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Standard Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable[1]

This standard is issued under the fixed designation E839; 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.

ε^1 NOTE—Added references to Tables X1.7 and X1.8 to 10.7.4 editorially in December 2016.

1. Scope

1.1 This document lists methods for testing Mineral-Insulated, Metal-Sheathed (MIMS) thermocouple assemblies and thermocouple cable, but does not require that any of these tests be performed nor does it state criteria for acceptance. The acceptance criteria are given in other ASTM standard specifications that impose this testing for those thermocouples and cable. Examples from ASTM thermocouple specifications for acceptance criteria are given for many of the tests. These tabulated values are not necessarily those that would be required to meet these tests, but are included as examples only.

1.2 These tests are intended to support quality control and to evaluate the suitability of sheathed thermocouple cable or assemblies for specific applications. Some alternative test methods to obtain the same information are given, since in a given situation, an alternative test method may be more practical. Service conditions are widely variable, so it is unlikely that all the tests described will be appropriate for a given thermocouple application. A brief statement is made following each test description to indicate when it might be used.

1.3 The tests described herein include test methods to measure the following properties of sheathed thermocouple material and assemblies.

1.3.1 *Insulation Properties:*

1.3.1.1 *Compaction*—direct method, absorption method, and tension method.

1.3.1.2 *Thickness.*

1.3.1.3 *Resistance*—at room temperature and at elevated temperature.

1.3.2 *Sheath Properties:*

1.3.2.1 *Integrity*—two water test methods and mass spectrometer.

1.3.2.2 *Dimensions*—length, diameter, and roundness.

1.3.2.3 *Wall thickness.*

1.3.2.4 *Surface*—gross visual, finish, defect detection by dye penetrant, and cold-lap detection by tension test.

1.3.2.5 *Metallurgical structure*.

1.3.2.6 *Ductility*—bend test and tension test.

1.3.3 *Thermoelement Properties:*

1.3.3.1 *Calibration*.

1.3.3.2 *Homogeneity*.

1.3.3.3 *Drift*.

1.3.3.4 *Thermoelement diameter, roundness, and surface appearance*.

1.3.3.5 *Thermoelement spacing*.

1.3.3.6 *Thermoelement ductility*.

1.3.3.7 *Metallurgical structure*.

1.3.4 *Thermocouple Assembly Properties:*

1.3.4.1 *Dimensions*—length, diameter, and roundness.

1.3.4.2 *Surface*—gross visual, finish, reference junction end moisture seal, and defect detection by dye penetrant.

1.3.4.3 *Electrical*—continuity, loop resistance, and connector polarity.

1.3.4.4 *Radiographic inspection*.

1.3.4.5 *Thermoelement diameter*.

1.3.4.6 *Thermal response time*.

1.3.4.7 *Thermal cycle*.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 *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.*

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[1] These test methods are under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.04 on Thermocouples.

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

E3 Guide for Preparation of Metallographic Specimens

E94 Guide for Radiographic Examination

E112 Test Methods for Determining Average Grain Size

E165 Practice for Liquid Penetrant Examination for General Industry

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E207 Test Method for Thermal EMF Test of Single Thermoelement Materials by Comparison with a Reference Thermoelement of Similar EMF-Temperature Properties

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

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

E235 Specification for Thermocouples, Sheathed, Type K and Type N, for Nuclear or for Other High-Reliability Applications

E344 Terminology Relating to Thermometry and Hydrometry

E585/E585M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Base Metal Thermocouple Cable

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

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

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

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1129/E1129M Specification for Thermocouple Connectors

E1350 Guide for Testing Sheathed Thermocouples, Thermocouples Assemblies, and Connecting Wires Prior to, and After Installation or Service

E1684 Specification for Miniature Thermocouple Connectors

E1751 Guide for Temperature Electromotive Force (EMF) Tables for Non-Letter Designated Thermocouple Combinations (Withdrawn 2009)[3]

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

2.2 *ANSI Standard*

B 46.1 Surface Texture[4]

2.3 *Other Standard*

USAEC Division of Reactor Development and Technology RDT Standard C 2-1T Determination of Insulation Compaction in Ceramic Insulated Conductors August 1970

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E344 shall apply to these test methods.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bulk cable, n*—a single length of thermocouple cable produced from the same raw material lots after completion of fabrication.

3.2.2 *cable lot, n*—a quantity of finished mineral–insulated, metal-sheathed thermocouple cable manufactured from tubing or other sheath material from the same heat, wire from the same spool and heat, and insulation from the same batch, then assembled and processed together under controlled production conditions to the required final outside diameter.

3.2.3 *cold-lap, n*—sheath surface defect where the sheath surface has been galled and torn by a drawing die and the torn surface smoothed by a subsequent diameter reduction.

3.2.4 *insulation compaction density, n*—the density of a compacted powder is the combined density of the powder particles and the voids remaining after the powder compaction. Sometimes the insulation compaction density is divided by the theoretical density of the powder particles to obtain a dimensionless fraction of theoretical density as a convenient method to express the relative compaction.

3.2.5 *raw material, n*—tubing or other sheath material, insulation and wires used in the fabrication of sheathed thermocouple cable.

3.2.6 *short range ordering, n*—the reversible short-ranged, order-disorder transformation in which the nickel and chromium atoms occupy specific (ordered) localized sites in the Type EP or Type KP thermoelement alloy crystal structure.

3.2.7 *thermal response time, n*—the time required for a sheathed thermocouple signal to attain the specified percent of the total voltage change produced by a step change of temperature at the sheath's outer surface.

4. Summary of Test Methods

4.1 *Insulation Properties:*

4.1.1 *Compaction*—These tests ensure that the insulation is compacted sufficiently *(1)* to prevent the insulation from shifting during use with the possibility of the thermoelements shorting to each other or to the sheath, and *(2)* to have good heat transfer between the sheath and the thermoelements.

4.1.2 *Insulation Resistance*—The insulation shall be free of moisture and contaminants that would compromise the voltage-temperature relationship or shorten the useful life of the sheathed thermocouple. Measurement of insulation resistance is a useful way to detect the presence of unacceptable levels of impurities in the insulation.

4.2 *Sheath Properties:*

4.2.1 *Integrity*—These tests ensure that *(1)* the sheath will be impervious to moisture and gases so the insulation and thermoelements will be protected, *(2)* surface flaws and cracks that might develop into sheath leaks are detected, and *(3)* the sheath walls are as thick as specified.

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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] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

4.2.2 *Dimensions*—Determination of length, diameter, and sheath roundness are often necessary to assure proper dimensional fit.

4.2.3 *Sheath Ductility*—The sheath shall be ductile enough to bend the required amount without breaking or cracking.

4.3 *Thermoelement Properties Service Life:*

4.3.1 *Calibration*—This test ensures that the temperature-emf relationship initially corresponds to standardized tolerances.

4.3.2 *Size*—The thermocouple sheath and thermoelement sizes are related to the service life and the thermoelement spacing is related to possible low insulation resistance or shorting.

4.3.3 *Thermoelement Ductility*—Ductility of the thermoelements shall be sufficient to allow the assembly to be bent during assembly or service without significant damage to the thermoelements.

4.4 *Thermocouple Assembly Properties*—The criteria listed above shall apply to both thermocouple assemblies and to bulk cable. In addition, the following tests are important for thermocouple assemblies.

4.4.1 *Continuity*—The loop continuity test assures that the thermocouple assembly has a completed circuit.

4.4.2 *Loop Resistance*—The loop resistance test can detect shorted or damaged thermoelements.

4.4.3 *Polarity*—The connector polarity test indicates whether the connector is correctly installed.

4.4.4 *Moisture Seal*—The moisture seal at the reference junction end of the thermocouple, if faulty, may allow contamination of the insulation with moisture or gases.

4.4.5 *Radiography*—Radiographic examination of the junction and sheath closure weld can indicate faulty junctions and sheath closures that will lead to early failure. Most internal dimensions can also be measured from the radiograph.

4.4.6 *Response Time*—The thermal response time gives an indication of the quickness with which an installed thermocouple will signal a changing temperature under the test conditions.

4.4.7 *Thermal Cycle*—The thermal cycle test will offer assurance that the thermocouple will not have early failure because of strains imposed from temperature transients.

5. Significance and Use

5.1 This standard provides a description of test methods used in other ASTM specifications to establish certain acceptable limits for characteristics of thermocouple assemblies and thermocouple cable. These test methods define how those characteristics shall be determined.

5.2 The usefulness and purpose of the included tests are given for the category of tests.

5.3 **Warning—**Users should be aware that certain characteristics of thermocouples might change with time and use. If a thermocouple's designed shipping, storage, installation, or operating temperature has been exceeded, that thermocouple's moisture seal may have been compromised and may no longer adequately prevent the deleterious intrusion of water vapor. Consequently, the thermocouple's condition established by test at the time of manufacture may not apply later. In addition, inhomogeneities can develop in thermoelements because of exposure to higher temperatures, even in cases where maximum exposure temperatures have been lower than the suggested upper use temperature limits specified in Table 1 of Specification E608/E608M. For this reason, calibration of thermocouples destined for delivery to a customer is not recommended. Because the EMF indication of any thermocouple depends upon the condition of the thermoelements along their entire length, as well as the temperature profile pattern in the region of any inhomogeneity, the EMF output of a used thermocouple will be unique to its installation. Because temperature profiles in calibration equipment are unlikely to duplicate those of the installation, removal of a used thermocouple to a separate apparatus for calibration is not recommended. Instead, *in situ* calibration by comparison to a similar thermocouple known to be good is often recommended.

6. General Requirements

6.1 All the inspection operations are to be performed under clean conditions that will not degrade the insulation, sheath, or thermoelements. This includes the use of suitable gloves when appropriate.

6.2 During all process steps in which insulation is exposed to ambient atmosphere, the air shall be clean, with less than 50 % relative humidity, and at a temperature between 20 and 26°C (68 and 79°F).

6.3 All samples which are tested shall be identified by material code, and shall be traceable to a production run.

7. Insulation Properties

7.1 *Insulation Compaction Density*—The thermal conductivity of the insulation, as well as the ability of the insulation to lock the thermoelements into place, will be affected by the insulation compaction density.

7.1.1 A direct method for measuring insulation compaction density is applicable if a representative sample can be sectioned so that the sample ends are perpendicular to the sample length and the sheath, thermoelements, and insulation form a smooth surface free of burrs. The procedure is as follows:

7.1.1.1 Weigh the sample section,

7.1.1.2 Measure the sheath diameter and length with a micrometer,

7.1.1.3 Separate the insulation from the thermoelement and sheath with the use of an air abrasive tool,

7.1.1.4 Weigh the thermoelements and sheath, and

7.1.1.5 Determine the sheath and thermoelements densities either by experiment or from references.

7.1.1.6 Determine the percentage of the maximum theoretical insulation density ρ as follows:

$$\%\rho = 100(A - B)/\{[0.785\, C^2 D - (E/F + G/H)]J\} \tag{1}$$

where:

A = total specimen mass, kg or lb,
B = sheath and wires mass, kg or lb,
C = sheath diameter, m or in.,
D = specimen length, m or in.,
E = sheath mass, kg or lb,

F = sheath density, kg/m^3 or lb/in.^{3},
G = wires mass, kg or lb,
H = wires density (averaged density if applicable), kg/m^3 or lb/in.^{3}, and
J = maximum theoretical density of the insulation, kg/m^3 or lb/in.^{3}.

7.1.2 Alternately, a liquid absorption method for determining the insulation compaction density may be utilized for MIMS samples with outside diameters 1.5 mm (.062 in.) and larger. This method is based upon a procedure detailed in RDT C 2-1T and requires the following: (*1*) the sample ends shall be perpendicular to the sample axis and have a smooth, unglazed surface which will readily absorb liquid and shall be free of burrs, (*2*) the outer surfaces of the thermoelements and the inner surface of the sheath shall be smooth and non-absorbent, and (*3*) the insulation shall readily support capillary absorption through the entire length of the sample. This procedure is as follows:

7.1.2.1 Determine the density of kerosene for the temperature at which the measurement is being performed if other than 16ºC (60ºF).

7.1.2.2 Cut a specimen approximately 2.5 mm (1 in.) long.

7.1.2.3 Measure and record the inside diameter of the cable's sheath and the outside diameter of the cable's thermoelements to within .025 mm (.001 in.).

7.1.2.4 Weigh the specimen and record its weight.

7.1.2.5 Measure and record the specimen's length to within .025 mm (.001 in.) using a vernier caliper.

7.1.2.6 Immerse the specimen in kerosene for a minimum of 24 h.

7.1.2.7 Re-weigh the specimen and record its weight.

7.1.2.8 Determine the percentage of the maximum theoretical insulation density ρ as follows:

$$\%\rho = 100\left[1 - \left(\{Y - X\}/0.785\, S\, L\, \{O^2 - PR^2\}\right)\right] \tag{2}$$

L = specimen length, cm or in.,
O = inside diameter of sheath, cm or in.,
P = number of thermoelements in the cable,
R = outside diameter of thermoelements, cm or in.,
S = specific gravity of the kerosene absorbed at 16°C (60°F), .81715 g/cm^3 or .02952 lb/in^3,
X = weight of the specimen before kerosene is absorbed, g or lb, and
Y = weight of the specimen after kerosene is absorbed, g or lb.

7.2 *Insulation Compaction, Assurance Test*—This is a destructive test on representative samples that determines if the thermoelements are locked together with the sheath by the compacted insulation, but this test does not measure the compaction density per se. This test is the complement of the tests of 7.1 and 7.2 that measures the insulation compaction density but does not establish that the thermoelements are locked to the sheath, since there is no established minimum compaction density where locking begins. This test can be performed concurrently with the tension test in 8.5.3.

7.2.1 Cut a test specimen about 0.5 m (20 in.) long from one end of a bulk cable length and strip both ends of the specimen to expose a minimum of 10 mm (0.4 in.) of the thermoelements.

7.2.2 Without sealing the exposed insulation, clean the thermoelements of insulation to provide good electrical contact and twist the wires together on one end to form a thermocouple loop (see Fig. 1).

7.2.3 Measure the electrical resistance of the thermocouple loop to ±0.01 Ω and measure the length of the thermocouple loop to establish the electrical resistance per unit length.

7.2.4 Place the test sample in the tension testing machine so that *(1)* the grips clamp only on the sample sheath, *(2)* the force will be applied longitudinally on the sheath, and *(3)* there is at least a 0.25-m (10-in.) distance between the grips where the force will be applied (see Fig. 2).

7.2.5 Attach an ohmmeter capable of measuring ±0.01 Ω to the exposed thermoelements and measure the resistance with no tension force applied; also measure the distance between the tension tester grips to establish the initial length, L_0, of the test sample that will be elongated.

7.2.6 Calculate the initial resistance, R_0, of the test specimen section that will be elongated, using the unit length electrical resistance obtained in 7.2.3.

7.2.7 Make a simultaneous record of the electrical resistance and the elongation of the sheath while stretching the test sample until the thermoelements break.

7.2.8 Examine the exposed ends of the thermoelements to see whether they have been drawn into the insulation during the elongation; any shortening of the exposed ends indicates low compaction of the insulation.

7.2.9 Plot the fractional change of resistance ($\Delta R/R_0$) versus the fractional change of length ($\Delta L/L_0$). The slope of the plot reveals if the thermoelements were locked to the sheath throughout the plastic deformation of the sheath and, if not, where the thermoelements began to elongate in a different manner than the sheath. Examples of criteria to evaluate the insulation locking are given in X1.9

7.3 *Insulation Thickness Measurement*—Determine the insulation thickness, dimension *C* of Fig. 3, using either of the following methods:

7.3.1 A metallographic mount, prepared in accordance with Practice E3, of a polished cross section of the thermocouple or cable using a microscope having at least a 60× magnification and a 2.5-mm (0.1-in.) reticle graduated in at least 0.03-mm

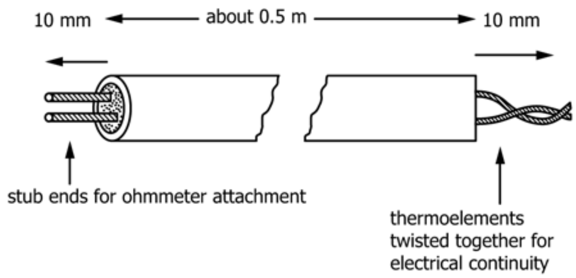


FIG. 1 Specimen of Sheathed Thermocouple Cable Prepared for Tension Testing

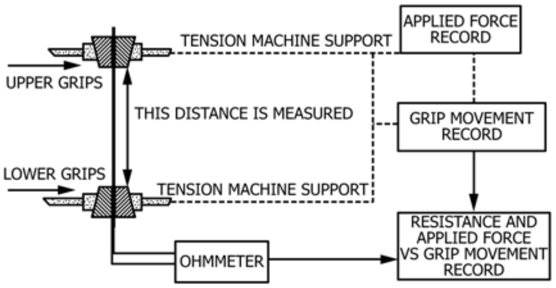
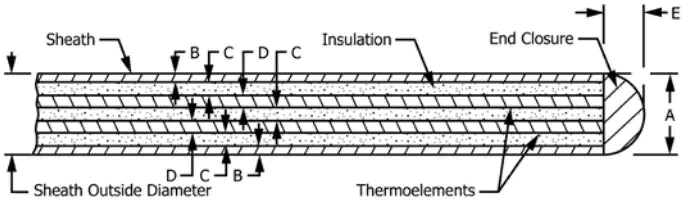
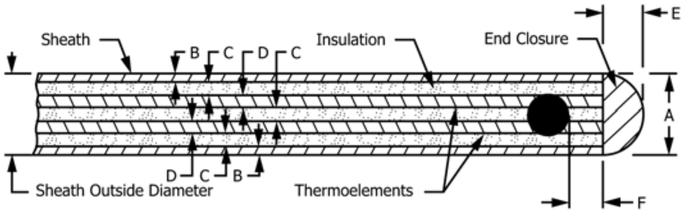


FIG. 2 The Thermocouple Positioned in the Tension Tester



(*a*) Style G Grounded Thermocouple Junction



(*b*) Style U Ungrounded Thermocouple Junction

FIG. 3 Sheathed Thermocouple Assembly

(0.001-in.) increments. This measurement test can be done at the same time as the measurements in 8.2.4.1 and 9.4.2.

7.3.2 A radiograph, or a projected enlargement of the radiograph, can be used with the microscope described in 7.3.1 to measure the insulation thickness C of Fig. 3 around the measuring junction. See also 10.7, Radiographic Inspection.

7.3.3 Sampling frequency, measurement tolerance, and insulation thickness shall be as stated in the standard specification relevant to the subject thermocouple. Examples of specifications for the insulation thickness are given in the Measuring Junction Configuration section of Specifications E608/E608M and E2181/E2181M for the junction area, in the General Dimensional Requirements of Specifications E585/E585M and E2181/E2181M and in Tables X1.1 and X1.2.

7.4 *Insulation Resistance, Room Temperature*—Measure the insulation resistance of sheathed thermocouple cable at room temperature using Test Method E780. Sampling frequency and insulation resistance shall be as stated in the relevant invoking thermocouple specification, or as agreed upon between the purchaser and the producer. See Table X1.3.

7.5 *Insulation Resistance, Elevated Temperatures*—The purpose of this test is to determine if the thermocouple insulation will be adequate for high temperature use of the thermocouple (**Warning—**All thermocouples may have changes in thermoelectric homogeneity produced by exposure to elevated temperatures; therefore, this test should be regarded as usually destructive.) Sampling frequency shall be as stated in the standard specification relevant to the subject thermocouple.

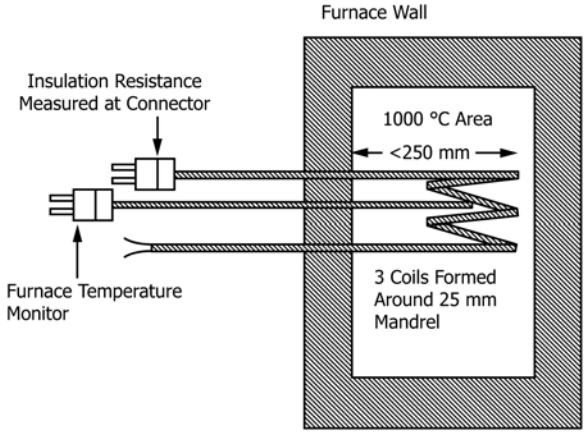
7.5.1 *Thermocouple Assembly*—Measure the electrical resistance between the thermocouple circuit and the sheath of a finished thermocouple assembly with a Style U ungrounded measuring junction (see Fig. 3) using the technique of Test Method E780. Insert the measuring junction of the finished thermocouple into a furnace or constant temperature bath to a depth that will yield maximum temperature stability (example: 20 sheath diameters). Then, the thermocouple junction can be heated to the test temperature. This procedure is not applicable to a Style G grounded measuring junction thermocouple assembly.

7.5.1.1 The minimum acceptable insulation resistance between the thermoelements and the sheath while the test specimen is at the specified elevated temperature shall be as stated in the standard specification relevant to the subject thermocouple assembly.

7.5.2 *Bulk Cable*—Insulation resistance tests on sheathed thermocouple cable at elevated temperatures have the purpose of determining *(1)* if excess moisture is in the insulation of the bulk cable, or *(2)* if the insulation contains excess impurities other than moisture, which will affect the insulation resistance at high temperatures.

7.5.2.1 *Elevated Temperature, Moisture and Impurities Combined*—The steps listed for this test are intended to evaluate the combined effects of insulation impurities and moisture contamination using elevated temperature insulation resistance testing of Type K or N bulk cable. **Warning—**Improper technique in constructing thermocouple assemblies can introduce additional insulation impurities and moisture contamination.

(1) Cut a specimen of approximately 1.2 m (4 ft) in length from the end of the bulk cable. Strip both ends of the sample about 25 mm (1 in.) to expose the thermoelements and at once seal the ends with an insulating sealant such as epoxy to prevent further moisture absorption. Wind the center section of the specimen around a 25-mm (1-in.) mandrel to form three coils, as shown in Fig. 4. The coils use about 0.3 m (1 ft) of the



NOTE 1—The ends of the test specimen are sealed with epoxy to prevent water vapor from being adsorbed or desorbed during the test.

FIG. 4 High Temperature Insulation Resistance Test Assembly to Test for Moisture Plus Impurities

specimen.

(2) Install a suitable connector on one end of the coil and test the room temperature insulation resistance as described in 7.4.

(3) Insert the sample coil into a furnace and bring the coil temperature to 1000 ± 10°C (1832 ± 18°F). The sealed ends of the sample should be kept near room temperature. Allow the sample to stabilize at 1000°C (1832°F) as measured by the furnace monitor thermocouple for at least 15 min.

(4) Measure the insulation resistance at the voltage and range appropriate for readability and the thermocouple sheath diameter. The charge time of the megohm tester should be at least 1 min before the measurement is recorded.

(5) Record the insulation resistance between each thermoelement, and from each thermoelement to the sheath.

7.5.2.2 *Elevated Temperature, Contaminants Other than Moisture*—The steps listed for this test evaluate the effects of impurities other than moisture in the insulation using insulation resistance testing of the bulk cable at elevated temperatures.

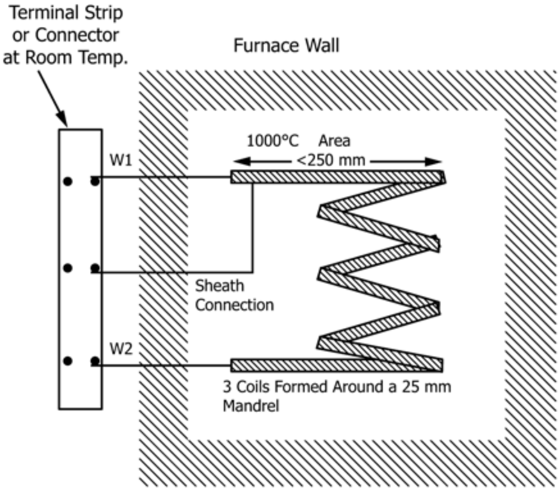
(1) Cut a specimen about 0.6 m (2 ft) long from the end of the bulk cable to be tested. Strip both ends about 25 mm (1 in.) to expose the thermoelements.

(2) Weld extension wires to each of the thermoelements and to the sheath, as shown in Fig. 5. The extension wires need not be the same composition as the thermoelements, but the extension wire must withstand the temperature of the test and the same composition extension wire should be used for all connections to the specimen.

(3) Wind the center section of the specimen around a 25-mm (1-in.) mandrel to form three coils, as shown in Fig. 5. The coils use about 0.3 m (1 ft) of the sample.

(4) Install a suitable terminal strip or connector to the extension wires, as shown in Fig. 5 and test the room temperature insulation resistance as described in 7.4.

(5) Insert the sample coil into a furnace so that the extension wires are in the same uniform temperature zone as the coil and bring the coil temperature to 1000 ± 10°C (1832 ± 18°F). Allow the sample to stabilize at the test temperature as measured by the furnace monitor thermocouple for at least 15 min.



Note 1—The ends of the test specimen are not sealed, allowing water vapor to escape before measuring the insulation resistance

FIG. 5 High Temperature Insulation Resistance Test, Insulation Contamination Other Than Moisture

(6) Measure the insulation resistance at the voltage appropriate for the thermocouple sheath diameter. The charge time of the megohm tester should be at least 1 min before the measurement is recorded.

(7) Record the resistance between each thermoelement, and from each thermoelement to the sheath.

8. Sheath Properties

8.1 *Sheath Integrity*—Leakage of air or moisture into the sheath can be detrimental to the life and local homogeneity of the sheathed thermoelements. Penetrations of the sheath may be caused by holes left during the fabrication of the sheath tubing, cracks due to welding, holes because of incomplete closures at either of the measurement ends, or other mechanical damage. Two major methods, water penetration and mass spectrometer measurements of helium penetration, are commonly used to assess sheath integrity. The mass spectrometer method is the most sensitive and the only one that can be used with Style G grounded measuring junction thermocouples. These sheath integrity test methods are given in order of increasing test sensitivity and difficulty. Before any sheath integrity tests are performed, wipe the sheath with a rag dampened in solvent, such as alcohol, to remove oily surface contaminants.

8.1.1 *Fast Sheath Integrity Test Using Water*—This test is usually performed on bulk cable using a less sensitive ohmmeter and a lower voltage test than the test used in 8.1.2; it is the fastest test, intended to detect the larger sheath penetrations.

8.1.1.1 Strip one end of the length of sheathed cable to expose at least 6 mm (0.25 in.) of thermoelements.

8.1.1.2 Check the opposite end of the length for any evidence of shorting of thermoelements to the sheath.

8.1.1.3 Seal the exposed ends of the compacted oxide insulation with an insulating sealant to prevent the absorption of water vapor.

8.1.1.4 Using a direct-current (dc) ohmmeter, reading to at least 20 megohm, connect the ground lead to the cable sheath and the other test lead to either thermoelement.

8.1.1.5 Then, slowly wipe the length of the sheath with a rag saturated with cold tap water. Apply a light pressure to the rag circumferentially around the sheath when wiping and start wiping from the end opposite the instrument connection.

8.1.1.6 As an alternative, immerse the entire cable length, in a coil if necessary, in tap water, except for 2 %, but not to exceed 0.3 m (1 ft), at each end.

8.1.1.7 With the ohmmeter range selection switch on the most sensitive readable range, interpret any noticeable reduction of insulation resistance as evidence of a leak in the sheath.

8.1.1.8 The leaking section may be cut from the length of cable and this test repeated to determine the acceptability of the remaining portion of the finished length.

8.1.2 *Basic Sheath Integrity Test Using Water.*

8.1.2.1 Strip one end of the length of sheathed cable to expose at least 6 mm (0.25 in.) of thermoelements.

8.1.2.2 Check the opposite end of the length for any evidence of shorting of thermoelements to the sheath.

8.1.2.3 Seal the exposed ends of the compacted oxide insulation with an insulating sealant to prevent the absorption of water vapor.

8.1.2.4 Using a megohmmeter on the most sensitive readable range with an applied voltage at a minimum of 10 Vdc and at a maximum of 50 Vdc, measure the insulation resistance between the sheath and thermoelements.

8.1.2.5 Then, using a clean rag saturated with unheated tap water dripping from the rag, wipe along the length of the sheath from the end opposite the instrument connection at a rate between 40 to 50 mm/s (7.9 to 9.8 ft/min) applying a light pressure to the rag circumferentially around the sheath, thereby forcing the water into and through any fissure in the sheath wall. Set the cable aside for at least 30 min after application of the water.

8.1.2.6 A more discriminating method to ensure detecting exceptionally small leaks is to immerse the entire length (coiled if necessary), including the welded measuring junction end, in unheated tap water. Allow up to 2 %, but no more than 0.3 m (1 ft) of length on ends with insulating sealant to remain out of the water. Leave the cable immersed in the water for a minimum of 16 h.

8.1.2.7 After the exposure to the water as required in 8.1.2.5 or 8.1.2.6, repeat the insulation resistance test of 8.1.2.4. Interpret a noticeable reduction in insulation resistance immediately upon exposure to the water, or after completion of either technique selected, as evidence of a leak in the sheath.

8.1.2.8 A technique to locate the leak, if one is detected, is to leave the voltage applied while the sheathed cable is exposed to the water. This will often pinpoint the location of a leak by emitting bubbles due to the electrolysis of the water.

8.1.2.9 The leaking section of the length of cable may be removed and this test repeated to determine acceptability of the remaining portion of the finished length.

8.1.3 *Sheath Integrity, Mass Spectrometer Method:*

8.1.3.1 Test the sheath and measuring end closure as follows: Weld, or otherwise hermetically seal the reference junction end to prevent the detrimental absorption of moisture. Wipe the test item clean with a cloth saturated with a solvent such as alcohol. Externally pressurize the sheath and measuring end closure with helium to at least 7.0 Mpa (66 atm) for a period of 5 to 10 min. Exclude the reference junction end moisture seal from helium pressurization to preclude damage. Wipe the test item again with a solvent-saturated cloth and insert it into a test chamber within 2 h of pressurization. Evacuate the interior of this chamber to a pressure of 7 kPa (50 mm Hg) or less, and test for the presence of helium using a mass spectrometer-type helium-leak detector. Monitor the test chamber for a time period of at least three times the system time response (see 8.1.3.3). Take an indication of helium leakage of 6×10^{-6} standard cubic centimeters per second as evidence of a leak.

8.1.3.2 Determine the sensitivity of the leak detector combined with the evacuated test chamber, hereafter called the system, using a standard leak or a calibrated leak of known leak rate before and after each test, or group of tests, on a given day. If the second sensitivity test shows system sensitivity less than the minimum value specified below, repeat all intervening leak tests on the item being tested.

8.1.3.3 Introduce the standard or calibrated leak into the system at the point farthest from the leak detector. The mass spectrometer-type helium-leak detector shall demonstrate a minimum system sensitivity of 3×10^{-9} standard cubic centimeters of helium per second as indicated on the smallest scale division on the leak detector meter. A leak rate of 6×10^{-9} standard cubic centimetres of helium per second shall produce an additional deflection on the leak-detector meter at least equal to the deflection produced by the combined background and noise signal from the leak detector itself. Perform the system sensitivity test as follows:

(1) With the standard, or calibrated leak at the location described above, introduce the standard leak into the system.

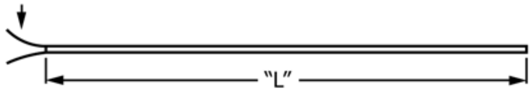
(2) Determine the time required for the leak detector to indicate a constant-leak rate caused by the standard leak. The system time response is defined as the time required to obtain the constant leak-detector indication.

(3) Note the constant-leak rate, and use this value to determine the system sensitivity.

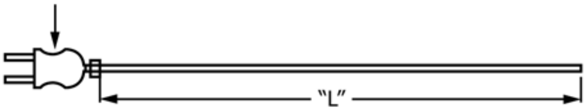
8.2 *Sheath Dimensions*—The sheath dimension measurements shall apply to either bulk cable or completed thermocouple assemblies.

8.2.1 *Sheath Length*—Measure the thermocouple assembly sheath length while the thermocouple assembly is lying straight on a level surface. Gentle axial tension may be applied to the thermocouple assembly to straighten sheath curvature during measurement. Make the measurements from the tip of the sheath closure to the start of the connector, the moisture seal, the transition piece, or the exposed wires (as shown in Fig. 6) using a steel tape or ruler with gradations of 2 mm (0.08 in.) or less.

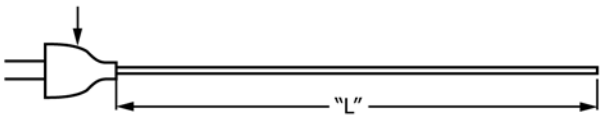
8.2.2 *Sheath Diameter*—Measure the outside diameter of the sheath at five random points along its length with an optical comparator, diameter gage, micrometer, or vernier calipers. If a micrometre or vernier calipers is used, readings shall be taken



(a) Exposed Wire Leads



(b) Connector



(c) Transition Piece

FIG. 6 Length Measurements of Thermocouple Assemblies

120° apart at each measurement point. Limits of sheath diameter variation shall be as stated in the standard specification relevant to the subject thermocouple. See Table X1.4.

8.2.3 *Sheath Roundness*—The difference between the maximum and minimum outside diameter measurements at any of the points from 8.2.2 shall be considered the roundness. The value of roundness tolerance shall be as stated in the standard specification relevant to the subject thermocouple. See X1.4.

8.2.4 *Sheath Wall Thickness*—Determine the sheath wall thickness, dimension B of Fig. 3, using either of the following two methods:

8.2.4.1 A metallographic mount, prepared in accordance with Practice E3, of a polished cross section of the thermocouple or cable using a microscope having at least a 60× magnification and a 2.5-mm (0.1-in.) reticle graduated in at least 0.03-mm (0.001-in.) increments. This measurement test can be done at the same time as the measurements in 7.3 and 9.4.2.

8.2.4.2 A radiograph, or a projected enlargement of the radiograph, can be used with the microscope described in 8.2.4.1 to measure the sheath wall thickness B of Fig. 3 around the measuring junction. See also 10.7, Radiographic Inspection.

8.2.4.3 Sampling frequency, sheath wall thickness and allowable variations of the sheath wall thickness shall be as stated in the standard specification relevant to the subject thermocouple. Examples of specifications for the sheath wall thickness are given in the Measuring Junction Configuration section of Specifications E608/E608M and E2181/E2181M for the junction area, in the General Dimensional Requirements of Specifications E585/E585M and E2181/E2181M and in Tables X1.1 and Table X1.4

8.3 *Sheath Surface*—There are no quantitative tests defining the conditions of the sheath cleanliness or reflectivity, and only semi-quantitative tests for surface roughness. The number of pieces of finished thermocouple cable to be tested and the criteria for acceptance shall be as stated in the standard specification relevant to the subject thermocouple.

8.3.1 *Gross Visual*—Visually examine the sheath surface of the thermocouple to verify that the sheath appears to be clean and has the specified color and brightness.

8.3.2 *Surface Finish*—Compare the surface of the sheath roughness standards in accordance with ANSI B46.1 to ensure a surface roughness that is no more than specified.

8.3.3 *Dye Penetrant Method*—Examine the surface of the sheath for any indications of cracks, seams, holes, or other defects when tested with dye penetrant in accordance with Test Method E165, Procedure A-2. Procedure A-2 is a post-emulsifiable fluorescent liquid penetrant inspection method. **Warning—**The Special Requirements section of Test Method E165 restricts the use of some solvents with some sheath materials.

8.3.4 *Sheath Condition Test*—This test is intended to detect cold-laps in the thermocouple sheath and can be performed at the same time as the tension test in 8.5.3 or the insulation compaction assurance test in 7.2.

8.3.4.1 Cut a test sample about 0.5 m (20 in.) long from one end of a bulk cable length and place the specimen in the tension testing machine as described in 7.2 and shown in Fig. 2.

8.3.4.2 After the tension specimen has been stretched to breaking, scrape a fingernail along the sheath surface of the stretched section; any sharp projections indicate cold-laps in the sheath surface.

8.4 *Metallurgical Structure of the Sheath*—Select samples of each production run with the location and number of samples as stated in the specification relevant to the subject thermocouple.

8.4.1 *Grain Size*—Examine a section from the sample thermocouple cable for grain size of the sheath using Practice E3 to prepare the metallographic specimen. Use Test Methods E112 to determine average grain size.

8.4.2 *Sheath Wall Defects*—Examine the metallographic specimen for sheath wall cracks or localized wall thinning, using the method in 8.2.4.

8.4.3 *Acceptance Criteria*—The acceptable grain size and wall defects acceptance levels shall be agreed upon between the purchaser and the producer. Sections 5.1.1 and 6.7 of Specification E235 may be used as a guide.

8.5 *Sheath Ductility:*

8.5.1 These tests are useful when it is important for thermocouple cable with a sheath of either austenitic stainless steel or nickel-chromium-iron alloy to be ductile. These are destructive tests, performed on one sample from each production run, unless otherwise specified.

8.5.2 *Sharp Bend Test*—Closely wind the selected section of the sheathed thermocouple cable three full turns around a mandrel with a diameter twice the sheath diameter. Check the continuity of each thermoelement and insulation resistance between each thermoelement and the sheath and all other thermoelements within the cable before and after bending (see X1.4.1).

8.5.2.1 Cut the center turn from the section and examine under 30× magnification. Any visual evidence of sheath cracking shall be an indication of failure.

8.5.3 *Tension Test*—This test is an alternative to the sharp bend test in 8.5.2 and can be performed at the same time as the insulation compaction assurance test in 7.2.

8.5.3.1 Cut a test sample about 0.5 m (20 in.) long from one end of a bulk cable length and place the sample in the tension testing machine as described in 7.2 and shown in Fig. 2.

8.5.3.2 Measure the distance between the grips of the tension testing machine to establish the initial length, L_0, of the test sample that will be elongated.

8.5.3.3 Stretch the test sample while recording the applied force and the amount of elongation until the test sample breaks.

8.5.3.4 Find the yield force of the test sample by drawing a line parallel to the initial straight line but offset by 0.3 % on a plot of the force versus elongation (stress-strain plot). The yield force is that indicated where the parallel offset line intercepts the plot (see Fig. 7).

8.5.3.5 The acceptance criteria for yield force and sheath rupture shall be as stated in the standard specification relevant to the subject thermocouple (see X1.4).

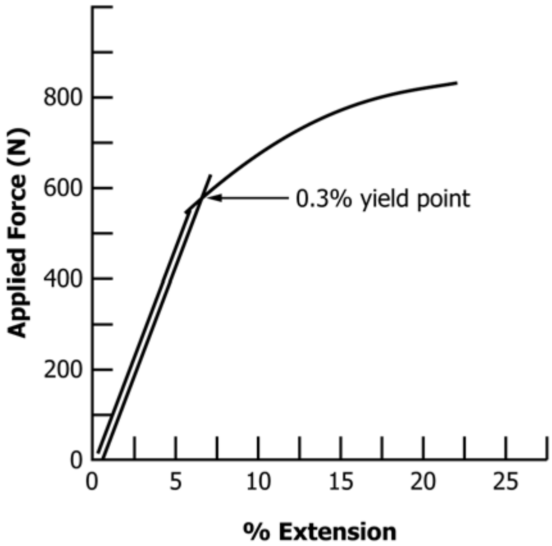


FIG. 7 Tension Test Evaluation of Thermocouples

9. Thermoelement Properties

9.1 *Calibration*—Test Method E220 describes suitable calibration techniques. Specification E230 lists the temperature-electromotive force (emf) tables for standard base metal, noble metal and refractory metal thermocouples and Guide E1751 lists temperature-emf tables for selected non-standard thermocouples. If agreed between the producer and user, Test Method E207 may be used to calibrate the individual thermoelements against a secondary reference standard. Because of varied requirements, calibration temperatures and accuracies shall be specified in the purchase documents. **Warning—**Type E and K thermoelements will experience changes in thermoelectric homogeneity produced by exposure to temperatures in the 320 to 540°C (600 to 1000°F) temperature range. Calibration of Types E and K thermocouple assemblies should be regarded as a possibly destructive test for subsequent use of the thermocouple assembly and should only be used to characterize a production run. (See 5.3.)

9.1.1 *Assembly Calibration Tests:*

9.1.1.1 Assemblies selected randomly from the production run shall be calibrated by Test Method E220.

9.1.1.2 The emf of the test assemblies shall be measured at each of the specified temperatures that range to the limits appropriate for the type and sheath size of thermocouples as shown in Table X1.5 or to lesser limits as stated in the standard specification relevant to the subject thermocouple.

9.1.1.3 The number of specimens randomly selected from the production run shall be as stated in the standard specification relevant to the subject thermocouple.

9.2 *Homogeneity*—Until standardization of a pending test method, homogeneity shall only be performed by agreement between the producer and the user.

9.3 *Short-Term Drift Test*—The purpose of this test is to ensure that manufacturing processes, such as contaminated insulation, incomplete annealing or residual cold work, will not result in changes of Seebeck coefficient in the thermoelements after they are brought to temperature. **Warning—**Some thermoelements, such as Type E or K, will have changes of thermoelectric homogeneity produced by this test and the test should be considered potentially destructive.

9.3.1 *Sheathed Thermocouple Drift*—Place the thermocouple in a protective tube with an inert atmosphere if the sheath is known to lose its protective ability after contact with air at the test temperature.

9.3.1.1 Place the test thermocouple in the test furnace so that it is at the same temperature as a reference temperature sensor that has been proven to drift less than 1 % of the acceptance criteria during the test period.

9.3.1.2 Heat the furnace to the test temperature as stated in the standard specification relevant to the subject thermocouple but limited to the upper temperature limits appropriate for the thermocouple's sheath material and diameter.

9.3.1.3 After the test thermocouple has stabilized at temperature, compare the emf of the test thermocouple to the stable reference temperature sensor for a period of 2 h.

9.3.1.4 The acceptance criteria for drift stability shall be as stated in the standard specification relevant to the subject thermocouple. A common criterion is that the emf of the thermocouple assembly should not drift more than the standard or special tolerances for that type thermocouple (see Table X1.6).

9.4 *Thermoelement Diameter*—The thermoelement diameter in the thermocouple assembly can be measured using any of the following three methods.

9.4.1 Strip the sheath and insulation from four random locations to obtain four 25 mm (1 in.) lengths of the thermoelements. Measure the diameter of the thermoelement midway of the sample length with an optical comparator, diameter gage, micrometer, or vernier caliper. If a micrometer or vernier caliper is used, the readings are to be 120° apart.

9.4.2 A metallographic mount prepared in accordance with Practice E3 of a polished cross section of the thermocouple or cable can be used with a microscope having at least a 60× magnification and a 2.5-mm (0.1-in.) reticle graduated in at least 0.03-mm (0.001-in.) increments to measure the diameters of the thermoelements. This measurement can be done at the same time as the measurements in 7.3 and 8.2.4.1.

9.4.3 A radiograph, or a projected enlargement of the radiograph, can be used with the microscope described in 9.4.2 to measure the thermoelement diameter at 25 mm (1 in.) intervals along a length of 200 mm (8 in.) of the radiograph. See also 10.7, Radiographic Inspection.

9.4.4 Use the average of the measurements made in 9.4.1 and 9.4.2 as the diameter of the thermoelement.

9.4.5 The thermoelement size and tolerance shall be as stated in the standard specification relevant to the subject thermocouple (see Tables X1.1 and X1.2).

9.5 *Thermoelement Roundness*—The difference between the maximum and minimum thermoelement diameters shall be considered the roundness and shall be determined from the measurements of 9.4. The value of the thermoelement roundness tolerance shall be as stated in the specification relevant to the subject thermocouple.

9.6 *Thermoelement Surface Appearance*—Examine the samples obtained for the test in 9.4.1 for surface nicks or voids with a microscope of at least 30× magnification. The size of the allowable defects shall be as stated in the specification relevant to the subject thermocouple.

9.7 *Thermoelement Spacing*—The thermoelement spacing in the finished assembly is measured as the dimension *C* in Fig. 3, using the metallographic mount and optical method described in 7.3, 8.2.4, and 9.4.2.

9.7.1 The acceptance criteria for thermoelement spacing shall be as stated in the standard specification relevant to the subject thermocouple.

9.7.2 Examples of thermoelement spacing, which is the same as the insulation thickness, are shown in Table X1.1 and Table X1.2.

9.8 *Thermoelement Ductility*—The thermoelement ductility shall be determined concurrently with the sheath ductility and flexibility tests in 8.5 (see X1.4).

9.9 *Thermoelement Metallurgical Structure*—Examine a section of the sample thermoelement for grain size and intergranular inclusions using Practice E3 to prepare the metallographic specimen. Use Test Methods E112 to determine the average grain size.

9.9.1 The acceptance criteria for grain size and intergranular inclusions shall be as stated in the specification relevant to the subject thermoelement.

10. Thermocouple Assembly Properties

10.1 The thermocouple assembly is the finished product and usually only nondestructive tests are performed on the assembly, whereas the destructive tests are confined to selected bulk cable specimens. If destructive tests, such as high temperature drift, calibration, ductility, or metallographic examination of the thermocouple assembly are desired, the tests are performed on selected specimens in the same manner as described for the bulk cable.

10.2 *Dimensions*—The dimensions are for completed thermocouple assemblies. The dimensional tolerances shall be as stated in the standard specification relevant to the subject thermocouple.

10.2.1 *Length*—The thermocouple assembly length shall be the distance from the tip of the sheath closure to the start of the connector, the transition piece, or the moisture seal, as shown in Fig. 6.

10.2.2 *Diameter*—Measure the outside diameter of the sheath at the junction end sheath closure and at five additional random points along its length with an optical comparator, diameter gage, micrometer, or vernier caliper. If a micrometer or vernier caliper is used, readings shall be taken 120° apart at each measurement point.

10.2.3 *Roundness*—The difference between the maximum and minimum outside diameter shall be considered the roundness and shall be determined by a micrometer or vernier caliper reading to find the high and low points around the circumference for any one cross section of the sheath. Examples—Typical roundness tolerances are given in Table X1.4.

10.3 *Sheath Surface*—There are no quantitative tests defining the conditions of the sheath cleanliness or reflectivity, and only semi-quantitative tests for surface roughness. The number of pieces of finished thermocouple assemblies to be tested and the criteria for acceptance shall be as stated in the standard specification relevant to the subject thermocouple.

10.3.1 *Gross Visual*—Visually examine the sheath surface of the thermocouple to verify that the sheath is not bent, kinked, or nicked, appears to be clean, and has the specified color and brightness. Visually examine the connector and sheath closure for the appearance of proper installation.

10.3.2 *Dye Penetrant Method*—Examine the surface of the sheath in the region of, and including, the weld closure for any indication of cracks, seams, holes, or other defects when tested with dye penetrant in accordance with 8.3.3.

10.3.3 *Surface Finish*—Compare the surface of the sheath to roughness standards in accordance with ANSI B46.1 to ensure that the surface is no rougher than specified.

10.4 *Moisture Seal*—This seal at the reference junction end of the thermocouple may be examined with the aid of a 10× optical magnifier to ensure that the seal material coats the compacted oxide insulation and is bonded to the thermoelements and sheath and is free of cracks, fractures, holes, or bubbles that violate the seal's integrity, rendering it ineffective.

10.4.1 *Moisture Seal Integrity Test*

10.4.1.1 This test evaluates the moisture resistance of the seal by creating a pressure differential across it to promote moisture migration, thus causing a degradation of the thermocouple's insulation resistance. This test is not designed to stress or destroy an intact thermocouple moisture seal. This test shall be performed on a thermocouple with an ungrounded measuring junction. For a grounded junction thermocouple, the manufacturer may perform an in-process test using a temporary ungrounded junction and welded end closure prior to fabricating the final grounded measuring junction. If the thermocouple includes extension wire or other components that would be damaged by water submergence, the moisture seal test may be performed prior to the addition of the extension wire or components.

10.4.1.2 *Apparatus Required:*

(1) Furnace-A furnace operating at 80+10/-0ºC (176+18/-0ºF) that is of sufficient size to accept the moisture seal and a minimum of 500 mm (20 in.) of the thermocouple's adjacent metal sheath length.

(2) Container of Water-A container of tap water that is of sufficient size to allow complete immersion of the thermocouple's moisture seal. Tap water is used because it is conductive. The use of purified water, such as deionized water, will decrease the probability of detecting a degradation of insulation resistance.

(3) Insulation Resistance Measuring Instrument-Refer to Test Method E780.

10.4.1.3 *Procedure:*

(1) Verify that the initial insulation resistance of the thermocouple exceeds the minimum acceptance criteria described in Table 3 of Specification E235 or in Table 4 of Specification E608/E608M or Specification E2181/E2181M using Test Method E780. Do not proceed with testing a thermocouple that does not satisfy this minimum insulation resistance criteria.

(2) Place the entire thermocouple assembly or the thermocouple's moisture seal and at least 500 mm (20 in.) of adjacent sheath into the furnace described in 10.4.1.2, Item 1, for a minimum of 1 h after the furnace reestablishes its 80ºC (176ºF) thermal equlibrium. The 80ºC (176ºF) temperature was chosen to create a pressure differential during 10.4.1.3, Item 3, with minimal mechanical stress and physical damage to the thermocouple's seal.

(3) Remove the heated thermocouple from the furnace and immerse it directly into the container of water described in 10.4.1.2, Item 2, making sure that the thermocouple's moisture seal and a minimum of 500 mm (20 in.) of adjacent sheath are fully immersed. The transfer time from the furnace to the water shall not exceed 15 s.

(4) Allow the thermocouple to soak in the water for at least 1 h.

(5) Remove the thermocouple from the water and blot off any residual water. Within 1 h of removing the thermocouple from the water, measure its insulation resistance using Test Method E780 and verify that the results continue to exceed the minimum acceptance criteria in Table 3 of Specification E235 or in Table 4 of Specification E608/E608M or Specification E2181/E2181M.

10.5 *Electrical Properties*—Measure the electrical properties of the thermocouple assembly before the thermocouple is placed in service in order that any subsequent deterioration of the thermocouple during service can be detected by comparing *in situ* measurements with archive data for the specific thermocouple assembly. Reference Guide E1350.

10.5.1 *Electrical Continuity*—Verify the electrical continuity of each assembly by attaching a commercial ohmmeter to the pins or the lead wires of the connector, unless continuity is measured as a part of another test.

10.5.2 *Loop Resistance*—The electrical resistance of the joined thermoelement circuit, or loop resistance in each thermocouple assembly shall be measured at room temperature using an ohmmeter capable of measuring to ± 0.01 Ω.

10.5.2.1 Measure the ohmmeter lead resistance and subtract that resistance from all subsequent measurements of the thermocouple loop resistance.

10.5.2.2 Measure the loop resistance in the direct and reverse polarity and record the average of the two measurements as the thermocouple loop resistance.

10.5.2.3 Loop resistance measurements of specimens in a given production lot shall be averaged to obtain a mean value. Acceptable tolerances of individual deviation from the mean value shall be as stated in the standard specification relevant to the subject thermocouple.

10.5.3 *Connector Polarity*—Verify the polarity of the thermocouple assembly by attaching the positive lead of a microvoltmeter to the positive pin or lead of the thermocouple connector and the negative lead of the microvoltmeter to the negative pin or lead of the thermocouple connector. Gently heat the junction end of the thermocouple assembly until it is warmer than the connector end and a significant indication on the microvoltmeter is observed. A negative voltage polarity indicates an improperly installed connector and the assembly connector must be removed and reinstalled with the correct polarity. The compatibility of the thermocouple connector with the thermoelements can be determined by the methods given in Specification E1129/E1129M and Specification E1684.

10.6 *Insulation Tests*—These tests provide comparative indications of insulation resistance, which have two effects on temperature measurements. First, the insulation at high temperature provides an electrical leakage path across the thermocouple; this can substantially change or invalidate its output. Second, the insulation resistance is very sensitive to contaminants, which will adversely affect the thermoelement homogeneity over a period of time. No correlation has been developed between room temperature and high-temperature insulation resistance tests; both are utilized by different users. Test Method E780 is a proven technique for measuring room temperature insulation resistance.

10.6.1 *Room Temperature Insulation Resistance*—This test can be performed only on Style U ungrounded measuring junction thermocouples (see Fig. 3).

10.6.1.1 Measure the insulation resistance, at room temperature, between the thermocouple connector pins or leads and the sheath using Test Method E780. The sampling frequency and insulation resistance shall be as stated in the standard specification relevant to the subject thermocouple (see Table X1.3).

10.7 *Radiographic Inspection*—The radiographic inspection can be used to determine the wire diameter and uniformity (see 9.4.3) or to inspect for sheath flaws. Usually, however, the radiographic inspection is confined to the measuring junction region of the thermocouple assembly.

10.7.1 Radiograph a minimum of 100 mm (4 in.) of the length of the thermocouple assembly, including the measuring junction and the weld closure.

10.7.2 Radiograph the thermocouple assembly in two directions 90° apart and perpendicular to the thermocouple axis.

10.7.3 Perform the radiography in accordance with Guide E94.

10.7.4 The design of the penetrameter shall be as specified in Method E1025, Fig. 1, except as follows: The penetrameter shall be 0.13 mm (0.005 in.) thick, of the design shown in Fig. 1 of Method E1025, detail for design for penetrameter thicknesses from 0.13 mm (0.005 in.) and including 1.3 mm (0.050 in.). The 1T hole diameter shall not be greater than 0.13 mm (0.005 in). The diameters of the 2T and 4T holes shall be no greater than 0.25 mm (0.010 in.) and 0.50 mm (0.020 in.), respectively. The penetrameter and its 1T hole shall be visible when radiographed on a block of material of the same nominal composition as the thermocouple sheath and equal in thickness to twice the nominal sheath wall thickness, mounted on an aluminum oxide or plastic block, or shim, such that the top of the penetrameter is at the same height as the top of the thermocouple sheath. The block, or shim, shall be at least 6.5 mm (0.255 in) wider and longer than the penetrameter, which shall be centered on the block. Refer to Tables X1.7 and X1.8. The placement of the block and the penetrameter shall be normal to the radiation beam and on the source side of the film. The block shall be no closer than 1.3 mm (0.50 in.) to the nearest thermocouple sheath.

10.7.5 The density of the individual films, as measured by a densitometer, shall be in the range from 2.0 to 3.0 density units in the area being examined. The film density at the penetrameter shall be within ±0.2 density *units* of that in the area of the thermocouple junction being examined.

10.7.6 The use of nonfilm techniques is permitted.

10.7.7 Acceptance criteria shall be as stated in the standard specification relevant to the subject thermocouple.

10.7.8 *Junction Dimensions*—For Style U ungrounded measuring junction thermocouples, measure the junction dimension F in Fig. 3 as the smallest distance obtained from either of the two radiographs made at 90° angles.

10.7.9 *Thermoelement Diameter*—Measure the thermoelement diameter in the assembly from the radiographs as described in 9.4.3.

10.8 *Thermal Response Time*—Thermal response time is a useful measurement if the thermocouple application requires measurements or controls to quickly follow temperature changes. The presence of a thermowell will make the thermal response time much longer and it is sometimes necessary to measure the response time of a thermocouple installed in a thermowell. The thermal response time shall then be reported as that for the combination of thermocouple-thermowell.

NOTE 1—The thermal response time is a function of the rate of heat flow into or out of the thermocouple assembly. The heat flow between the thermoelements and the sheath is affected by the type, thickness, and amount of compaction of the insulation between the sheath and the thermoelements. The heat flow between the sheath and the surrounding fluid is a function of the type of fluid and the boundary layer conditions which, in turn, are determined by the velocity, temperature, turbulence, etc. of the fluid. These external conditions must be controlled to obtain reproducible response time measurements.

10.8.1 *General Test Method*—The test thermocouple assembly is stabilized at room temperature and then immersed rapidly in a flowing fluid, usually water, at an elevated temperature. The voltage from the thermocouple assembly is measured as a function of time until it reaches thermal equilibrium. The time from the instant of immersion until the voltage has attained the specified percentage of its total change is recorded as the thermal response time.

10.8.2 *Temperature Control*—It is necessary to measure the thermocouple's voltage change to within 1μV during the test in order to obtain an accuracy of 0.5 % for the time for 63.2 % of the voltage range. The thermal response time is the time-dependence of the voltage change and has only a weak dependence on the absolute temperature, so it is not necessary to know either the room or bath temperature with great precision. It is necessary, however, that both the bath and room temperatures be stable during the test.

10.8.3 *Apparatus*—A typical water bath arrangement is shown in Fig. 8.

10.8.3.1 *Water Bath*—The bath consists of a drum fitted with radial flow baffles and mounted on a vertical shaft driven by an adjustable speed motor. The water velocity past the fixed thermocouple is equal to the product $[(2\pi R) \times (\text{rotations per second})]$, where R is the distance from the thermocouple to the center of rotation and the rotations per second are the uniform rate of the drum rotation. This system provides a known and adjustable water velocity. A practical upper limit of fluid velocity for water is about 1 m/s (3 ft/s), since at higher flow rates fluid separation may occur, resulting in significant error. The effects of variations of fluid velocity become large at low velocity, so more consistent results are produced if the bath velocity is maintained at just the upper limit of 1 m/s (3 ft/s). The water is circulated through an external heater using a pump with the pump intake at the bottom-center of the drum and the pump discharge at the top outer edge of the drum; an arrangement that provides a uniform radial and axial water temperature. The heater power is controlled to regulate the bath water temperature to a minimum of 10 °C above room temperature.

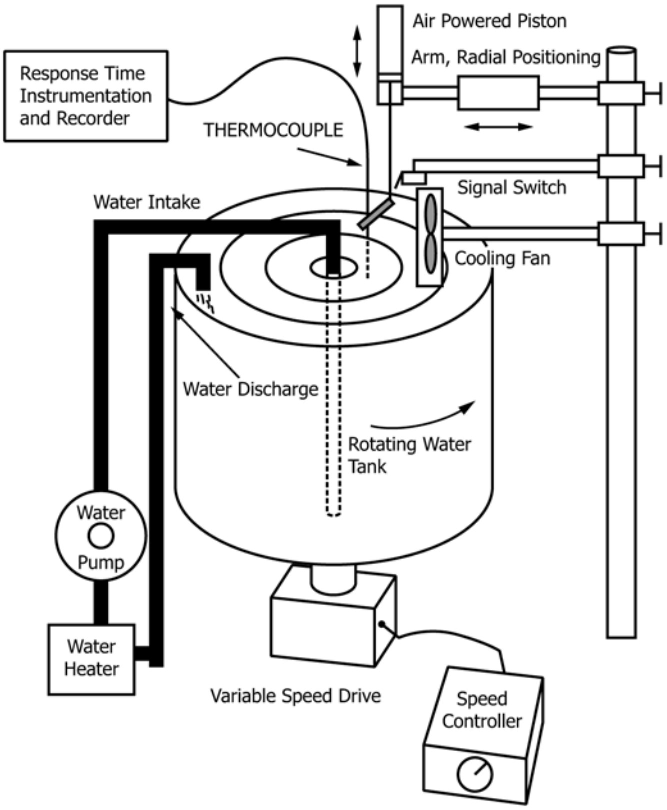


FIG. 8 Thermal Response Time Apparatus

10.8.3.2 *Thermocouple Assembly Mount*—The thermocouple assembly is held on the end of a movable arm that positions it at a fixed radius in the bath. The arm is driven by an air-powered cylinder, or other means, and adjusted to obtain insertion speeds equal to the bath rotational velocity, usually 1 m/s (3 ft/s). The arm in its raised position allows the thermocouple to stabilize at room temperature in the fan draft before being plunged into the rotating water bath. A switch activated by the movable arm and adjusted to close just as the thermocouple sheath touches the bath, signals the start of the timing period.

10.8.3.3 *Voltage Recorder*—A readout circuit compatible with the thermocouple voltage change and having a linear voltage output suitable for a voltage-versus-time recorder can be used. The time base of the recorder shall be calibrated. The recorder must be started by, or in some way indicate, the signal from the movable arm switch. The recording must contain the time-voltage measurement from the start of the record until the thermocouple output voltage has attained at least 99 % of its final equilibrium reading . A sample circuit schematic is shown in Fig. 9.

10.8.3.4 *Specimen Installation*—Mount the thermocouple assembly, or the thermocouple-thermowell combination, in a suitable fixture on the movable arm so that the thermocouple junction region is in the fan draft and, when the movable arm is actuated, the thermocouple junction will be immersed to a depth of at least ten times, the sheath diameter, or as appropriate for that particular design.

NOTE 2—If the thermocouple sheath diameter is < 3 mm (.125 in.), there may be whipping motions of the sheath induced by the flowing water. To stiffen the thermocouple sheath, a thick-walled tube with an inside diameter just sufficient to allow the thermocouple to be inserted may be mounted in the moveable arm fixture. Adjust the length of the thick-walled tube so it just clears the water when the thermocouple is inserted into the bath.

10.8.4 *Preparation for Testing*—Adjust the voltage span and time axis of the recorder by trial runs on a typical specimen in the flowing water at the test temperature to obtain a record of the appropriate amplitude and length. Stabilize the bath temperature while the bath is rotating at the desired velocity by maintaining a constant heater power. Verify the bath temperature stability by inserting a typical specimen and recording the temperature for a time at least ten times as long as the time span set for the test, or 50 times as long as the anticipated response time. If no significant temperature drift is obtained the test can proceed.

NOTE 3—A typical water bath requires at least 10 min to obtain a stable velocity where the water attains the same uniform velocity as the rotating container. The rotation of the bath should not be stopped or changed during the course of the tests without suspending the tests until the bath velocity has stabilized. Small changes of relative velocity can be made without affecting the velocity stability of the bath by adjusting the radial position of the thermocouple assembly in relation to the rotating bath (10.8.3.1).

10.8.5 *Set Up for Measurement*—Stabilize the thermocouple voltage and zero the voltage recorder with the thermocouple in the raised position at ambient air temperature in the fan blast. Insert the thermocouple assembly into the bath and adjust the gain of the amplifier to give the desired voltage span on the recorder. Adjust the trigger switch so that the recorder starts just as the thermocouple's measuring junction enters the bath.

10.8.6 After the thermocouple temperature has stabilized in the raised position, activate the movable arm to immerse the thermocouple into the moving water. The voltage recorder shall start automatically at the instant the sheath enters the bath, or a voltage signal on the record shall indicate the instant of immersion, and the record shall continue for the scheduled time span. The response time is determined from the record of the voltage versus time. Make at least three measurements on each thermocouple assembly and report the mean value of the response times and the variation from the mean for each thermocouple assembly and for the thermocouple assemblies of the same type.

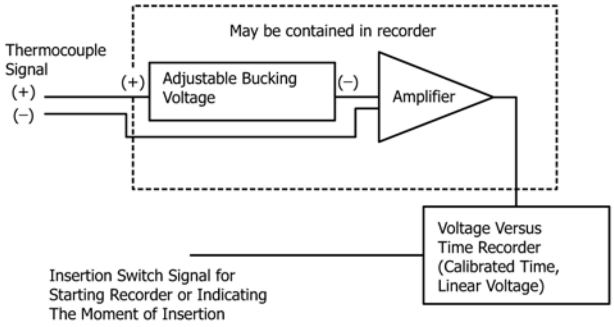


FIG. 9 Sample Circuit Schematic for Thermal Response Time

NOTE 4—With supplier and customer agreement, an alternate approach may be used. The thermocouple's measuring junction end, plus a sheath length of at least 20 sheath diameters, may be heated in air above the water bath (see 10.8.3.1) that is at room temperature and plunged into the water per 10.8.3.2. This alternate approach tends to conservatively simulate the primary method.

10.9 *Thermal Cycle*—The purpose of this test is to ensure that the thermocouple assembly can withstand anticipated temperature changes without rupture of the thermoelements or sheath. This test is usually used only for thermocouples that will encounter demanding thermal cycles.

10.9.1 The testing medium shall be noncorrosive and shall be maintained at a temperature agreed upon between the producer and the user, usually a somewhat higher temperature than the anticipated service conditions.

10.9.2 Cycle by immersing the thermocouple's measuring junction end and adjacent sheath into the testing medium to a depth that will simulate the thermocouple's intended service conditions or a minimum depth of 76 mm (3 in.), whichever is greater, and hold until the thermocouple indicates within 1°C of the test medium temperature. Remove from the testing medium and cool to room temperature within 5 s using a noncorrosive medium. A water quench may be used for thermocouple sheaths not subject to damage by water contact at the specified temperatures. The total lapsed time at room temperature shall be no less than 1 min before recycling.

10.9.3 After five consecutive thermal cycles, measure the loop resistance of the thermocouple to ensure that cracks, detectable as resistance changes, have not opened in the thermoelements and that thermoelements have not touched each other or the sheath at any point other than the junction. If the thermocouple shows an open circuit, the failed thermoelement of a Style U ungrounded measuring junction thermocouple assembly can be identified by measuring the loop resistance between the sheath and each thermoelement. Repeat the insulation resistance measurements of 7.4 to verify that the sheath is intact.

11. Report

11.1 Report the following information:

11.1.1 The results of each test called for in the purchase documents or applicable specifications.

11.1.2 Actual test values, rather than merely go-no go attributes, unless otherwise specified in the purchase document.

11.2 Detailed reports of test configuration and equipment used should be maintained for reference in case of disagreement between the purchaser's and producer's tests. These details shall be supplied to the purchaser only if so specified in the purchase documents.

12. Precision and Bias

12.1 The precision of the Compaction Density Test Method in 7.1 is based on an interlaboratory study (ILS) of E839, Standard Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable, conducted in 2009. Six laboratories participated in this compaction density study, five analyzing using the direct method described in 7.1.1 of Test Methods E839, and four analyzing using the method described in RDT C 2-1T (now the liquid absorption method described in 7.1.2 of Test Methods E839). Each of the labs reported multiple test results for three different diameters of insulated cable. Every "test result" reported represents an individual determination. Except for the use of only five laboratories for the E839 analysis, and four laboratories for the RDT C 2-1T analysis, Practice E691 was followed for the design and analysis of the data. The details are given in ASTM Research Report No. E20-1002.[5]

12.1.1 *Repeatability limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

12.1.1.1 Repeatability limits are listed in Tables 1 and 2 .

12.1.2 *Reproducibility limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that material; "*R*" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

TABLE 1 Compaction Density per ASTM E839 (gm/cm^3)

Nom. MIMS Dia.	Average[A]	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	S_r	S_R	r	R
0.125 in.	77.137	1.097	2.187	3.071	6.124
0.188 in.	77.378	0.620	2.226	1.737	6.233
0.250 in.	78.006	0.652	3.793	1.826	10.620

[A] The average of the laboratories' calculated averages.

TABLE 2 Compaction Density per RDT C 2–1T (gm/cm^3)

Nom. MIMS Dia.	Average[A]	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	S_r	S_R	r	R
0.125 in.	80.425	1.202	5.436	3.367	15.220
0.188 in.	79.123	0.517	5.210	1.446	14.588
0.250 in.	80.865	0.778	2.711	2.177	7.590

[A] The average of the laboratories' calculated averages.

12.1.2.1 Reproducibility limits are listed in Tables 1 and 2.

12.1.3 The above terms repeatability limit and reproducibility limit are used as specified in Practice E177.

12.1.4 Any judgment in accordance with statements 12.1.1 and 12.1.2 would normally have an approximate 95 % probability of being correct, however the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of materials tested and laboratories reporting results guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. The repeatability limit and the reproducibility limit should be considered as general guides, and the associated probability of 95 % as only a rough indicator of what can be expected.

12.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

12.3 The precision statement was determined through statistical examination of 87 results, from six laboratories, on three insulated cable sizes.

12.4 To judge the equivalency of two test results, it is recommended to choose the material closest in characteristics to the test material.

13. Keywords

13.1 high temperature insulation test; insulation resistance; sheath integrity; sheathed thermocouple; thermal cycle; thermal response time; thermocouple; thermocouple assembly properties; thermoelement; thermoelement properties

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[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E20-1002.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLES OF SPECIFICATIONS, TOLERANCES, AND ACCEPTANCE CRITERIA

X1.1 Sheath, Thermoelement, and Insulation Thickness Examples

X1.1.1 The numerical values cited in Tables X1.1 and X1.2 are not to be construed as specification requirements. The tabulated quantities were extracted from ASTM specifications and are intended to familiarize the reader with previously used numbers. To haphazardly use these cited quantities without complete analysis of the specific requirement is extremely inappropriate.

X1.2 Insulation Resistance

X1.2.1 See Table X1.3.

X1.3 Sheath Roundness and Wall Thickness for Various Sheath Diameters

X1.3.1 See Table X1.4.

X1.4 Bend Test and Tension Test Acceptance Criteria (Examples)

X1.4.1 An example of acceptance criteria for sheaths of austenitic stainless steel or nickel-chromium-iron is that the lot of cable shall be rejected if there is a reduction in the insulation resistance by a factor of 10 or more, an open thermoelement, or a short between the thermoelements or between either thermoelement and the sheath.

X1.4.2 An example of acceptance criteria for sheaths of austenitic stainless steel or nickel-chromium-iron is that *(1)* the yield force is less than 70 % of the breaking force, and *(2)* the sheath elongates at least 15 % before it breaks.

X1.5 Upper Temperature Limit for Various Sheath Diameters

X1.5.1 Since the upper temperature limits of noble and refractory metal thermocouples are dependent on the insulation characteristics, the sheath properties, and the surrounding atmosphere, exact temperature limits are not justified.

TABLE X1.1 Examples of Minimum Dimensional Requirements for Two Thermoelement Cable (Metric Units)

Nominal Sheath Outside Diameter, mm	Thermoelement Outside Diameter, mm	Insulation Thickness, mm[A]
0.50	0.08	0.04
1.00	0.15	0.07
1.50	0.23	0.11
2.00	0.30	0.14
3.00	0.45	0.21
4.50	0.68	0.32
6.00	0.90	0.42

[A] Same as thermoelement spacing. Table derived from Specifications E585/E585M and E2181/E2181M.

TABLE X1.2 Examples of Minimum Dimensional Requirements for Two Thermoelement Cable (Inch-Pound Units)

Nominal Sheath Outside Diameter, in.	Thermoelement Outside Diameter, in.	Insulation Thickness, in.[A]
0.020	0.003	0.001
0.032	0.005	0.002
0.040	0.006	0.003
0.062	0.009	0.004
0.093	0.014	0.007
0.125	0.019	0.009
0.188	0.028	0.013
0.250	0.038	0.018
0.375	0.056	0.026

[A] Same as thermoelement spacing. Table derived from Specifications E585/E585M and E2181/E2181M.

TABLE X1.3 Example of Room-Temperature Insulation Resistance (IR) Requirements

Nominal Sheath Outside Diameter		Applied Voltage min, V, dc	Insulation Resistance, min,, MΩ	
mm	in.		Bulk Cable[A]	Assemblies[B]
<0.8	<0.030	50	1000	100
³0.8 to 1.45	³0.030 to 0.057	50	5000	500
>1.45	>0.057	500	10 000	1000

[A] Values were obtained from Specifications E585/E585M and E2181/E2181M.

[B] Values were obtained from Specifications E608/E608M and E2181/E2181M.

TABLE X1.4 Example of Thermocouple Sheath Dimensions and Tolerance Limits

Nominal Outside Diameter		Roundness Limits		Minimum Wall Thickness[A]	
mm	in.	±mm	±in.	mm	in.
8.0	0.375		0.0038	0.80	0.038
6.0	0.250	0.060	0.0024	0.60	0.025
4.5	0.188	0.045	0.0018	0.45	0.018
3.0	0.125	0.030	0.0012	0.30	0.012
	0.093		0.001		0.009
2.0		0.025		0.20	
1.5	0.062	0.025	0.001	0.15	0.006
1.0	0.040	0.025	0.001	0.10	0.004
	0.032		0.001		0.003
0.5	0.020	0.025	0.001	0.05	0.002

[A] The wall thickness shall be at least 10 % of the nominal sheath diameter and shall be uniform in thickness within 20 % of the minimum wall thickness.

X1.5.2 Table X1.5 gives the suggested upper temperature limits for the various base metal thermocouples in several common sheath sizes. It does not take into account environmental temperature limitations of the sheath material itself, nor does it address compatibility considerations between the thermoelement materials and the sheath containing them. The maximum practical temperature in a particular situation will generally be limited to the lowest temperature among the

TABLE X1.5 Examples of Upper Temperature Limits for Base Metal Thermocouples[A]

Upper Temperature Limit for Various Sheath Diameters, °C (°F)					
Nominal Sheath Diameter		Thermocouple Type			
mm	in.	T	J	E	K,N
0.5	0.020	260 (500)	260 (500)	300 (570)	700 (1290)
	0.032	260 (500)	260 (500)	300 (570)	700 (1290)
1.0	0.040	260 (500)	260 (500)	300 (570)	700 (1290)
1.5	0.062	260 (500)	440 (825)	510 (950)	920 (1690)
2.0	---	260 (500)	440 (825)	510 (950)	920 (1690)
	0.093	260 (500)	480 (900)	580 (1075)	1000 (1830)
3.0	0.125	315 (600)	520 (970)	650 (1200)	1070 (1960)
4.5	0.188	370 (700)	620 (1150)	730 (1350)	1150 (2100)
6.0	0.250	370 (700)	720 (1330)	820 (1510)	1150 (2100)
8.0	0.375	370 (700)	720 (1330)	820 (1510)	1150 (2100)

[A] Values were derived from Specification E608/E608M.

TABLE X1.6 Examples of Tolerances on Initial Values of EMF versus Temperature[A]

Thermocouple Type	Temperature Range, °C	Tolerance-Reference Junction 0 °C	
		Standard °C (%)	Special °C (%)
T	0 to 370	1.0 (0.75)	0.5 (0.4)
J	0 to 760	2.2 (0.75)	1.1 (0.4)
E	0 to 870	2.2 (0.75)	1.0 (0.4)
K, N	0 to 1260	2.2 (0.75)	1.1 (0.4)

[A] Values given in this table were derived from Specification E608/E608M.

TABLE X1.7 Penetrameter and Shim Thickness for Metric Unit Thermocouple Diameters

Thermocouple Diameter, mm	Shim Thickness, mm	Penetrameter Thickness, mm	Essential Hole
0.5	0.140	0.050	1T
1.0	0.280	0.075	1T
2.0	0.560	0.075	1T
3.0	0.840	0.100	1T
4.5	1.260	0.100	1T
6.0	1.680	0.100	1T

several factors involved. The user should consult MNL-12[6] and other literature sources for further application information.

X1.5.3 The temperature limits given here are intended only as a guide to the user and should not be taken as absolute values nor as guarantees of satisfactory life or performance. These types and sizes are sometimes used at temperatures above the given limits, but usually at the expense of stability or life, or both. In other instances, it may be necessary to reduce the given limits in order to achieve adequate service.

TABLE X1.8 Penetrameter and Shim Thickness for Inch-Pound Unit Thermocouple Diameters

Thermocouple Diameter, in.	Shim Thickness, in.	Penetrameter Thickness, in.	Essential Hole
0.020	0.006	0.002	1T
0.032	0.009	0.003	1T
0.040	0.012	0.003	1T
0.062	0.020	0.003	1T
0.093	0.027	0.004	1T
0.125	0.040	0.004	1T
0.188	0.060	0.004	1T
0.250	0.080	0.004	1T
0.375	0.107	0.005	1T

X1.6 Tolerances on Initial Values of EMF versus Temperature

X1.6.1 Tolerances in Table X1.6 apply to new sheathed thermocouples or thermocouple cable when used at temperatures not exceeding the recommended limits of Table X1.6. If used at higher temperatures these tolerances may not apply.

X1.6.2 Tolerances apply to new thermocouples or cable as produced and *do not allow for calibration drift during use*. The magnitude of such changes depends upon such factors as sheath and thermoelement size, temperature, time of exposure, and environment.

X1.6.3 Where tolerances are given in percent, the percent applies to the temperature being measured.

X1.7 Radiographic Penetrameter and Shim Thickness

X1.7.1 Examples of criteria are that *(1)* cracks, voids, or inclusions in the sheath wall should be less than 15 % of the sheath wall or 0.5 mm (.02 in.), whichever is greater, and *(2)* there should be no cracks, voids, inclusions, discontinuities, or local reduction in the thermoelements, insulation or sheath diameter greater than 0.05 mm (.002 in.) in or near the thermocouple junction.

X1.8 Bend and Tension Test

X1.8.1 An example of acceptance criteria is that the thermoelements not rupture during the sharp bend test in 8.5.2 or, for Type K or N, before 15 % sheath elongation in the tension test in 8.5.3.

X1.9 Evaluation of Sheath to Thermoelement Locking

X1.9.1 A slope of $(\Delta R/R_0)/(\Delta L/L_0) \geq 2.0$ in the tension test plot in 7.2.9 indicates that the thermoelements elongate the same amount as the sheath and the insulation is well compacted. A slope < 2.0 indicates that the thermoelements are not elongating uniformly the same amount as the sheath because the insulation has low compaction.

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[6] "Manual on the Use of Thermocouples in Temperature Measurement," MNL-12, ASTM, 1993.

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