from the ambient temperature, and it is here we assumed that the effect is greatest.

The dry-block results are compared with and without ceramic wool and by bath measuring. Similar comparisons are made but this time between the UUT immersed to the underside of the flange and immersed so deeply it is practically possible.

Results dry block at 120°C:

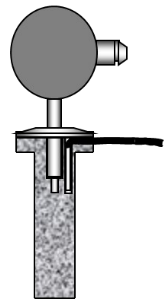
Sensor without insulation

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
119,996	145,421	119,421	-0,575	0,900

Sensor insulated with ceramic wool

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
120,005	145,9548	119,597	-0,408	0,900

Difference: 0,17°C



Results dry block at -10°C:

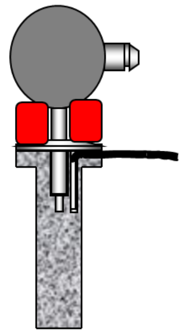
Sensor without insulation

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
-10,003	96,0993	-9,966	0,037	0,350

Sensor insulated with ceramic wool

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
-9,999	96,134	-9,878	0,121	0,350

Difference: 0,08°C



Results liquid bath at 120°C

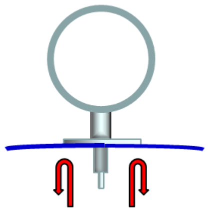
Sensor immersed to liquid surface

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
119,838	145,8243	119,356	-0,482	0,899

Sensor totally immersed

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
119,833	145,9164	119,597	-0,236	0,899

Dfference: 0,25°C



Results liquid bath at –10°C

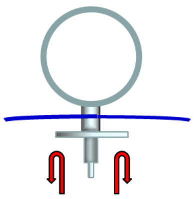
Sensor immersed to liquid surface

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
-9,966	96,0885	-9,993	-0,027	0,350

Sensor totally immersed

t(ref) °C [°C]	UUT read [Ohm]	UUT IEC751 [°C]	Deviation [°C]	Specification [°C]
-9,966	96,0744	-10,03	-0,064	0,350

Difference: 0,04°C



Influence of the applied insert:
The insert must fit perfectly to the UUT and drilled with recommended tolerances (diameter plus 0.2 mm), and in general custom-fitted to the length and diameter variations.

Influence of instructions suitability:
As with all calibrations, detailed instructions should be used in order to reproduce calibrations correctly.

CONCLUSION AND DISCUSSION

When calibrating sensors with particularly poor thermal design, it is recommended to perform an initial calibration in a suitable liquid bath first, in order to create the basis for a ´ final assessment of whether a dry block calibrator is suitable. In the case presented here, a dry block calibration was valid, since the maximum deviation was measured to less than 0.1°C. This difference could conceivably be added to the already calculated measurement uncertainty, and thus it would probably be reasonable to assume a definitive measurement uncertainty of about ± 0.2°C. If this uncertainty is acceptable in relation to the process in question, then using a dry-block calibration creates an opportunity for a "pure" calibration and, in most cases, also an automated calibration which saves time.

In this case, when it comes to calibration of a sanitary flange sensor, it is necessary to use the mentioned special insert, which allows for optimal transmission of heat/cold to the flange so as to minimize the energy transport in or out of the sensor.

It is also necessary to use a dual-zone dry block, in which the zones are individually controlled.