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Calibration White Paper

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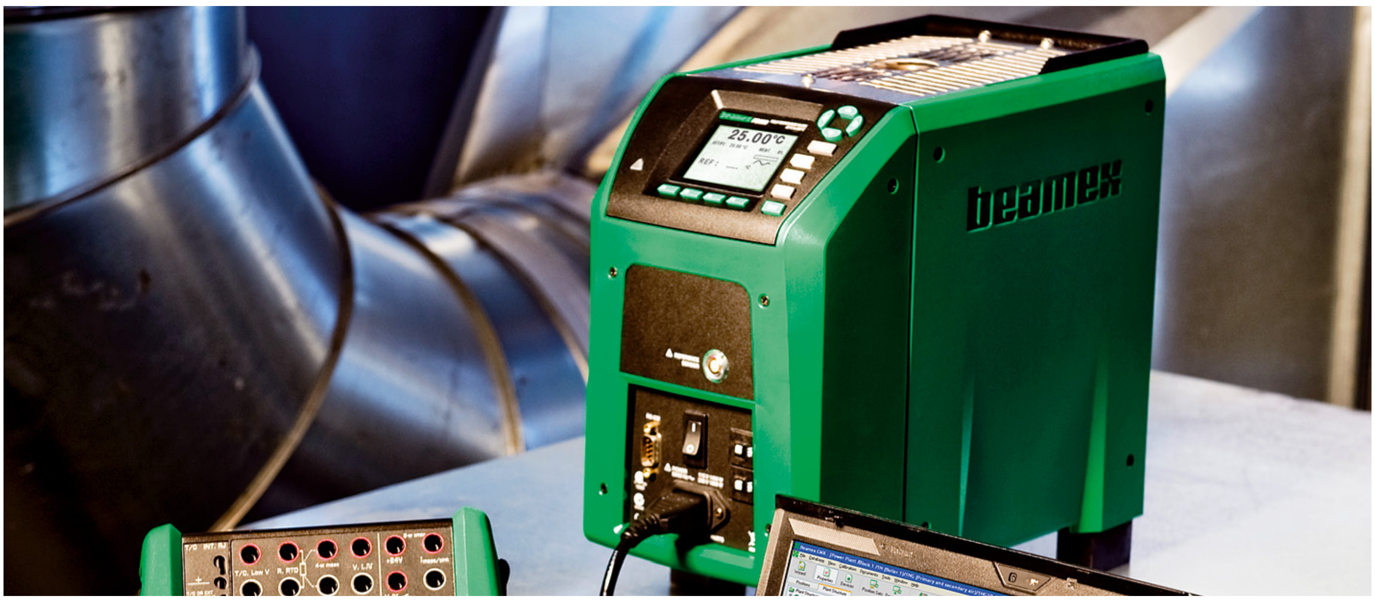

Calculating Total Uncertainty of Temperature Calibration with a Dry Block

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Calculating Total Uncertainty of Temperature Calibration with a Dry Block

In Calibration World magazine (Spring/Summer 2011) there was an article on temperature and the calibration of temperature instruments. In this article we continue with temperature-related articles. We will discuss the various uncertainty components related to temperature calibration using a temperature dry-block. Also, we will discuss how to calculate the total uncertainty of a calibration performed with a dry block.

Temperature dry block

First, let's discuss what a temperature dry block is:

- consists of a heatable and/or coolable metallic block, controller, an internal control sensor and optional readout for external reference sensor. This article will focus on models that use interchangeable metallic multi-hole inserts.
- There are fast and lightweight dry blocks for industrial field use as well as models that deliver near bath-level stability in laboratory use.
- There are also some work safety issues that favor dry blocks in preference to liquid baths. For example, in temperatures above 200 °C liquids can produce undesirable fumes or there may be fire safety issues. If a drop of water gets into hot silicon oil, it could even cause a small steam explosion which may splash hot oil on the user.
- Dry blocks are almost without exception meant to be used dry. Heat transfer fluids or pastes are sometimes used around or inside the insert, but they don't necessarily improve performance. They may actually even impede the dry block's performance and damage its internal components.

EURAMET

The EURAMET guideline (EURAMET /cg-13/v.01, July 2007 [previously EA-10/13]):

- This Euramet calibration guide defines a normative way to calibrate dry blocks. As most of the manufacturers nowadays publish their product specifications including the main topics in the Euramet guide, the products are easier to compare.
- Main topics in the EURAMET guideline include:
  - Display accuracy
  - Axial uniformity
  - Radial uniformity
  - Loading
  - Stability over time
  - Hysteresis
  - Sufficient immersion (15 x diameter)
  - Stem loss for 6 mm or greater probes
  - Probe clearance
    (<= 0,5 mm at –80 … 660 °C)
    (<= 1,0 mm at +660 … 1300 °C)

Related uncertainty components

Let's have a look at the various uncertainty components that are related to temperature calibration done using a dry block. These components are relevant to all manufacturers' dry blocks. Some manufacturers specify these components and some do not.
It is possible to use a dry block with the block's internal measurement as the reference (true value), or you can also use an external reference temperature probe inserted in the block as a reference measurement.

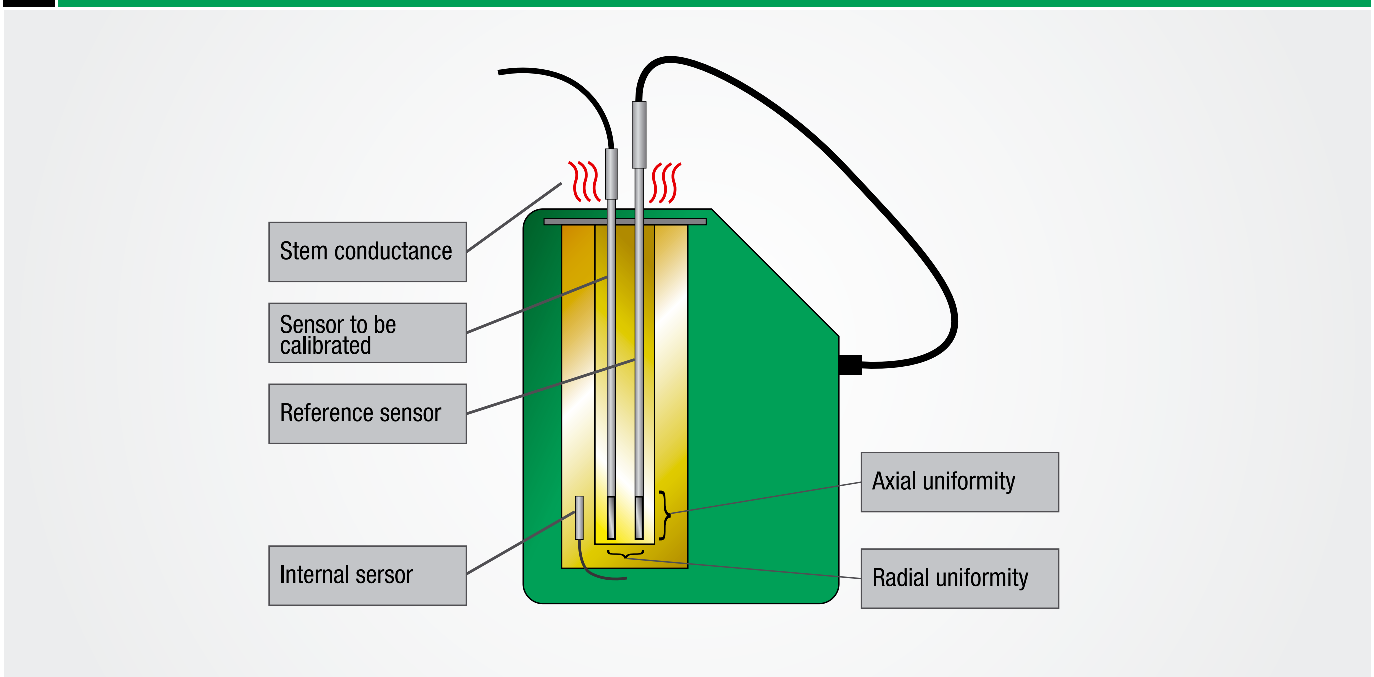
Internal measurement as reference

First, let's discuss the uncertainty components related to the use of a dry block's internal measurement as reference.

The following components should be taken into account:

- Display accuracy (accuracy of the internal measurement)
  - It is important to remember that all of the thermometers based on thermal contact measure their own temperature. With dry blocks, the internal control sensor is typically located inside the actual block, whereas the probes to be calibrated are immersed in the insert. There is always thermal resistance between the internal sensor and the probes inside the insert and other sources of uncertainty need to be considered.

MAIN PARTS OF THE DRY BLOCK



- Axial uniformity
  - Axial uniformity refers to the variation in temperature along the vertical length of the insert. The Euramet calibration guide states, “dry wells should have a zone of sufficient temperature homogeneity of at least 40 mm in length” at the bottom of the insert. The purpose of this homogenous measurement zone is to cover various sensor constructions. The thermocouple typically has its “hot junction” close to the tip of the probe whereas the PRT sensing element may be 30 to 50 mm long. With this in mind, a homogenous zone of at least 60 mm is recommended.

- Radial uniformity
  - Radial uniformity refers to the variation in temperature between the holes of the insert. Related uncertainty is caused, for example, by the placement of the heaters, thermal properties of materials and alignment of the insert holes. Non-symmetrical loading or probes with significantly different thermal conductivity (for example large diameter probes) may cause additional temperature variation.

- Loading effect
  - Every probe in the insert conducts heat either from or into the insert. The more the load, the more the ambient temperature will affect the measurements. Sufficient immersion depth and dual zone control helps to reduce load-related uncertainties. The loading effect is not visible in the control sensor indication and the controller cannot completely compensate for this shift.

- Stability over time
  - Stability describes how well the temperature remains the same during a given time.
  - The Euramet calibration guide defines stability as a temperature variation over a 30-minute period, when the system has reached equilibrium.

- Immersion
  - Sufficient immersion is important in any temperature measurement. The Euramet calibration guide states that the immersion depth should be at least 15 x the probe's outer diameter. To minimize the stem conduction error it's recommended, as a rule of thumb, to use immersion depth of 20 x the diameter, plus the length of the sensing element. As the probe constructions vary greatly (sheet material, wall thickness, lead wire thermal conductivity etc.), a test for each individual probe type to be calibrated should be made. If sufficient recommended immersion cannot be reached, then the uncertainty caused by the insufficient immersion should be estimated/evaluated.

- Hysteresis
  - Hysteresis causes the internal sensor to be dependent on its previous exposure. This means that the temperature of the dry block may be a bit different depending on the direction from which the set point is approached. The hysteresis is greatest at the mid-point and is proportional to the temperature range.

The specifications for the above uncertainty components should be in the block's specifications. If some component has not been specified, it should be estimated or evaluated.

Using an external reference sensor as reference

Unlike using the dry block's internal sensor as a reference, the external reference sensor is inside the insert together with the probes to be calibrated. Therefore, the external reference enables more accurate measurement of the temperature of the probes to be calibrated. Using an external reference sensor enables smaller total uncertainty of the system. The internal sensor has to deal with quick temperature changes, vibration and possible mechanical shocks so it has to be quite a robust mechanically. Unfortunately, mechanical robustness is usually inversely proportional to good performance: stability, hysteresis, etc.

The internal sensor is used just to adjust temperature close to the desired calibration point and keep it stable. There are many advantages to using a separate reference sensor. It helps to minimize calibration uncertainty but also provides reliability in measurements.

In the case of using an external reference sensor, the following uncertainty components should be taken into account:

- Axial uniformity
  - Axial uniformity-related uncertainty can be minimized by aligning the centers of the sensing elements. In many cases, the user can reduce the axial uniformity well below specification. In case the probe to be calibrated is short and won't reach the measurement zone at the bottom of the insert, the reference probe can be drawn out to match the immersion. Of course, the stem conductance has to be taken into account. If the reference sensor and the sensor to be calibrated are sufficiently similar in diameter and thermal conductivity, the user may obtain good results.

- Radial uniformity
  - Radial uniformity is still present when using an external reference probe and should be taken into account as specified.

- Loading effect
  - Since the internal sensor cannot completely compensate the load-related temperature shift inside the insert, the external reference sensor is within the same calibration volume as the sensors to be calibrated. The loading effect is usually much less significant with an external reference sensor.

- Stability over time
  - The external reference sensor can be used to measure the actual temperature deviation inside the insert, and it may often be smaller than the specification. It also helps the user to see when the unit has truly stabilized. Dry blocks usually have a stability indicator, but depending on, for instance, the different loads, there may still be some difference between the block and the insert temperatures when the indicator shows the unit has stabilized.

- External reference sensor
  - The external reference sensor (PRT) is typically much more capable of producing accurate measurements than the internal sensor. However, using an external reference does not automatically mean better results. All of the previously mentioned uncertainty factors need to be carefully considered.
  - Uncertainty related to the reference probe components includes the probe's calibration uncertainty, drift, hysteresis, stem conduction, and the readout device's uncertainty.
  - Of course, the external reference sensor needs a unit that measures the sensor. It can be the block or an external device.

CALCULATION EXAMPLES

There we calculate two total uncertainty examples. One is done using the internal temperature measurement and the other with a reference probe. In both cases the MB155R is used as the dry block. The temperature in both examples is 0 °C.

Due to the rectangular probability distribution of the specifications, they are divided by the square root of three to get the Standard Uncertainty. The standard uncertainties are combined as the root sum of the squares. Finally the combined uncertainty has been multiplied by two to get the expanded uncertainty.

As can be seen in the examples the total expanded uncertainty using the internal reference sensor is 135 mK (0.135 °C). When using an external reference sensor the total expanded uncertainty is 34 mK (0.034 °C).

The various uncertainty components used in the examples can be found in the specifications in the product brochures.

MB155R with internal measurement @0°C

Component	Specification (°C)	Standard Uncertainty (°C)
Display Accuracy	0.10	0.058
Hysteresis	0.025	0.014
Axial Uniformity	0.02	0.012
Radial Uniformity	0.01	0.006
Stability	0.005	0.003
Loading Effect	0.05	0.029
	Combined Uncertainty:	0.067
	Expanded Uncertainty:	**0.135**

MB155R with external measurement @0°C

Component	Specification (°C)	Standard Uncertainty (°C)
Axial Uniformity	0.02	0.012
Radial Uniformity	0.01	0.006
Stability	0.005	0.003
Loading Effect	0.005	0.003
Ref sensor measurement	0.006	0.003
	Combined Uncertainty:	0.014
	Expanded Uncertainty:	**0.028**
Reference Sensor (Beamex RPRT-420)		
Component	Specification (°C)	Standard Uncertainty (°C)
Short-term repeatability	0.007	0.004
Drift	0.007	0.004
Hysteresis	0.01	0.006
Calibration uncertainty	0.01	0.006
	Combined Uncertainty:	0.010
	Expanded Uncertainty:	**0.020**
MB155R and RPRT-420		
	Combined uncertainty:	0.017
	Expanded Uncertainty:	**0.034**

All specifications have a rectangular probability distribution.
That is why they are divided by the square root of three to get Standard Uncertainty.