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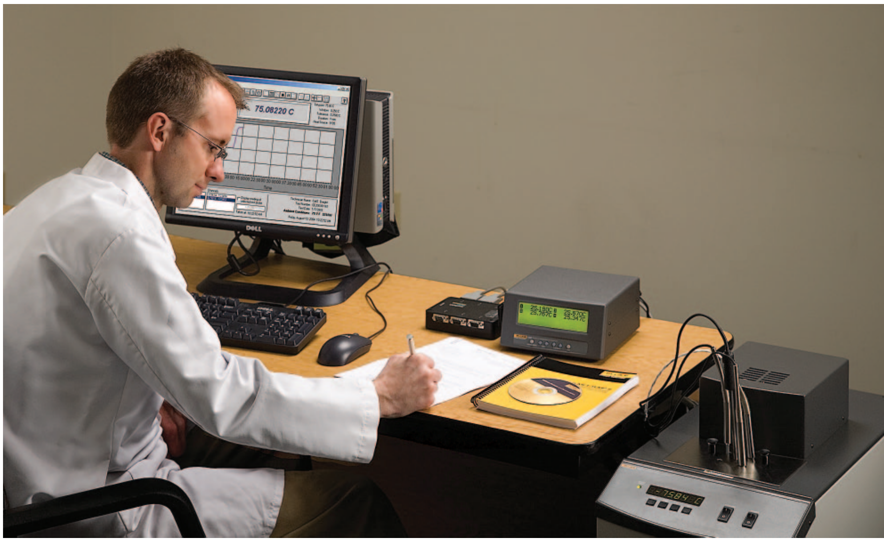
Calibration

Calculating calibration uncertainties in an automated temperature calibration system

Application Note



Some of the basic calibration uncertainties to consider with an automated temperature calibration system like the Hart 7380 bundles are the calibration uncertainties of the reference PRT, the drift of the PRT, uncertainties arising from bath uniformity and stability, and the uncertainties associated with the readout used to measure the unit under test and the reference PRT. This application note describes the evaluation of those uncertainties. Additional uncertainties that depend on the performance of the specific unit under test or the entire class of instruments for which the procedure applies may also be evaluated and included on a case-by-case basis. These include hysteresis, short-term stability, immersion effects, and self-heating.

The table below presents a sample uncertainty budget for the 7380-USR. An uncertainty budget is a tool that is used to help track and evaluate the uncertainties associated with a calibration. The uncertainty budget shown below offers one method of aggregating some of the most important contributors to the uncertainty of the 7380-USR system. Each uncertainty has been given a code B1 through B6 to facilitate discussion below.

B1 Some of the values needed for an uncertainty budget can be found on the report of calibration for the model 5615-12. They are the 5615-12's own calibration uncertainties shown in the table.

If calibration uncertainties are required at points between those expressed on the calibration report, such as at –80 °C, then a rigorous approach would include calculating the propagated uncertainties using the law of propagation of uncertainties as described in the GUM. A reasonable and less strenuous method for establishing the uncertainties between calibration points would be a technique called linear interpolation. That is, we assume that the uncertainty changes linearly between –196 °C and –38 °C from ± 0.024 °C to ± 0.011 °C.

5615 calibration uncertainties

	Temperature		Expanded Uncertainty (k=2)
T1	–196 °C	U1	0.024 °C
T2	–38 °C	U2	0.011 °C
T3	0 °C	U3	0.010 °C
T4	200 °C	U4	0.018 °C
T5	420 °C	U5	0.029 °C

Specifications and cal report data

Non statistical evaluation (type B approach)	Code	Data source	Type	–80 °C (mK)	–38 °C (mK)	0 °C (mK)	100 °C (mK)
Reference PRT calibration (model 5615-12)	B1	Cal report	Uncertainty	14.0	11.0	10.0	14.0
Reference PRT drift (model 5615-12)	B2	Manual (TPW)	Specification	6.8	8.4	10.0	13.9
Bath uniformity (model 7380)	B3	Manual	Specification	8.0	10.0	12.0	12.0
Bath stability (model 7380)	B4	Manual	Specification	6.0	8.0	10.0	10.0
Reference PRT readout (model 1529)	B5	Manual	Specification	4.0	5.0	6.0	9.0
Unit under test readout (model 1529)	B6	Manual	Specification	4.0	5.0	6.0	9.0
Total standard uncertainty (comparison measurements)	U			10.41	11.18	12.79	15.77
Total expanded uncertainty (k=2) (comparison measurements)	U'			21	22	26	32

With that assumption, we can just use the equation of a line, to solve for the slope of the line to get m = –8.23E-05

(1) $$m = \frac{U2 - U1}{T2 - T1}$$

Rearranging the equation, we can solve for the uncertainty at any point between the temperatures T1 and T2:

(2) $$U_{-80} = m(T_{-80} - T1) + U1$$

By plugging in the numbers from the uncertainty table above and the value we calculated for into equation 2, we find that the "propagated" calibration uncertainty at –80 °C is ± 0.014 °C.

B2 One key specification used in determining calibration uncertainties is the drift rate. The specification for the model 5615-12 secondary reference PRT reported by the manufacturer is: "Drift at 0.010 °C equals ± 0.010 °C per 100 hours exposure to the maximum temperature of 420 °C." To determine the equivalent drift at any other temperature, use equation 3

(3) $$\Delta T_2 = \Delta T_1 \frac{R_{T90}}{R_{TPW}} \times \frac{Sensitivity_{TPW}}{Sensitivity_{T90}}$$

Taking –80 °C as an example and pulling the data from the Ω table below that contains nominal values for the 5615, we obtain the equivalent drift rate at –80 °C or $\Delta \boldsymbol{T}_{-80}$ = ± 0.007 °C.

$\Delta \boldsymbol{T}_1$ = ±0.010 °C

$\boldsymbol{R}_{-80}$ 67.72 Ω ***Sensitivity***$_{TPW}$0.4 Ω/°C

$\boldsymbol{R}_{TPW}$100Ω***Sensitivity***$_{-80}$ = 0.41 Ω/°C

B3 and B4 Other required values for the uncertainty budget are bath stability and uniformity. These can be found in the manufacturers' specifications.The table is an example. You can rely on these numbers for a preliminary uncertainty budget. Better results (and lower uncertainties) can be obtained by monitoring and evaluating the bath in use and using this information in the uncertainty budget. To estimate the stability and uniformity values between –80 °C and 0 °C, for example, assume the changes are linear between the two points. This allows you to use equations 1 and 2 above to determine the stability or uniformity between specifications at two adjacent temperatures.

7380 bath specifications

Temperature	Stability	Uniformity	Fluid
–80 °C	± 0.006 °C	± 0.008 °C	Ethanol
0 °C	± 0.010 °C	± 0.012 °C	Ethanol
100 °C	± 0.010 °C	± 0.012 °C	Oil 5012

Nominal resistance (Ω) vs. temperature tables (°C)

	0	**–10**	**–20**	**–30**	**–40**	**–50**	**–60**	**–70**	**–80**	**–90**
–200	17.08									
–100	59.51	55.37	51.22	47.04	42.84	38.61	34.35	30.06	25.74	21.4
0	100	96.01	92.01	87.99	83.97	79.93	75.87	71.81	67.72	63.62
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
0	100	103.98	107.94	111.9	115.84	119.77	123.68	127.59	131.48	135.36
100	139.23	143.09	146.93	150.77	154.59	158.4	162.2	165.98	169.76	173.52
200	177.27	181.01	184.74	188.46	192.16	195.86	199.54	203.21	206.87	210.51
300	214.15	217.77	221.39	224.99	228.58	232.15	235.72	239.28	242.82	246.35
400	249.87	253.38	256.88	260.36	263.84	267.3	270.75	274.19	277.61	281.03
500	284.43									

Sensitivity (Ω/°C) vs. temperature tables (°C)

	0	**–10**	**–20**	**–30**	**–40**	**–50**	**–60**	**–70**	**–80**	**–90**
–200	0.43									
–100	0.41	0.41	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.43
0	0.40	0.40	0.40	0.40	0.40	0.40	0.41	0.41	0.41	0.41
	0.00	**10.00**	**20.00**	**30.00**	**40.00**	**50.00**	**60.00**	**70.00**	**80.00**	**90.00**
0	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.39
100	0.39	0.39	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
200	0.38	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.36
300	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.35	0.35
400	0.35	0.35	0.35	0.35	0.35	0.35	0.34	0.34	0.34	0.34
500	0.34	0	0	0	0	0	0	0	0	0

1529 reference readout specifications

T (°C)	R (Ω)	1529 Resistance Accuracy Specification	Conversion Equation	Solution
–200 °C	17.08	0 Ω to 20 Ω: ± 0.0005 Ω	$\Delta T = \dfrac{\pm 0.0005}{Sensitivity_{T90}}$	± 0.0116 °C
–80 °C	67.72	20 Ω to 400 Ω: ± 25 ppm of reading	$\Delta T = \dfrac{\pm \dfrac{25}{1000000} \times R_{T90}}{Sensitivity_{T90}}$	± 0.0041 °C

Uncertainty evaluation

Type B standard uncertainties	Code	Coverage factor	–80 °C (mK)	–38 °C (mK)	0 °C (mK)	100 °C (mK)
Reference PRT calibration (model 5615-12)	B1	1	7.0	5.5	5.0	7.0
Reference PRT drift (model 5615-12)	B2	1	3.9	4.8	5.8	8.0
Bath uniformity (model 7380)	B3	1	4.6	5.8	6.9	6.9
Bath stability (model 7380)	B4	1	3.5	4.6	5.8	5.8
Reference thermometer readout (model 1529)	B5	1	2.3	2.9	3.5	5.2
Unit under test readout (model 1529)	B6	1	2.3	2.9	3.5	5.2
Total standard uncertainty (does not include evaluation of unit under test)	U	1	10.4	11.2	12.8	15.8
Total expanded uncertainty (k=2) (comparison measurements)	U'	2	21	22	26	32

B5 and B6 The 1529 manual contains accuracy specifications for the readout. As with most readouts, these are expressed in engineering units of resistance (or voltage) rather than temperature. So equations are used to convert the resistance accuracy specification into a temperature accuracy specification. For example, the 1529 accuracy specifications for PRTs are given in the table, with the appropriate conversion equation and solutions for the 5615 at two temperatures (–200 °C and –80 °C).

Combining uncertainties

In order to combine all of the uncertainty components that have been evaluated, they first must be converted to standard uncertainties. There are two kinds of uncertainties in the table. Some of them are limits of error, and some of them are based on a known or assumed probability distribution. The PRT calibration uncertainties are given as k=2 uncertainties. When uncertainties are stated with a k=2 coverage factor, it means a normal, or Gaussian, distribution has been assumed. To convert this kind of uncertainty to a standard uncertainty, all that is required is to divide it by two. The rest of the uncertainties are limits of error that were assigned without probability distributions. Without a known probability distribution, a rectangular distribution is assumed. To convert an uncertainty with a rectangular distribution to a standard uncertainty, the value is divided by the square root of three. The individual standard uncertainties are combined through a process called Root Sum Squares or RSS. This means that each uncertainty is squared before adding all of the squared components together. The square root of the result is taken as the total combined standard uncertainty.

Root Sum Squares

$$U = \sqrt{B1^2 + B2^2 + B3^2 + B4^2 + B5^2 + B6^2 \ldots}$$

The total expanded uncertainty is obtained by multiplying the resulting value by a factor of two (k=2) and is show in the table above.

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