Testing Temperature Uniformity on a Flat-Plate Infrared Calibrator

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Abstract

There are a number of instruments used to perform infrared (IR) thermometer and IR imager calibration. These instruments fall into two categories, cavities and flat-plates. To calculate the uncertainty in using these instruments, the temperature uniformity must be known. This is especially true with flat-plates. This uncertainty may be given in an instrument's specification. However, there is not a standardized test method to test the uniformity of a flat-plate calibrator as there is with other classes of temperature calibrators such as dry block calibrators.

What compounds this problem is that a uniformity specification may mean something different for the IR imager user than it does for the IR thermometer user. This is because an IR thermometer measures the radiation emitted by a sizable area of the calibration surface. In effect, the IR thermometer averages the temperature over this area. By contrast, the IR imager measures many areas that are much smaller. This type of measurement approaches a point temperature measurement.

This paper discusses how uniformity is measured by a flat-plate manufacturer. It discusses what this means for both the calibration of an IR imager and the user of an IR thermometer. It then proposes a test method that may become a standard for testing flat-plates. This paper should be of interest to anybody who calibrates or tests either IR imagers or IR thermometers.

1. Introduction

With developments in IR temperature measurement, there has been a greater demand for IR calibrators. The calibrator commonly used for low-temperature handheld instruments is a flat-plate calibrator. There are a number of uncertainties that involve the use of a flat-plate calibrator. Among these are calibration temperature, emissivity, reflected ambient radiation, heat-loss effects, ambient conditions and surface uniformity.

2. Discussion on Uniformity

Uniformity is an important topic for any flat-plate IR calibrator. A thorough understanding of uniformity is important for an IR thermometry or thermal imager measurement. Uniformity or thermal homogeneity must be interpreted differently for IR thermometer and thermal imager calibrations. This is due to how these two classes of instruments measure temperature. The IR thermometer's readout is based on an average of thermal radiation over an area on the flat plate. This radiation is converted to a temperature by the IR thermometer's electronics. The thermal imager measurement is more along the lines of a number of point measurements of radiation over an array of pixels corresponding to the imager display.

2.1 Flat-plate Uniformity
Flat-plate uniformity can be radiometrically measured by two different means.

First, a thermal imager can be used to measure uniformity. This has one major disadvantage. Most thermal imagers have a non-cooled detector array. This causes uniformity variations in the way the thermal imager measures temperature across the array. In order to correct for this problem, the imager periodically undergoes what is called a non-uniformity correction (NUC). However, the NUC may not fully compensate for non-uniformity. Testing should be done to see how uniformly temperature is being measured by the thermal imager.

An IR thermometer can be also used. The IR or radiation thermometer has two major disadvantages. First, even the most high-end radiation thermometer is measuring an area corresponding to its spot size. Thus, it is more difficult to detect thermal anomalies on the flat-plate surface using a radiation thermometer. Second, measurements cannot be made to determine temperature at the edge of the flat-plate, due to the radiation thermometer's spot-size.

2.2 IR Thermometers
For IR thermometer uncertainty, the useful way to express uniformity is as an average temperature within a circle compared to the center of the flat-plate surface. This is shown mathematically in Equations (1) and (2) [1]. This way, the IR thermometer's size-of-source or field-of-view can be measured at various diameters corresponding to diameters where flat-plate uniformity was measured. For this discussion, this uniformity will be called areal uniformity.

$$T_{AVG}(D) = \frac{1}{A}\int T dA = \frac{4}{\pi D}\int_0^{D/2}\int_0^{2\pi} T(r,\theta) r d\theta dr \tag{1}$$

where:
T_{AVG} is the average temperature within D
D is the diameter under consideration

$$T_{UNIF}(d) = T_{AVG}(D_{MAX}) - T_{AVG}(D_{MIN}) \tag{2}$$

D_{MAX} is the diameter of largest average temperature
D_{MIN} is the diameter of smallest average temperature
$D_{MAX} < d$ and $D_{MIN} < d$

2.3 Thermal Imagers
For thermal imager uncertainty, variation of temperatures at various points is of interest. This type of uniformity can be expressed as the amount of temperature variance from the center of the plate at any given point within a diameter. For this discussion, this uniformity will be termed as local uniformity.

2.4 Related Standards

At the time of this writing there were no standards covering testing for temperature uniformity or testing for temperature uniformity on a flat-plate calibrator. EURAMET CG-13 covers testing for temperature uniformity for temperature block calibrators [2]. The tests outlined in the guide cover axial (vertical) uniformity and temperature difference between borings (horizontal uniformity).

3. Testing for Uniformity

For this research, uniformity was tested with both a thermal imager and a radiation thermometer. The methodology for each of these methods is outlined below.

3.1 Use of Thermal Imagers

The first step in testing with a thermal imager is to test the quality of the thermal imager's NUC. To perform this testing, the thermal imager was tested at five points on the thermal imager's display as shown in Figure 1. This testing was done three times during different NUC cycles to ensure repeatability. After the quality of the NUC was tested, three thermal images were taken of the flat plate surface. The center and edges of the flat-plate under test correspond to the points on the imager display as shown in Figure 1.

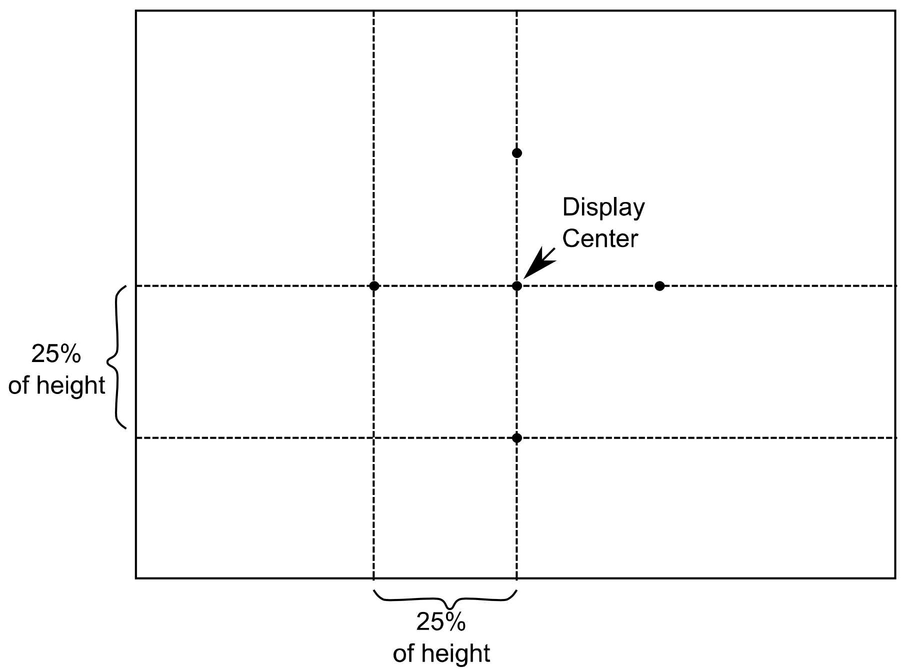

Figure 1: Test points for thermal imager quality of non-uniformity correction

3.2 Use of IR / Radiation Thermometers

A radiation thermometer with a pyro-electric detector was used to measure the flat-plate uniformity. The field-of-view for the radiation thermometer was 10 mm diameter (99%), measuring distance: 362 mm.

This data was taken at the points shown in Figure 2. These tests were performed three times to ensure repeatability. Data was taken at the center of the plate, and points corresponding to the diameters of interest. In no case was data taken at closer than one spot-size diameter from the edge of the flat-plate.

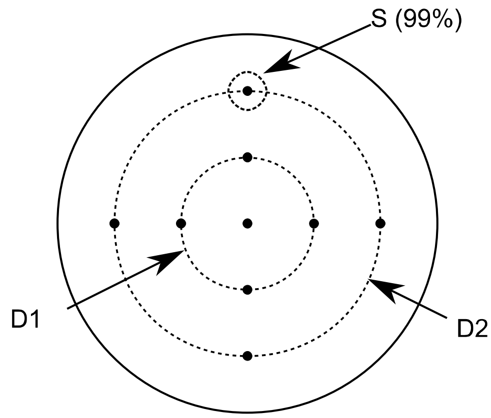

Figure 2: Test points radiation thermometer measurements

4. Results of Testing

The testing was done as described in the previous section. Uniformity was considered for both the areal and the local cases. The diameters considered in the interpretation of the results were 40 mm and 115 mm. Testing was done three times for two different flat-plates at three different temperatures.

4.1 Radiation Thermometer

The results of the radiation thermometer testing are shown in Table 1. A weighted average was calculated based on the points shown in Figure 2. Zone 1 is everything inside D1, and Zone 2 is everything inside of D2. The $T_{AVG} – T_{CENT}$ column corresponds to the areal uniformity case. The T_{VAR} and 2σ columns correspond to the local uniformity case. The T_{VAR} column shows the difference between the maximum and minimum temperatures, and 2σ shows two times standard deviation of the points measured within each zone.

Zone 1	T_{AVG} - T_{CENT} (°C)	T_{VAR} (°C)	2σ (°C)
4181 100°C	0.06	±0.11	0.17
4181 200°C	-0.07	±0.25	0.39
4180 100°C	0.08	±0.09	0.15

Zone 2	T_{AVG} - T_{CENT} (°C)	T_{VAR} (°C)	2σ (°C)
4181 100°C	-0.02	±0.41	0.49
4181 200°C	-0.16	±0.75	0.89
4180 100°C	-0.05	±0.24	0.36

Table 1. Results of radiation thermometer testing

4.2 Thermal Imager

The results of the thermal imager NUC quality testing are shown in Table 1. They showed a sizeable deviation on the portion of the imager array considered. Because of this difference, these results were not considered for determining uniformity.

Temperature (°C)	**Maximum Deviation** (°C)	**Repeatability** (°C)
100	0.41	0.12
200	1.00	0.62

Table 2. Results of NUC quality test

4.3 Correlation of Data

A comparison of the data taken on one axis for one of the flat-plates is shown in Figure 3. The thermal imager temperature measurement varied towards the edges of the flat-plate. This variation corresponds to the values shown in the NUC uniformity test. The imager would likely provide misleading values for uniformity. This data is representative of only one imager and not the entire class of instruments. The imager results are well within the imager's accuracy specification.

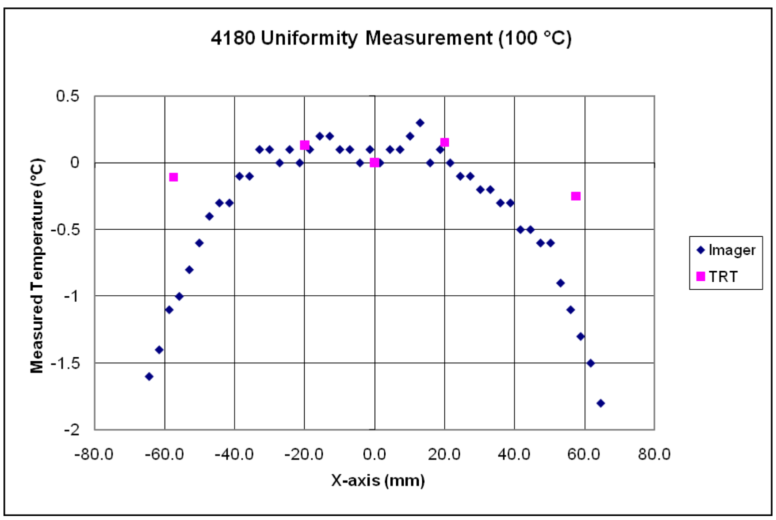

Figure 3. Comparison of radiation thermometer and imager uniformity testing

5. Conclusion

Knowledge of flat-plate uniformity is important when calculating uncertainty budgets for IR thermometry. By proper testing, uniformity can be calculated properly for use in an uncertainty budget. Methods for determining uniformity should be standardized, so that the IR thermometry metrology community can have a common way to test the uniformity of flat-plates.

References

1. F. Liebmann, Determining Size Of Source for Handheld Infrared Thermometers – Theory and Practice, Proceedings of Measurement Science Conference, 2008.

2. EURAMET cg-14/v.01, Calibration of Temperature Block Calibrators, European Association of National Metrology Institutes, Braunschweig, Germany, 2007.