Designation: E220 − 19

Standard Test Method for Calibration of Thermocouples By Comparison Techniques[1]

This standard is issued under the fixed designation E220; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method describes the principles, apparatus, and procedure for calibrating thermocouples by comparison with a reference thermometer. Calibrations are covered over temperature ranges appropriate to the individual types of thermocouples within an overall range from approximately −195 °C to 1700 °C (−320 °F to 3100 °F).

1.2 In general, this test method is applicable to unused thermocouples. This test method does not apply to used thermocouples due to their potential material inhomogeneity—the effects of which cannot be identified or quantified by standard calibration techniques. Thermocouples with large-diameter thermoelements and sheathed thermocouples may require special care to control thermal conduction losses.

1.3 In this test method, all values of temperature are based on the International Temperature Scale of 1990. See Guide E1594.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1 Specification for ASTM Liquid-in-Glass Thermometers
E77 Test Method for Inspection and Verification of Thermometers
E230 Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
E344 Terminology Relating to Thermometry and Hydrometry
E452 Test Method for Calibration of Refractory Metal Thermocouples Using a Radiation Thermometer
E563 Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
E644 Test Methods for Testing Industrial Resistance Thermometers
E1129/E1129M Specification for Thermocouple Connectors
E1594 Guide for Expression of Temperature
E1684 Specification for Miniature Thermocouple Connectors
E1751 Guide for Temperature Electromotive Force (emf) Tables for Non-Letter Designated Thermocouple Combinations
E2846 Guide for Thermocouple Verification

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E344 shall apply to this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *check standard, n*—a measurement instrument or standard whose repeated results of measurement are used to determine the repeatability of a calibration process and to verify that the results of a calibration processes are statistically consistent with past results.

3.2.2 *isothermal block, n*—a piece of solid material of high thermal conductivity used to promote thermal equilibrium between two or more thermometers.

3.2.3 *reference junction compensation, n*—the adjustment of the indication of a thermocouple such that the adjusted indication is equivalent to the emf or temperature that the thermocouple would indicate if the reference junctions were maintained at 0 °C.

3.2.3.1 *Discussion*—In most cases, the thermocouple indication is adjusted by measuring the temperature of a terminal block where the thermocouple is connected, and then adding to the thermocouple emf an additional emf equal to the emf of the

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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.

thermocouple reference function evaluated at the temperature of the terminal block. Because the emf-temperature relationship of any actual thermocouple differs slightly from that of the reference function, reference junction compensation typically introduces higher uncertainties compared to the use of a well prepared ice bath.

3.2.4 *reference junction compensator, n*—a device that implements reference junction compensation.

3.2.5 *reference thermometer, n*—thermometer that establishes the value of temperature in a given system containing additional temperature sensors.

3.2.5.1 *Discussion*—In a calibration system the reference thermometer is a calibrated thermometer capable of indicating values of temperature with known uncertainty. The reference thermometer provides the standard temperature for the system at the time of test.

3.2.6 *thermocouple type, n*—a standardized thermoelectric class of thermoelement materials that, used as a pair, have a normal relationship between relative Seebeck emf and temperature.

3.2.6.1 *Discussion*—For common, commercially available thermocouples, a thermocouple type is identified by a letter designation (types B, C, E, J, K, N, R, S, and T). The letter designation scheme is given in Guide E2846. The tables in E1751 give temperature-EMF relationships for a number of additional thermocouple compositions that are not identified by a letter designation.

4. Summary of Test Method

4.1 Comparison calibration consists of measuring the emf of the thermocouple being calibrated in an isothermal medium while simultaneously measuring the temperature of the medium with a reference thermometer. The reference thermometer may be any thermometer with sufficient accuracy at the temperature of calibration.

5. Significance and Use

5.1 For users or manufacturers of thermocouples, this test method provides a means of verifying the emf-temperature characteristics of the material prior to use.

5.2 This test method can be used to calibrate a thermocouple for use as a reference, or it can be used to calibrate thermocouples representing a batch of purchased, assembled thermocouples.

5.3 This test method can be used for the verification of the conformance of thermocouple materials to temperature tolerances for specifications such as the tables in Specification E230 or other special specifications as required for commercial, military, or research applications.

6. Interferences

6.1 Since the success of this test method depends largely upon the ability to maintain the measuring junction of the thermocouple being calibrated and the reference thermometer at the same temperature, considerable care must be taken in choosing the media and conditions under which the comparisons are made. Stirred liquid baths, uniformly heated metal blocks, tube furnaces, and dry fluidized baths, properly used, are acceptable temperature comparison environments. In the case of large diameter thermoelements and sheathed thermocouples, special attention must be given to effects of thermal conduction.

6.2 Voltage measurement instruments with sufficiently high input impedance must be used for measuring thermocouple emf to eliminate instrument loading as a significant source of error. The ratio of input impedance to thermocouple loop resistance should be significantly (at least 10^4) greater than the ratio of the measured emf to the desired emf uncertainty.

6.3 The test method relies on the assumption that test thermoelements are homogeneous. If so, their output voltage at a given measuring junction temperature is independent of temperature variations along the length of the thermocouple. Departures from this ideal contribute to uncertainty in the use of test results. The effects typically are negligibly small for new, unused thermocouple material, but not for used thermocouples, especially those of base-metal composition. The effects of inhomogeneity can be identified, but not accurately quantified, by the techniques described in Appendix X4 in this test method and in section 8.2 of Guide E2846. Descriptions of the testing of used thermocouples may be found Guide E2846 and Manual MNL 12 (**1**)[3].

6.4 This test method presumes that the tested thermocouples are suitable for use in air throughout the range of calibration temperatures. To avoid oxidation of the thermoelements, refractory-metal thermocouples that have not been hermetically sealed in a sheath suitable for use in air should be tested in an inert gas environment at temperatures above approximately 500 °C. In this case, use of this test method is recommended in combination with the furnaces and related procedures described in Test Method E452.

7. Apparatus

7.1 The choice of apparatus used for the comparison test will depend primarily on the temperature range to be covered and on the desired calibration uncertainty. The apparatus required for the application of this test method will depend in detail upon the temperature range being covered but in all cases shall be selected from the equipment described as follows:

7.2 *Comparison Baths and Furnaces*—A controlled temperature comparison medium (bath or furnace) shall be used in which the measuring junction of the thermocouple to be calibrated is brought to the same temperature as a reference thermometer. The spatial uniformity of temperature within the nominally isothermal calibration zone shall be established. Acceptable methods include measurements of the calibration zone at the time of testing or the use of control charts that display the periodic calibration of check standards or the periodic characterization of the calibration zone. The frequency of such testing will depend on the inherent stability of the bath or furnace. The uniformity of the calibration zone shall be remeasured sufficiently often such that any deviations in

[3] The boldface numbers in parenthesis refer to the list of references at the end of this standard.

uniformity may be corrected prior to significant adverse affect on the readings. All thermocouples being calibrated and the reference thermometer must be immersed into this zone to an extent sufficient to ensure that the measuring junction temperature is not significantly affected by heat conduction along the thermocouple and reference thermometer assemblies. To avoid contaminating the thermoelements and insulation of unsheathed thermocouples, direct contact with calibration bath fluids should be avoided.

7.2.1 *Liquid Baths*—In the range from −150 °C to 630 °C (−240 °F to 1170 °F) the comparator bath shall usually consist of a well stirred liquid bath provided with controls for maintaining a constant and uniform temperature. Suitable types are described in the appendix to Test Method E77. At the liquid nitrogen boiling point, −196 °C (−321 °F), an isothermal block of copper suspended in an open dewar of liquid nitrogen can provide a very effective single-point liquid bath. In the range between −196 °C (−321 °F) and −150 °C (−240 °F), the bath construction is relatively complex, and commercial systems that rely on liquid nitrogen for cooling are recommended. A properly constructed liquid bath will have temperature gradients that are small relative to either fluidized powder baths or tube furnaces. A disadvantage of liquid baths is the relatively small operating range of any one bath fluid. The temperature gradients in a liquid bath will be repeatable provided that the bath liquid does not thermally decompose at high temperatures and that the conditions of bath heating and cooling are comparable to those that existed when the bath gradients were characterized. Periodic evaluation of bath gradients is necessary when using oil baths, since oil viscosity can increase significantly after use at high temperatures. Baths with multiple heaters require a monitoring system that enables the user to readily determine that all heaters are operational.

7.2.2 *Fluidized Powder Baths*—In the range from −70 °C to 980 °C (−100 °F to 1800 °F) the comparator bath may consist of a gas-fluidized bath of aluminum oxide or similar powder. Temperature equalizing blocks are almost always necessary within fluidized baths to minimize spatial and temporal temperature variations. The repeatability of thermal gradients within such a block depends on maintaining a constant fill level of powder in the bath and maintaining a uniform gas flow through the powder. The thermal gradients of a fluidized powder bath shall be verified by including either a second reference thermometer or a check-standard thermocouple in each comparison test.

7.2.3 *Tube Furnaces*—At temperatures above approximately 620 °C (1150 °F) an electrically heated tube furnace with a suitable nominally isothermal zone will usually be used. Laboratory type tube furnaces may be used at any temperature provided that the increased uncertainty due to their spatial temperature variance is accounted for. Any one of a wide variety of designs may be suitable, but it shall be demonstrated that the furnace chosen can maintain a temperature stability of ±1 °C over a period of 10 min at any temperature in the range over which the furnace is to be used. The axial temperature profile of a tube furnace shall be mapped to determine the location of the region with the best temperature uniformity. Furnaces with multiple heaters require a monitoring system that enables the user to visually determine that all heaters are operational and will require periodic remeasurement of the axial temperature profile. Single-zone furnaces may vary in temperature profile slowly as the heater element ages and will require only infrequent remapping of the temperature profile.

NOTE 1—Further discussions of suitable tube furnaces are given in Appendix X1.

7.2.4 *Other Baths*—The one essential design feature of any bath to be used with this test method is that it brings the measuring junction of the thermocouple being calibrated to the same temperature as the reference thermometer. Copper blocks immersed in liquid nitrogen have been used successfully at low temperatures. The blocks are provided with wells for the test thermocouples and the reference thermometer. Similarly, uniformly heated blocks have been used at high temperatures. Such baths are not excluded under this test method, but careful explorations of existing temperature gradients must be made before confidence may be placed in such an apparatus.

7.2.5 *Isothermal Blocks*—The use of an isothermal block can substantially reduce the temperature differences between the reference thermometer and the test thermocouples. Such a block should be manufactured from a material of high thermal conductivity that will not contaminate the thermocouples under test. High thermal conductivity reduces the spatial temperature variations in the block, resulting in better thermal equilibrium between the reference thermometer and the test thermocouples. An isothermal block may also be used to reduce temporal fluctuations of the thermometers. The fluctuations will decrease as either the heat capacity of the block is increased or the heat transfer to the surrounding furnace or bath is decreased. A consequence of this decrease in fluctuations is an increase in the time for the isothermal block to reach a steady-state temperature, so care must be exercised that the block is neither too large nor too well insulated. The temperature differences between the test thermocouples and the reference thermometer should be evaluated over the full temperature range of the apparatus by performing calibrations of check-standard thermocouples at a variety of immersions in the block and with the various thermometers inserted into different bores of the block. Similar temperature differences should also be measured as a function of time, following an adjustment of the furnace or bath temperature, to determine the length of time needed to reach thermal steady-state following a temperature change. Welding the measuring junctions of the test thermocouples and of a thermocouple used as a reference thermometer is a special case of an isothermal block formed by the common measuring junction.

7.3 *Reference Junction Temperatures*— A controlled temperature medium in which the temperature of the thermocouple reference junctions is maintained constant during a measurement cycle at a known or measured value shall be provided. A commonly used reference temperature is 0 °C (32 °F), usually realized through use of the ice point, but other temperatures may be used if desired. Reports of data taken with reference temperatures other than the ice point should be corrected to reflect the results that would have been obtained if the reference junction had been at the ice point, and the report shall state both the reference junction temperature and whether the