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Standard Guide for
Testing Sheathed Thermocouples Prior to, During, and After Installation[1]

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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 negligible to life-threatening. Often, an expensive loss of equipment, product, or operating time will result. The user should weigh the potential consequences of thermocouple failure when considering what tests should be performed either prior to, during, or after installation.

This standard is a guide for the field testing of thermocouples 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 the most basic tests to assure the thermocouple was properly installed to simple 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 forms of these conditions may be detected 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.

The user should always remember that a voltage (not a temperature) is measured when a thermocouple is used. Any extraneous voltages that are introduced in the thermocouple circuit will be interpreted as a temperature, resulting in an error in the indicated temperature. Although the extension wires are not usually a part of the sheathed thermocouple, they are a portion of the measuring system and, if the extension wires are improperly installed with incorrectly matched material or polarity, the extension wires can produce voltages that will introduce substantial errors into the temperature measurements. When high accuracy measurements are made with calibrated thermocouples, it is especially important that the extension wires have thermoelectric properties closely matched to those of the thermocouple over the temperature range to which the extension wires are exposed.

1. Scope

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

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. They are not, generally, applicable to 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 variables of installed sheathed thermocouple assemblies and to provide benchmark data for determining if the thermocouple assembly is subsequently damaged in operation:

1.3.1 *Loop Resistance*:

1.3.1.1 Thermoelements,

1.3.1.2 Combined extension wires and the thermoelements,

1.3.2 *Insulation Resistance*:

1.3.2.1 Insulation, thermocouple assembly,

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

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 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:*

E 344 Terminology Relating to Thermometry and Hydrometry[3]

E 780 Test Method for Measuring the Insulation Resistance of Sheathed Thermocouple Material at Room Temperature[3]

E 839 Test Methods of Testing Sheated Thermocouples and Sheathed Thermocouple Material[3]

E 1129/E 1129M Specification for Thermocouple Connectors[3]

E 1684 Specification for Miniature Thermocouple Connectors[3]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E 344 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*—class 2 junctions are electrically isolated from conductive sheaths and from reference ground and class 1 junctions are electrically connected to conductive sheaths.

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 two thermoelements in ceramic insulation within a metal protecting tube, electrically joined at a junction to form a thermocouple, 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. If, however, 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 E 1129/E 1129M and E 1684.

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 shorted to each other (for example, at the thermocouple connector) during the installation process.

4.1.2 *Sensing Circuit*—The measurements are 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 connections are secure. The resistance of the extension wires should be determined before they are joined to the thermocouple assembly.

4.2 *Insulation Resistance Measurements*:

4.2.1 *Thermocouple Assembly*—The room temperature insulation resistance of the installed Class 2 thermocouple assembly is compared to the resistance measured before installation to ensure that the sheath and moisture seal has not been damaged or that the thermoelements are not shorted to the sheath during installation.

NOTE 1—This test applies only to thermocouple assemblies with Class 2 thermocouple junctions. Thermocouples with junctions attached to the sheath cannot be tested in this manner.

4.2.2 *Sensing Circuit*—The measurement is to establish that the electrical isolation of the thermocouples with class 2 junctions is not 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 Class 1 thermocouples are used.

4.3 *Seebeck Voltage Measurements*:

4.3.1 *Thermocouple Assembly*—The measurement, dependent on a temperature difference between the measuring junction and the terminal block, is to establish that the thermocouple connector is mated to the thermoelements with the proper polarity.

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

5. Significance and Use

5.1 These test procedures ensure 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

[3] *Annual Book of ASTM Standards*, Vol 14.03.

procedures will provide benchmark data to verify failure and to help evaluate 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 indicate temperatures accurately. Such assurance derives from proper thermocouple and instrumentation selection and proper placement in the location where 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 thermocouples.

6. General Requirements

6.1 These test procedures presume that the loop resistance and the room temperature insulation resistance of the delivered thermocouples was already found to be appropriate by Test Method E 839 before installation.

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

6.3 The procedures require that the circuit have electrical continuity.

7. Procedure: Loop Resistance Measurements

7.1 *Thermocouple Loop Resistance*—With the thermocouple disconnected from the extensions and temperature measuring instruments, measure the loop resistance at the plug connector pins or at the terminal block. The most basic measurement is simply to establish circuit continuity. For accurate loop resistance measurements to establish benchmark data and to assure that the thermoelements are not shorted to each other (for example at the thermocouple connector assembly) an ohmmeter capable of measuring the indicated resistance to at least 0.1 Ω must be used. Because any Seebeck voltage from the thermocouple will affect the measured resistance, two resistance measurements must be made, with the second measurement at reversed polarity from the first measurement. The average of the two measurements is the thermocouple loop resistance. (**Warning**—Ohmmeters operate by measuring a voltage produced by passing a current through the measured resistance. If the thermocouple is in a temperature gradient so that the measuring and reference junctions are at different temperatures, the Seebeck voltage from the thermocouple will add to or subtract from the voltage measured by the ohmmeter. The purpose of averaging loop resistance measurements in forward and reverse directions is to eliminate the effect of the Seebeck voltage on the resistance measurements. If, however, a thermocouple with a low loop resistance is measured while it is installed in a high temperature zone, the Seebeck voltage from the thermocouple may then be greater than the voltage produced by the ohmmeter, resulting in a measured negative voltage at the ohmmeter (see 7.1.3). Some digital multimetres do not indicate a negative resistance and thus averaging both forward and reverse resistances as positive will result in an erroneous resistance measurement.)

7.1.1 If accurate resistance measurements are to be made, measure the ohmmeter lead resistance. If the ohmmeter lead resistance is significant (>0.1 %), compared to the thermocouple loop resistance, subtract the ohmmeter lead resistance from all subsequent measurements of the thermocouple loop resistance.

NOTE 2—The installed thermocouples will often be at a different temperature than when they were measured before installation. The different temperature will produce a different loop resistance which should not be interpreted as a thermocouple defect.

7.1.2 If several thermocouples of the same type are installed in the same location and in the same thermal environment, compare the resistance per unit length, for the group before and after installation. See Note 2. Suspect damage has occurred in a given thermocouple if the measured before-and-after difference of resistance per unit length is significantly (>10 %) different than the before-and-after difference of resistance per unit length of its companion thermocouples.

NOTE 3—If the loop resistance is greatly different after the thermocouple assembly has been installed (that is, particularly if the resistance shows open circuit or near zero), then the thermocouple must be replaced or repaired. If, for example, the thermocouple connector was rotated in relation to the sheath during installation, the thermoelements could have been broken or shorted at the connector and might be repairable.

7.1.3 An alternative method to determine the loop resistance of a thermocouple at elevated temperatures is to shunt the thermocouple at the connector prongs with a switchable variable resistor. Measure the open-switch thermocouple Seebeck voltage between the connector prongs with a high impedance voltmeter capable of measuring in the microvolt range (see Fig. 1). The measuring junction must be at constant temperature and the connector prongs must remain at the same terminal temperature during this test. Close the switch and adjust the resistance of the variable resistor until the closed-switch measured voltage is ½ that of the open-switch Seebeck voltage (at which time the variable resistor has the same resistance as the thermocouple loop). The variable resistor is then removed from the circuit and its resistance measured directly with an ohmmeter. This method avoids the complication of the Seebeck voltage that is referred to in 7.1.

NOTE 4—At elevated (>800°C) temperatures the insulation resistance of a thermocouple with a class 2 junction may be so low that significant electrical shunting may occur either between the thermoelements or the thermoelement and the sheath. In that case neither of the loop resistance measurements nor the temperature measurements will produce an accurate result. The insulation resistance of a thermocouple with a class 2 junction at elevated temperature should be measured (see 8.3) before any other measurements are made.

7.2 *Sensing Circuit Loop Resistance*—With the extension wires disconnected from the temperature indicating instrument but connected to the thermocouple assembly, measure the loop

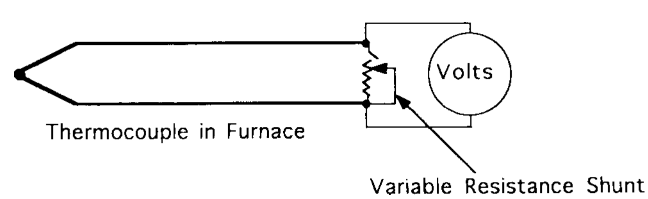

FIG. 1 An Alternative Method to Measure Loop Resistance

resistance of the combined thermocouple assembly and the extension wires using 7.1 to at least establish the continuity of the combined extension wires and thermocouple assembly. If accurate measurements are desired, subtract the thermocouple assembly resistance measured in 7.1.2 or 7.1.3 from the combined resistance to find the resistance of the extension wire. Record the resistance of the extension wire for benchmark data. If the resistance per unit length of a given extension wire is >5 % different from extension wires of the same type and length, then the extension wire is suspect and should be examined. For example, if the wire is interrupted by terminal blocks, then a loose or corroded connection can increase resistance and possibly open in service, or a shorted connection can result in a false temperature indication.

7.2.1 If, during operation, the temperature indication becomes erratic or has an unexplained abrupt shift of indicated temperature the error may be either in the thermocouple-extension wire circuit or in the temperature indication instrumentation. If instrumentation is not at fault, the thermocouple and extension wire can simply be replaced. For failure analysis, remeasure the combined loop resistance of the extension wire and the thermocouple assembly and compare the measurement with the benchmark data. If there is a significant change in the combined resistance then the thermocouple and the extension wire loop resistances should be measured separately to establish where the change has occurred. Note that a superimposed dc voltage would also affect indicated temperature and resistance measurements.

8. Procedure: Insulation Resistance Measurements

8.1 The insulation resistance test can only be applied to a thermocouple assembly of Class 2 construction (junction electrically isolated from the sheath). For a Class 1 thermocouple assembly, the insulation resistance of the extension wires should be measured before they are connected to the thermocouple.

8.2 *Thermocouple Assembly Before Installation*—Measure the insulation resistance, at room temperature, between a connector prongs, terminal block, or leads and the sheath using Test Method E 780. Compare the measured insulation resistance with that measured in the acceptance tests when the thermocouples were delivered from the supplier. This test is to establish that the moisture seal has not been damaged nor deteriorated during storage. Record the insulation resistance value for benchmark reference in subsequent tests.

8.3 *Thermocouple Assembly After Installation*—The insulation resistance shall be measured under room temperature conditions just after the thermocouples have been installed in order to compare the pre- and post-installation measurements. Measure the insulation resistance of the installed thermocouple assembly at the thermocouple connector plug pins or terminal block before extension wires are attached. Measure between the thermoelements and the thermocouple sheath if possible. Otherwise, if the thermocouple sheath is connected to ground, measure between the thermoelements and a common reference ground. A decrease of insulation resistance by 2 orders of magnitude (100×) or more from the initial measurement indicates damage to either the sheath or the moisture seal during installation. If the thermocouple assembly is at an elevated temperature after installation, then a decrease in insulation resistance is to be expected because of the temperature (see Note 5). The before and after insulation resistance of companion thermocouple assemblies can be compared in order to estimate the amount of insulation resistance decrease that is usual for the particular temperature distribution.

NOTE 5—If the thermocouple is at an elevated (>800°C) temperature the insulation resistance should be measured using the techniques of Test Methods E 839, but it is recommended that not more than 10 V be applied for the insulation resistance measurements.

8.4 *Sensing Circuit*—With the extension wires connected to the thermocouple assembly but disconnected from the temperature indicator instrument, measure the insulation resistance between a common reference ground and the combined extension wire and thermocouple assembly. Do not use a test voltage that exceeds that of the extension wire insulation rating. For a Class 1 thermocouple assembly the insulation resistance of the extension wires should be measured before they are connected to the thermocouple or the indicator instrument.

8.4.1 A reduction of insulation resistance is to be expected because of the inclusion of the extension wires in the system; however, a reduction by more than 2 orders of magnitude compared to the measurement of 8.3 may indicate partial shorting in the extension wires, likely at dirty or moist terminal connections. Such a result could also occur if the extension wires passed through a zone of temperature higher than the rated temperature limit of the extension wire insulation. The user should, as good practice, take care that no portion of the extension wire passes through areas where the temperature may approach the rated limits of the insulation of the wire or the limits of Seebeck matching or compensation (see 3.2.2).

8.4.2 Remeasure the insulation resistance (using 8.4) if, during operation, the temperature indication becomes erratic or has an unexplained change. A decrease of insulation resistance by more than two orders of magnitude (compared to the initial measurement of 8.4) indicates the temperature measurement is no longer reliable because of either a sheath or moisture seal leak or because of terminal connectors that are dirty or moist.

9. Procedure: Seebeck Voltage Measurement Tests

9.1 *Thermocouple Assembly Polarity and Integrity Tests*—Perform these tests before the thermocouple assembly is installed. The purpose of the tests is to ensure that the thermocouple plug and any intermediate connection has the proper polarity and that significant inhomogeneities (caused by manufacturing or field assembly error) are not present in the sheathed assembly. Use a warm air blower, whose air temperature is lower than that which would damage any component of the system tested, to detect spurious sources of Seebeck voltage in the thermocouple circuit. The test methods may require two operators in communication.

9.1.1 Attach the positive lead of a micro-voltmeter (or thermocouple indicator) to the positive pin of the thermocouple connector and the negative lead of the voltmeter to the negative pin of the thermocouple connector. While observing the signal at the thermocouple connector plug pin, use a warm air blower to heat the junction end and adjacent portion of the thermocouple assembly (but do not heat the thermocouple connector). An increasing signal should be observed. A decreasing signal when the measuring junction is heated indicates the thermoelements are improperly connected to the thermocouple connector. If the signal does not change while heating the measuring junction, the thermoelements may be shorted somewhere between the measuring junction and the thermocouple connector.

9.1.2 Shield and heat sink the junction and adjacent sections of the thermocouple so its temperature will not vary by more than 0.017°C/s (1°C/min).

9.1.3 While observing the voltage (or temperature indication) at the thermocouple connector, pass the warm air stream from the blower progressively along the thermocouple sheath between, but not including, the thermocouple connector and the heat-sinked junction area. This test is to detect any large inhomogeneity between the junction and the connector of the sheathed thermocouple. An observed change of signal that would correspond to a change of more than 2°C for the type thermocouple being tested would indicate a serious flaw in the sheathed thermoelements (such as a splice of different materials or shorted thermoelements).

9.2 *Installed Thermocouple Polarity Tests*—Two alternative tests are described. Both tests are intended to be performed just after the thermocouple assembly has been installed but before the extension wires are connected. The purpose of the tests is to assure that the thermocouple assembly has not been damaged during the installation or, if terminal blocks are used, that the correct polarity has been maintained. The first, simpler, test method can be used if the thermocouple assembly has been installed in a facility where the temperature of the measuring junction is known to be enough hotter or colder than the connecting pins or terminals to produce a stable measurable signal. The second test method, which involves applying heat to the thermocouple assembly, can be used only if the installed thermocouple is accessible.

9.2.1 For the first test method (a measurable voltage exists after installation) measure the voltage of the thermocouple assembly at the thermocouple connector plug pins or terminal block by attaching the positive lead of a micro-voltmeter (or thermocouple indicator) to the positive pin of the thermocouple connector and the negative lead of the voltmeter to the negative pin of the thermocouple connector. The thermoelements are attached to the thermocouple connecter plug with the correct polarity if *(1)* a negative voltage is found when the measuring junction is known to be at a *lower temperature* than the connecting pins or terminals or *(2)* a positive voltage is found when the measuring junction is known to be at a *higher temperature* than the connecting pins or terminals. Record the voltage magnitude and polarity for each thermocouple assembly before the extension wires are connected.

9.2.2 The second test method (measurable voltage not present) may require two operators in communication. While observing the voltage at the thermocouple connector plug pins or terminal block, use a warm air blower to gently heat the junction region of the thermocouple assembly. An increasing signal should be observed. A negative voltage indicates the thermocouple assembly wires are connected improperly to the plug pins or terminal block. If the observed voltage is not sensitive to the applied heat, the connector plug may have been rotated during installation so the thermoelements are shorted at the connector plug.

9.3 *Sensing Circuit Polarity Tests*—Two alternative tests are described. Both tests are intended to be performed just after the thermocouple extension wires have been installed. The purpose of the tests is to assure that the thermocouple extension wires are connected with the proper polarity. These tests are essential to discover multiple reversals of polarity along the circuit that cannot be detected simply by observing the polarity of voltage change in response to heating or cooling of the measuring junction alone. If the extension wires are color coded the connections should be inspected to assure that the correct code was maintained throughout.

9.3.1 With the extension wires connected to the thermocouple assembly, measure and record the magnitude and polarity of the voltage at the point where the extension wires will be connected to the temperature indicating instrument.

9.3.1.1 The first test method (a measurable voltage exists after installation) is identical to the test described in 9.2.1 except that the extension wires are connected to the thermocouple assembly. Compare the measured voltage polarity with that measured in the 9.2.1 step. A change of polarity at the point where the extension wires will be connected to the temperature indicating instrument indicates the extension wires were connected with the wrong polarity at one terminal between the thermocouple assembly and the temperature indicating instrument. Note that this test may not indicate a change of voltage or polarity if the extension wires are reverse connected at both ends.

9.3.1.2 The second test method (measurable voltage not present) may require two operators in communication. While observing the voltage at the instrument connection end of the extension wires, use a warm air blower to heat the connections between the thermocouple assembly and extension wires. A change of voltage indicates the extension wires are either the wrong material or were connected with reversed polarity.

9.3.2 As a general rule, the warm air blower should be passed along the entire accessible length of the thermocouple assembly and extension wires adjacent to and including any connection. Whenever a connection is made from the original thermoelement to the extension wires or if the extension wires are interrupted or spliced, verify the polarity of the connection.

9.3.3 If the thermocouple or extension wires are found to be connected with reversed polarity, it is imperative that they be connected properly rather than simply making a second change of polarity at the temperature indicating instrument (an action which would yield the correct polarity on the temperature indicating instrument, but which would introduce a measurement error).

10. Report

10.1 The results of each test made after installation should be entered into companion documentation for the thermocouple assembly made before installation, when required.

10.2 The data measured at intervals during the operation of the thermocouple assembly should be entered into the same documentation to provide chronological documentation of thermocouple assembly condition.

11. Precision and Bias

11.1 As the validation tests of this guide are qualitative, precision and bias statements are not appropriate.

12. Keywords

12.1 sheathed thermocouples; thermocouple installation; thermocouple testing; thermocouples