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Standard Guide for
Thermocouple Verification[1]

This standard is issued under the fixed designation E2846; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

NOTE- Balloted and approved Figures X2.1, X2.2, X2.3, and Tables X3.1 and X3.2 have been included in the standard and the year date was changed on October 7, 2014.

INTRODUCTION

A thermocouple should be periodically verified (tested for compliance with specifications) to ensure that it has not incurred physical, metallurgical, or chemical changes that inhibit or prevent temperature measurements with acceptable accuracy. Unlike many other sensors, the signal generated by a thermocouple depends on the physical and chemical state of the region of the thermocouple wires or thermoelements where temperature gradients exist rather than the state of the measuring junction. Physical or chemical degradation of the thermocouple along only part of its length results in thermocouple inhomogeneity. Such inhomogeneity causes the measured temperature to depend on the intermediate thermal environment between the measuring and reference junctions of the thermocouple. If a thermocouple becomes more inhomogeneous with time, the temperature measured by that thermocouple may appear to drift from its original value, even though the actual temperature it is measuring is constant. If the intermediate thermal environment during use is different from that during calibration, the temperature measurement of an inhomogeneous thermocouple will be inaccurate. Thermocouples used in a harsh environment often become progressively more inhomogeneous; for such thermocouples it is particularly important to make periodic tests of their performance. In addition, a thermocouple becomes unreliable if it undergoes certain other physical changes. It will not measure properly if its wires or the measuring junction are broken or if its thermoelements are in electrical contact in a location other than the measuring junction. Metal-sheathed thermocouples will perform unreliably if there is excessive electrical leakage between the sheath and the thermocouple wire; this can occur if holes have developed in the sheath or the seal of the end closure develops a leak. Periodic tests can check for these undesirable changes, allowing the user to know whether the performance of the thermocouple can be trusted. These tests are particularly important before the calibration of a thermocouple, because they determine whether the thermocouple's performance is worthy of the effort and expense of calibration.

1. Scope

1.1 This guide describes tests that may be applied to new or previously used thermocouples for the purpose of verification. Some of the tests perform a suitable verification by themselves, but many tests merely alert the user to serious problems if the thermocouple fails the test. Some of the tests examine inhomogeneity and others detect wire or measuring-junction breakage. For Style U mineral-insulated metal-sheathed (MIMS) thermocouples with ungrounded measuring junctions, this guide includes tests that examine the electrical isolation of the sheath as well as sheath deterioration.

1.2 The first set of tests involves measurement verifications designed to be performed while the thermocouple is in its usage environment. The second set is composed of electrical tests and visual inspections designed to evaluate the functionality of the thermocouple; these tests may be performed either in house or in a calibration laboratory. The third set is made up of homogeneity tests designed to be performed in a calibration laboratory. Some of the tests provide simple methods to identify some, but not all, defective thermocouples, and alone do not suffice to verify a used thermocouple. They may need to be complemented by other tests for a complete verification.

1.3 The reader of this guide should decide which of the described tests need to be performed. This decision is dependent on whether the reader uses thermocouples for temperature measurement or performs thermocouple calibrations in a laboratory. For users of thermocouples, it is recommended that appropriate tests from the first and second sets be performed initially, as they

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provide immediate on-site verification of the thermocouples. The appropriateness of a test is dependent upon the user's temperature measurement uncertainty requirements. Some tests may have lower uncertainties in their verification measurements than others. If these tests do not clearly determine the suitability of the thermocouples, they should be sent to a calibration laboratory for performing appropriate tests from the third set, which give the most complete information on the thermocouple homogeneity. For those who perform thermocouple calibrations in a laboratory, it is recommended that appropriate tests from the second and third sets be performed prior to calibration. The appropriateness of a test is dependent on the calibration laboratory's capability and convenience for performing the test, as well as the characteristics of the unit under test (UUT).

1.4 This guide may be used for base metal and noble metal thermocouples. Some of the methods covered may apply to refractory metal thermocouples but caution is advised as suitable reference devices at high temperatures may not be readily available.

1.5 *This guide may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
E220 Test Method for Calibration of Thermocouples By Comparison Techniques
E344 Terminology Relating to Thermometry and Hydrometry
E563 Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
E585/E585M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Base Metal Thermocouple Cable
E608/E608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples
E780 Test Method for Measuring the Insulation Resistance of Mineral-Insulated, Metal-Sheathed Thermocouples and Thermocouple Cable at Room Temperature
E839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable
E1350 Guide for Testing Sheathed Thermocouples, Thermocouples Assemblies, and Connecting Wires Prior to, and After Installation or Service
E2181/E2181M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E344 apply to terms used in this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *expanded measurement uncertainty, n*—product of a combined standard measurement uncertainty and a factor larger than the number one.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.1.1 *Discussion*—

The term "factor" in this definition refers to a coverage factor *k*. For *k*=2 (the most common coverage factor), a measurement instrument measures correctly to within its expanded measurement uncertainty with a 95.4 % probability.

3.2.2 *gradient zone, n*—the section of a thermocouple that is exposed during a measurement to temperatures in the range from $t_{amb} + 0.1(t_m - t_{amb})$ to $t_{amb} + 0.9(t_m - t_{amb})$, where t_{amb} is ambient temperature and t_m is the temperature of the measuring junction.

3.2.2.1 *Discussion*—

This term is used as part of the description of the thermal profile along the length of the thermocouple. The gradient zone definition is intended to describe, in an approximate way, the section of thermocouple in which most of the emf was created.

3.2.3 *half-maximum heated length, n*—the distance between the measuring junction and the position along the length of the thermocouple wires or sheath where the temperature equals the average of the calibration-point and ambient temperatures.

3.2.3.1 *Discussion*—

This term is used as part of the description of the thermal profile along the length of the thermocouple.

3.2.4 *homogeneous, adj*—having uniform thermoelectric properties along the length of the thermocouple or thermoelement.

3.2.5 *homogeneous Seebeck coefficient, n*—the temperature-dependent Seebeck coefficient of a thermocouple or thermoelement when it is in a homogeneous state.

3.2.5.1 *Discussion—*

The homogeneous Seebeck coefficient is usually determined from measurements of the Seebeck coefficient of the thermocouple or thermoelement when it is new, because then it is usually homogeneous. If segments of the new thermocouple or thermoelement are inhomogeneous, the homogenous Seebeck coefficient is determined from measurements made on the segments demonstrated to be homogeneous.

3.2.6 *inhomogeneity, n*—the deviation of the Seebeck coefficient of a segment of a thermocouple or thermoelement at a given temperature from its homogeneous Seebeck coefficient at that temperature.

3.2.6.1 *Discussion—*

In practice, only variations in the Seebeck coefficient along the length of a thermocouple that is exposed to temperature gradients affect the voltage output of a thermocouple. Inhomogeneity of a thermocouple is often reported as a fractional variation in the Seebeck coefficient.

3.2.7 *minimum immersion length, n*—the depth that a thermometer should be immersed, in a uniform temperature environment, such that further immersion does not produce a change in the indicated temperature greater than the specified tolerance.

3.2.8 *referee thermocouple, n*—a thermocouple made from the same lot of wire or MIMS cable as the UUT group, using identical construction design and methods and identical annealing methods but not having been placed into permanent service.

3.2.8.1 *Discussion—*

Because of the high value of referee thermocouples for performing verification tests by the user, it is strongly recommended that after users receive new lots of thermocouple wire, they construct referee thermocouples along with the thermocouples intended for regular use.

3.2.9 *sensing point, n*—the location on a thermometer where the temperature is (or is assumed to be) measured.

3.2.9.1 *Discussion—*

A thermocouple's sensing point is its measuring junction. A resistance temperature detector (RTD) contains a sensing element that may be large enough to experience spatial temperature variations; in this case the sensing point is the central point in the element where the temperature is assumed to be that measured by the RTD.

3.2.10 *standard measurement uncertainty, n*—measurement uncertainty expressed as a standard deviation.

3.2.10.1 *Discussion—*

A measurement instrument measures correctly to within its standard uncertainty with a 68.2 % probability.

3.2.11 *tolerance, n*—in a measurement instrument, the permitted variation of a measured value from the correct value.

3.2.11.1 *Discussion—*

If a measurement instrument is stated to measure correctly to within a tolerance, the instrument is classified as "in tolerance" and it is assumed that measurements made with it will measure correctly to within this tolerance. An instrument that is not classified as "in tolerance" is classified as "out of tolerance."

3.2.12 *UUT, n*—abbreviation for "unit under test."

3.2.13 *validation, n*—the process of testing a thermometer for acceptable accuracy in its intended use.

3.2.14 *verification, n*—the process of testing a thermometer for compliance with specifications.

3.2.14.1 *Discussion—*

Here, "specifications" normally refers to specification tolerances for uncalibrated thermometers and to calibration uncertainties for

calibrated thermometers. The same tests may be used for a less stringent verification called validation, defined as "the process of testing a thermometer for acceptable accuracy in its intended use."

4. Summary of Verification Tests

4.1 *In Situ Measurement Verification:*

4.1.1 *Verification with the Reference Thermometer in the Same Access Point*—A UUT is verified *in situ* at an appropriate constant temperature by comparison to a known reference thermometer in the same access point. For the comparison, the thermocouple is temporarily replaced by the reference thermometer in the access point, making sure that the measuring point of the sensor is at the same immersion depth as the measuring junction of the thermocouple. For open access points, the reference thermometer may be a referee thermocouple, a non-referee thermocouple that is new or determined to be homogeneous, or another temperature sensor unaffected by inhomogeneity such as a resistance temperature detector (RTD) or thermistor. If the reference thermometer is not a referee thermocouple, its minimum immersion length shall be less than the immersion depth of the UUT. For access points that are thermowells or protection tubes, the reference thermometer shall be a referee thermocouple.

4.1.2 *Verification with the Reference Thermometer in an Adjacent Access Point*—A thermocouple is verified *in situ* at an appropriate constant temperature by comparison to a known reference thermometer located in an adjacent access point. In this case the comparison can be made without removing the UUT. The reference thermometer may be a referee thermocouple, a non-referee thermocouple that is new or determined to be homogeneous, or another temperature sensor unaffected by inhomogeneity such as an RTD or thermistor. If the reference thermometer is not a referee thermocouple, its minimum immersion length shall be less than the immersion depth of the UUT.

4.2 *Thermocouple Functionality Tests:*

4.2.1 *Measurement of the Loop Resistance*—The loop resistance of the thermocouple circuit is measured to verify that the thermoelements and welded measuring junction are continuous. This test may also be used to identify conditions where the thermoelements are in contact with each other at a point other than at the measuring junction. It may be difficult to identify multiple contact points when they occur near the measuring junction.

4.2.2 *Measurement of the Insulation Resistance of Thermocouples with Style U Measuring Junctions*—The resistance of the insulation between the UUT sheath and the thermoelements is measured to determine if the electrical isolation between them has deteriorated.

4.2.3 *Measurement of Sheath Diameter (Metal-Sheathed Thermocouples)*—Measurements of the UUT sheath diameter are made and compared to measurements made prior to installation to monitor metal erosion in the sensor sheath that may cause the UUT to perform unreliably.

4.2.4 *Visual Inspection of Metal-sheathed Thermocouples*—An inspection is made to look for holes, severe pits, and creases in the sheath and for separation of the end closure from the sheath. All of these items may cause the UUT to perform unreliably.

4.3 *Laboratory Verification of Thermocouples:*

4.3.1 *Ice Point Test*—The measuring junction and reference junction of the UUT are both immersed in ice baths. No thermocouple extension wires are used. If the measured emf is beyond a certain tolerance, the UUT is inhomogeneous. The immersion depth of the measuring junction may be varied to examine for inhomogeneity in different segments of the thermocouple.

4.3.2 *Single Point Verification*—Inhomogeneity is checked by comparing the temperature measured by the UUT with that of a reference thermometer at a single temperature. The difference is compared to that from the original calibration at that temperature. This test is not truly a measurement of inhomogeneity, but rather a test for consistent temperature measurement of the UUT under one particular set of conditions. While an inconsistent measurement will demonstrate that the UUT is inhomogeneous, a consistent measurement does not necessarily indicate that the UUT is free from inhomogeneities.

4.3.3 *Multiple Fixed Immersions in a Furnace or Bath*—Temperatures measured using the UUT are compared with those measured using a homogeneous reference thermocouple or other reference thermometer while the two are in the same thermal environment at a given immersion depth in the liquid bath. The consistency of the temperature measured by the UUT relative to that measured by the reference thermometer at different immersion depths provides information on the measurement errors of the UUT due to inhomogeneity.

4.3.4 *Single-Gradient Scanning*—The measuring junction of the UUT is immersed into a temperature-controlled liquid bath at a constant rate or in a series of steps. The UUT passes through a large temperature gradient near the top surface of the liquid. The UUT emf is recorded as a function of immersion depth into the liquid bath. The data provide information on the location and magnitude of the inhomogeneity.

4.3.5 *Double-Gradient Scanning*—Measurements of Seebeck coefficient variations are made along the length of the UUT using a short movable high-temperature zone. The two gradient zones to which the UUT is exposed are at the edges of the high-temperature zone. The measured emf is used to determine the Seebeck coefficient variation along the segment of the UUT between the two gradient zones. By scanning the UUT along the high temperature zone, this Seebeck coefficient variation is determined as a function of position on the UUT; the result is used to estimate the total inhomogeneity as a function of position on the UUT.

5. Significance and Use

5.1 These verification tests may be performed by users or calibrators of thermocouples. The methods are useful for both new and used thermocouples. They provide a means to assess the accuracy with which a thermocouple is capable of measuring temperature.

5.2 Results from these tests may be used to determine whether to use or discard a thermocouple. If the thermocouple is subsequently used, the test results may be included in the measurement uncertainty budget. In many circumstances, the results of *in situ* verifications may be used to recalibrate a used thermocouple. Laboratory measurements, on the other hand, may be used only to verify the original thermocouple calibration or to determine the uncertainty of temperature measurements with the tested thermocouple. Laboratory measurements generally do not suffice to determine the emf-versus-temperature response of a thermocouple found to be inhomogeneous.

6. In Situ Measurement Verification

6.1 These verification tests are used to verify a UUT in its normal measurement environment by comparison with a reference thermometer. The tests in 6.3 and 6.4 are designed to detect drift in the temperature measured by the UUT at a constant temperature. Both short-term and long-term drifts of this sort are the direct result of changes in the Seebeck coefficient, or inhomogeneity, so measuring this drift is an indirect measure of inhomogeneity. These tests subject the thermocouple to minimal disturbance and do not involve sending it away to a calibration laboratory.

6.2 Any *in-situ* test should only be performed by trained personnel having the necessary qualifications to work on instrumentation and electrical equipment in the usage environment. Precautions and measurements to ensure that thermocouple sensors are not in contact with electrical circuits other than those intended for use with the thermocouple should be made.

6.3 *Uncertainty and Tolerance*—The verification tests described below involve the concepts of measurement uncertainty and measurement tolerance. The terms "standard measurement uncertainty," "expanded measurement uncertainty," and "tolerance" are defined in Section 3. Descriptions of uncertainties and their determination are based on the ISO Guide to Uncertainty in Measurement (1). Standard uncertainties are represented by the variable u, expanded uncertainties are represented by the variable U, and tolerances are represented by the variable τ. These variables generally are written with a descriptive subscript. A UUT that passes a tolerance test that meets ANSI/NCSL Z540.3-2006 standards (2) will measure correctly to within the stated tolerance with a probability of 98 % (Section 5.3, Clause b). A tolerance may be related to an expanded uncertainty with a coverage factor of $k = 2.33$, as both correspond to a 98 % confidence interval. The relationship between a UUT's tolerance τ and its expanded uncertainty with $k = 2$ is then $U_{UUT}(k = 2) = 0.858\ \tau$.

6.4 *UUT Criterion*—The criterion for verification is that the UUT measures correctly to within the specified value of either $U_{UUT}(k = 2)$ or τ. If the UUT meets this criterion, it is deemed acceptable. If it does not meet this criterion, it should be rejected. The first step in performing an *in situ* verification is to specify these values. The three most common values are described below.

6.4.1 *Specification Tolerance Criterion*—The UUT measures correctly to within its stated specification tolerance τ_{spec}, that is, $\tau = \tau_{spec}$. The expanded measurement uncertainty of the UUT corresponding to this tolerance is then $U_{UUT}(k = 2) = 0.858\ \tau_{spec}$.

6.4.2 *Calibration Uncertainty Criterion*—The UUT measures correctly to within its expanded calibration uncertainty U_{UUT_cal}, that is, $U_{UUT}(k = 2) = U_{UUT\_cal}$. The tolerance related to this uncertainty is $\tau = 1.165\ U_{UUT\_cal}$.

6.4.3 *Measurement Needs Criterion*—The UUT measures correctly to within an uncertainty U_{UUT_accept} based on the measurement needs of the user, that is, $U_{UUT}(k = 2) = U_{UUT\_accept}$. The tolerance related to this uncertainty is $\tau = 1.165\ U_{UUT\_accept}$.

TABLE 1 Summary of In Situ Measurement Verification Tests

Test	Provides	Comments
Verification with the Reference Thermometer in Same Access Point	Verification of thermocouple temperature measurement	Compares thermocouple with a reference thermometer. The thermocouple's access port is used by the reference thermometer. May not be used with active control thermocouples.
Verification with the Reference Thermometer in an Adjacent Access Point	Verification of thermocouple temperature measurement	Compares thermocouple with a reference thermometer. A nearby access port is used by the reference thermometer. May be used with active control thermocouples.

6.5 *Methods of In Situ Verification*—The second step in performing an *in situ* verification is deciding which of the two methods of verification is needed. These methods are described below.

6.5.1 *Measurement Agreement*—This method compares the UUT measurement with a reference measurement, and determines if the two measurements agree to within the combined uncertainty of the measurements. If the two measurements agree, the UUT is deemed acceptable; otherwise, it should be rejected. As the uncertainty of the measurements increases, the probability that a UUT that should be rejected is actually accepted increases. However, the probability that an acceptable UUT is rejected is always constant (4.6 % for $k = 2$).

6.5.2 *Tolerance Verification*—This method determines whether the UUT measures temperature to within the stated tolerance τ, based on a comparison with a reference measurement. The verification test provides a result of either "pass" or "fail." If the UUT passes the test, the UUT is deemed acceptable; otherwise, it should be rejected. The test also provides a calculated value, based on the total measurement uncertainty in the comparison, quantifying the probability that the result is wrong. This probability increases as the total measurement uncertainty increases. An advantage of tolerance verification is that the test criterion may be adjusted to ensure that a minimal number of UUTs that should be rejected are accepted; however, such an adjustment greatly raises the number of acceptable UUTs that are rejected.

6.6 *Reference Measurement*—A reference measurement used for *in situ* verification requires the use of a reference thermometer. The type of reference thermometer to be used depends on the type of access point being used.

6.6.1 *Open Access Point*—The reference thermometer may be a referee thermocouple, a non-referee thermocouple that is new or determined to be homogeneous, or another temperature sensor unaffected by inhomogeneity, such as an RTD or thermistor. The thermal cross section of the reference thermometer shall be similar to that of the UUT. If the reference thermometer is not a referee thermocouple, its minimum immersion length shall be less than the immersion depth of the UUT.

6.6.2 *Thermowell or Protection Tube Access Point*—The reference thermometer shall be a referee thermocouple. It shall be placed in the thermowell or protection tube in the same manner as for the UUT.

6.7 *Verification Test with Reference Thermometer in the Same Access Point*—In this test, a UUT is verified in situ at an appropriate temperature by comparison to a known reference thermometer. The UUT and reference thermometer alternately use the same access point, which is that normally used by the UUT, as shown in Fig. 1.

NOTE 1—This method cannot be used to evaluate a control sensor as removing it would cause the system to go out of control.

6.7.1 *Measurement Protocol*—The temperature of the environment shall be constant with small fluctuations about an average value. For the comparison, the UUT performs a first set of measurements of the temperature at its measuring junction over a period long enough to average out the temperature fluctuations. A minimum of 20 equally spaced measurements are made over this period, and these measurements are used to calculate an average $T_{UUT}(a)$ and standard deviation σ_{UUT} for the temperature, where the "a" in parenthesis labels the measurement set. Here, the standard deviation characterizes the fluctuations of the temperature measurements over the measurement period. Afterwards, the UUT is temporarily replaced by the reference thermometer in the access point. When inserting the reference thermometer, the sensing point of the thermometer should be at the same immersion depth as the measuring junction of the UUT; this may sometimes require that the end of reference thermometer be inserted to a greater immersion depth than the UUT, as shown in Fig. 1. The reference thermometer makes a similar set of temperature measurements, yielding an average T_{ref} and standard deviation σref for the temperature. Finally, the UUT is placed back in the
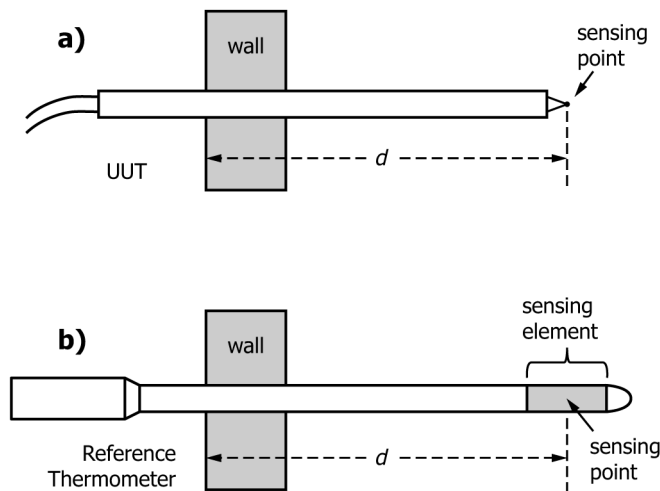

FIG. 1 Verification of a UUT by a reference thermometer in a single access point. In this figure, the reference thermometer is an RTD. In (*a*) temperature measurements are made while the UUT is placed in the access point with immersion depth *D*. In (*b*) the UUT is re-placed by the RTD with the same immersion depth and temperature measurements are repeated. The sensing point of the RTD is lo-cated at the center of the sensing element. As a result, the end of the RTD probe is immersed further than that of the thermocouple.

access point, ensuring that the measuring junction is at the same immersion depth as before, and a second set of temperature measurements are made to calculate an average $T_{UUT}(b)$. The temperature measured by the UUT is then represented by

$$T_{UUT} = [T_{UUT}(a) + T_{UUT}(b)]/2 \qquad (1)$$

6.7.2 *Data Analysis*—The data described in Table 2 are used for determining whether the UUT meets the verification criterion. It includes the temperature measurements of the UUT and reference thermometers as well as the standard uncertainty values described in the table and in 6.7.3. The verification data may be used for one of the following tests: (*1*) comparison of measurements by the UUT and the reference thermometer, and (*2*) comparison of earlier and present measurements by the UUT and the reference thermometer. The first test provides the best result if the reference thermometer is a referee thermocouple or is calibrated; otherwise, the second test may provide the best results (assuming earlier measurement results are available).

6.7.2.1 *Measurement Agreement Method*—The calculation for the first test determines whether the UUT and reference thermometer measurements agree to within the expanded total measurement uncertainty, considering the verification criterion for the UUT. The calculation for the second test determines whether the earlier and present UUT measurements agree to within the expanded total measurement uncertainty, considering the verification criterion for the UUT.

6.7.2.2 *Tolerance Verification Method*—The calculation for the first test determines whether the UUT and reference thermometer measurements agree to within the UUT specified tolerance. The calculation for the second test determines whether the earlier and present UUT measurements agree to within the UUT specified tolerance. Both calculations provide a result of either "accept" or "reject" for the UUT. The measurement uncertainty is used to quantify the chance that this result is wrong.

6.7.2.3 *Calculations*—The equation needed for determining the expanded total measurement uncertainty from the uncertainty elements is presented in X1.1. The equation used to determine measurement agreement is presented in X2.1, and include example calculations. The equations used to determine tolerance verification are presented in X3.2.1 and X3.3.2. As these calculations are not trivial, it is recommended that qualified software engineers design software tools to facilitate these calculations for those who must regularly perform verification tests.

6.7.3 *Description of Uncertainties*—In the table, σ_{UUT} and σ_{ref} are the standard deviations of the measurements made with the UUT and reference thermometer, respectively, and represent the stability of the measurements. Also, u_{UUT_inst} and u_{ref_inst} are the standard instrument measurement uncertainties, and u_{UUT_RJC} and u_{ref_RJC} are the standard uncertainties of the reference junction compensation (if relevant), and u_{ref_cal} is the standard reference-thermometer calibration uncertainty (if relevant). The instrument measurement uncertainties and reference junction compensator uncertainties are described in the respective manufacturer specifications and may depend on the environment in which the measurements are made. The reference thermometer calibration uncertainty is obtained from its calibration report. If the comparison is made using a referee thermocouple and the user wishes to verify that the UUT measurements are identical to those of the referee thermocouple, then $u_{ref\_cal} = 0$. If an ice bath is used for the reference junction by the UUT or the reference thermometer, or both, instead of an electronic reference junction compensator, then $u_{UUT\_RJC} = 0$ or $u_{ref\_RJC} = 0$, or both, respectively.

The uncertainty u_{drift} is the uncertainty due to drift in the temperature of the environment between the measurements $T_{UUT}(a)$ and $T_{UUT}(b)$. Based on the ISO Guide to Uncertainty in Measurement (**1**), udrift may be estimated as

TABLE 2 Data Used for Verification Calculation for Test With Reference Thermometer in the Same Access Point

Temperature Data	Description
$T_{UUT}(a)$	First temperature measurement made by the UUT
T_{ref}	Temperature measurement made by the reference thermometer
$T_{UUT}(b)$	Second temperature measurement made by the UUT
Uncertainties	
σ_{UUT}	Repeatability of measurements made by the UUT
σ_{ref}	Repeatability of measurements made by the reference thermometer
u_{UUT_inst}	Measuring instrument for the UUT
u_{ref_inst}	Measuring instrument for the reference thermometer
u_{UUT_RJC}	Reference-junction compensator of the UUT (if relevant)
u_{ref_RJC}	Reference-junction compensator of the reference thermometer (if relevant)
u_{ref_cal}	Calibration of the reference thermometer (if relevant)
u_{drift}	Drift between $T_{UUT}(a)$ and $T_{UUT}(b)$
u_{imm}	Immersion depth of the reference thermometer (RTD only)

$$u_{drift} = \frac{1}{2\sqrt{3}}|T_{UUT}(a) - T_{UUT}(b)| \tag{2}$$

The uncertainty u_{imm}, relevant only when an RTD is used as the reference thermometer, is the uncertainty due to temperature non-uniformities along the length of the RTD's sensing element; these non-uniformities make the measured temperature dependent on the RTD immersion depth. The value of u_{imm} is estimated by first placing the RTD's sensing point at the same immersion depth D as the measuring junction of the UUT. The RTD is then immersed further a distance $\Delta/2$, where Δ is the manufacturer-estimated length of the RTD sensing element, to measure $T(D + \Delta/2)$. Afterwards the RTD is moved back a distance Δ to measure $T(D - \Delta/2)$. These immersion depths are illustrated in Fig. 2. The value of u_{imm} is then (1)

$$u_{imm} = \frac{1}{2\sqrt{3}}|T_{ref}(D + /2) - T_{ref}(D - 2)| \tag{3}$$

NOTE 2—For thermocouple reference thermometers, u_{imm} is omitted.

6.8 *Verification with the Reference Thermometer in an Adjacent Access Point:*

6.8.1 *Measurement Protocol*—The UUT is verified *in situ* at an appropriate temperature by comparison to a known reference thermometer that is inserted in an adjacent access point, as shown in Fig. 3. The reference thermometer may be a referee thermocouple, a thermocouple that is new or determined to be homogeneous, or another temperature sensor unaffected by inhomogeneity, such as an RTD or thermistor. The thermal cross section of the reference thermometer shall be similar to that of the UUT. If the reference thermometer is not a referee thermocouple, its minimum immersion length shall be less than the immersion depth of the UUT. The reference thermometer is inserted so that the sensing point of the thermometer is located at the same immersion depth as the measuring junction of the thermocouple; this may sometimes require that the end of the reference thermometer be inserted to a greater immersion depth than the thermocouple, as shown in Fig. 1. The temperature is maintained with minimal drifts and fluctuations.

For the comparison, a first series of simultaneous temperature measurements are performed by the UUT and the reference thermometer over a period long enough to average out the temperature fluctuations. A minimum of 20 equally spaced measurements are made over this period, and these measurements are used to calculate averages $T_{UUT}(a)$ and $T_{ref}(a)$ for the UUT and reference thermometer, respectively, and standard deviations $\sigma_{UUT}(a)$ and $\sigma_{ref}(a)$ for the UUT and reference thermometer, respectively. Here, the "a" in parenthesis refers to the first series of measurements. If possible, the access points for the UUT and reference thermometer are switched, and the set of measurements described above is repeated to obtain $T_{UUT}(b)$ and $T_{ref}(b)$, $\sigma_{UUT}(b)$ and $\sigma_{ref}(b)$. The final values of T_{UUT}, T_{ref}, σ_{UUT} and σ_{ref} are obtained by averaging the two sets "a" and "b." If it is not possible to switch the access points (for example, the UUT is a control thermocouple), the values for T_{UUT}, T_{ref}, σ_{UUT} and σ_{ref} are represented by their values in set "a."

6.8.2 *Data Analysis*—The data described in Table 3 are used for determining if the UUT meets the verification criterion. It includes the temperature measurements of the UUT and reference thermometer as well as the standard uncertainty values described in the table and in 6.8.3. The verification data may be used for one of the following tests: (1) comparison of measurements by the UUT and the reference thermometer, and (2) comparison of earlier and present measurements by the UUT and the reference thermometer. The first test provides the best result if the reference thermometer is a referee thermocouple or is calibrated; otherwise, the second test may provide the best results (assuming earlier measurement results are available).

6.8.2.1 *Measurement Agreement Method*—The calculation for the first test determines whether the UUT and reference thermometer measurements agree to within the expanded total measurement uncertainty, considering the verification criterion for the UUT. The calculation for the second test determines whether the earlier and present UUT measurements agree to within the expanded total measurement uncertainty, considering the verification criterion for the UUT.
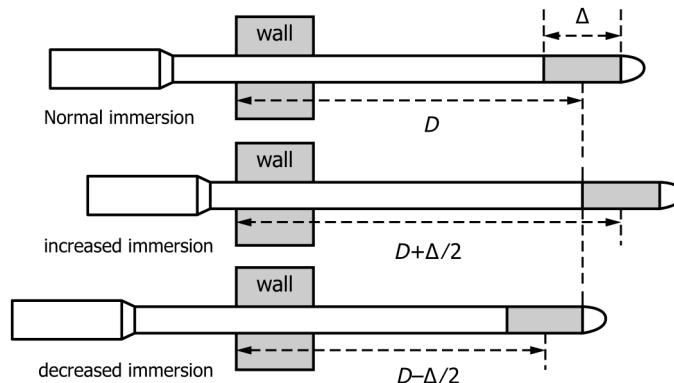

FIG. 2 Placement of Reference RTD at increased and decreased immersion depths for determination of the immersion uncertainty component in the verification test. Here, Δ is the length of the RTD sensing element.
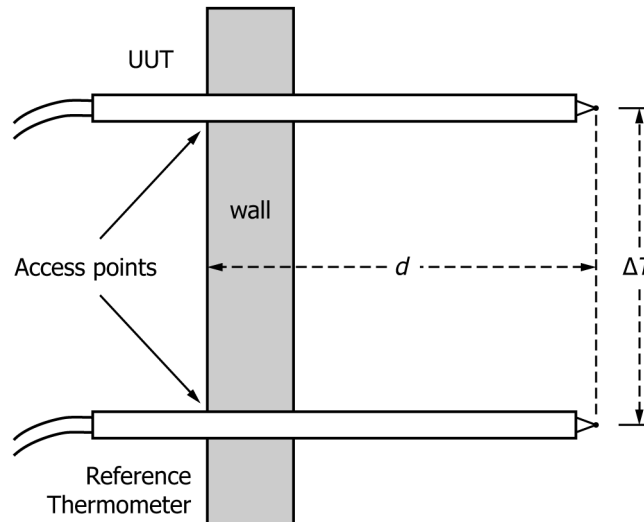
FIG. 3 Verification of a UUT by a reference thermometer using two adjacent access points. Here, the reference thermometer is a thermocouple. Temperature measurements are simultaneously made while the UUT and reference thermometer are placed in the access points with immersion depth *D*. Because of the spatial separation between the sensing points, a temperature difference ΔT between them may exist and must be estimated.

TABLE 3 Data Used for Verification Calculation for Test With Reference Thermometer in an Adjacent Access Point

Temperature Data	Description
T_{UUT}	Temperature Measurement made by the UUT
T_{ref}	Temperature Measurement made by the reference thermometer
Uncertainties	
σ_{UUT}	Repeatability of the measurements made by the UUT
σ_{ref}	Repeatability of the measurements made by the reference thermometer
u_{UUT_inst}	Measuring instrument for the UUT
u_{ref_inst}	Measuring instrument for the reference thermometer
u_{UUT_RJC}	Reference-junction compensator of the UUT (if relevant)
u_{ref_RJC}	Reference-junction compensator of the reference thermometer (if relevant)
u_{ref_cal}	Calibration of the reference thermometer (if relevant)
$u_{\Delta T}$	Temperature difference between the sensing points of the UUT and the reference thermometer
u_{imm}	Immersion depth of the reference thermometer (RTD only)

6.8.2.2 *Tolerance Verification Method*—The calculation for the first test determines whether the UUT and reference thermometer measurements agree to within the UUT specified tolerance. The calculation for the second test determines whether the earlier and present UUT measurements agree to within the UUT specified tolerance. Both calculations provide a result of either "accept" or "reject" for the UUT. The measurement uncertainty is used to quantify the chance that this result is wrong.

6.8.2.3 *Calculations*—The equation needed for determining the expanded total measurement uncertainty from the uncertainty elements is presented in X1.2. The equation used to determine measurement agreement is presented in X2.2, which includes example calculations. The equations used to perform tolerance verification are presented in X3.2.2 and X3.3. As these calculations are not trivial, it is recommended that qualified software engineers design software tools to facilitate these calculations for those who must regularly perform verification tests.

6.8.3 *Description of Uncertainties*—Most of the uncertainties shown in Table 3 are described in section 6.7.3. The one uncertainty that is not described there, $u_{\Delta T}$, is the uncertainty due to the temperature difference ΔT between the measuring junction of the UUT and the sensing point of the reference thermometer; this difference is due to temperature non-uniformities in the environment. If the access points are switched as described in 6.8.1, $u_{\Delta T} = 0$ because it is cancelled out by averaging sets "a" and

"b". If the access points are not switched, efforts shall be made to estimate Δ*T*, for example by placing the reference thermometer in a third nearby access point and determining the difference between the temperatures measured in it and the second access point.

7. Thermocouple Functionality Tests

7.1 The following tests examine the functionality of a thermocouple using electrical and dimensional measurements, as well as visual inspections. They can be performed by the user as well as in a calibration laboratory. While these tests are fast and simple, they do not by themselves verify a UUT; they are primarily useful for quickly detecting specific problems that would render the UUT unsuitable for use. The tests, which are based on those described in Test Methods E839 and Guide E1350, are listed in Table 4.

7.2 Electrical tests on a thermocouple performed in an industrial environment should only be conducted by trained personnel having the necessary qualifications to work on instrumentation and electrical equipment in such environments. Before performing any electrical tests on a thermocouple, it should be disconnected from its temperature measurement/control electrical circuit. Precautions should be taken and measurements should be made to ensure that the thermocouple is not in contact with live circuits other than those used in the test.

7.3 *Measurement of Thermocouple Loop Resistance*—For proper performance of the thermocouple, its wires should not be broken, its separate thermoelements should not be in electrical contact except at the measuring junction, and the weld at its measuring junction shall not be broken. These problems may be tested for by measuring *ex situ* the loop resistance of the thermocouple while it is disconnected from temperature-measurement instruments. The methods for this measurement are described in Test Methods E839. The results of the loop resistance tests are then compared with those from similar tests performed before the UUT was used or on an unused thermocouple from the same manufacturing lot. If the loop resistance has changed significantly (for example, 20 %) since the earlier measurements, the UUT should not be used until other tests, particularly those of Section 6, have verified it.

NOTE 3—Before performing loop resistance measurements, the thermocouple should be disconnected from its temperature measurement/control electrical circuit.

7.4 *Measurement of Insulation Resistance of Style U Mineral-Insulated Metal-sheathed (MIMS) Thermocouples*—The sheath of a Style U MIMS thermocouple should be electrically isolated from the thermocouple circuit. This isolation can be verified by measuring *ex situ* the room-temperature insulation resistance between the sheath and the wires while it is disconnected from temperature-measurement instruments. The methods for this measurement are described in Test Method E780. The tests described in this guide assume knowledge of the insulation resistance of the thermocouple immediately before installation. If this information is not available, Table 4 of Specification E608/E608M or Table 4 of Specification E2181/E2181M may be used to approximate this initial insulation resistance. If the insulation resistance has changed significantly (for example, 20 %) since the earlier measurements, it is recommended that the UUT be verified using full verification tests, such as those described in Section 6. Examples of causes of insulation-resistance changes are sheath rupture, a damaged cold seal, and external contamination of wires or pins.

7.5 *Measurement of the Diameter of Mineral-Insulated Metal-sheathed (MIMS) Thermocouples*—Changes in the diameter of a sheathed thermocouple can be used to assess wear and sheath degradation. In hostile environments the sheath may have a high rate of material loss, leading eventually to sensor failure. Common sheath walls are not sufficiently thick to protect the thermoelements in cases where material loss is significant. Many factors such as velocity, chemical compatibility and abrasion will affect sensor wear. A baseline measurement of the diameter at installation is required. Subsequent measurements can track the wear and make reasonable predictions of failure. Dimensional requirements for the metal-sheathed thermocouple cable used in the manufacture of mineral-insulated metal-sheathed base metal thermocouples can be found in Specification E585/E585M.

TABLE 4 Summary of Thermocouple Functionality Tests

Test	Provides	Comments
Loop Resistance Measurement	Detection of fatal damage to thermocouple	Fast, simple test. Requires multimeter.
Insulation Resistance Measurement	Information to help detect damage or deterioration	Fast, simple test. Requires megohmmeter.
Sheath Diameter Measurement	Information to help detect deterioration	Fast, simple test. Requires micrometer.
Sheath Inspections	Information to help detect damage or deterioration	Fast, simple test. Microscope needed. Helium mass spectrometer needed for leak detection.