FLUKE®

Calibration

How to select thermocouple calibration equipment

Application Note

Thermocouple application note series

This is the second of four application notes on thermocouples:

1. Thermocouple fundamentals
2. How to select thermocouple calibration equipment
3. Calculating uncertainties in a thermocouple calibration system
4. How to calibrate a thermocouple

Characteristics of thermocouples

Thermocouples can be constructed from almost any material with thermoelectric properties. The mixtures of materials in thermocouples are chosen for specific behavior and applications. A thermocouple produces a voltage output change when exposed to a change in temperature. In contrast, thermistors and PRTs produce a resistance change when the sensing element is exposed to a temperature change. Table 1 contrasts the key characteristics of thermocouples compared to thermistors and PRTs.

Table 1. Comparing characteristics of thermocouples, thermistors and PRTs

Thermocouple	Thermistor	PRT
Temperature range: -200 °C to 1700 °C*	Temperature range: 0 °C to 100 °C	Temperature range: −200 °C to 1000 °C**
Accuracy is dependent on TC type and wire tolerances (Standard or Special Limits)*** Approximate accuracy ranges are: Type J ± 2.2 °C or ± 0.75 % of reading (Standard) Type S ± 0.6 °C or ± 0.75 % of reading (Special)	Accuracy: ± 0.001 °C to ± 0.01 °C	Accuracy: ± 0.006 °C to ± 0.04 °C
Stable	Very stable	Very stable
Rugged	Moderately delicate	Very delicate
Low priced	Moderately priced	Highly priced

*Represents the combined temperature range of common TC types. A single TC cannot be used over the full listed range.
**Represents the combined temperature range of common PRTs. A single PRT cannot be used over the full listed range.
***Standard Limits of Error thermocouples use standard grade wire, are more common, and are less expensive. Special Limits of Error thermocouples are made of higher grade wire which increases accuracy, but are more expensive.

Thermocouple calibration equipment

Calibration is performed by measuring the voltage output of the thermocouple unit under test (UUT) while the measuring (hot) junction is exposed to a temperature source and the reference (cold) junction is maintained at a reference (usually 0 °C). The following instruments are required:

- Reference probe
- Readout(s) for the reference probe and thermocouple under test
- Temperature source for the reference probe, thermocouple under test, and thermocouple reference junction

Reference probe

Depending upon the accuracy required, the reference probe will be an SPRT, a PRT, or a thermocouple of better quality and calibration than the thermocouples under test. Since this instrument is the reference for calibration, its accuracy and stability are important.

SPRTs
SPRTs are the most accurate and stable reference probes available. Generally a glass-sheath version is used. These instruments are standardized since they are part of the ITS-90 definition, which means there are minimum requirements for the purity of the platinum wire and the type of construction used. This results in less confusion concerning the suitability of the instrument for a particular application and confidence in its performance if calibrated and used correctly. These instruments are highly stable and accurate, but they are expensive and extremely delicate. They should be reserved for high accuracy applications only.

PRTs
When accuracy requirements are less critical, PRTs can be used successfully. PRTs are available in many configurations. However, PRTs which are suitable for use as calibration standards are generally available as stainless steel or Inconel-sheathed probes. These instruments are not as accurate as SPRTs but are generally more rugged and easier to work with. Unlike SPRTs, the design of PRTs is left to the discretion of the manufacturer. Not all designs perform to the level required for use as a reference. Use care in selecting a PRT to ensure that the type selected is appropriate for use as a calibration reference over the range of interest and with the required accuracy.

Thermocouples
Reference grade thermocouples are available with uncertainties and stability approaching a PRT (or even an SPRT) at high temperatures. This grade is suitable as a calibration standard. Reference grade thermocouples are standardized in composition but not construction. Take precautions to ensure that the model selected will perform as required over the temperature range of interest.

Special considerations
In addition to accuracy requirements, there are other characteristics which must be considered. For example, the reference junction end of the thermocouple must be long enough to allow proper immersion into the reference temperature source (typically an ice bath). Also, some of the common sheath materials used in thermocouple probes should not be used at high temperatures. Ensure that the sheath material is compatible with the calibration process for which it is intended.

Readout

Since thermocouples produce a voltage output, the requirements for a thermocouple readout are different from those for an SPRT, PRT, or thermistor readout. Unless the reference probe is a thermocouple also, two readouts will be required. The thermocouple reference junction must be considered. Most thermocouple readouts have "electronic reference junctions," often referred to as "cold junction compensation." This is an additional circuit, which measures the temperature at the thermocouple readout connection when connecting thermocouple wire directly to the readout, and it compensates for the non-zero reference temperature. This type of compensation is very convenient, but not usually as accurate as an actual ice point bath.

Best results will be obtained with readouts designed specifically for thermocouple calibration. DMMs severely limit the flexibility with usually no cost savings or accuracy increase.

The voltage output from a thermocouple is very low, and a small voltage uncertainty equates to a large temperature uncertainty. The voltage measurements must be extremely accurate even for moderate accuracy temperature calibrations. Also, at the low voltage levels that will be measured when calibrating thermocouples, the readout floor error (noise limit or zero offset limit) becomes very significant. Ensure that the readout has a voltage range (usually to 100 mV range) and accuracy appropriate for thermocouple calibrations. Consider an example using a high accuracy 7.5 digit DMM to measure a type S thermocouple at 500 °C. The following example shows the relative contribution from the DMM sources of error.

DMM accuracy on 100 mV range	= (20 ppm of reading + 2 ppm of range)
Type S output at 500 °C	= 4.2333 mV
Type S slope at 500 °C	= 0.0099 mV/°C

Accuracy calculations:

$$= \frac{(4.2333 \text{ mV x } 20 \text{ ppm}) + (100 \text{ mV x } 2 \text{ ppm})}{0.0099 \text{ mV/°C}}$$

$$= \frac{(0.00008466 \text{ mV}) + (0.0002 \text{ mV})}{0.0099 \text{ mV/°C}} = 0.0288 \text{ °C}$$

In this example, the uncertainty resulting from the DMM floor is much larger than the error due to the DMM range accuracy. This situation is more pronounced at lower temperatures and less pronounced at higher temperatures. This illustrates the importance of readout floor error.

Temperature source

The most common temperature sources for thermocouple calibration are dry-wells and furnaces. When even higher accuracy is required, calibration baths can be utilized. For the lowest temperatures (below –100 °C) an LN2 (liquid nitrogen) comparison device is required.

Stability and uniformity should be considered in selecting the temperature source since these factors will contribute to the thermocouple calibration uncertainty:

- Stability specifies how precisely the temperature source maintains a set-point temperature over time.
- Uniformity specifies how consistent the temperatures are throughout the temperature source.

Bare wire thermocouples should never be immersed directly into bath fluid. A protection tube should be used. Thermocouple probes are not usually massive, but immersion depth must still be considered. Insufficient immersion depth will result in calibration errors. At elevated temperatures, precautions must be taken to avoid damage to the reference probe. Additionally, if an external reference junction is to be used, ensure that the temperature source selected is sufficiently insulated so that the external surfaces do not get hot enough to damage the ice bath. Carefully evaluate your requirements before selecting the temperature source to ensure the instrument will match your application.

Table 2. Fluke Calibration equipment recommended for thermocouple calibration

Reference Probes			
Model	**Range**	**Size**	**Basic Accuracy ***
SPRTs			
5698-25	–200 °C to 670 °C	Quartz, 485 mm x 7 mm (19.1 in x 0.28 in)	< 0.006 °C/100 hours at 670 °C
Secondary Standard PRT			
5626	–200 °C to 661 °C	305 or 381 mm x 6.35 mm (12 or 15 in x 0.25 in)	± 0.007 °C at 0 °C
Secondary Reference PRT			
5615-9	–200 °C to 420 °C	229 mm x 4.76 mm (9 in x 0.19 in)	± 0.013 °C at 0.010 °C
5615-12	–200 °C to 420 °C	305 mm x 6.35 mm (12 in x 0.25 in)	± 0.013 °C at 0.010 °C
Precision Industrial PRT			
5627A-9	–200 °C to 300 °C	229 mm x 4.7 mm (9 in x 0.19 in)	± 0.05 °C at 0 °C
5627A-12	–200 °C to 420 °C	305 mm x 6.35 mm (12 in x 0.25 in)	± 0.05 °C at 0 °C
Type R and S Standard Thermocouples			
5649/5650-20	0 °C to 1450 °C	508 mm x 6.35 mm (20 in x 0.25 in)	± 0.7 °C at 1100 °C
5649/5650-25	0 °C to 1450 °C	635 mm x 6.35 mm (25 in x 0.25 in)	± 0.7 °C at 1100 °C
*Basic accuracy includes calibration uncertainty and short-term repeatability. It does not include long-term drift.			

FLUKE ®
Calibration

Table 2 continued. Fluke Calibration equipment recommended for thermocouple calibration

Readouts			
Model	**Probe Types**	**Accuracy**	**Features**
1523	PRTs, Thermocouples, Thermistors	± 0.015 °C at 0 °C (PRTs) ± 0.24 °C at 0 °C (Type K TC)	Battery-powered, handheld reference thermometer; INFO-CON connector reads coefficients without programming; saves 25 readings on demand; graphs trends
1524	PRTs, Thermocouples, Thermistors	± 0.015 °C at 0 °C (PRTs) ± 0.24 °C at 0 °C (Type K TC)	Handheld reference thermometer same as 1523 but with inputs for two thermometers; logs up to 15,000 readings and stores 25 more on demand
1529	PRTs, Thermocouples, Thermistors	± 0.006 °C at 0 °C (PRTs) ± 0.4 °C at 600 °C (Type K TC, int CJC)	Four channels can all be measured simultaneously; battery-powered; logs up to 8,000 readings; flexible display
1586A with DAQ-STAQ Multiplexer	PRTs, Thermocouples, Thermistors	± 0.005 °C at 0 °C (PRTs) ± 0.29 °C at 0 °C (Type K TC, int CJC)	40 channels with scan rate of 10 channels per second; automates sensor calibration when connected to a Fluke Calibration temperature source

Temperature Sources		
Model	**Range**	**Accuracy**
Field Metrology Wells		
9142	-25 °C to 150 °C	± 0.2 °C
9143	33 °C to 350 °C	± 0.2 °C
9144	50 °C to 660 °C	± 0.35 °C at 50 °C ± 0.35 °C at 420 °C ± 0.5 °C at 660 °C
Metrology Wells		
9170	-45 °C to 140 °C	± 0.1 °C
9171	-30 °C to 155 °C	± 0.1 °C
9172	35 °C to 425 °C	± 0.1 °C at 100 °C ± 0.15 °C at 225 °C ± 0.2 °C at 425 °C
9173	50 °C to 700 °C	± 0.2 °C at 425 °C ± 0.25 °C at 660 °C
Thermocouple Furnaces		
9150 (vertical)	150 °C to 1200 °C	± 5 °C
9118A (horizontal)	300 °C to 1200 °C	± 5 °C

Fluke Calibration
PO Box 9090,
Everett, WA 98206 U.S.A.

Fluke Europe B.V.
PO Box 1186, 5602 BD
Eindhoven, The Netherlands

For more information call:
In the U.S.A. (877) 355-3225 or Fax (425) 446-5116
In Europe/M-East/Africa +31 (0) 40 2675 200 or Fax +31 (0) 40 2675 222
In Canada (800)-36-Fluke or Fax (905) 890-6866
From other countries +1 (425) 446-5500 or Fax +1 (425) 446-5116
Web access: http://www.flukecal.com

Printed in U.S.A. 12/2014 6004060a-en
Pub-ID 13272-eng