FLUKE ®

Calibration

Understanding the uncertainties associated with the use of Metrology Wells

Application Note

Introduction

Dry-well calibrators are stable heat sources used in process and laboratory environments for calibration of temperature sensors. All heat sources introduce measurement errors as a result of their mechanical design and thermodynamic properties. These effects can be quantified in an effort to determine the heat sources' contribution to the measurement uncertainty. Fluke Calibration has developed Metrology Wells to reduce the errors typically seen in the usage of dry-wells. Metrology Wells come with a calibrated control sensor and have an option for a built-in thermometer readout. The Metrology Well's uncertainty will significantly vary depending on mode of use. The uncertainties associated with each method of use are discussed. The purpose of this application note is to help technicians and metrologists understand and quantify the measurement uncertainty when using Metrology Wells.

Uncertainties associated with the use of Metrology Well and its built-in reference thermometer input

Best performance is usually realized when Metrology Wells are used as stable heat sources and an external reference thermometer or the optional built-in reference thermometer input is used as the reference standard (see examples 1 and 2 on page 4). Typically, the major sources of uncertainty are caused by imperfect axial and radial uniformity, loading, instability, stem conduction, reference thermometer accuracy, and unit under test characteristics.

Axial uniformity

Each Metrology Well insert (removable sleeve with several drilled wells) is exposed to ambient environment at the top end and to a controlled temperature along a portion of its length. The vertical gradient in the insert is termed "axial uniformity." Due to dissimilarities in construction and length of temperature sensing elements, one must consider the axial uniformity of Metrology Wells. According to EA (European Accreditation) guideline 10/13, dry-wells should have a "zone of sufficient temperature homogeneity of 40 mm" from the bottom of the well. We recommend a zone of at least 60 mm to cover sensor lengths of the units under test (UUTs) and the reference standard, which often needs at least 50 mm.

Application Tip: Axial uniformity errors can often be improved beyond the specification by aligning the centers of the sensing element of the reference probe and the UUT (see Figure 4).

Radial uniformity

The thermal gradient from one well to another is referred to as radial uniformity. Measurement errors caused from imperfect radial uniformity are attributed to the distance between wells and heaters, the thermal properties of the insert material, and effects from uneven heat distribution caused by non symmetrical loading.

Application Tip: Best results are found when using a comparison insert (Insert B, D, or E) with a reference probe of the same diameter as the UUT and measuring directly across from the UUT.

Loading effect

The number of probes inserted into a Metrology Well impacts the amount

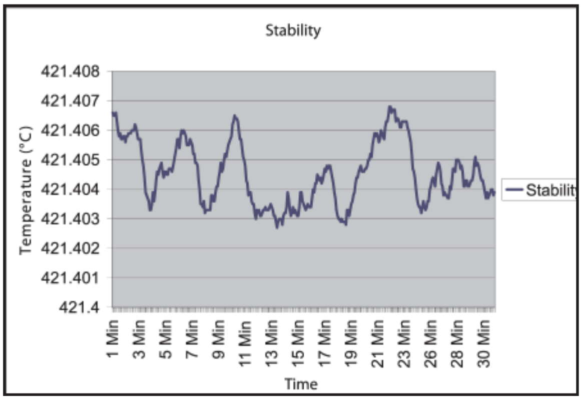

Figure 1. The Metrology Well display can help determine when stability is reached, but a better practice is to rely on display of the reference that offers more resolution.

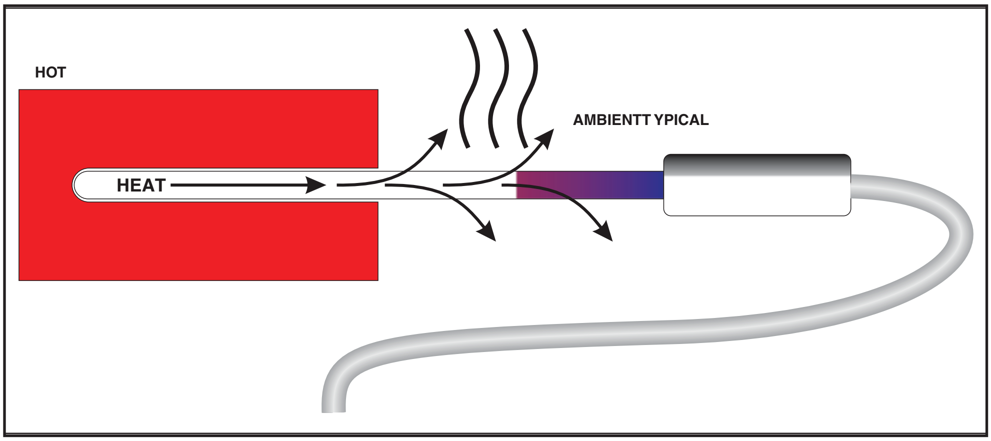

Figure 2. Stem conduction

Application Tip: Stem conduction error can be determined by immersing the probe into a bath and noting its change in temperature when raised at set increments. This is the best practice in that each probe has unique characteristics that contribute to stem conduction and should be evaluated individually.

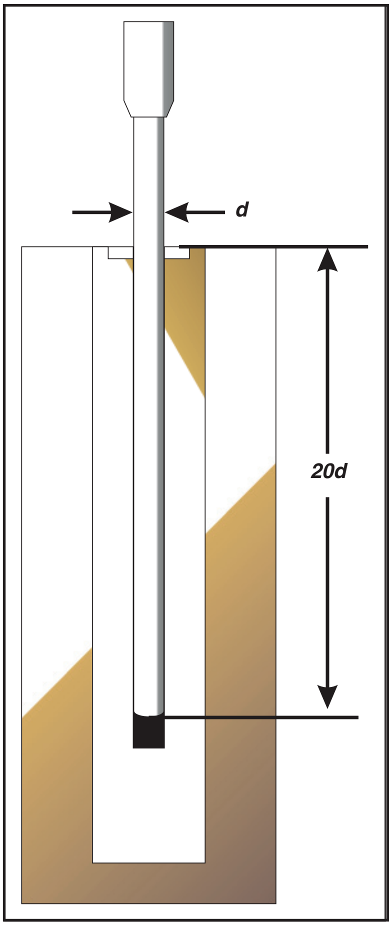

Figure 3. Recommended depth for probe immersion

of heat drawn away from or into a Metrology Well. This is referred to as "loading effect," which can be measured by inserting probes into wells and noting the change in the reference reading. Metrology Well design characteristics, such as 203 mm (8 in) of immersion and dual-zone control, help minimize the loading error.

Stability

Stability over time affects calibrations. EA 10/13 defines stability as a temperature variation "over a 30-minute period." The Metrology Well display can help determine when stability is reached, but there can be a significant difference between the actual and indicated temperature during stabilization. The better practice is to rely on the display of the thermometer readout, which offers more resolution (see Figure 1).

Stem conduction error

Stem conduction is heat flux along the length of the thermometer stem. This affects both the reference thermometer and the UUT (see Figure 2). Recommended depth of immersion for a probe is calculated as follows: [20 x probe OD] + [length of the sensor] (see Figure 3). Because Metrology Wells have deep immersion (160 mm [6.3 in] to 203 mm [8 in]), the error from stem conduction is usually a very small contributor to the over all uncertainty.

Reference probe, thermometer readout, and UUT considerations

There are many other sources of uncertainty to consider that result from the use of a reference probe, reference readout, UUTs, and their readouts. These errors include reference probe and thermometer readout calibration uncertainty or accuracy, reference probe drift and hysteresis, reference probe self-heating, UUT short-term drift and hysteresis, and UUT readout accuracy. This paper does not go into detail on these contributors, but more information can be obtained by contacting Fluke Calibration at www.flukecal.com.

Uncertainties associated with the use of a Metrology Well and its calibrated control sensor

Metrology Well control sensors come calibrated with a traceable certificate of calibration and an accuracy statement which allows the display to be used as a reference standard. Many measurement errors contribute to the uncertainty when using the Metrology Well in this manner.

Axial uniformity

The vertical gradients in Metrology Wells are more apparent when using the calibrated control sensor as the reference than when using the external reference thermometer. This is because it's not always practical to align the sensing elements of the control sensor (which is fixed in the block) to the UUTs (see Figures 4 and 5).

Radial uniformity

The calibrated control sensor is fixed in the block and is often not equidistant to the UUTs from the heaters. Thus, radial uniformity is a contributing factor and is considered.

Loading effect

Errors from loading typically are much larger when using the control sensor as the reference standard as opposed to an external reference probe, because the control sensor is isolated in the block and does not compensate for the loading of the wells in the insert.

Short-term and long-term drift

Each Metrology Well control sensor has a short- and long-term drift associated with its use. Drift will vary depending on use and care of the Metrology Well. Sensor drift can be determined by regular calibration or intermediate checks at a fixed temperature.

Hysteresis

Hysteresis is the difference in a Metrology Well's actual temperature resulting from the direction from which that temperature was approached. It is greatest at the mid-point of a Metrology Well's range.

Control senor calibration

Metrology Well control sensors are calibrated and come with NIST-traceable reports of calibration. The accuracy of the control sensor may vary from ±0.1 °C to ±0.25 °C. The calibrated display becomes most useful when it is used in the same way it was calibrated— when the 6.35 mm (0.25 in) hole is loaded with the UUT and readings are compared against the display temperature.

Other considerations

The errors from short-term drift, hysteresis, and readout accuracy of the UUT apply in the same way as when a Metrology Well is used with an external reference.

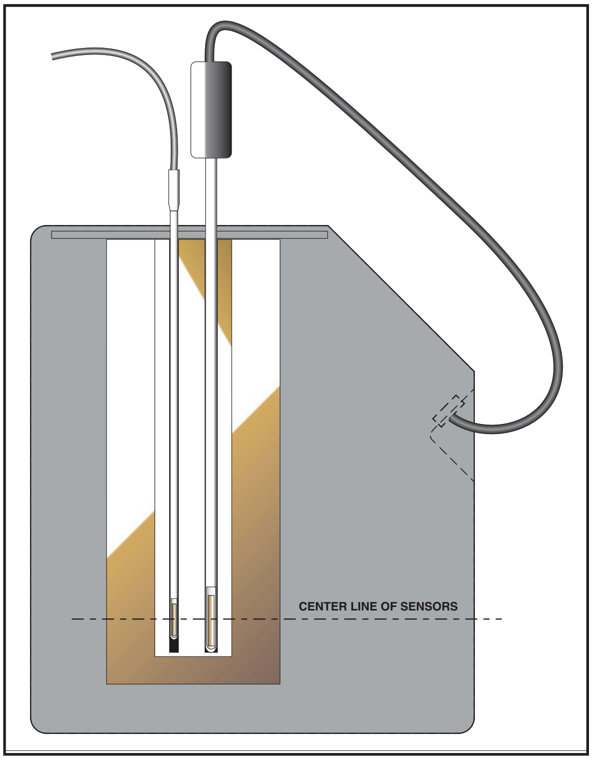

Figure 4. Aligning the centers of the sensing element of the reference probe and the UUT

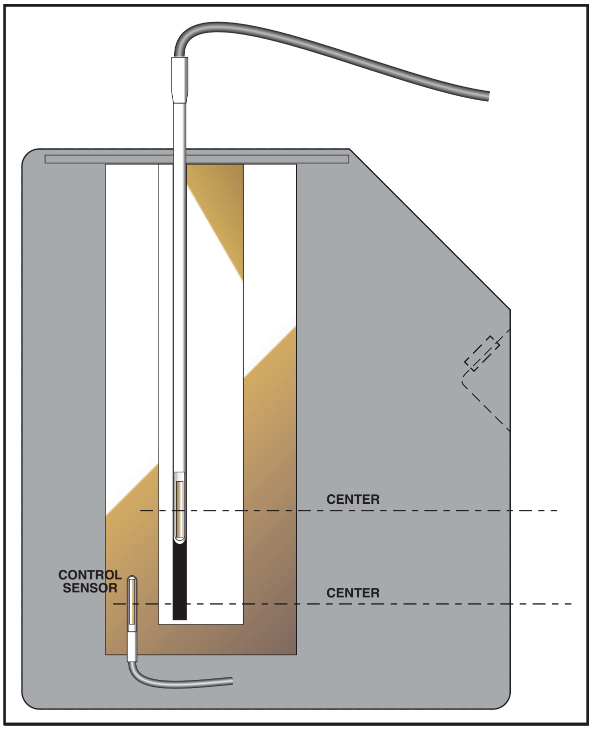

Figure 5. The vertical gradients in Metrology Wells are more apparent when using the calibrated control sensor as the reference.

Example 1 – Uncertainty calculation associated with Metrology Wells using a reference probe and a thermometer readout as the standard.

The example in Table 1 illustrates the calibration measurement uncertainty contributed by Metrology Wells. The actual values will vary with application and temperature. This example does not consider sources of uncertainty originating from characteristics of the UUT. This example is at 0 °C. Equipment considered for this example consists of the following:

- Model 9171-B-R, Metrology Well with built-in reference input
- Model 5626-15-D, High-temperature, Secondary PRT, 100 ohm

Table 1.

	Specification (mK)	Probability Distribution	Uncertainty (mK)
Axial uniformity	20	Rectangular	11.55
Radial uniformity	10	Rectangular	5.77
Loading effect	5	Rectangular	2.89
Stability	5	Rectangular	2.89
Reference probe calibration	4	Rectangular	2.31
Reference probe drift, including hysteresis	3	Rectangular	1.73
Reference probe stem conduction	2	Rectangular	1.15
Thermometer readout accuracy	6	Rectangular	3.46
Combined Standard Uncertainty (RSS)			14.32
Expanded Uncertainty (k=2)			28.64

Example 2 – Uncertainty calculation associated with Metrology Wells using the calibrated display as the reference standard

The example in Table 2 illustrates the calibration measurement uncertainty contributed by the Metrology Well. The actual values will vary with application and temperature. This example does not consider sources of uncertainty originating from characteristics of the UUT. This example is at 0 °C. Equipment considered for this example consists of the following:

- Model 9171-B, Metrology Well with calibrated control sensor used as the reference standard.

Table 2.

	Specification (mK)	Probability Distribution	Uncertainty (mK)
Axial uniformity	20	Rectangular	11.55
Radial uniformity	10	Rectangular	5.77
Loading effect	5	Rectangular	2.89
Stability	5	Rectangular	2.89
Hysteresis	25	Rectangular	14.43
Control sensor accuracy	100	Rectangular	57.74
Long-term drift	100	Rectangular	57.74
Combined Standard Uncertainty (RSS)			84.06
Expanded Uncertainty (k=2)			168.13

Note pertaining to Examples 1 and 2: Standard Uncertainty calculated by dividing the stated specification by the 3 to obtain a "standard deviation like" quantity based on rectangular distribution. Combined standard uncertainty uses a root sum square method assuming that individual standard uncertainties behave independently.

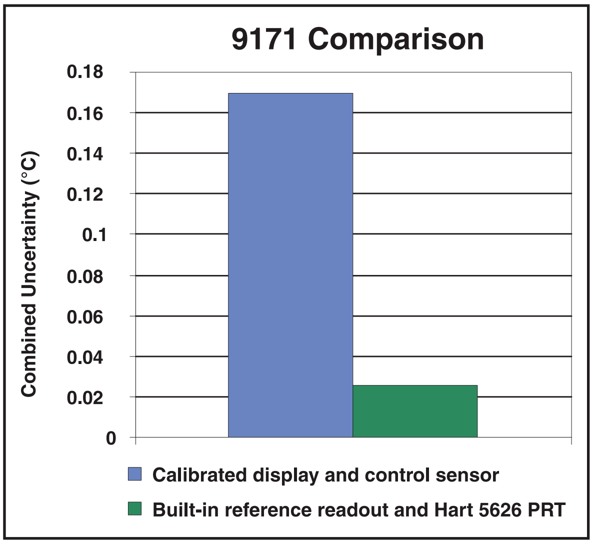

Figure 6. Total uncertainty is significantly reduced when using an external reference thermometer as the reference standard as shown above.

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Printed in U.S.A. 9/2012 2510068B_EN