TEMPERATURE CALIBRATION

Overview

This document discusses important concepts related to the procedures used to calibrate Thermonics' precision temperature forcing systems (PTFS). It provides an overview of commonly used calibration methods. In addition, it provides a discussion of the various factors that can affect the accuracy and reliability of calibrations and the advantages of storing multiple calibrations.

Calibration Overview

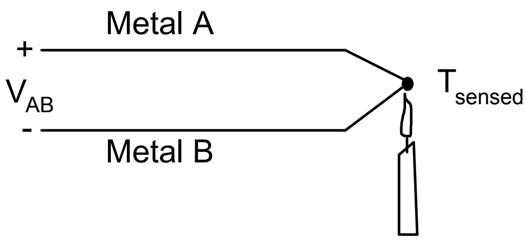
The calibration process serves to systematically adjust and standardize the temperature measurement system of the PTFS. Typically, the process involves a comparison between the temperature measured by the PTFS and an external standard. The PTFS temperature metering is adjusted to match the external temperature standard.

In more specific terms, calibration is an adjustment of the scaling of the temperature measurement system. It adjusts for any offset or change in gain between how the system measures a temperature and how a standardized external measurement instrument measures the same temperature. By taking sample measurements at diverse setpoints (such as -55C and +125C), a scaling adjustment can be entered into the system, which will accommodate for a wide range of temperatures.

PTFS Temperature Measurement

Several pertinent issues related to how the PTFS monitors and controls a temperature setpoint must be understood to obtain an accurate assessment of the complexity of temperature measurement systems. These issues are: how a thermocouple (TC) works, thermocouple voltage vs. temperature, cold junction compensation, thermocouple isolation, and the importance of traceability and accuracy of temperature calibration.

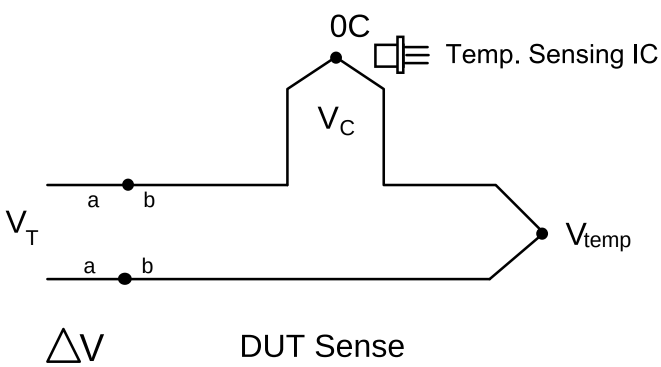
Thermocouples
The PTFS measures the temperature of the air stream or the DUT (device under test) using thermocouples. Thermocouples are temperature-sensing devices that are made of dissimilar metals that form a junction that produces a voltage as a function of temperature. A voltage (EMF - Electro-motive Force) is generated that is proportional to the difference in the temperature of the junctions. Because the properties of most thermocouples are known, a specific voltage can be translated as a specific temperature. See following illustration:



$V_{AB} = f T$; where T is the sensed temperature.

The system software converts V_{AB} to a temperature reading by using a look-up table.

<u>Cold Junction Compensation</u>
One of the challenges of accurately measuring the response of a thermocouple is created by the measurement system itself. Whenever there is a junction of dissimilar metals, such as between a thermocouple and voltage measurement system, an EMF is generated that is in opposition to the EMF generated by the thermocouple junction from which the desired reading is to be obtained. The result is a skewed reading that is proportional to the difference in temperature between the desired thermocouple junction and the junction with the voltage measurement system.



$V_{temp} = V_T - V_C$

$T = f(V_{temp})$

To compensate for this, Thermonics has added an additional thermocouple to the loop. This is commonly referred to as a cold junction or ice-point compensation (See above diagram). It has two benefits. Firstly, the additional thermocouple creates a junction with the PTFS using similar metals; hence, no opposing EMF's are generated. Secondly, it provides a reference point from which software compensation can be made so that an accurate EMF can be determined. The adjusted EMF is used in a look-up table to determine the temperature.

Look-Up Table

Because of the variations in the voltages measured on the thermocouple the relationship between a temperature and a specific voltage is not linear. As a result, the calculation required by the system can be very computer intensive and is performed much faster using a look-up table. A specific voltage is translated as a specific temperature. If a reading is between values in the table, interpolation is used to determine the temperature.

Thermocouple Isolation

Sometimes, it can be difficult to obtain accurate readings from the thermocouple used to monitor and control the DUT. This is particularly true in noisy, high frequency environmental conditions. The result is an unstable temperature response of the DUT. The random and unpredictable fluctuations of the thermocouple signal mask the desired information content making control of the system less effective. This is particularly true when the thermocouple is grounded, or when connected to a conductive surface such as a device enclosed in a metal can.

Thermonics has developed a technique for attenuating the noise problem. The technique consists of filtering the incoming DUT signals so that more accurate control is obtained. This is accomplished by isolating the common mode noise from the differential signal. In addition, low-pass filtering enhances the desired frequency response characteristics of the signal.

The Importance of Traceability and Accuracy

One of the important goals of the calibration is to provide a systematic and standardized technique of assuring accurate temperature performance that is recognized as valid by the test community at large. Most importantly, the calibration technique must provide repeatability and traceability as defined by ANSI (American National Standards Institute) traceability standards. These goals are easily accommodated by using an instrument that is pre-calibrated to an industry or known standard, commonly referred to as a secondary standard.

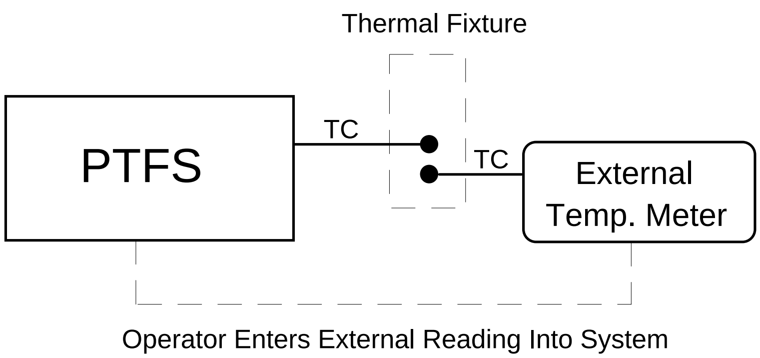
The thermocouple sensors that can be calibrated include the fixture air temperature sensor and the DUT temperature sensor. DUT temperature sensors may be either T-type or K-type. Temperature calibrations can be stored separately and recalled for use in specific testing situations.

Methods of Temperature Calibration

Several temperature-measuring instruments are commonly used for calibration. These are an external temperature measurement meter, an external millivolt source and the RTD (Resistor, Temperature Dependent). These instruments can provide for an adequate calibration of the PTFS; though, each technique has its own inherent strengths and limitations.

External Temperature Meters

The temperature meter is used in conjunction with a thermocouple to gain an independent reading of the air or DUT temperature. The readings from the meter are entered into the system and used to adjust the temperature scaling by recalculating the offset and slope.



This procedure requires that the systems' refrigeration unit is ready for operation and the system has achieved temperature stability. Total calibration time is about twenty minutes.

Using an external temperature meter for calibration is an extremely accurate way to calibrate the PTFS because it provides a calibration that accounts for all of the extraneous factors that can affect temperature performance. When these factors are not accounted for, such as when calibrating with a millivolt source, the calibration can be inaccurate. These factors are:

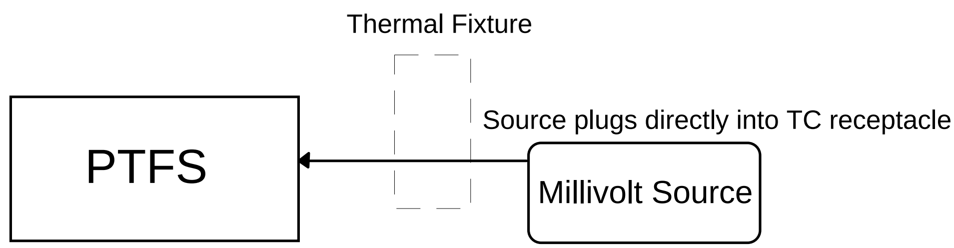
Air Flow Rate

The flow of air affects the thermal characteristics of the thermal fixture. Using an external temperature-registering device allows calibration to be performed with air flowing, enabling any necessary compensation to occur. This is particularly important when calibrating the air temperature measurement to the sensed air temperature close to the DUT.

<u>Test Sensor Location</u>
Accurate calibration requires the thermocouple from the external standard be placed in close proximity to the thermocouple from the PTFS. The advantage of using an external meter is that the thermocouple from the meter can be placed within 50 mils of the system thermocouple assuring accurate results.

<u>Long-Term Consistency of Thermal Characteristics</u>
The only extraneous factor that affects the long-term consistency of the calibration is the aging of electronic components. The effect of the aging process is minimal.

External Millivolt Sources
A millivolt source is plugged into the thermocouple receptacle in place of the thermocouple. When the system requires input from the thermocouple, it is supplied by the source.

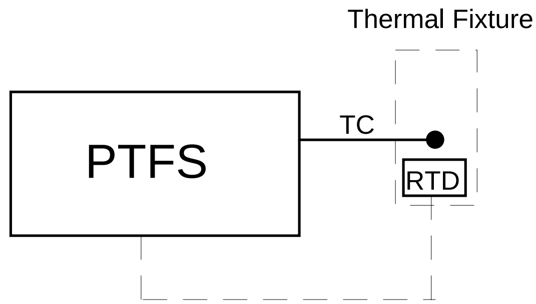


Millivolt Source Replaces Thermocouple

An external millivolt source is capable of generating voltages equivalent to those a thermocouple generates at the calibration setpoints. It provides a very accurate voltage reference the internal metering system uses to adjust temperature scaling. The advantage of using an external millivolt source is that it is a fast way to calibrate the system. It has the limitation of not assuring the calibration for the entire system in a global sense, because it does not accommodate for airflow, test sensor location, or thermocouple variations. If the PTFS existed in the best of all possible worlds, where no outside influences other than temperature were at play, then this technique would be sufficient.

Thermonics' RTD
An RTD is typically used as the standard during automatic calibration procedures.

The RTD series of dual-in-line temperature calibration devices permits accurate temperature calibration of the PTFS by providing a secondary standard that measures the cavity temperature of a semiconductor package. Under test conditions in a thermal fixture, an RTD chip will attain the same temperature as a semiconductor chip in a similar package prior to application of power. By substituting the RTD 1000 chip for the device to be tested, an accurate calibration for an item of a particular mass can be performed. The temperature versus resistance response of the RTD 1000 is approximately 3.75 ohms/C and the resistance at 0.0C is 1000 ohms. The RTD can also aid in determination of soak times.



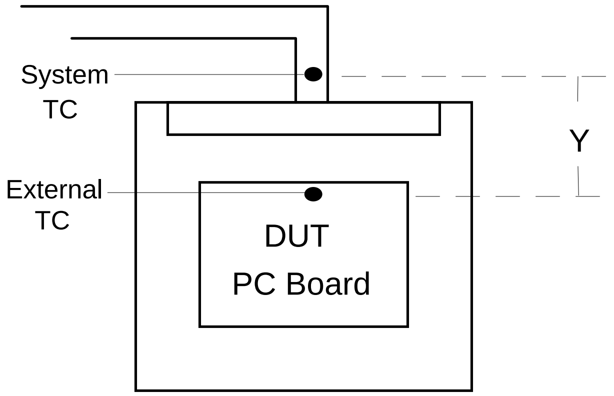
RTD is Used for Auto-Calibration

The RTD can confidently be used as secondary standard because it can be easily monitored for accuracy. Using a temperature meter and ohm meter, the response of the RTD can be evaluated if any question arises as to its accuracy.

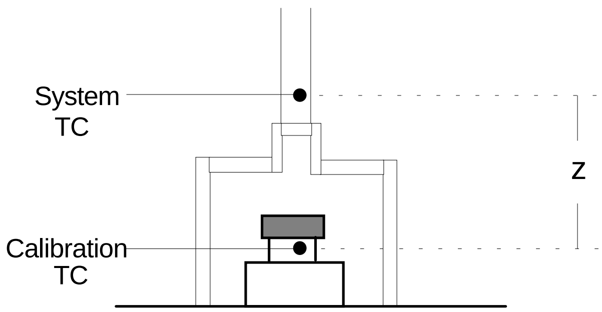
The recommended method of temperature measurement is to ground one terminal of the RTD and force 1.0 ma of current into the other terminal and read the voltage (V) on that terminal. The temperature can then be found by measuring the resistance of the RTD and using a resistance vs. temperature table to determine the actual temperature.

Advantages of Storing Multiple Calibrations

Thermonics' precision temperature forcing systems make provisions for storing multiple calibrations. The advantage of being able to store multiple calibrations is that you can assure accuracy for varying system applications. This includes using different or alternative thermal fixtures and compensation for the position of the test device. This makes it possible to set an air temperature that will be the temperature of the device under test.



In a large thermal fixture, an adjustment can be made for the offset between how the system air temperature TC registers a temperature and the actual temperature of the PC board.



In like manner, an adjustment can be made for the offset between how the system air temperature TC registers a temperature and the actual temperature of the underside of the DUT.

<u>Conclusions</u>

Temperature calibration of the PTFS is a way of insuring that the systems' internal temperature measurement system is accurate. Several calibration methods for precision temperature forcing systems are commonly used. Of these, use of a calibrated, external temperature meter provides a reliable and comprehensive calibration technique. Additionally, use of and RTD is a good way to calibrate temperature readings. The ability to store multiple calibrations provides a means of calibrating the system for specific applications.