

Temperature “Back to basics”

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Abstract

This paper will show you:

- How do you know that your standard is in tolerance after returning from the vendor?
- What to do when the data only states report on value.
- How to check if your standard is in tolerance by drift of previous to current data.
- How some vendors calculate drift values.
- Methods you can use to do a drift check.
- Determine the best method - Triple Point of Water vs. Ice Bath.
- Decide what equipment is needed to read your standard.
- Choose between Ohm Meter vs. Resistance Bridge.

This “Back to Basics” paper was inspired by my search for an outside calibration lab to calibrate/verify my overflow items. Through my search, I found that three calibration labs didn’t check tolerance conditions of their primary standard although they did file the cert and data. One of the labs quoted me better uncertainty than NIST using a thermocouple and handheld digital read out.

Back to the basics means starting with the primary standard. By educating smaller calibration labs on how to verify their standards, we can rely on them for overflow/verification work.

Introduction

In the world of temperature measurements I tell everyone “It is art not science.” Ok there is a lot of science involved and handling of your equipment is of the utmost importance. This paper is an introduction or refresher covering the basics in temperature with an emphasis on maintaining “in tolerance” conditions to reduce impact on product.

1. Are you in Tolerance?

It is a best practice to monitor your tolerance condition between calibrations of your probe. Measure the resistance at the Triple Point of Water (TPW) and calculate the drift from the TPW value on your certificate. The TPW is the resistance measurement of your probe at .01°C and is a key fixed point for the ITS-90. By measuring this point on a

regular basis, you can determine if your probe is in tolerance or when it is drifting out of tolerance by control charting.

Many factors can cause drift including how the vendors process the probe. Most vendors will anneal your probe before they calibrate it to remove stress and oxidization of the wire. This process repairs the probe if it was handled roughly in shipping; however, annealing will sometimes cause the probe to shift to a new curve. ^[6]Normally this is not problematic unless you did not close the loop on all the calibration work you did with your probe before you sent it to the vendor for calibration. A single point drift check, explained later, at 0°C or .01°C (Triple Point of Water or “TPW”) to close the loop on all calibration done between the TPW checks should be sufficient to address any drift and can save time and money. The methods and equipment necessary will be discussed later.

If you don't have the equipment to monitor the tolerance condition of your probe between calibrations you will need to calculate the drift when your probe is returned from the vendor. You will know that it is functioning properly based on the certificate and data but you won't know if the probe changed (drifted) enough to impact product. This is important. Imagine that your probe drifts enough to impact a production process and you don't find out for 6 to 12 months. The small change to your standard can have a snowball effect on product potentially resulting in millions of dollars of impact to your company or Clients' company.

The vendor will send a “Report of Calibration” with your PRT or SPRT. This report should contain temperature and resistance values, five or more temperature test points, a set of ITS-90 “International Temperature Scale of 1990” coefficients and a table. The table can be in terms of Resistance vs. Temperature or in terms of Ratio (Wt90) versus Temperature (°C). The table is key to determining the tolerance condition (in or out) of the probe and if there is an impact on product. If the data returned only states a report of value or a report of calibration, a drift check is necessary to determine if the probe meets tolerance.

1.1 Check for Drift

To complete a drift check, you will need to review or generate Resistance vs. Temperature tables. Using these tables and a set of tables from the last calibration of the probe; compare multiple points through the range of the probe. If you don't have the tables, you can generate them using the report of calibration or certificate and a software tool such as TableWare by Hart Scientific. A tool such as this can produce tables using either raw data (temperature points and resistance values) or coefficients.

Methods to Determine Drift

Once you have the necessary data, use one of these methods to determine drift.

Method 1:

Uses MS Excel See Table 1

These values come from the new and previous calibration Resistance vs. Temperature tables. This method centers at 101.5°C.

The formula for the sensitivity is:

$$\text{Sensitivity} = (\text{Resistance for } 101^{\circ}\text{C}_{\text{current}} - \text{Resistance for } 100^{\circ}\text{C}_{\text{current}}).$$

The drift from last formula is:

$$(\text{Resistance for } 100^{\circ}\text{C}_{\text{current}} - \text{Resistance for } 100^{\circ}\text{C}_{\text{previous}}) / \text{sensitivity}.$$

Example with calculator:

$$\text{Sensitivity} = (139.63616 - 139.24973) = 0.3864$$

$$\text{Drift} = (139.24973 - 139.24691) / 0.3864 = 0.0072976 \text{ }^{\circ}\text{C}$$

Table 1

Previous Resistance for 100°C		139.24691	
100°C			
Current	100°C	Ω	139.24973
Current	101°C	Ω	139.63616
Sensitivity			
		0.3864	
Drift From Last Calibration			
		0.0072976 °C	

Test Point	Lower Limit	Upper Limit	As Found	
100°C	-0.018	0.018	0.0072976	Pass

Method 2:

Uses MS Excel See Table 2

Method 2 centers the sensitivity at 100.

All the values come from new and previous Resistance vs. Temperature tables.

The formula for the sensitivity is:

$$\text{Sensitivity} = (\text{Resistance for } 101^{\circ}\text{C}_{\text{current}} - \text{Resistance for } 99^{\circ}\text{C}_{\text{current}}) / 2.$$

The drift from last formula is:

$$(\text{Resistance for } 100^{\circ}\text{C}_{\text{current}} - \text{Resistance for } 100^{\circ}\text{C}_{\text{previous}}) / \text{sensitivity}.$$

Example with calculator:

$$\text{Sensitivity} = (139.63616 - 138.86317) / 2 = 0.3865$$

$$\text{Drift} = (139.24973 - 139.24691) / 0.3865 = 0.0072963 \text{ }^{\circ}\text{C}$$

Table 2

Previous Resistance for 100°C			139.24691
100°C			
Current	99	°C	138.86317
Current	100	°C	139.24973
Current	101	°C	139.63616
Sensitivity			
		0.3865	
Drift From Last Calibration		0.00730	°C

Test Point	Lower Limit	Upper Limit	As Found	
100°C	-0.018	0.018	0.0072963	Pass

1.2 How some vendors calculate drift values.

A method used by some vendors uses actual data not tables. ^[4] It shows how to calculate drift:

$$\text{normalized} = R_{\text{new}} - (\text{actual } t_{\text{new}} - \text{actual } t_{\text{previous}})(\text{sensitivity}).$$

$$\Delta t = (R_{\text{normalized}} - R_{\text{previous}}) / \text{sensitivity}$$

^[4]Hart Scientific also uses method one as a means to calculate drift.

If you search for accuracy on websites or catalogs for PRTs or SPRTs, they are not normally stated. You will usually find drift per year or in hours for a specific range. Starting with this data, use the drift spec and your intended use to determine your own tolerance. Talk with the manufacture of your probe to determine recommended amount of drift before calibration is required.

1.3 Maintaining Tolerance

Now that your Standards are in tolerance, you must maintain them. One way to do this is by monitoring probe drift between calibration cycles. This can prevent or minimize an out of tolerance condition. There are two methods you can use depending on the tolerance of your probe. You can use an Ice Bath or Triple Point of Water Cell (TPW). The Ice Bath has an actual temperature of 0°C and is the less accurate of the two. The TPW has an actual temperature of 0.01°C; however, the accuracy differs depending on the manufacture of TPW. The difference in accuracy will probably not impact you unless you are calibrating high end SPRTs. See Figure 2 below for accuracy of Hart Scientific made TPW.

1.4 Ice Bath

The best and most cost efficient method to monitor drift for a PRT/IPRT (± .018 and higher) is an Ice Bath. You will need to review and follow ^[5]ASTM E563 when creating

your Ice Bath. I ran a test on my ice bath (Hart Scientific Model 7911) using dionized ice and water. I monitored it with a standard thermistor (standardized with a TPW and 1 ppm digital read out) and was able to maintain a temperature of 0.001 to 0.0018°C for 1 hour.

1.5 Triple Point of Water Cell

The best method to monitor drift for a SPRT (all) and a PRT(<.003 °C to .010 typical) is the TPW as it will demonstrate great accuracy and repeatability. The TPW takes more time to make because you must go through the process of freezing the mantle. ^[3] The cell should be frozen by refrigerating the inside of the reentrant well so that water freezes from the reentrant well outward to form a mantle of ice around the well. A variety of refrigeration methods are used to freeze a cell including refrigerated cold fingers, heat pipes, LN2 chilled rods and dry-ice. The manual for your TPW will walk you through this process, step by step.

To maintain your TPW after the mantle is created; you can use Hart’s 2028 Dewar or Hart’s 7012 and 7312 maintenance bath. Figure 1 shows Harts Quick Stick freezing the Ice Mantel of a TPW.

Method for Calculating Drift

Using either the Ice Bath or TPW, table 3 is a method to calculate probe drift.

Table 3

Cert. TPW Resistance	New TPW Resistance	Sensitivity dR/dT @ 0°C from cert.
25.504186	25.504196	0.101539281

Change in RTPW	0.000010
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Drift °C	0.000098
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New TPW Resistance – Cert. TPW Resistance / Sensitivity = Drift °C

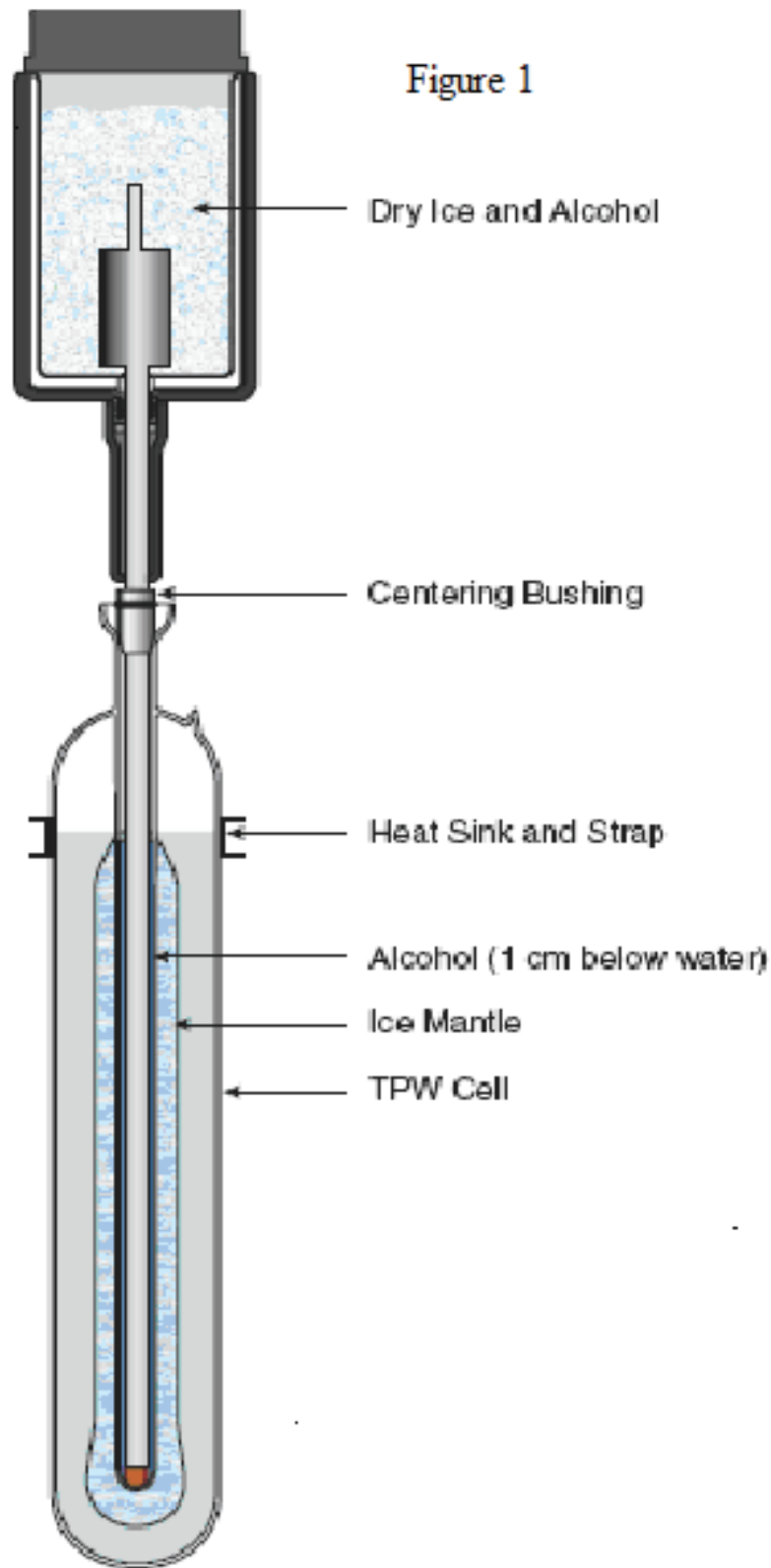
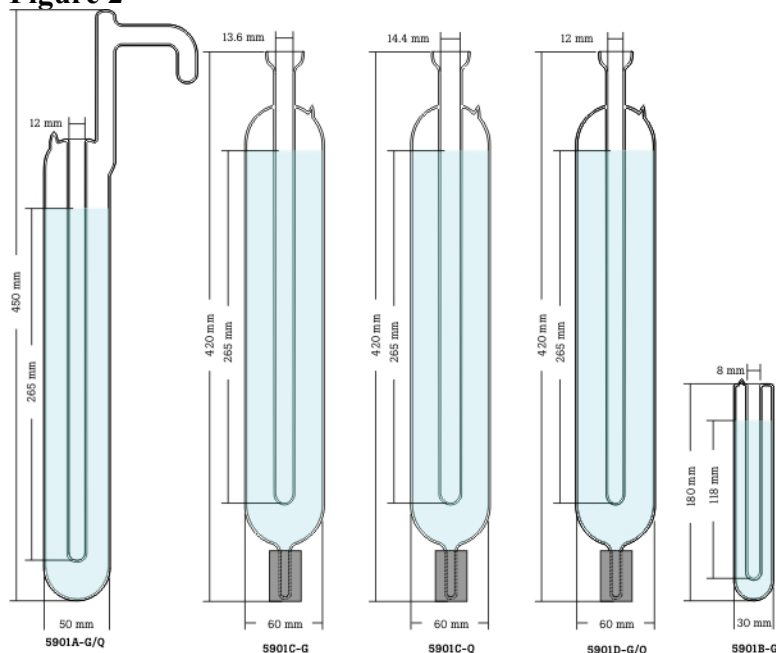


Figure 2 Freeze an Ice mantle using a "Quick Stick"

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[3] Figure 2 Hart Scientific Triple Point of Water Cell “TPW”
Expanded Uncertainty (k=2) < 0.0001°C Mini cell < 0.0002°C

Figure 2



Used with permission of Hart Scientific

1.6 Thermometry: DMM or Resistance Bridge

There are different types of digital read outs; portable or bench top; DMM, Resistance Bridge, or even digital read outs called Super Thermometer. To select the optimal device, you should consider your needs and the following information.

You will need some sort of digital read out that will read your probe in temperature and also in resistance (to aid in calculating drift). You probably don't need something as accurate as a resistance bridge (± 0.1 ppm) unless you are calibrating SPRTs. If you have a SPRT that you use to calibrate other PRTs ($\pm 0.018^\circ\text{C}$ and higher), I recommend a digital read out with accuracy of 4ppm or better. One consideration is if 4ppm just gets you by, is it more cost effective to buy a 1ppm and reduce the possible out of tolerance condition. You should always complete an uncertainty calculation before making the investment.

Most temperature calibration labs do not use a DMM for thermometry. If you decide to use a DMM; check the output current and accuracy. There are some DMMs that will display the temperature and allow you to input ITS-90 coefficients for your probes. A good example is the Fluke 8508A. Note that most DMMs are not built for temperature and will not yield the accuracies that a temperature digital read will.

Summary

This was a refresher on selecting and maintaining your temperature standards. As you can see a great deal of care goes into the process. But being the foundation of everything thing you do and build and some stake there reputation on, the extra effort will directly reflect on your product or service.

Out of tolerance conditions can be costly even if the out of tolerance doesn't impact the product. An out of tolerance condition can impact a lot of people's time ranging from technicians to managers. Monitoring your probes for drift between calibrations can give you confidence in your measurements. Closing the loop on calibrations done between drift checks can reduce or prevent a costly impact.

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