Designation: E 839 – 96

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

INTRODUCTION

Thermocouples are widely used in industry and they provide reliable service. However, if thermocouples fail in service, the results can range from negligible to life threatening. Often a 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. No tests are required by this document except those specifically ordered by the user. This document lists methods for testing sheathed thermocouples and thermocouple material but does not state criteria for acceptance. The acceptance criteria for the particular thermocouple, when subjected to the tests, are given in other ASTM standard specifications for that thermocouple. 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 given here as examples only.

1. Scope

1.1 These are test methods for sheathed thermocouple material and assemblies.

1.2 The tests are intended to ensure quality control and to evaluate the suitability of sheathed thermocouple material 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 and 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
absorption method and tension method,

1.3.1.2 Thickness, and

1.3.1.3 Resistance—room temperature and elevated temperature.

1.3.2 *Sheath Properties*:

1.3.2.1 Integrity
water test (two 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, and

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, and

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 end seal, and defect detection by dye penetrant,

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

1.3.4.4 Insulation resistance—room temperature, and elevated temperature,

1.3.4.5 Radiographic inspection,

1.3.4.6 Thermoelement diameter,

1.3.4.7 Thermal response time, and

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[1] These test methods are under the jurisdiction of Committee E-20 on Temperature Measurement and are the direct responsibility of Subcommittee E20.04 on Thermocouples.

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1.3.4.8 Thermal cycle.

2. Referenced Documents

2.1 *ASTM Standards:*

D 2771 Test Methods for Compaction Density of Electrical Grade Magnesium Oxide[2]

E 3 Methods of Preparation of Metallographic Specimens[3]

E 94 Guide for Radiographic Testing[4]

E 112 Test Methods for Determining the Average Grain Size[3]

E 142 Method for Controlling Quality of Radiographic Testing[4]

E 165 Practice for Liquid Penetrant Examination[4]

E 207 Method of Thermal EMF Test of Single Thermoelement Materials by Comparison with a Secondary Standard of Similar EMF-Temperature Properties[5]

E 220 Method for Calibration of Thermocouples by Comparison Techniques[6]

E 230 Specification for Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples[5]

E 235 Specification for Thermocouples, Sheathed, Type K, for Nuclear or for Other High-Reliability Applications[5]

E 344 Terminology Relating to Thermometry and Hydrometry[5]

E 585 Specification for Sheathed Base-Metal Thermocouple Materials[5]

E 608 Specification for Metal-Sheathed Base-Metal Thermocouples[5]

E 780 Test Method for Measuring the Insulation Resistance of Sheathed Thermocouple Material at Room Temperature[5]

E 988 Temperature-Electromotive Force (EMF) Tables for Tungsten-Rhenium Thermocouples[5]

E 1129/E 1129M Specification for Thermocouple Connectors[5]

2.2 *ANSI Standard*

B 46.1 Surface Texture[7]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E 344 shall apply to these test methods.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bulk material length (BML)*, *n*—a single length of thermocouple material (produced from the same raw material lot) after completion of fabrication resulting in sheathed thermocouple material.

3.2.2 *cold-laps*, *n*—sheath surface defects where the sheath surface has been galled and torn by a drawing die and the torn surfaces smoothed by a subsequent diameter reduction.

3.2.3 *insulation compaction density*, *n*—the density of a compacted powder is the combined density of the powder particles and of 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.

3.2.4 *production run*, *n*—the quantity of BMLs (produced at one time and from the same material lot) that travel together continuously through the same processing steps, that is, assembly, size reduction, annealing, etc.

3.2.5 *raw material*, *n*—material components (tubing, insulators, and thermoelements) as received, prior to any manufacturing procedures.

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 *thermocouple assembly*, *n*—the cut-to-length, finished assembly consisting of thermocouple material with thermoelements having one end joined in a measuring junction. The assembly has the sheath closed at the measuring end and has a moisture seal at the reference junction end of the sheath. The assembly does not include a reference junction but may include a thermocouple connector, thermocouple extension, or compensating wire.

4. Summary of Test Methods

4.1 *Insulation Properties*:

4.1.1 *Compaction*—These tests ensure the insulation is compacted enough (*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 *Resistance*—The insulation must be free of moisture and contaminants that would compromise the voltage-temperature relation 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 (*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.

4.2.2 *Dimensions*—If the sheath must fit in a fixed space the dimensions of length, diameter, and sheath roundness must be determined.

4.2.3 *Ductility*—If the sheath must be bent during installation or service, then the sheath must be ductile enough to bend the required amount without breaking or cracking.

4.3 *Thermoelement Properties Service Life*:

4.3.1 *Calibration*—These tests ensure the temperature (emf) relation corresponds to the standard values both initially and after a short time of heating to service temperatures.

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

4.3.3 *Ductility*—Thermoelement ductility is necessary if the thermocouple assembly must be bent during installation or service.

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[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

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

[6] Discontinued. See *1994 Annual Book of ASTM Standards*, Vol 14.03.

[7] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

4.4 *Thermocouple Assembly Properties*—The criteria listed above must apply to both thermocouple assemblies and to bulk sheathed material, and in addition the following tests are important for thermocouple assemblies.

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

4.4.2 *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 *End Seal*—The reference end seal, if faulty, may allow the 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. The 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 These tests provide a description of test methods for use in ASTM specifications that establish certain acceptable limits for characteristics of thermocouple assemblies and thermocouple materials.

5.2 The intended use of these test methods is to define the methods by which the characteristics shall be determined.

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

6. General Requirements

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

6.2 During all process steps in which insulation is exposed to ambient atmosphere, the air must 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 Test Methods D 2771 is a test on representative samples to measure the compaction density of electrical grade magnesium oxide. Two methods are used to find the density: Test Method A for water displacement and Test Method B for oil absorption. Both Test Methods A and B require precision weighing and careful procedure.

7.1.2 A direct measurement test of insulation compaction density is applicable if a representative sample can be sectioned so the sample ends are perpendicular to the sample length and the sheath, thermoelements, and insulation form a smooth surface free of burrs. The test procedure is to:

7.1.2.1 Weigh the sample section,

7.1.2.2 Measure the sheath diameter and length with a micrometer,

7.1.2.3 Separate wires, sheath, and insulation by use of an air abrasive tool (air-driven abrasive particles) to remove the insulation from the sample,

7.1.2.4 Weigh the thermoelements and sheath, and

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

7.1.3 The fraction of the maximum theoretical insulation density is determined as follows:

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

where:

A = total specimen mass, g or lb,
B = sheath and wires mass, g or lb,
C = sheath diameter, mm or in.,
D = specimen length, mm or in.,
E = sheath mass, g or lb,
F = sheath density, kg/m^3 or lb/in.^{3},
G = wires mass, g 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}.

7.2 *Insulation Compaction, Tension Test Method*—This is a destructive test on representative samples that determines if the thermoelements are locked together with the sheath by the compacted insulation, but the test does not measure the compaction density per se. This tension test is the complement of the tests of 7.1 that measure 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 sheath ductility test (8.5.3).

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

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

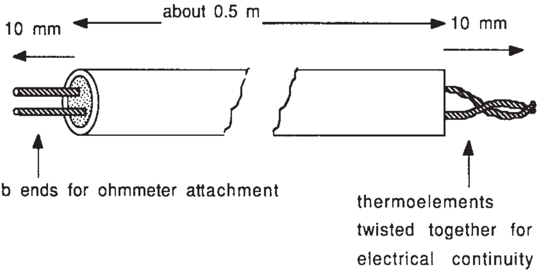


FIG. 1 Specimen of Sheathed Thermocouple Material Prepared for Tension Testing

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 (Fig. 2).

7.2.5 Attach an ohmmeter capable of measuring $\pm 0.01\ \Omega$ 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 sample 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 dimension *C* of Fig. 3 from a metallographic mount (prepared by Methods E 3) of a polished cross section of the thermocouple 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. 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 Specification E 608 for the junction area, in Table 1 of Specification E 585 for base-metal thermocouples, and Tables X1.1 and X1.2.

7.4 *Insulation Resistance, Room Temperature*—Measure the insulation resistance of sheathed thermocouple material at room temperature using Test Method E 780. Sampling frequency and insulation resistance shall be as agreed upon between the purchaser and the producer. See Table X1.3.

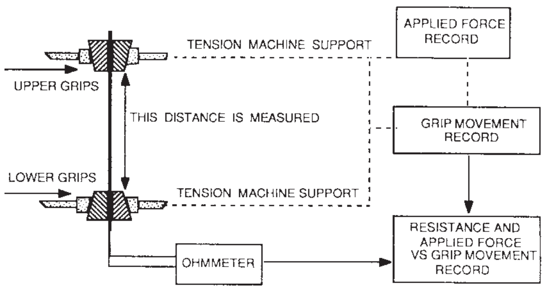
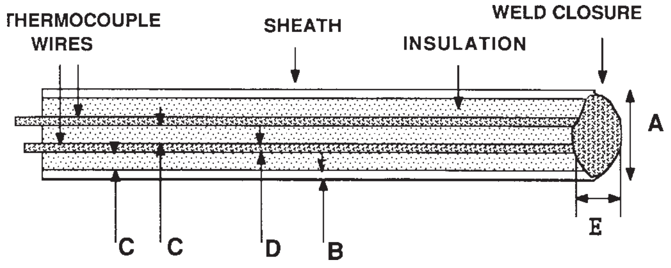
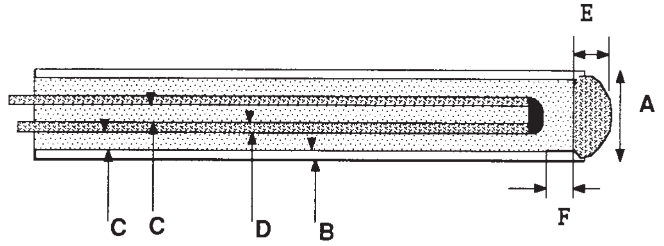


FIG. 2 The Thermocouple Positioned In The Tension Tester



(*a*) Class 1 Grounded Thermocouple Junction



(*b*) Class 2 Insulated Thermocouple Junction

FIG. 3 Sheathed Thermocouple Assembly

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 (**Caution**—See Note 1). Sampling frequency shall be as stated in the standard specification relevant to the subject thermocouple.

NOTE 1—**Caution:** Some thermocouples, such as Type E or K, may have changes in thermoelectric homogeneity produced by exposure to elevated temperatures; therefore, this test should be regarded as possibly destructive.

7.5.1 *Thermocouple Assembly*—Measure the electrical resistance between the thermoelements and the sheath for a Class 2 (insulated junction) finished thermocouple assembly (Fig. 3) using the technique of Test Method E 780 (Resistance Measurement). Insert the finished thermocouple assembly, measuring the junction end first, into a furnace or constant temperature bath to a depth that will yield maximum temperature stability (example: 20 sheath diameters). Then, the thermocouple can be heated to the maximum temperature of intended use.

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 Material*—Insulation resistance tests on sheathed thermocouple material at elevated temperatures have the purpose of determining (*1*) if excess moisture is in the insulation of the bulk material 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 on the elevated temperature resistance of Type K or N bulk material.

NOTE 2—**Caution:** Improper technique in constructing thermocouple assemblies can introduce additional insulation impurities.

(1) Cut a sample of approximately 1.2 m (4 ft) in length from the end of the bulk material. 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 adsorption. Wind the center section of the sample 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 sample.

(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. The sealed ends of the sample should be at about room temperature. Allow the sample to stabilize at 1000°C for at least 15 min, as measured by the furnace monitor thermocouple.

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

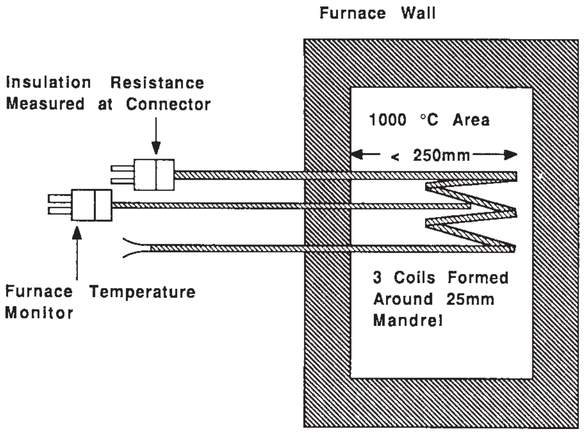
(5) Record the insulation resistance between each thermoelement, and from each thermoelement to the sheath.

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

NOTE 3—**Caution:** Improper practice in forming the junction and sheath closure may change the insulation resistance of the thermocouple assembly.

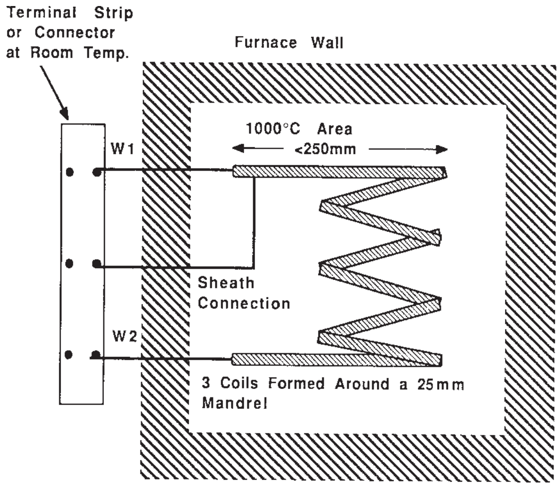
(1) Cut a sample about 0.6 m (2 ft) long from the end of the bulk material to be tested. Strip both ends about 25 mm (1 in.) to expose the thermoelements.

(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 sample.



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



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

(3) Wind the center section of the sample 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. Allow the sample to stabilize at 1000°C for at least 15 min, as measured by the furnace monitor thermocouple.

(6) Measure the insulation resistance at the voltage appropriate for the thermocouple size. The charge time of the megohm tester should be 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 through the sheath can be detrimental to the life and local homogeneity of the sheathed thermoelement. 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 by other mechanical damage. Two major methods, water penetration and mass spectrometer measurements of helium penetration, are commonly used for assessing sheath integrity. The mass spectrometer method is the most sensitive and the only one that can be used with Class 1 (grounded junction) thermocouples. These sheath integrity test methods are given in order of increasing test sensitivity and difficulty.

8.1.1 *Fast Sheath Integrity Test Using Water*—This test is usually a test on bulk material 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 to bare a 6 mm (0.25 in.) length 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 open ends 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 MΩ, connect the ground lead to the cable sheath and the other test lead to either thermoelement.

8.1.1.5 Then immerse by using a rag saturated with cold tap water. Wipe along the length of the sheath from the end opposite the instrument connection slowly with a light pressure applied to the sheath.

8.1.1.6 As an alternative, immerse the entire 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 material and this test repeated to determine 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 sheathed material to expose a minimum of 6 mm (0.25 in.) of the 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 open ends 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 V dc and at a maximum of 50 V dc, measure the insulation resistance between the sheath and thermoelements.

8.1.2.5 Then, using a clean rag saturated with unheated tap water (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 material aside for 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 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 material 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 a leak is found) is to leave the voltage applied while the sheathed material is exposed to the water. This will often pinpoint the location of a leak by emitted bubbles due to the electrolysis of water.

8.1.2.9 The leaking section of the length of material 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 closures as follows: Weld shut the open ends of the sheath or otherwise hermetically seal. Wipe the test item clean with a solvent-saturated material. Recommended solvents are alcohol, methyl ethyl ketone, or methyl isobutyl ketone (see Note 4). Pressurize the sheath externally with helium to at least 7.0 Mpa (66 atm) for a period of 5 to 10 min. Wipe the test item again with a solvent-saturated tissue and insert within 2 h into a test chamber. 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* (8.1.3.3). Take an indication of helium leakage of 6×10^{-6} standard cubic centimeters per second as evidence of a leak.

NOTE 4—**Caution:** These solvents can be considered as hazardous and possibly toxic. Refer to applicable Material Safety Data Sheets.

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 a 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 per smallest scale division on the leak detector meter. A leak rate of 6×10^{-9} standard cubic centimeter 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 tests will apply to either bulk material or completed thermocouple assemblies.

8.2.1 *Sheath Length*—Measure the thermocouple assembly length while the thermocouple assembly is laying 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 smaller.

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, or micrometer calipers. If a micrometer is used, readings are taken 90° 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 shall be considered the roundness tolerance and shall be determined by a micrometer reading to find the high and low points around the circumference at any one cross section of the sheath. The value of roundness tolerance shall be as stated in the standard specification relevant to the subject thermocouple. See X1.4.

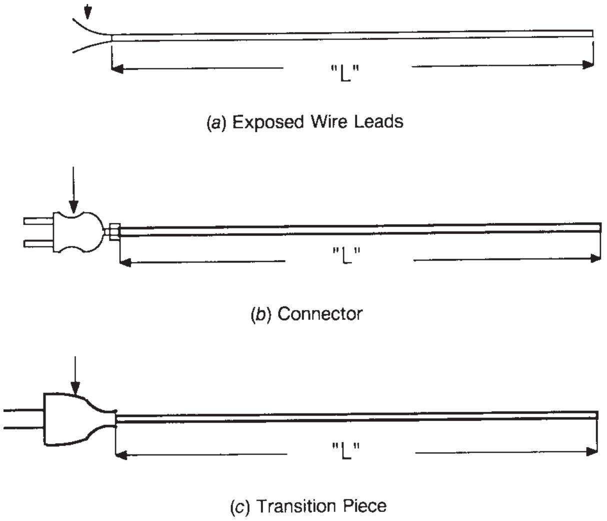
8.2.4 *Sheath Wall Thickness*—Determine the sheath wall thickness, dimension B of Fig. 3, from a metallographic mount (Methods E 3) of a polished cross section of the thermocouple with a microscope having at least a 60 × magnification and a 2.5-mm (0.1-in.) reticle graduated in at least 0.03-mm (0.001-in.) increments. This test may be performed at the same time as the test in 7.3. Sheath wall thickness and allowable variations of sheath wall thickness shall be as stated in the standard specification relevant to the subject thermocouple. See 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 material 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 see that the sheath appears to be clean and has the color and brightness specified.

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 Practice E 165, Procedure A-2. Procedure A-2 is a post-emulsifiable fluorescent liquid penetrant inspection method.



(*a*) Exposed Wire Leads

(*b*) Connector

(*c*) Transition Piece

FIG. 6 Length Measurements of Thermocouple Assemblies

NOTE 5—**Caution:** the Special Requirements section of Practice E 165 points out that some solvents should not be used on some sheath materials.

8.3.4 *Tension Test*—This test is intended to detect cold-laps in the thermocouple sheath and can be performed at the same time as the sheath ductility test in 8.5 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 material 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 material for grain size of the sheath. This test may be done at the same time as the tests in 8.2.4 or 8.5.2.1 using Methods E 3 to prepare the metallographic specimen and Test Methods E 112 to determine the 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 between the purchaser and the producer. Specification E 235, paragraphs 5.1.1 and 6.7 may be used as a guide.

8.5 *Sheath Ductility*:

8.5.1 These tests are useful when it is important for thermocouple material 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 material three full turns on a mandrel with a diameter twice the sheath diameter. Check continuity and insulation resistance, each thermoelement to sheath and thermoelement to thermoelement, 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 material 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 (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).

9. Thermoelement Properties

9.1 *Calibration*—Method E 220 describes suitable calibration techniques. Specification E 230 lists the temperature-electromotive force (emf) tables for standardized thermocouples. If agreed between the producer and user, Method E 207 may be used to calibrate the individual thermoelements against a secondary reference standard. Because of varied requirements, calibration temperatures and accuracies must be specified in the purchase documents (Caution—See Note 6).

NOTE 6—**Caution:** Type E and K thermoelements will have changes in thermoelectric homogeneity produced by exposure to temperatures in the 320 to 540°C 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. Type E or K thermocouple calibrations should be used only to characterize a production run.

9.1.1 *Assembly Calibration Tests*:

9.1.1.1 Assemblies selected randomly from the production run shall be calibrated by the method of Method E 220 or E 988 (for tungsten-rhenium thermocouples).

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 Table 1 of E 988 (for tungsten-rhenium thermocouples), 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.

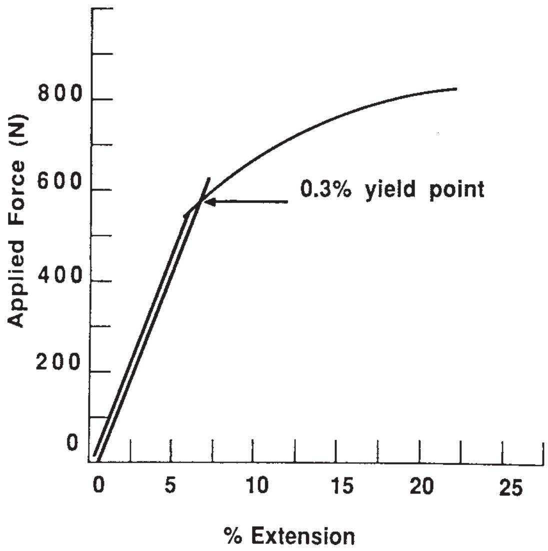


FIG. 7 Tension Test Evaluation of Thermocouples

9.2 *Homogeneity*—Until standardization of a pending test method, homogeneity will 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.

NOTE 7—**Caution:** Some thermoelements, such as Type E or K, will have changes of thermoelectric homogeneity produced by this test and the test should be considered (possibly) destructive.

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

9.3.1.1 The test thermocouple is to be placed in the test furnace so 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 The furnace is to be heated to the upper temperature limits appropriate to the sheath and thermoelement sizes of the test thermocouple (see Table X1.5) or to a temperature as stated in the standard specification relevant to the subject thermocouple.

9.3.1.3 After the test thermocouple is at stable temperature, the emf of the test thermocouple is to be compared 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 usual criteria is that the emf of the thermocouple assembly should not drift more than the standard or special tolerances for that type thermocouple (Table X1.6).

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

9.4.1 Strip the sheath and insulation to obtain four 25 mm (1 in.) lengths of the thermoelements from random locations. Measure the diameter of the thermoelement midway of the sample length with an optical comparator, diameter gage, or micrometer calipers. If a micrometer is used, readings are to be 90° apart.

9.4.2 A metallographic mount (Methods E 3) of a polished cross section of the thermocouple 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 test can be done at the same time as the tests in 7.3 and 8.2.4.

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

9.4.4 Use the average of the measurements made in 9.4.1 and 9.4.3 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 shall be considered the roundness tolerance 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.

9.8 *Thermoelement Ductility*—The thermoelement ductility is determined concurrently with the sheath ductility and flexibility tests in 8.5 (see X1.1).

9.9 *Thermoelement Metallurgical Structure*—Examine a section of the sample thermoelement for grain size and intergranular inclusions. This test may be done at the same time as the test in 8.2.4, 8.4.1, or 8.5.2.1 using Methods E 3 to prepare the metallographic specimen and Test Methods E 112 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 specimens of bulk material. If destructive tests, such as high temperature drift, calibration, ductility, or metallographic examination, are desired on the thermocouple assembly, the tests are performed on selected specimens in the same manner as described for the bulk material.

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, or micrometer calipers. If a micrometer is used, reading are taken 90° apart at each measurement point.

10.2.3 *Roundness*—The difference between the maximum and minimum outside diameter shall be considered the roundness tolerance and shall be determined by a micrometer reading to find the high and low points around the circumference for any one cross section of the sheath.

10.2.4 *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 see that the sheath is not bent, kinked, or nicked and appears to be clean and has the color and brightness specified. 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 *Reference End Seal*—The reference end seal is examined before the thermocouple connector or transition section is installed. The seal is examined with the aid of a 10 × optical magnifier to ensure that the seal material coats the insulation and is bonded to the thermocouple wires and the thermocouple sheath and is free of cracks, fractures, holes or bubbles that would render the seal ineffective.

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

10.4 *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. This is not recommended for sheath sizes of less than 1.6 mm (0.062 in.) o. d.

10.4.1 *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.

10.4.2 *Loop Resistance*—The electrical resistance of the joined thermoelements (loop resistance) in each thermocouple assembly is measured at room temperature using an ohmmeter capable of measuring to $\pm 0.01\Omega$.

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

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

10.4.2.3 Loop resistance measurements of specimens in a given production run 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.

10.4.3 *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 voltmeter to the negative pin or lead of the thermocouple connector. Slightly warm the junction end of the thermocouple assembly above the connector temperature until a significant voltage measurement 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 compatability of the thermocouple connector with the thermoelements can be determined by the methods given in Specification E 1129/E 1129M.

10.5 *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 E 780 is a proven technique for measuring room temperature insulation resistance.

10.5.1 *Room Temperature Insulation Resistance*—This test can be made only on Class 2 (insulated junction) thermocouples (Fig. 3).

10.5.1.1 Measure the insulation resistance, at room temperature, between the thermocouple connector pins or leads and the sheath using Test Method E 780. The sampling frequency and insulation resistance shall be as stated in the standard specification relevant to the subject thermocouple (see Table X1.3).

10.6 *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 junction region of the thermocouple assembly.

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

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

10.6.3 Perform the radiography in accordance with Practice E 94.

10.6.4 The design of the penetrameter shall be as specified in Method E 142, except as modified as follows: 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 6.4 mm (0.25 in.) wider and longer than the penetrameter, which shall be centered on the block. 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 13 mm (0.50 in.) to the nearest thermocouple sheath. See X1.7 and X1.8 for examples of penetrameter and shim thickness.

10.6.5 The density of the individual films, as measured by a densitometer, shall be in the range from 2.0 to 3.0 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. (The term *density* is defined in Guide E 94).

10.6.6 The use of nonfilm techniques is permitted.

10.6.7 Acceptance criteria shall be as stated in the standard specification relevant to the subject thermocouple (see Note 1 and X1.7).

10.7 *Junction Dimensions*—For Class 2 (insulated 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.

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

10.9 *Thermal Response Time*—The thermal response time is 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 outer surface. This measurement is useful 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 will then be reported as that for the combination of thermocouple-thermowell.

NOTE 8—The response time is a function of the rate of heat flow into or out of the thermocouple assembly. The heat flow bewteen 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, and turbulence, etc. of the fluid. These external conditions must be controlled to obtain reproducible response time measurements.

10.9.1 *General Test Method*—The test thermocouple assembly is stabilized at room temperature and then immersed rapidly in a flowing fluid, usually water, at a higher temperature. The voltage from the thermocouple assembly is measured as a function of time until it comes to 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.

10.9.2 *Temperature Control*—It is necessary to measure the change of voltage of the thermocouple to within 1 µV sensitivity 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, thus it is not necessary to know either the room or bath temperature to high precision. It is necessary, however, that the bath and room temperatures be stable during the test.

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

10.9.3.1 *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

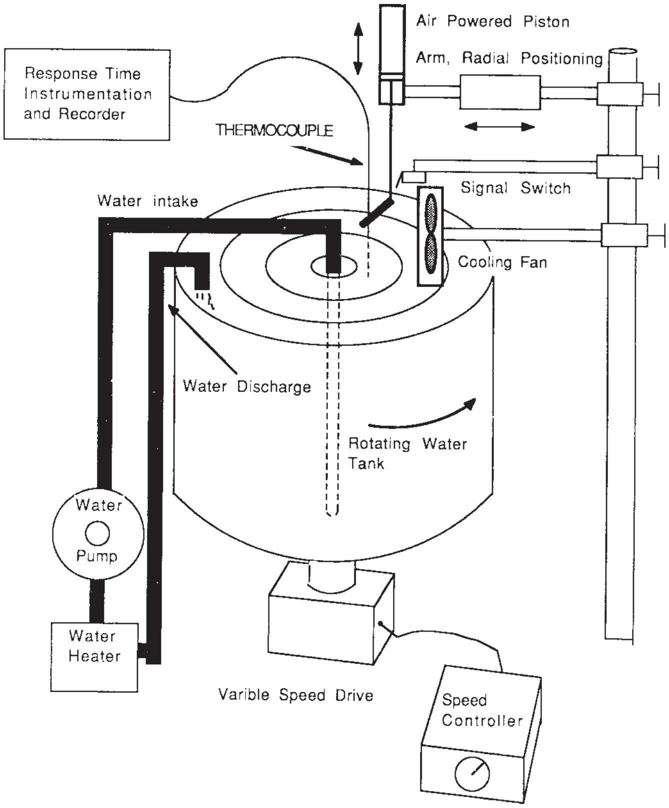


FIG. 8 Thermal Response Time Apparatus

thermocouple is equal to the product [(2πr) × (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 just at 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 about 10°C above room temperature.

10.9.3.2 *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.

10.9.3.3 *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 (five times the response time). A sample circuit schematic is shown in Fig. 9.

10.9.3.4 *Specimen Installation*—Mount the thermocouple assembly (or the thermocouple-thermowell combination) in a suitable fixture on the movable arm so 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 9—If the thermocouple is <3-mm sheath diameter, 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.

10.9.4 *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 (that is, 50 times as long as the anticipated response time); if no significant temperature drift is obtained the test can proceed.

NOTE 10—A typical water bath requires at least 10 min to obtain a stable velocity (that is, for the water to attain 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 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 (10.9.3.1).

10.9.5 *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 the recorder starts just as the thermocouple sensing junction enters the bath.

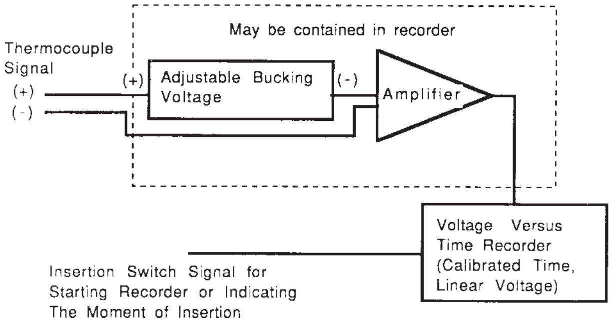


FIG. 9 Sample Circuit Schematic for Thermal Response Time

10.9.6 After the thermocouple temperature has stabilized in the raised position, activate the movable arm to immerse the thermocouple in 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 response time and the variation from the mean for each thermocouple assembly and for the thermocouple assemblies of the same type.

NOTE 11— After supplier and customer agreement, an alternate approach may be used. The thermocouple junction end (plus a sheath length of at least 20 sheath diameters) may be heated in air above the 10.9.3.1 water bath that is at room temperature and plunged into the water per 10.9.3.2. This alternate approach tends to conservatively simulate the primary method.

10.10 *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.

10.10.1 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.

10.10.2 Cycle by immersing the measuring junction end of the thermocouple assembly in the testing medium at a minimum depth of 76 mm (3 in.) 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. (Use a water quench 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.

10.10.3 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 the thermoelements have not touched each other or the sheath at other than the junction. If the thermocouple shows an open circuit the failed thermoelement of a Class 1 (grounded 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 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 producer and user tests. These details shall be supplied to the user only if so specified in the purchase documents.

12. Precision and Bias

12.1 No statement is made either on the precision or on the bias of these test methods for testing mechanical or electrical properties of sheathed thermocouples, since the test results merely state whether there is conformance to the criteria for success. No generally accepted method for determining precision and bias of these measurements is currently available.

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

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

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

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 material 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 must be less than 70 % of the breaking force and (*2*) the sheath must elongate 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.

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 several factors involved. The user should consult MNL-12[8] and other literature sources for further application information.

TABLE X1.1 Examples of Minimum Thermoelement Sizes (Metric Units)^A

Nominal Sheath Outside Diameter, mm	Thermoelement Outside Diameter, mm	Insulation Thickness, mm
0.50	0.08	0.05
1.00	0.15	0.10
1.50	0.22	0.15
2.00	0.30	0.20
3.00	0.45	0.30
4.50	0.68	0.45
6.00	0.90	0.60

^{A} Same as thermoelement spacing. Table derived from Specification E 585.

TABLE X1.2 Examples of Minimum Thermoelement Sizes (Inch-Pound Units)^A

Nominal Sheath Outside Diameter, in.	Thermoelement Outside Diameter, in.	Insulation Thickness, in.
0.020	0.003	0.002
0.032	0.005	0.003
0.040	0.006	0.004
0.062	0.010	0.005
0.093	0.014	0.009
0.125	0.020	0.012
0.188	0.028	0.019
0.250	0.040	0.024
0.375	0.056	0.038

^{A} Same as thermoelement spacing. Table derived from Specification E 585.

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

Nominal Sheath Outside Diameter		Minimum Applied Voltage dc Volts	Minimum IR, MΩ	
mm	in.		Bulk Material^A	Assemblies^B
<0.8	<0.030	50	1 000	100
≥0.8 to 1.5	≥0.030 to 0.059	50	5 000	500
>1.5	>0.059	500	10 000	1 000

^{A} Values were obtained from Specification E 585.
^{B} Values were obtained from Specification E 608.

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.
	0.375		0.0038		0.038
6.0	0.236	0.060	0.0024	0.51	0.020
4.5	0.177	0.045	0.0018	0.45	0.018
3.0	0.118	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	0.039	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} Wall thickness has the same allowable variations as the roundness limits. The wall thickness shall be at least 10 % of the nominal sheath diameter and shall be uniform in thickness within 10 % of the average wall thickness. Values were derived from Specification E 585.

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[8] "Manual on the Use of Thermocouples in Temperature Measurement," MNL-12, ASTM, 1983.

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

Sheath Diameter mm	Sheath Diameter in.	T	J	E	K,N
0.5	0.020	260	260	300	700
0.8	0.031	260	260	300	700
1.0	0.039	260	260	300	700
1.6	0.063	260	440	510	920
2.4	0.094	260	480	580	1000
3.2	0.126	315	520	650	1070
4.8	0.189	370	620	730	1150
6.3	0.248	370	720	820	1150
9.5	0.374	370	720	820	1150

Upper Temperature Limit for Various Sheath Diameters, °C; Thermocouple Type: T, J, E, K,N

[A] Values were derived from Specification E 608.

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.

X1.6 Tolerances on Initial Values of EMF versus Temperature

X1.6.1 Tolerances in Table X1.6 apply to new sheathed thermocouple material 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 material 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.

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 350	1.0 (0.75)	0.5 (0.4)
J	0 to 750	2.2 (0.75)	1.1 (0.4)
E	0 to 900	1.7 (0.5)	1.0 (0.4)
K, N	0 to 1250	2.2 (0.75)	1.1 (0.4)

[A] Values given in this table were derived from Specification E 608.

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

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

[A] Values of table were derived from Specification E 608.

TABLE X1.8 Examples of Penetrameter and Shim Thickness for Inch-Pound Unit Thermocouple Diameters[A]

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

[A] Values were derived from Specification E 608.

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, whichever is greater and (*2*) there should be no cracks, voids, inclusions, discontinuities, or local reduction in the thermoelements, insulation or sheath diameter in or near the thermocouple junction greater than 0.05 mm.

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