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An American National Standard

Standard Guide for Testing Sheathed Thermocouples, Thermocouple Assemblies, and Connecting Wires Prior to, and After Installation or Service[1]

This standard is issued under the fixed designation E1350; 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.

INTRODUCTION

Thermocouples are widely used in industry and provide reliable service when used within their specified temperature range. However, if thermocouples fail in service the consequences can range from insignificant to life-threatening. Often, a costly loss of equipment, product, or operating time will result. The user should weigh the potential consequences of thermocouple failure when considering which tests should be performed either prior to, during, or after installation.

This standard is a guide for the field testing of thermocouples, thermocouple assemblies, and their connecting wires to ensure that they were not damaged during storage, installation, or use rather than being a guide for acceptance testing of thermocouples as delivered from the vendor. The test methods range from basic tests to verify that the thermocouple was properly installed to tests necessary for failure analysis. Thermocouple tests such as homogeneity, capacitance, and loop-current step-response require elaborate equipment and sophisticated analysis and are not included in this guide.

Faulty installation practices and in-service operation beyond prescribed limits are frequently the cause of failure in properly made sheathed thermocouples. Many of the most common types of these application errors may be identified through use of the test methods described in this document. For further information, the reader is directed to MNL 12, Manual on the Use of Thermocouples in Temperature Measurement,[2] which is an excellent reference document on metal sheathed thermocouples.

1. Scope

1.1 This guide covers methods for users to test metal sheathed thermocouple assemblies, including the extension wires just prior to and after installation or some period of service.

1.2 The tests are intended to ensure that the thermocouple assemblies have not been damaged during storage or installation, to ensure that the extension wires have been attached to connectors and terminals with the correct polarity, and to provide benchmark data for later reference when testing to assess possible damage of the thermocouple assembly after operation. Some of these tests may not be appropriate for thermocouples that have been exposed to temperatures higher than the recommended limits for the particular type.

1.3 The tests described herein include methods to measure the following characteristics of installed sheathed thermocouple assemblies and to provide benchmark data for determining if the thermocouple assembly has been subsequently damaged in operation:

1.3.1 *Loop Resistance:*

1.3.1.1 Thermoelements,

1.3.1.2 Combined extension wires and thermoelements.

1.3.2 *Insulation Resistance:*

1.3.2.1 Insulation, thermocouple assembly,

1.3.2.2 Insulation, thermocouple assembly and extension wires.

1.3.3 *Seebeck Voltage:*

1.3.3.1 Thermoelements,

1.3.3.2 Combined extension wires and thermocouple assembly.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

[1] This guide is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.14 on Thermocouples - Testing.

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[2] *Manual on the Use of Thermocouples in Temperature Measurement*, MNL 12, ASTM. Available from ASTM International, www.astm.org.

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:*[3]

E230 Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples

E344 Terminology Relating to Thermometry and Hydrometry

E780 Test Method for Measuring the Insulation Resistance of Mineral-Insulated, Metal-Sheathed Thermocouples and Mineral-Insulated, Metal-Sheathed Cable at Room Temperature

E839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable

E1129/E1129M Specification for Thermocouple Connectors

E608/E608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples

E1684 Specification for Miniature Thermocouple Connectors

E2181/E2181M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable

MNL 12 Manual on the Use of Thermocouples in Temperature Measurement

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *extension wires, n*—pair of wires having temperature-emf characteristics that match the thermocouple temperature-emf characteristics over a specified temperature range.

3.2.2 *junction class, n*—Style U junctions are electrically isolated from conductive sheaths and from reference ground and Style G junctions are electrically connected to conductive sheaths.[4]

3.2.3 *sensing circuit, n*—the combination of the thermoelements and extension wires, but excluding active signal conditioning components such as reference junction compensators, amplifiers, and transmitters.

3.2.4 *sheathed-thermocouple assembly, n*—an assembly consisting of one or more pairs of thermoelements within ceramic insulation contained within a metal protective sheath (also referred to as MIMS), having a junction, or junctions, electrically joined to form a thermocouple, or thermocouples, with its associated parts.

3.2.4.1 *Discussion*—An assembly may include associated parts such as a terminal block and a connection head. The metal protecting tube, or sheath, has a moisture seal at the reference junction end. Usually the metal sheath is welded closed at the measuring end. However, if the thermocouple has an exposed junction, it must have an effective moisture seal at the measuring end as well as at the reference junction end.

3.2.5 *terminal block, n*—a terminal device for mechanical connection of thermoelements and extension wires or for the connection of extension wires to each other or to instruments.

3.2.6 *thermocouple connector, n*—a quick-connect plug and jack in which the electrically connecting components have temperature-emf characteristics matching the extension wires or thermoelements they are intended to connect.

3.2.6.1 *Discussion*—The temperature-emf characteristics of the connector parts will match the extension wires or the thermoelements only over a specified temperature range. Thermocouple connectors are described in Specifications E1129/E1129M and E1684.

4. Summary of Tests

4.1 *Loop Resistance Measurements:*

4.1.1 *Thermocouple*—The electrical loop resistance is compared to the resistance measured before installation to ensure that the thermoelements have not been broken or been short circuited (for example, at the thermocouple connector) during the installation process.

4.1.2 *Sensing Circuit*—The measurements may be used to establish the loop resistance of the combined thermocouple assembly and extension wires and to ensure that the extension wires are not shorted and that all connections are secure. The resistance of the extension wires should be measured separately before they are connected to the thermocouple assembly.

4.2 *Insulation Resistance Measurements:*

4.2.1 *Thermocouple Assembly*—The room temperature insulation resistance of the installed Style U thermocouple assembly is compared to the resistance measured before installation to ensure that the sheath and moisture seal have not been damaged and that the thermoelements were not shorted to the sheath during installation.

NOTE 1—This test applies only to thermocouple assemblies with Style U thermocouple junctions or exposed junction thermocouples with an effective moisture seal at the junction. Thermocouples having Style G junctions cannot be tested in this manner.

4.2.2 *Sensing Circuit*—The measurement is to establish that the electrical isolation of the Style U thermocouples has not been degraded by the extension circuit.

4.2.3 *Extension Wires*—The measurement is to establish that the extension wires are continuous and not shorted to each other, or to any other component, including earth ground. This is a necessary measurement when Style G thermocouples are tested.

4.3 *Seebeck Voltage Measurements:*

4.3.1 *Thermocouple Assembly*—The measurement, dependent on a temperature difference between the measuring

[3] 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.

[4] Historically referred to as class 1 and class 2 junctions.

junction and the terminal block, is to verify that the thermocouple connector is mated to the thermocouple with proper polarity.

4.3.2 *Sensing Circuit*—The measurement, dependent on a temperature difference between the measuring junction and the terminating hardware, is to verify that correct polarity has been maintained in connecting the extension wires to the thermocouple.

5. Significance and Use

5.1 These test procedures confirm and document that the thermocouple assembly was not damaged prior to or during the installation process and that the extension wires are properly connected.

5.2 The test procedures should be used when thermocouple assemblies are first installed in their working environment.

5.3 In the event of subsequent thermocouple failure, these procedures will provide benchmark data to verify failure and may help to identify the cause of failure.

5.4 The usefulness and purpose of the applicable tests will be found within each category.

5.5 These tests are not meant to ensure that the thermocouple assembly will measure temperatures accurately. Such assurance is derived from proper thermocouple and instrumentation selection and proper placement in the location at which the temperature is to be measured. For further information, the reader is directed to MNL 12, Manual on the Use of the Thermocouples in Temperature Measurement[2] which is an excellent reference document on metal sheathed thermocouple uses.

6. Apparatus

6.1 *Digital Ohm-meter or Multi-meter,* a direct current resistance measurement instrument having a measuring range from zero ohms to at least 1 megohm with a resolution of 10 milliohms or better. If a digital multimeter is used, readings require the capability to indicate a negative resistance.

6.2 *Megohmeter or Megohm Bridge,* with ranges from 5×10^4 ohm to 10^{12} ohm with an accuracy of better than ±10.0 % of the measured resistance and a test voltage selectable between 10 and 500 dc volts (VDC).

6.3 *Heat Source or Cold Source,* a small propane type torch or an electric heat gun as a heat source. Freeze spray can be used as a cold source.

7. General Requirements

7.1 The following test procedures assume that the loop resistance and room temperature insulation resistance of the delivered thermocouple were already found to be acceptable by Test Method E839 prior to installation.

7.2 All thermocouple assemblies to be tested should be identified by a serial number or by some other type of unique identifier traceable to pre-installation tests and to a manufacturer's production run.

7.3 These procedures require that all circuits have electrical continuity.

7.4 For all connections the color codes and material composition of the extension wires should be appropriate for the particular thermocouple type being tested. See Specification E230 for standard thermocouple type color codes.

8. Procedure: Loop Resistance Measurements

8.1 *Thermocouple Loop Resistance*—With the thermocouple disconnected from its extension wires and temperature measuring instrument, measure the loop resistance at the plug connector pins or at the terminal block. The basic measurement is simply to establish circuit continuity. For accurate loop resistance measurements to establish benchmark data and to ensure that the thermoelements are not shorted to each other (for example, at the thermocouple connector) use a digital ohmmeter able to measure resistance with a resolution less than 0.01 ohm. Because any Seebeck voltage generated by the thermocouple will affect the resistance value measured, two resistance measurements shall be made, with the second measurement taken with reversed polarity from the first. The average of the two measurements is the thermocouple's true loop resistance. **Warning—**Ohm-meters function by measuring the voltage produced by passing a small DC current through the unknown resistance. If the thermocouple is in a temperature gradient zone such that the measuring and reference junctions are at different temperatures, the thermocouple's Seebeck voltage will add to or subtract from the voltage measured by the ohm-meter. The objective of averaging the loop resistance measurements in forward and reverse polarities is to eliminate the effect of the thermocouple's Seebeck voltage. However, if a thermocouple with low loop resistance is tested while it is installed in a high temperature zone, the Seebeck voltage may be greater than the voltage produced by the ohm-meter, resulting in a negative voltage at the ohm-meter's terminals (see 8.1.3). Some digital multimeters may not indicate negative resistance and thus averaging the forward and reverse polarity measurements will result in an erroneous loop resistance measurement.

8.1.1 If very accurate resistance measurements are required, measure the ohm-meter's test lead resistance. If the ohm-meter's lead resistance is significant (>0.1 % compared to the thermocouple's loop resistance), subtract the ohm-meter's test lead resistance from all subsequent measurements of the thermocouple's loop resistance.

NOTE 2—An installed thermocouple will often be at a different temperature than when it was tested before installation. The different temperature will result in a different loop resistance that should not be interpreted as a thermocouple defect.

8.1.2 If several thermocouples of the same type are installed near the same location and in the same thermal environment, compare the resistance per unit length, for all thermocouples in the group before and after installation. Damage may be suspected in a given thermocouple if its resistance per unit length is significantly different (>10 %) from the before and after installation readings compared to companion thermocouples in the group.

NOTE 3—A loop resistance measurement, taken after the thermocouple assembly has been installed, which differs significantly from the initial loop resistance measurement will require replacement or repair of the thermocouple. If, for example, the thermocouple connector was rotated in relation to the sheath during installation, the thermoelements might have been broken or shorted at the connector and may be repairable.

8.1.3 An alternative method which may be used to determine the loop resistance of a thermocouple which is in service is to shunt the thermocouple at its connector pins with a variable resistor. Measure the thermocouple's open circuit Seebeck voltage between the connector pins with a high impedance voltmeter capable of measuring accurately in the microvolt range (see Fig. 1). The temperature of the thermocouple's measuring junction and the connector's pins must remain stable during the test. Close the switch and adjust the resistance of the variable resistor until the closed circuit voltage is half of the open circuit Seebeck voltage (this will occur when the variable resistor has the same resistance as the thermocouple's loop). The variable resistor is then disconnected from the circuit and its resistance measured directly with an ohmmeter. This method avoids the problem of the Seebeck voltage that is described in 8.1.

NOTE 4—At elevated (>800 °C) temperatures the insulation resistance of a thermocouple with a Style U junction may become so low that significant electrical shunting may occur either between the thermoelements or between the thermoelements and the sheath. In that case neither the loop resistance measurements nor the temperature measured by the thermocouple will be accurate. The insulation resistance of a thermocouple with a Style U junction at elevated temperature should be measured (see 9.3) before other test measurements are taken.

8.2 *Sensing Circuit Loop Resistance*—With the extension wires disconnected from the temperature measuring instrument but still connected to the thermocouple assembly, measure the total loop resistance of the combined thermocouple assembly and the extension wires in accordance with 8.1. This measurement is to establish if electrical continuity of the extension wires and thermocouple assembly exists. If an accurate measurement of the extension wires' loop resistance is required, subtract the thermocouple assembly's loop resistance, measured in 8.1.2 or 8.1.3, from the total resistance measured. Record the loop resistance of the extension wires for benchmark data. If the resistance per unit length of a given extension wire differs by more than >5 % from other extension wires of the same type, then the extension wires or circuit connections are suspect and should be carefully examined for damage. For example, terminal blocks having loose or corroded connections can increase circuit resistance, or cause open or short circuits; any of which will result in incorrect temperature measurements.

8.2.1 If during normal operation a temperature reading becomes erratic or shows an abrupt shift, a defect may be found either in the thermocouple-extension wire circuit or in the instrumentation itself. If the instrumentation is not at fault, either or both the thermocouple and extension wire can be replaced. For failure analysis, re-measure the total loop resistance of the extension wire and the thermocouple assembly and compare the measurement with the circuit's benchmark data. If there has been a significant change in the total resistance then the thermocouple's and the extension wires' loop resistances can be measured separately to establish where the change has occurred. Note that a stray, superimposed dc voltage will also affect a thermocouple's temperature reading and loop resistance measurements.

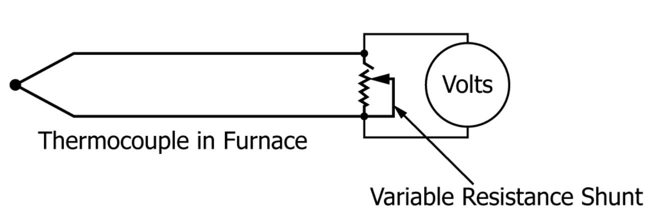

FIG. 1 An Alternative Method to Measure Loop Resistance

9. Procedure: Insulation Resistance Measurements

9.1 The insulation resistance test can only be performed on Style U thermocouples or exposed junction thermocouples with a measuring junction moisture seal which is still intact.

9.2 *Thermocouple Assembly Prior to Installation*—This test's objective is to verify that the moisture seal has neither been damaged nor deteriorated during storage. Measure the room temperature insulation resistance between the connector pins, terminal block, or leads and the metal sheath in accordance with Test Method E780. Compare the insulation resistance value with the value measured during thermocouple's delivery acceptance testing. A decrease of insulation resistance by two orders of magnitude (100×) or more from the acceptance test measurement value indicates damage to either the sheath or moisture seal during storage. If the result is acceptable, record the insulation resistance value obtained as a benchmark for the future.

9.3 *Thermocouple Assembly After Installation*—Measure the room temperature insulation resistance in accordance with Test Method E780 immediately after the thermocouple has been installed. The measurement shall be taken before connection of the extension wires between the connector pins, terminal block, or leads and the metal sheath. Compare the results "prior to" installation with the results after installation. A decrease of insulation resistance by two orders of magnitude (100×) or more from the "prior to" installation measurement value indicates damage to either the sheath or moisture seal during installation. If the result is acceptable, record the insulation resistance value obtained as a benchmark for the future.

9.3.1 If the thermocouple assembly is subject to its service temperature (or an ambient temperature considerably higher than room temperature) immediately after installation, a lower insulation resistance may be expected as a consequence of the higher temperature's known effect on insulation resistance values (see Note 5). In this event, the "prior to" and "after" insulation resistance values of similar and nearby thermocouple assemblies can be compared. This comparison is used to estimate the decrease in insulation resistance that may be expected for the particular temperature distribution to which the thermocouple assembly is exposed.

NOTE 5—If the thermocouple is at an elevated (>800 °C) temperature, insulation resistance should be measured using the procedures given in Test Methods E839, but it is recommended that no more than 10 V DC be applied for the insulation resistance test.

9.4 *Sensing Circuit*—With the extension wires connected to the thermocouple assembly but disconnected from the temperature measuring instrument, measure the insulation resistance in