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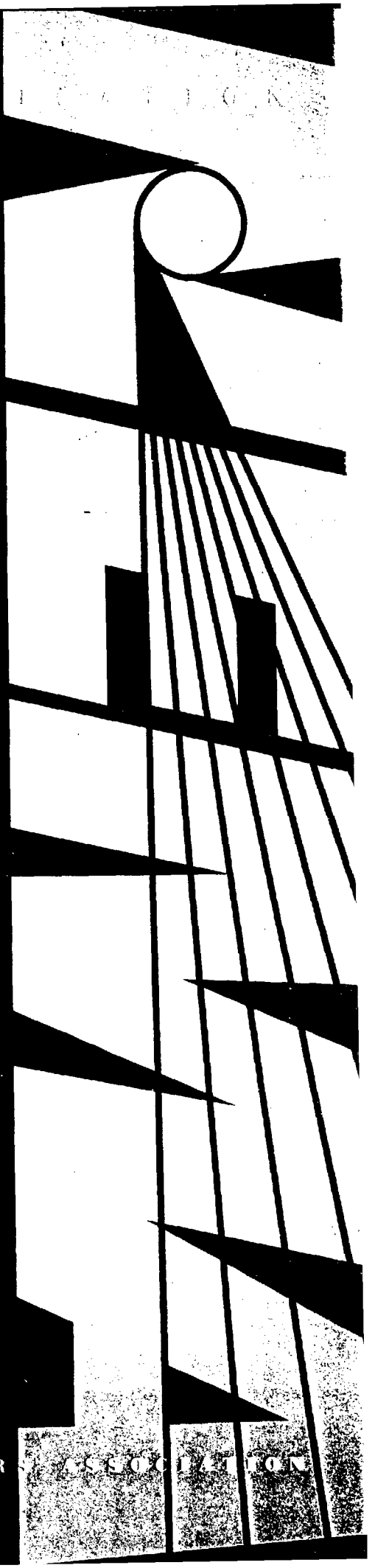
NEMA STANDARDS PUBLICATION

# NEMA WC 55/
# ICEA S 82 552

# INSTRUMENTATION CABLES AND THERMOCOUPLE WIRE



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# ICEA S-82-552
# ANSI/NEMA WC 55-1992

*Instrumentation Cables and Thermocouple Wire*

Revision 2, 1998
Approved as ANSI Standard, August 31, 1990

*Prepared and Sponsored by:*

**Insulated Cable Engineers Association**
**P.O. Box 440**
**South Yarmouth, MA 02664**

*Published by:*

**National Electrical Manufacturers Association**
1300 North 17th Street
Rosslyn, VA 22209

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# ICEA S-82-552
# ANSI/NEMA WC 55-1992

# INSTRUMENTATION CABLES AND THERMOCOUPLE WIRE

Revision 1, August 1994
Approved as ANSI Standard, August 31, 1990

*Prepared and Sponsored by:*
**Insulated Cable Engineers Association**
P.O. Box 440
South Yarmouth, MA 02664

*Published by:*
**National Electrical Manufacturers Association**
2101 L Street, N.W.
Washington, DC 20037

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# ICEA S-82-552
# ANSI/NEMA WC 55-1992

## INSTRUMENTATION CABLES AND THERMOCOUPLE WIRE

Reaffirmed with Revisions, May 18, 1992
Approved as ANSI Standard, August 31, 1990

*Prepared and Sponsored by:*

**Insulated Cable Engineers Association**
P.O. Box 440
South Yarmouth, MA 02664

*Published by:*

**National Electrical Manufacturers Association**
2101 L Street, N.W.
Washington, DC 20037

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## Foreword

This Standards Publication for Instrumentation Cables and Thermocouple Wire (ICEA S-82-522/NEMA WC 55-1992) was developed by the Insulated Cable Engineers Association Inc. (ICEA) and approved by the National Electrical Manufacturers Association (NEMA).

ICEA/NEMA Standards are adopted in the public interest and are designed to eliminate misunderstanding between the manufacturer and the user and to assist the user in selecting and obtaining the proper product for his particular need. Existence of an ICEA/NEMA Standard does not in any respect preclude the manufacturer or use of precautioned to observe any health or safety regulations and rules relative to the manufacture and use of cable made in conformity with this standard.

This standard does not specify any specific frequencies for sampling for test purposes, cable products or components. One program of sampling frequencyes is given in Publication ICEA T-26-465/NEMA WC 54-1990.

Requests for interpretation of this standard must be submitted in wrinting to the Insulated Cable Engineers Association, P.O. Box 440, South Yarmouth, Massachusetts 02664. An official written interpretation will be provided, once approved by ICEA and NEMA. Suggestions for improvements gained in the use of this publication will be welcomed by the Association.

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# INSTRUMENTATION CABLES AND THERMOCOUPLE WIRE

## PART 1
## GENERAL

### 1.1 SCOPE

This standard applies to materials, constructions, and testing of multiconductor instrumentation cables rated up to and including 125° C including thermocouple extension cables. Instrumentation cables are multiconductor cables which convey low energy electrical signals (circuits which are inherently power limited) used for monitoring or controlling electrical power systems and their associated processes. Instrumentation cables convey signals from process monitors to process analyzers (usually electronic equipment) and from the analyzers to control equipment in the electric power system. Construction details and test requirements for cables rated above 125° C can be found in the NEMA HP-100 series of standards.

### 1.2 GENERAL INFORMATION

This publication is so arranged that cables can be selected in numerous constructions covering a broad range of installation and service conditions. Parts 2 to 4 cover the major components of the cables:

Part 2-Conductors
Part 3-Insulation
Part 4-Shieldings and Coverings

Each of these parts designates the materials, material characteristics, dimensions, and test applicable to the particular component.

Shields and shielding as described in Part 4 of this standard differ in function from power cable shielding as described in standards for those products.

Part 5 covers assembly, cabling, and identification of the insulated individual conductors, with or without associated shields.

Part 6 describes some, but not all of the test methods applicable for the component materials and completed cables. Other test methods are found in Publication ICEA T-27-581/NEMA WC 53.

Part 7 is reserved for future use.

Part 8 contains Appendices with reference data such as definitions, abbreviations, material characteristics, and application and installation information. Particular attention is called to Appendix A, which gives the title and date of industry standards and other publications referenced herein.

In classifying components in this standard, the following definitions apply:

*Metal Tape*—a relatively thin and narrow metal strip which includes straps and ribbons.

*Jacket*—a polymeric (nonmetallic) protective covering applied over the insulation, core, sheath, or armor of a cable; e.g., a PVC jacket. It is not impervious to water or other liquids.

*Sheath*—a metallic covering, impervious to water and other liquids, applied over the insulation or jacket of a cable; e.g., a lead sheath.

Conductor sizes are expressed by American Wire Gauge (AWG). Steel armor wire sizes expressed by Birmingham Wire Gauge (BWG).

Temperatures are expressed in degrees Celsius. The Fahrenheit equivalents of degrees Celsius can be calculated by the equation °F = (1.8 × °C) + 32. Room temperature is defined as a temperature from 20°C to 28°C inclusive.

Mass is expressed in grams. The ounce equivalents to grams can be calculated by dividing the number of grams by 28.35. Other values are expressed in non-metric units commonly used in North America.

To convert values in a non-metric unit to the approximate values in appropriate metric units, multipliers given in the following table should be used:

| From | To | Multiplier |
|---|---|---|
| inches (in) | millimeter (mm) | 25.4 |
| ohms per 1000 ft (Ω/1000 ft) | milliohm per meter (mΩ/m) | 3.28 |
| square inch ($in^2$) | square millimeter ($mm^2$) | 645 |
| circular mil (cmil) | square millimeter ($mm^2$) | $5.07 \times 10^{-4}$ |
| pounds per square inch (psi) | megapascal (MPa) | $6.89 \times 10^{-3}$ |
| gigaohms—1000 ft (GΩ—1000 ft) | gigaohm-meter (GΩm) | 305 |

### 1.3 INFORMATION TO BE SUPPLIED BY PURCHASER

When requesting proposals from cable manufacturers, the prospective purchaser should described the cable by reference to pertinent parts of this standard. To help avoid misunderstandings and possible misapplication of cable, he should also provide pertinent information concerning the intended application. (This paragraph has been approved by NEMA as Authorized Engineering Information.)

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# PART 2
# CONDUCTORS

## 2.1 GENERAL

Conductor requirements shall be determined in accordance with the procedures or methods designated by the referenced ASTM standard unless otherwise specified in this standard.

The following technical information on typical conductors can be found in Appendix B:

a. Approximate diameters of stranded copper conductors.

b. Approximate weights of copper conductors.

## 2.2 WIRES, PHYSICAL AND ELECTRICAL PROPERTIES

The wires used in conductors shall be copper in accordance with 2.3 or various specific metallic elements for thermocouple extension wires in accordance with 2.4.

## 2.3 COPPER CONDUCTORS

### 2.3.1 Wires

Copper wires shall meet the chemical requirements of ASTM B-5 and either 2.3.1.1 or 2.3.1.2.

**2.3.1.1** Soft or annealed copper wires intended for a stranded conductor shall meet the elongation, finish, and coating continuity requirements of one of the following:

(1)ASTM B-3 for uncoated wires.

(2)ASTM B-33 for tin coated wires.

(3)ASTM B-189 for lead or lead alloy coated wires.

**2.3.1.2** Copper wires if removed from a concentric lay stranded conductor, annealed after stranding, shall meet the elongation requirements of ASTM B 8, Section 7.4, 7.5, and 7.6.

### 2.3.2 Solid Conductors

A solid copper conductor shall consist of a single round wire meeting the requirements given in 2.3.1.1.

### 2.3.3 Stranded Conductors

Stranded conductors shall consist of 7 wires or 19 wires individually meeting the appropriate requirements of 2.3.1. Diameters of individual wires in stranded conductors are not specified. The requirements for lay and joints shall be in accordance with ASTM B-8 for concentric-lay Class B or Class C stranded copper conductors.

### 2.3.4 Conductor dc Resistance per Unit Length

The dc resistance per unit length of each conductor in a production or shipping length of completed cable shall not exceed the value determined from the schedule of maximum dc resistances specified in Table 2-1 when using the appropriate nominal value from Table 2-2. The dc resistance shall be determined in accordance with 2.3.4.1 or 2.3.4.2.

When the resistance is measured on a single conductor sample taken from a multiple conductor cable, or when the resistance is calculated, the appropriate maximum resistance value specified for the single conductor shall apply.

#### 2.3.4.1 DIRECT MEASUREMENT OF DC RESISTANCE PER UNIT LENGTH

The dc resistance per unit length shall be determined by dc resistance measurements made in accordance with ICEA T-27-581/NEMA WC 53 to an accuracy of 2 percent or better.

If measurements are made at a temperature other than 25°C, the measured value shall be converted to resistance at 25°C by using the methods specified in ICEA T-27-581/NEMA WC 53.

If verification is required for the dc resistance measurement made on an entire length of completed cable, a sample at least one foot long shall be cut from that reel length, and the dc resistance of each conductor shall be measured using a Kelvin-type bridge or a potentiometer.

#### 2.3.4.2 CALCULATION OF DC RESISTANCE PER UNIT LENGTH

The dc resistance per unit length at 25°C shall be calculated using the following formula:

$$R = 10^3 K\rho/A$$

Where: R = Conductor resistance in ohm/1000 ft.
K = Weight increment factor
$\rho$ = Volume resistivity in ohm.cmil/ft.
A = Cross-sectional area of conductor in cmil

(a) Volume resistivity ($\rho$) of the conductor material shall be determined in accordance with ASTM B 193 using round wires.

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b. Cross-sectional area (A) of solid and concentric lay stranded conductors shall be determined in accordance with ICEA T-27-581/NEMA WC 53.
c. Weight increment factor (K) shall be taken as 1.02 or it shall be calculated in accordance with ASTM B-8.

### 2.3.5 Conductor Diameter

The diameter of a solid conductor shall be measured in accordance with ICEA T-27-581/NEMA WC 53. The diameter of a solid conductor shall not differ from the nominal values shown in Table 2-3 by more than plus or minus five percent. No diameter requirements apply to stranded conductors.

The five percent diameter tolerance for solid conductors is provided to enable a designer of connectors to determine the range of conductor sizes which will fit a particular connector; however, a conductor meeting the minimum diameter requirement does not necessarily meet the requirement for maximum dc resistance specified in 2.3.4. (This paragraph has been approved by NEMA as Authorized Engineering Information.)

**Table 2-1**
**SCHEDULE FOR ESTABLISHING MAXIMUM DIRECT CURRENT RESISTANCE PER UNIT LENGTH OF COMPLETED CABLE**

| Cable Type | Maximum dc Resistance |
|---|---|
| Single Conductors[a] | Table 2-2 Value Plus 2%<br>[R max = R × 1.02] |
| Multiple Conductor Cables | Table 2-2 Value Plus 2%<br>One of the following:<br>2% – One Layer of Conductors<br>[R max = R × 1.02 × 1.02]<br>3% – More than One Layer of Conductors<br>[R max = R × 1.02 × 1.03]<br>4% – Pairs or Other Precabled Units<br>[R max = R × 1.02 × 1.04]<br>5% – More than One Layer of Pairs or Other Precabled Units<br>[R max = R × 1.02 × 1.05] |

[a]Applies to a sample only, see 2.3.4.

**Table 2-2**
**NOMINAL DIRECT CURRENT RESISTANCE IN OHMS PER 1000 FEET AT 25°C OF SOLID AND CONCENTRIC LAY STRANDED COPPER CONDUCTORS**

| Conductor Size | Solid Copper | | Stranded Copper | | |
|---|---|---|---|---|---|
| AWG | uncoated | coated | uncoated | coated | |
| | | | Class B,C | Class B | Class C |
| 22 | 16.5 | 17.2 | 16.7 | 17.9 | 18.1 |
| 20 | 10.3 | 10.7 | 10.5 | 11.1 | 11.3 |
| 19 | 8.20 | 8.52 | 8.33 | 8.83 | 8.96 |
| 18 | 6.51 | 6.76 | 6.67 | 7.07 | 7.14 |
| 17 | 5.15 | 5.35 | 5.21 | 5.52 | 5.64 |
| 16 | 4.10 | 4.26 | 4.18 | 4.43 | 4.44 |

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**Table 2-3**
**NOMINAL DIAMETERS FOR SOLID COPPER CONDUCTORS**

| Conductor Size | Solid Diameters |
|---|---|
| AWG | inch |
| 22 | 0.0253 |
| 20 | 0.0320 |
| 19 | 0.0359 |
| 18 | 0.0403 |
| 17 | 0.0453 |
| 16 | 0.0508 |

## 2.4 CONDUCTORS FOR THERMOCOUPLE EXTENSION WIRES

### 2.4.1 Conductor Material

The conductor elements shall be in accordance with ANSI MC96.1 and Table 2-4 for the listed types of thermocouple extension wires.

### 2.4.2 Size and Diameter

Conductors shall be solid or stranded. Stranded conductors shall be composed of seven wires. Applicable sizes and nominal diameters shall be in accordance with Table 2-5.

**Table 2-4**
**EXTENSION WIRE ELEMENTS**

| Type | Extension Wire | Conductor Material** |
|---|---|---|
| T | TX | TPX Copper<br>TNX Constantan |
| J | JX | JPX Iron<br>JNX Constantan |
| E | EX | EPX Chromel*, Tophel*, T-1*<br>ENX Constantan |
| K | KX | KPX Chromel*, Tophel*, T-1*<br>KNX Alumel*, Nial*, T-2* |
| R or S | SX | SPX Copper<br>SNX Copper Nickel Alloy |
| B | BX | BPX Copper<br>BNX Copper |

* Trade Name

** Materials are listed as typical of those commerically available at present, and their listing implies no endorsement by this standard.

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**Table 2-5**
**NOMINAL DIAMETERS OF THERMOCOUPLE WIRES**

| Conductor Size | Solid Conductor | Stranded | |
|---|---|---|---|
| | | Individual Wire | Stranded Conductor |
| AWG | inch | inch | inch |
| 20 | 0.0320 | 0.0126 | 0.038 |
| 18 | 0.0403 | 0.0159 | 0.048 |
| 16 | 0.0508 | 0.0201 | 0.060 |

### 2.4.3 Direct-Current (dc) Resistance of Conductors

The approximate dc resistance at 20°C of thermocouple conductor materials is given in Table 2-6. If specific maximum or minimum limitations on dc resistance are required, such limitations shall be specified by the purchaser.

### 2.4.4 Temperature Limits of Conductors

The temperature limitations for use of the various thermocouple extension wire conductors shall be in accordance with ANSI MC96.1, Section 3.

### 2.4.5 Limits of Error of Conductors

The limits of error for the various thermocouple extension wire conductors shall be in accordance with ANSI MC96.1, Section 3.

**Table 2-6**
**NOMINAL DIRECT CURRENT RESISTANCE IN OHMS PER 1000 FEET AT 20°C OF SOLID OR STRANDED THERMOCOUPLE CONDUCTORS**

| Size (AWG) | Conductor Material | | | | | | |
|---|---|---|---|---|---|---|---|
| | KNX | EPX | KPX | ENX TNX | JNX | TPX SPX BPX BNX | SN SNX | JPX |
| 20 | 173 | 415 | | 287 | | 10.1 | 27.4 | 69.9 |
| 18 | 111 | 266 | | 184 | | 6.39 | 17.5 | 44.6 |
| 16 | 68.3 | 164 | | 113 | | 4.02 | 10.8 | 27.6 |

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# Part 3
# INSULATION

## 3.1 MATERIALS

The insulation shall consist of one of the materials shown below.

Crosslinked Polyethylene (XLPE), Type I
Crosslinked Polyethylene (XLPE), Type II
Ethylene Propylene Rubber (EP), Type I
Ethylene Propylene Rubber (EP), Type II
Silicone Rubber (SR)
Chlorosulfonated Polyethylene (CSPE)
Polyvinyl Chloride (PVC)
Polyethylene (PE)
Composite EP/CPSE or EP/Neoprene (CR)
Thermoplastic Elastomer (TPE), Type I
Thermoplastic Elastomer (TPE), Type II

## 3.2 THICKNESS

The minimum average thickness shall not be less than specified in Table 3-1. The minimum thickness at any one point shall not be less than 90 percent of the specified value.

### 3.2.1 SR

0.005 inch of the specified average SR insulation thickness may be replaced by not less than 0.005 inch of a closely woven and impregnated glass braid. (This sentence has been approved by NEMA as Authorized Engineering Information.)

**Table 3-1**
**INSULATION THICKNESS**

| Conductor Size AWG | Thickness, inch | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | XLPE | EP | SR | CSPE | PVC | PE | Composite EP &CR EP & CSPE | TPE |
| | | | | | 300 Volts | | | |
| 22 | 0.020 | 0.020 | 0.025 | 0.025 | 0.020 | 0.015 | 0.010 | 0.020 |
| 20 | 0.020 | 0.020 | 0.025 | 0.025 | 0.020 | 0.015 | 0.010 | 0.020 |
| 18 | 0.020 | 0.020 | 0.025 | 0.025 | 0.025 | 0.020 | 0.010 | 0.020 |
| 16 | 0.020 | 0.020 | 0.025 | 0.025 | 0.025 | 0.020 | 0.010 | 0.020 |
| | | | | | 600 Volts | | | |
| 20 | 0.025 | 0.025 | 0.030 | 0.030 | 0.025 | 0.025 | 0.010 | 0.025 |
| 18 | 0.025 | 0.025 | 0.030 | 0.030 | 0.030 | 0.025 | 0.010 | 0.025 |
| 16 | 0.025 | 0.025 | 0.030 | 0.030 | 0.030 | 0.025 | 0.010 | 0.025 |

**Table 3-1M**
**INSULATION THICKNESS**

| Conductor Size AWG | Thickness, mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | XLPE | EP | SR | CSPE | PVC | PE | Composite EP &CR EP & CSPE | | TPE |
| | | | | | 300 Volts | | | | |
| 22 | 0.381 | 0.510 | 0.635 | 0.635 | 0.381 | 0.381 | 0.381 | 0.254 | 0.510 |
| 20 | 0.381 | 0.510 | 0.635 | 0.635 | 0.381 | 0.381 | 0.381 | 0.254 | 0.510 |
| 18 | 0.381 | 0.510 | 0.635 | 0.635 | 0.510 | 0.510 | 0.381 | 0.254 | 0.510 |
| 16 | 0.381 | 0.510 | 0.635 | 0.635 | 0.510 | 0.510 | 0.381 | 0.254 | 0.510 |
| | | | | | 600 Volts | | | | |
| 20 | 0.635 | 0.635 | 0.762 | 0.762 | 0.635 | 0.635 | 0.510 | 0.254 | 0.635 |
| 18 | 0.635 | 0.635 | 0.762 | 0.762 | 0.762 | 0.635 | 0.510 | 0.254 | 0.635 |
| 16 | 0.635 | 0.635 | 0.762 | 0.762 | 0.762 | 0.635 | 0.510 | 0.254 | 0.635 |

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### 3.2.2 PE

For cables rated 600 volts, 0.010 inch of the specified average PE insulation thickness may be replaced by not less than 0.010 PVC meeting the physical and aging requirements of Table 3-2. For 300 volt or 600 volt cables, 0.004 inch of the specified average PE insulation thickness may be replaced by not less than 0.004 inch nylon, except the thickness of polythylene may not be less than 0.015 inch. (This paragraph has been approved by NEMA as Authorized Engineering Information.)

### 3.2.3 PVC

For 300 volt or 600 volt cables, 0.004 inch of the specified PVC insulation thickness may be replaced by not less than 0.004 inch nylon. (This paragraph has been approved by NEMA as Authorized Engineering Information.)

## 3.3 REQUIREMENTS

When tested in accordance with the appropriate methods specified in Part 6, the insulation shall meet the applicable requirements specified in Table 3-2.

### 3.3.1 XLPE

Crosslinked Polyethylene (XPLE) insulation, Type I and Type II shall be suitable for use in wet or dry locations at a temperature not exceeding 90°C.

### 3.3.2 EP

Ethylene Propylene Rubber (EP) insulation, Type I and Type II shall be suitable for wet or dry locations at a temperature not exceeding 90°C.

### 3.3.3 SR

Ozone Resisting Silicone Rubber (SR) shall be suitable for use in dry locations at a temperature not exceeding 125°C.

### 3.3.4 CPSE

Chlorosulfonated Polyethylene (CSPE) insulation shall be suitable for use in wet or dry locations at a temperature not exceeding 90°C.

### 3.3.5 PVC

Polyvinyl Chloride insulation shall be suitable for use in wet or dry locations at a temperature not exceeding 75°C. When tested in accordance with 6.20 the insulation shall have a dielectric strength retention of not less than 60 percent of the original value. Conductors having a nylon covering shall not show any cracks when subjected to the wrap test given in Part 6. Wrinkles in the covering shall not constitute failure of this requirement.

### 3.3.6 PE

Polyethylene insulation shall be suitable for use in wet or dry locations at a temperature not exceeding 75°C. The polyethylene material, prior to application to the conductor, shall comply with the requirements of ASTM D 1248 for Type 1, Classes A, B, or C, Category 4 or 5, Grade E4 or E5. These requirements do not apply to insulation removed from the conductor. Conductors having a nylon covering shall not show any cracks when subjected to the wrap test given in Part 6. Wrinkles in the covering shall not constitute failure of this requirement. For 300 Volt rated cable, the insulation thickness may be reduced by 0.005 inch, provided that the tensile strength of the insulation is 2000 p.s.i. minimum.

### 3.3.7 Composites

Composite insulation shall be suitable for wet or dry locations at a temperature not exceeding 90°C. The composite insulation shall consist of an inner layer of Type I or Type II EP with an outer layer of insulating CSPE or Neoprene (CR). When the inner and outer insulating layers can be separated without injury to either layer they shall be tested separately for compliance with the physical and aging requirements given in Table 3-2. When the layers cannot be separated they shall be tested as a unit for compliance with the physical and aging requirements given in Table 3-2. The composite insulation shall be tested as a unit to determine compliance with the electrical and moisture absorption requirements given in Table 3-2.

### 3.3.8 TPE

Thermoplastic elastomer insulation, Type I and Type II, shall be suitable for use in wet or dry locations at a temperature not exceeding 75°C or, in dry locations only at a temperature not exceeding 90°C.

### 3.3.9 Repairs

When repairs in the insulation are required, they shall be made such that the repaired part meets the dielectric withstand requirements specified in 3.4 and the insulation resistance requirements specified in 3.5. The thickness of the repaired part shall conform to the thickness requirements given in 3.2.

## 3.4 VOLTAGE TESTS

Each production or shipping length of completed cable shall be tested in accordance with ICEA T-27-581/NEMA WC 53 except that the test may be made without immersion in water. The insulated conductors shall withstand for five minutes either the ac or dc test voltage given in Table 3-3. The test voltage shall be based on the rated voltage of the cable and the conductor size and not on the apparent thickness of the insulation.

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# Table 3-2
# INSULATION REQUIREMENTS

| Properties | XLPE | | EP Rubber | | SR Rubber | CSPE Rubber | PVC | PE | TPE | | Composite Insulation[d] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Separable Layers | | | Non-separable Layers |
| | | | | | | | | | | | EP | | CSPE or CR | Composite EP/CSPE or EP/CR |
| | Type I | Type II | Type I | Type II | | | | | Type I | Type II | Type I | Type II | | |
| Initial Tensile Strength, minimum psi | 1800 | 1800 | 700 | 1200 | 800 | 1500 | 2000 | 1400 | 1500 | 1500 | 700 | 1200 | 1500 | 1000 |
| Initial Elongation at Rupture, minimum % | 250 | 150 | 250 | 150 | 250 | 300 | 150 | 350 | 300 | 300 | 250 | 150 | 300 | 250 |
| Tensile Stress, | | | | | | | | | | | | | | |
| At ____ Percent Elongation, | ... | ... | ... | 100 | ... | ... | ... | ... | ... | ... | ... | 100 | ... | ... |
| Minimum, psi | ... | ... | ... | 500 | ... | ... | ... | ... | ... | ... | ... | 500 | ... | ... |
| Retention, minimum % of | | | | | | | | | | | | | | |
| Tensile Strength | 75 | 85 | 75 | 75 | 500(a) | 85 | 80 | 75 | 75 | 75 | 75 | 75 | 85 | 75 |
| Elongation | 75 | 60 | 75 | 75 | 125(a) | 50 | 75 | 75 | 75 | 75 | 75 | 75 | 40 | 50 |
| After Air Oven Exposure at | | | | | | | | | | | | | | |
| °C±1°C | 121 | 121 | 121 | 121 | 200 | 121 | 121 | 100 | 121 | 121 | 121 | 121 | 121 | 121 |
| For ____ Hours (indicated hours) | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 48 | 168 | 168 | 168 | 168 | 168 | 168 |
| Retention, Minimum % of | | | | | | | | | | | | | | |
| Tensile Strength | ... | ... | ... | ... | ... | 60 | 85 | ... | ... | ... | ... | ... | ... | ... |
| Elongation | ... | ... | ... | ... | ... | 60 | 85 | ... | ... | ... | ... | ... | ... | ... |
| After Oil Immersion | | | | | | | | | | | | | | |
| °C±1°C | ... | ... | ... | ... | ... | 121 | 70 | ... | ... | ... | ... | ... | ... | ... |
| For ____ Hours (indicated hours) | ... | ... | ... | ... | ... | 18 | 4 | ... | ... | ... | ... | ... | ... | ... |
| Heat Distortion, | | | | | | | | | | | | | | |
| Maximum % | 30 | 30 | ... | ... | ... | ... | 25 | ... | 25 | 25 | ... | ... | ... | ... |
| at °C±1°C | 121 | 121 | ... | ... | ... | ... | 121 | ... | 121 | 121 | ... | ... | ... | ... |
| Hot Creep @ 150°C±2°C | (e) | (e) | (e) | (e) | (e) | (e) | ... | ... | ... | ... | (e) | (e) | (e) | (e) |
| Ozone Resistance After 3 Hours Exposure | ... | ... | ... | ... | Pass | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Heat Shock @ 121°C±1°C | ... | ... | ... | ... | ... | ... | No Cracks | ... | ... | ... | ... | ... | ... | ... |
| Type A Flame Test | ... | Pass | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Type B Flame Test | ... | ... | ... | ... | ... | Pass | Pass | ... | Pass | Pass | ... | ... | ... | ... |
| Cold Bend After 1 Hour | | | | | | | | | | | | | | |
| At °C±2°C | ... | ... | ... | ... | ... | –25 | –30 | ... | ... | ... | ... | ... | ... | ... |
| Minimum Requirement | ... | ... | ... | ... | ... | No Cracks | No Cracks | ... | ... | ... | ... | ... | ... | ... |

(Continued on next page)

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## Table 3-2 (*continued*)

| Properties | XLPE Type I | XLPE Type II | EP Rubber Type I | EP Rubber Type II | SR Rubber | CSPE Rubber | PVC | PE | TPE Type I | TPE Type II | Composite Insulation[d] Separable Layers EP Type I | Composite Insulation[d] Separable Layers EP Type II | Composite Insulation[d] Separable Layers CSPE or CR | Composite Insulation[d] Non-Separable Layers Composite EP/CSPE & EP/CR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Environmental Stress Cracking | — | — | — | — | — | — | — | No cracks | — | — | — | — | — | — |
| Electrical Properties After Immersion in 75°C±1°C Water, Permittivity (SIC) after 24 hours, maximum | 6.0 | 6.0 | 4.0 | 6.0 | — | 10.0 | 10.0 | — | 3.0 | 4.0 | — | — | — | 4.5 |
| Increase in Capacitance Maximum % | | | | | | | | | | | | | | |
| 1-14 days | 3.0 | 4.0 | 3.5 | 5.0 | 10.0 | 6.0 | 4.0 | — | 3.0 | 4.0 | — | — | — | 3.5 |
| 7-14 days | 1.5 | 2.0 | 1.5 | 3.0 | 3.0 | 2.0 | 2.0 | — | 1.5 | 2.0 | — | — | — | 2.0 |
| *Stability Factor after 14 days, maximum | 1.0 | 1.0 | 1.0 | 1.0 | — | 1.0 | — | — | 1.0 | 1.0 | — | — | — | 1.0 |
| *Alternate to Stability Factor, maximum difference, 1-14 days | 0.5 | 0.5 | 0.5 | — | — | 0.5 | — | — | 0.5 | 0.5 | — | — | — | — |
| Insulation Resistance Constant at 15.6°C, minimum, gigaohms—1000 feet[c] | 10 | 10 | 20 | 10 | 4 | 1 | 2 | 50[b] | 40 | 40 | — | — | — | 12 |
| Mechanical Water Absorption, maximum Milligrams per Square Inch after 168 hrs at 70°C ± 1°C | — | — | — | — | — | — | — | — | — | — | — | — | — | 35 |
| Specific Surface Resistivity minimum gigaohms[c] | — | — | — | — | — | — | — | — | — | — | — | — | — | 200 |

NOTES: [a]Values are minimum tensile strength (psi) and elongation (%) after exposure, not retained percentages.

[b]Value shall be not less than 30, based on the sum of the thicknesses of the two layers, when a layer of PVC is applied over the PE.

[c]It may be more convenient at times to express this value in megohms (1 gigaohm=$10^3$ megohms)

[d]See 3.3.7.

[e]Authorized Engineering Information only.

*Only one of these requirements needs to be satisfied, not both.

A DASH UNDER ANY INSULATION INDICATES THAT A PARTICULAR VALUE FOR THE APPLICABLE PROPERTY IS NOT REQUIRED.

**Table 3-3**
**TEST VOLTAGES IN KILOVOLTS**

| Conductor Size | Rated Voltage 300 Volts | | 600 Volts | |
|---|---|---|---|---|
| AWG | ac | dc | ac | dc |
| 22 | 1.5 | 4.5 | — | — |
| 20 | 1.5 | 4.5 | 2.5 | 7.5 |
| 18 | 1.5 | 4.5 | 2.5 | 7.5 |
| 16 | 1.5 | 4.5 | 2.5 | 7.5 |

## 3.5 INSULATION RESISTANCE

Each insulated conductor in the completed cable when tested according to ICEA T-27-581/NEMA WC 53, shall have an insulation resistance of not less than that corresponding to the applicable insulation resistance constant (K) specified in Table 3-2. The insulation resistance in gigaohms-1000 feet at a temperature of 15.6 °C shall not be less than the value of R calculated as follows:

$$R = K \log_{10} D/d$$

Where:
R = Insulation resistance in gigaohms – 1000 feet
K = Constant for insulation, in gigaohms – 1000 feet
D = Diameter over insulation
d = Diameter under insulation

Resistance measurements taken at temperatures other than 15.6 °C shall be converted to readings at 15.6 °C by use of an appropriate factor according to ICEA T-27-581/NEMA WC 53.

When a nonconducting separator is applied between the conductor and the insulation, or when an insulated conductor is individually covered with a nonmetallic jacket, the insulation resistance shall not be less than 60 percent of that required for the insulation based on the thickness of the insulation.

### 3.5.1 Exceptions

The 60 percent reduction does not apply to composite insulations (see 3.3.7).

## 3.6 TYPE A FLAME TEST ▲

When tested in accordance with Part 6, a single conductor specimen of a multiple conductor cable shall not burn longer than one minute after any flame application. Not more than 25 percent of the extended portion of the indicator shall be burned. The cotton under the specimen shall not be ignited by flaming particles or drippings from the specimen. Flameless charring of the cotton shall be disregarded.

## 3.7 TYPE B FLAME TEST ▲

When tested in accordance with Part 6, a single conductor specimen of a multiple conductor cable shall not burn longer than one minute after the last flame application. Not more than 25 percent of the extended portion of the indicator shall be burned.

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# PART 4

# SHIELDINGS AND COVERINGS

## 4.1 SHIELDING, GENERAL

Shielding of instrumentation cable is for the purpose of reducing or eliminating (1) electrostatic interference between conductors or groups of conductors within the cable, or (2) outside interference on cable conductors. Electrostatic shields are non-magnetic tapes or braids applied over one or more of the cable conductors. A shield, when used, shall meet the requirements of one of the shield types described in 4.1.3 and 4.1.4. This standard does not cover methods for reducing electromagnetic interference. (Consult the manufacturer for recommendations.)

### 4.1.1 Shield Continuity

Each shield shall be electrically continuous throughout the cable length when tested in accordance with 6.22.

### 4.1.2 Shield Isolation

When necessary to allow for single point grounding, shields shall be electrically insulated or isolated from other metallic cable components such as other shields and grounding conductors.

Such isolation may be achieved by covering the shield with a coating, tape, or jacket. (This sentence has been approved by NEMA as Authorized Engineering Information.)

When tested in accordance with 6.21, the insulation resistance between shields shall not be less than one megohm based on 1000 cable feet or the shields shall withstand a 600 volt dc voltage applied between shields in accordance with 6.21.

### 4.1.3 Metal Tape Shields

Metal tape shields shall be smooth or corrugated and provide 100 percent coverage of the enclosed conductors. They shall be applied either helically or longitudinally with an overlap of sufficient width to prevent opening during normal bending in installation but not less than 3/16 inch or 121 percent of tape width, whichever is greater. Metal tapes shall be a non-magnetic material such as copper, copper alloy, or aluminum. Metal tapes may be coated or uncoated, all metal or laminated to a non-metallic backing or reinforcement. Drain wires (see 4.1.3.1) shall be used in conjunction with metal tapes less than 0.001 inch in thickness.

#### 4.1.3.1 Drain Wires

Drain wires shall be copper or coated copper in accordance with Part 2.2 and not smaller than 22 AWG. Coated wires shall be used in conjunction with aluminum tape shields to protect against electrolytic corrosion. Drain wires shall be positioned adjacent to the metal tape so as to maintain effective grounding contact and shall be considered an integral part of the shield.

### 4.1.4 Metal Braid Shields

When shielding is applied in the form of a braid, the coverage shall be determined by the following formula:

$$\text{Percent Coverage} = 100(2F - F^2)$$

Where:
- $F = NP.d/\sin a$
- $a$ = Angle of braid wires with longitudinal axis of enclosed core = $\tan^{-1}[2\pi(D + 2d)P/C]$, degrees
- $D$ = Diameter of core under shield, inches
- $d$ = Diameter of individual braid wires, inches
- $C$ = Number of carriers
- $F$ = Fill or space factor
- $N$ = Number of braid wires per carrier
- $P$ = Picks per inch

### 4.1.5 Metal Wire Shields

When shielding is applied in the form of a serving or wrap, the coverage shall be determined by the following formula:

$$\text{Percent Coverage} = Nd/W \times 100$$

Where:
- $N$ = Number of parallel wires
- $d$ = Diameter of individual wires in inches
- $W = \pi D \cos a$
- $D$ = Diameter under shield in inches
- $a$ = Angle between serving wires and axis ofcable
- $\tan a = \pi D/C$
- $C$ = Pitch of serving in inches

## 4.2 JACKETS

Jackets are either thermoplastic or crosslinked (as defined by Table 4-2) and may be one of the materials shown below:

Polyvinyl Chloride (PVC)
Black Polyethylene (PE)
Styrene-Butadiene Rubber (SBR)
Chloroprene (Neoprene) Rubber (CR)
Nitrile-Butadiene/Polyvinyl Chloride (NBR/PVC)
Chlorosulfonated Polyethylene Rubber (CSPE)
Chlorinated Polyethylene (CPE)
Thermoplastic Elastomer (TPE)

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Because of different maximum temperature ratings of the insulations given in Part 3, not all of the materials given above are necessarily suitable for all insulations or all applications. Consult the manufacturer for further information. (This paragraph has been approved by NEMA as Authorized Engineering Information.)

### 4.2.1 Thickness

The minimum average thickness shall not be less than specified in Table 4-1. The minimum thickness at any one point shall not be less than 80 percent of the specified value.

**Table 4-1**
**JACKET THICKNESS**

| Calculated Diameter of Cable Under Jacket | Thickness |
|---|---|
| inch | inch |
| 0.425 or less | 0.045 |
| 0.426-0.700 | 0.060 |
| 0.701-1.500 | 0.080 |
| 1.501-2.500 | 0.110 |
| 2.501 and larger | 0.140 |

### 4.2.2 Requirements

When tested in accordance with the appropriate methods specified in ICEA T-27-581/NEMA WC 53, the jacket shall meet the applicable requirements specified in Table 4-2.

#### 4.2.2.1 REPAIRS

The jacket may be repaired in accordance with good commercial practice. Cables with repaired jackets must be capable of meeting all applicable requirements of this standard. (NEMA Authorized Engineering Information).

### 4.2.3 Binder

A separator or binder tape may be used under the overall jacket. (This sentence has been approved by NEMA as Authorized Engineering Information.)

## 4.3 METALLIC AND ASSOCIATED COVERINGS

This section covers requirements for metallic and associated coverings recommended for use where normal conditions of installation and service for instrumentation cables exists. When conditions exist, which require additional mechanical strength or protection (for example submarine cable, riser cable, etc.), they shall be defined before cable design is completed. When tested according to the appropriate methods in ICEA T-27-581/NEMA WC 53, metallic coverings shall meet the applicable requirements given herein. The manufacturer should be consulted for recommendations. (This sentence has been approved by NEMA as Authorized Engineering Information.)

### 4.3.1 Types of Metallic Coverings

Interlocked Metal Tape Armor (see 4.3.1.1)
Galvanized Steel Wire Armor (see 4.3.1.2)
Flat Metal Tape Armor (see 4.3.1.3)
Continuously Corrugated Metal Armor (see 4.3.1.4)

#### 4.3.1.1 INTERLOCKED METAL TAPE ARMOR

This section covers flat metal strip for use as interlocking armor. All tests shall be made prior to the application of the strip to the cable.

##### 4.3.1.1.1 Tape Material

The flat metal strip shall be one of the following:

1. Galvanized steel tapes meeting the requirements of ASTM A 459.
2. Non-magnetic metal tapes, e.g., aluminum, brass, bronze, zinc, Ambrac*, Monel*, and stainless steel (Representative values of tensile strength and elongation are given in Appendix C).
3. Plain steel tape meeting the tensile strength and elongation requirements of ASTM A 459 shall be permitted when a polymeric covering is used over the armor.

##### 4.3.1.1.2 Width

The width of a metal tape shall be permitted to be less than, but not be greater than specified in Table 4-3. For any width of metal tape used, the tolerance in width shall be not more than plus 0.010 inch and minus 0.005 inch, except for aluminum which shall be not more than plus or minus 0.010 inch.

*TRADE NAMES - The listing of these materials implies no endorsement by this standard.

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## Table 4-2
## JACKET REQUIREMENTS

| Properties | Thermoplastic Jackets | | | | | Crosslinked Jackets | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | TPE | | General Purpose | | | | Heavy Duty | | | |
| | PVC | PE | CPE | General Purpose | Heavy Duty | SBR | CR | NBR/PVC | CPE | CR | NBR/PVC | CSPE | CPE |
| Initial Tensile Strength, minimum psi | 1500 | 1400 | 1400 | 1500 | 1800 | 1800 | 1500 | 1500 | 1500 | 1800 | 1800 | 1800 | 1800 |
| Initial Elongation at Rupture, Minimum % | 100 | 350 | 150 | 350 | 350 | 300 | 250 | 250 | 300 | 300 | 300 | 300 | 300 |
| Tensile Stress at 200% Elongation, Minimum psi | — | — | 1000[c] | — | 400 | — | — | — | — | 500 | 500 | 500 | 500 |
| Set, Maximum % | — | — | — | — | — | 20 | 20 | 20 | 35 | 20 | 30 | 30 | 30 |
| Retention, Minimum % | | | | | | | | | | | | | |
| Tensile Strength | 85 | 75 | 85 | 75 | 75 | 1600[b] | 50 | 50 | 55 | 50 | 50 | 85 | 85 |
| Elongation | 60 | 75 | 50 | 75 | 75 | 300[b] | 50 | 50 | 55 | 50 | 50 | 65 | 55 |
| After Air Oven Exposure at °C | 100 | 100 | 121 | 121 | 121 | 70 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ± 1°C for Hours | 120 | 48 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 |
| Retention, Minimum % Tensile Strength | 80 | — | 60 | 75 | 75 | — | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Elongation | 60 | — | 60 | 75 | 75 | — | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| After Oil Immersion at °C ± 1°C | 70 | — | 100 | 70 | 70 | — | 121 | 121 | 121 | 121 | 121 | 121 | 121 |
| for hours | 4 | — | 18 | 4 | 4 | — | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Heat Distortion, Maximum % at | 50 | — | 25 | 25 | 25 | — | — | — | — | — | — | — | — |
| °C ± 1°C | 121 | — | 121 | 121 | 121 | — | — | — | — | — | — | — | — |
| Heat Shock @ 121°C ± 1°C | No cracks | — | — | — | — | — | — | — | — | — | — | — | — |
| Cold Bend after 1 Hour at °C ± 1°C | −35 | — | −35 | — | — | — | — | — | — | — | — | — | — |
| Minimum | No cracks | — | No cracks | — | — | — | — | — | — | — | — | — | — |
| Environmental Stress Cracking | — | No cracks | — | — | — | — | — | — | — | — | — | — | — |
| Absorption Coefficient Minimum Milli Absorbance/ Meter | — | 320[a] | — | — | — | — | — | — | — | — | — | — | — |

[a]In lieu of testing finished cable jackets, a certification by the manufacturer of the polyethylene compound that this requirement has been completed with shall suffice.

[b]Values are minimum tensile strength (psi) and elongation (%) after exposure, not retained percentages.

[c]Elongation shall be 100%.

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**Table 4-3**
**WIDTH OF METAL TAPE FOR INTERLOCKED ARMOR**

| Calculated Diameter of Cable Under Armor | Maximum Width of Metal Tape Armor |
|---|---|
| inch | inch |
| 0-0.500 | 0.500 |
| 0.501-1.000 | 0.750 |
| 1.001-2.000 | 0.875 |
| 2.001 and larger | 1.000 |

#### 4.3.1.1.3 THICKNESS

The average thickness of a metal tape shall be as specified in Table 4-4. For any thickness of metal tape used, the tolerance in thickness of an individual type shall not be more than plus or minus 0.003 inch. The zinc-coated tape shall not be more than 20 percent thicker than the stripped tape thickness. The thickness tolerance of bare metal tape shall apply to the stripped tape.

### 4.3.1.2 GALVANIZED STEEL WIRE ARMOR

This section covers zinc-coated low-carbon steel wire for use as a served wire armor. The steel wire shall meet the requirements ASTM A-411 prior to armoring. The weight of zinc coating shall be in accordance with Table 4-5.

**Table 4-4**
**THICKNESS OF METAL TAPE FOR INTERLOCKED ARMOR**

| Calculated Diameter of Cable Under Armor | Average Thickness | | |
|---|---|---|---|
| | Ambrac*, Brass Stainless Steel Bronze & Monel* | AL Zinc | Plain Steel Galvanized Steel |
| inch | inch | inch | inch |
| 0-1.000 | 0.020 | 0.025 | 0.020 |
| 1.001-1.500 | 0.020 | 0.025 | 0.020 |
| | 0.025 | 0.030 | 0.025 |

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**Table 4-5**
**MINIMUM WEIGHTS OF ZINC COATING FOR WIRE ARMOR**

| Nominal Diameter of Coated Wire | Nominal Wire Size | Ounces Per Square Foot of Exposed Wire Surface |
|---|---|---|
| inch | BWG | |
| 0.022 | 24 | 0.30 |
| 0.028 | 22 | 0.30 |
| 0.035 | 20 | 0.40 |
| 0.049 | 18 | 0.40 |
| 0.065 | 16 | 0.50 |
| 0.083 | 14 | 0.60 |

#### 4.3.1.2.1 SIZE OF ARMOR

The nominal size of the served armor wires shall be as given in Table 4-6.

**Table 4-6**
**SIZE OF GALVANIZED STEEL WIRE ARMOR**

| Calculated Diameter of Cable Under Armor (or Bedding) | Nominal Wire Size | |
|---|---|---|
| inch | BWG | inch |
| 0-0.250 | 24 | 0.022 |
| 0.251-0.350 | 22 | 0.028 |
| 0.351-0.500 | 20 | 0.035 |
| 0.501-0.670 | 18 | 0.049 |
| 0.671-0.900 | 16 | 0.065 |
| 0.901-1.200 | 14 | 0.083 |

#### 4.3.1.2.2 DIAMETER TOLERANCES

The tolerances of the diameters of the galvanized wire shall be as given in Table 4-7.

**Table 4-7**
**GALVANIZED STEEL WIRE DIAMETER TOLERANCES**

| Wire Diameter | Tolerance |
|---|---|
| inch | inch |
| 0.020-0.064 | +0.002 |
| 0.065 and larger | +0.003 |

#### 4.3.1.2.3 COVERAGE

The number of wires for serving any given core shall be adjusted to yield a coverage of not less than 85 percent.

#### 4.3.1.2.4 LAY

The length of lay of the armor wires shall be not less than seven nor more than twelve times their pitch diameter.

"Lay" is defined as follows: "The Lay of any helical element of a cable is the axial length of a turn of the helix of that element."

Successive layers of bedding (see 4.3.2) and armor shall be laid in opposite directions.

### 4.3.1.3 FLAT METAL TAPE ARMOR

This section covers flat metal strip for use as flat armor. All tests shall be made prior to the application of the strip to the cable.

#### 4.3.1.3.1 TAPE MATERIAL

See 4.3.1.1.1.

#### 4.3.1.3.2 WIDTH

The nominal width of metal tape shall be as given in Table 4-8. For nominal width 1.000 inch or less, the tolerance in width for an individual tape shall be + 0.030 inch. For nominal width greater than 1.000 inch, the tolerance in width for an individual tape shall be + 0.045 inch.

**Table 4-8**
**WIDTH OF METAL TAPE FOR FLAT ARMOR**

| Calculated Diameter of Cable under Bedding* | Maximum Width of Metal Tape |
|---|---|
| inch | inch |
| 0-0.450 | 0.750 |
| 0.451-1.000 | 1.000 |
| 1.001-1.400 | 1.250 |
| 1.401-2.000 | 1.500 |
| 2.001-3.500 | 2.000 |
| 3.501 and larger | 3.000 |

*For Flat twin cable, the maximum width shall be based on the calculated major core diameter.

#### 4.3.1.3.3 THICKNESS

The thickness of metal tape is not specified and shall be as agreed upon between user and manufacturer.

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**Table 4-9**
**MINIMUM THICKNESS OF METAL FOR CORRUGATED ARMOR**

| Calculated Diameter of Cable Under Armor | Aluminum | Copper | Steel |
|---|---|---|---|
| inch | inch | inch | inch |
| 0-2.180 | 0.022 | — | — |
| 2.181-3.190 | 0.029 | — | — |
| 3.191-4.200 | 0.034 | — | — |
| 0-2.365 | — | 0.017 | — |
| 2.366-3.545 | — | 0.021 | — |
| 3.546-4.200 | — | 0.025 | — |
| 0-1.905 | — | — | 0.016 |
| 1.906-3.050 | — | — | 0.020 |
| 3.051-4.200 | — | — | 0.024 |

#### 4.3.1.3.4 APPLICATION, LAY, AND SPACING

One or two tapes shall be applied helically over the bedding (see 4.3.2). When two tapes are used and the total cross-sectional area of the conductors is 50,000 circular mils or greater, the two tapes shall be applied in the same direction.

When the outer tape is applied in the same direction as the inner tape, the outer tape shall be approximately centered over the spaces between the convolutions of the inner tape. The maximum space between turns shall not exceed 20 percent of the width of the tape or 0.20 inch, whichever is greater.

When required, a corrosion inhibiting compound shall be applied to plain metal tapes.

### 4.3.1.4 CONTINUOUSLY CORRUGATED METAL ARMOR

This section covers continuously corrugated metal armor. The metal armor is formed by a flat metal tape which is longitudinally folded around the cable core, seam welded and corrugated, or by applying over the cable core a seamless sheath or tube which is then corrugated.

#### 4.3.1.4.1 TYPE OF METAL

When metal armor is formed by a flat metal tape, the tapes used shall be aluminum, copper, steel, or alloys thereof.

When metal armor is formed by applying a seamless sheath or tube the metal shall be aluminum or an aluminum alloy.

#### 4.3.1.4.2 THICKNESS

The minimum thickness of tape or of the sheath or tube before corrugation shall be as shown in Table 4-9.

#### 4.3.1.4.3 FLEXIBILITY

The armored cable shall be capable of being bent around a mandrel having a diameter of 14 times the cable diameter. The armor shall show no evidence of fracture visible to the unaided eye. The test shall be conducted in accordance with the procedure given in Part 6.

#### 4.3.1.4.4 CORROSION PROTECTION

When required, a corrosion protective covering shall be applied over the armor.

The cable manufacturer should be consulted for recommendations for corrosion protection. (This sentence has been approved by NEMA as Authorized Engineering Information.)

### 4.3.2 Core Covering for Nonsheathed and Nonjacketed Cable with Metallic Armor

A covering of tape, braid or jute, or other material shall be applied over the core of nonsheathed and nonjacketed cable to act as a protective bedding.

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**Table 4-10**
**THICKNESS OF COVERING OVER METALLIC ARMOR**

| Calculated Diameter of Cable Over Armor | Thickness | |
|---|---|---|
| | Interlocked or Corrugated Corrugated Armor | All other Armor |
| inch | inch | inch |
| 0-0.425 | 0.040 | 0.050 |
| 0.426-1.500 | 0.050 | 0.065 |
| 1.501-2.250 | 0.060 | 0.080 |
| 2.251-3.000 | 0.075 | 0.095 |
| 3.001 and larger | 0.085 | 0.110 |

### 4.3.3 Thermoplastic or Crosslinked Coverings over Metallic Armor

Thermoplastic or crosslinked coverings, when used, shall be extruded either directly over the metallic armor or over an optional separator or binder tape located between the armor component and overall jacket. The overall covering and tape shall conform to the core. The coverings shall be one of the types given in 4.2 and shall meet the requirements of 4.2, except thickness shall be in accordance with 4.3.3.1.

#### 4.3.3.1 THICKNESS

The minimum average thickness of the covering shall not be less than specified in Table 4-10. The minimum thickness at any point shall not be less than 70 percent of the specified value. The minimum and maximum thickness of the covering shall be determined directly with a micrometer, or a micrometer microscope on a ring of covering removed from the cable. The average of these determinations shall be taken as the average thickness of the jacket.

### 4.3.4 Spark Test on Each Length of Cable

The covering shall withstand the ac spark test voltage given in Table 4-11, except that thermoplastic CPE jackets shall withstand the test voltage specified for crosslinked coverings.

**Table 4-11**
**AC-SPARK TEST VOLTAGE FOR COVERING OVER ARMOR**

| Covering Thickness | Thermoplastic | Crosslinked |
|---|---|---|
| inch | kV | kV |
| 0.040 | 3.5 | 1.5 |
| 0.050 | 4.0 | 2.0 |
| 0.060 | 5.5 | 2.5 |
| 0.065 | 6.0 | 2.5 |
| 0.075 | 6.5 | 3.0 |
| 0.080 | 7.0 | 3.0 |
| 0.085 | 7.5 | 3.5 |
| 0.095 | 8.5 | 4.0 |
| 0.110 | 10.0 | 4.5 |

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# PART 5
# ASSEMBLY, FILLERS, AND CONDUCTOR IDENTIFICATION

## 5.1 ASSEMBLY OF MULTIPLE CONDUCTOR CABLES

### 5.1.1 Round Cables

The length of lay of the individual conductors or subassemblies in the outer layer of cables shall not exceed the value calculated from the factors given in Table 5-1. Where there is more than one layer of conductors or subassemblies, the inner layers shall have a length of lay not greater than those in the outer layer unless the inner layer consists of a single conductor or subassembly.

The direction of lay may be changed at intervals throughout the length of the cable. The intervals need not be uniform. In a cable in which the direction of lay is reversed:

a) Each area in which the lay is right- or left-hand for a minimum of five complete twists (full 360° cycles) shall have the conductors or subassemblies cabled with a length of lay that is not greater than the values calculated from the factor given in Table 5-1.

b) The length of each lay-transition zone (oscillated section) between these areas of right- and left-hand lay shall not exceed 1.8 times the maximum length of lay values calculated from the factor given in Table 5-1.

c) The length of lay of the conductors or subassemblies shall be determined by measuring, parallel to the longitudinal axis of the cable, the pitch of each successive convolution of one conductor or subassembly. When the direction of lay is reversed, the beginning and end of area of reversal shall be defined on either side by the last convolution that does not exceed the maximum lay requirement on either side of the reversal area.

If the direction of lay is not reversed in a cable containing layers of conductors or subassemblies, the outer layer of conductors or subassemblies shall have a left-hand lay and the direction of lay of the conductors or subassemblies in the inner layers shall be governed by the cabling machine.

If the direction of lay is not reversed in a single layer cable, the conductors or subassemblies shall have a left hand lay.

A left-hand lay is defined as a counter-clockwise twist away from the observer.

The length of lay of the conductors in subassemblies shall be in accordance with Table 5-2. Staggered lay lengths shall be permitted but not required in subassemblies.

**Table 5-1**
**FACTORS FOR MAXIMUM LAY LENGTH**

| Number of Conductors or Subassemblies in Cable | Multiplying Factors Based on Calculated Diameter |
|---|---|
| 2 | 30 times largest conductor or subassembly diameter |
| 3 | 35 times largest conductor or subassembly diameter |
| 4 | 40 times largest conductor or subassembly diameter |
| 5 or more | 15 times assembled diameter |

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**Table 5-2**
**LENGTH OF LAY OF SUBASSEMBLIES**

| Conductor Size | Pairs | Triads | Quads |
|---|---|---|---|
| AWG | inch ± ¼" | inch ± ¼" | inch ± ¼" |
| 22 | 2 | 2 | 2 |
| 20 | 2 | 2 | 2 |
| 19 | 2 | 2¼ | 2¼ |
| 18 | 2 | 2¼ | 2¼ |
| 17 | 2 | 2¼ | 2¼ |
| 16 | 2 | 2½ | 3 |

### 5.1.2 Flat Twin Cables

Flat twin cables shall consist of two insulated conductors laid parallel.

## 5.2 FILLERS

Fillers shall be used in the interstices of round cables where necessary to give the completed cable a substantially circular cross-section.

## 5.3 BINDERS

Separators or binders may be used within the cable construction.

## 5.4 CONDUCTOR IDENTIFICATION

When required, conductors shall be identified by any suitable means.

See Appendix E for recommendation. (This sentence approved by NEMA as Authorized Engineering Information.)

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# Part 6

# TEST METHODS

## 6.1 TESTING—GENERAL

All wires and cables shall be tested at the factory in accordance with Part 6 to determine their compliance with the requirements given in Parts 2, 3, 4, and 5. When there is a conflict between test methods given in Part 6 and publications of other organizations to which reference is made, Part 6 shall apply.

## 6.2 CONDUCTOR TEST METHODS

See ICEA T-27-581/NEMA WC 53.

## 6.3 THICKNESS MEASUREMENTS FOR INSULATIONS AND NONMETALLIC JACKETS

See ICEA T-27-581/NEMA WC 53.

## 6.4 PHYSICAL AND AGING TESTS FOR INSULATIONS AND JACKETS

### 6.4.1 Size and Preparation of Specimens

The test specimens shall be of a suitable length, shall have no surface incisions, and shall be as free as possible from other imperfections. For insulated wire, the test specimen shall be taken prior to the application of any additional coverings and shall be the entire cross-section of the insulation. See 3.3.7 for composite insulations. The specimens shall not be cut longitudinally.

*Exception: If it is not possible to obtain a specimen of insulation prior to the application of a covering, the specimen shall be taken after the application of a covering, provided such covering can be removed without injury to the insulation.*

Specimens for tests on jacket compounds shall be taken from the completed wire or cable and cut parallel to the axis of the wire or cable. The test specimen shall be a suitably cut segment or a shaped specimen cut out with a die, and shall have a cross-sectional area not greater than 0.025 square inch after irregularities, corrugations, and reinforcing cords or wires have been removed.

### 6.4.2 Calculation of Area of Test Specimens

**6.4.2.1** When the total cross-section of the insulation is used, the area shall be taken as the difference between the area of the circle whose diameter is the average outside diameter of the insulation and the area of the conductor. The area of a stranded conductor shall be calculated from its maximum diameter.

**6.4.2.2** When a slice cut from the insulation by a knife held tangent to the wire is used and when the cross-section of the slice is the cross-section of a segment of a circle, the area shall be calculated as that of the segment of a circle whose diameter is that of the insulation. The height of the segment is the wall of insulation on the side from which the slice is taken. The values may be obtained from a table giving the areas of segments of a unit circle for the ratio of the height of the segment to the diameter of the circle. (This sentence has been approved by NEMA as Authorized Engineering Information.)

When the cross-section of the slice is not a segment of a circle, the area shall be calculated from a direct measurement of the volume or from the specific gravity and the weight of a known length of the specimen having a uniform cross-section.

**6.4.2.3** The dimensions of specimens to be aged shall be determined before the aging test.

### 6.4.3 Physical Test Procedures

Physical tests on both the unaged and aged test specimen shall be made at approximately the same time.

#### 6.4.3.1 Test Temperature

Physical tests shall be made at room temperature. The test specimens shall be kept at room temperature for not less than 30 minutes prior to the test.

#### 6.4.3.2 Type of Testing Machine

The testing machine shall be in accordance with ASTM D 412.

## 6.5 TENSILE STRENGTH TEST

The tensile strength test shall be made on specimens prepared in accordance with 6.4.2 and 6.4.3. The length of all the specimens for the test shall be equal. Specimens shall have a length of 4.5 or 6 inches. Either ASTM D 412 Die C or D shall be used with specimens at least 4.5 inches in length with the gauge marks placed one inch

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apart. Either ASTM D 412 Die B or E shall be used with specimens at least 6 inches in length with the gauge marks placed two inches apart except that one inch gauge marks shall be used for polyethylene regardless of specimen length.

Cross sectional area between gauge marks shall be determined in accordance with 6.4.2. The jaws of the testing machine for 6-inch long specimens shall be 4 inches apart. The jaws of the testing machine for 4.5-inch long specimens shall be 2.5 inches apart. Each specimen shall be stretched at the rate of 20 ± 2 inches per minute (jaw speed) until it breaks. The tensile and elongation determinations for polyethylene compounds for which the compound manufacturer certifies that the base resin content is more than 50 percent by weight of high density polyethylene (having a density of 0.926 $Mg/m^3$ or greater), shall be permitted to be tested at a jaw separation rate of 2 inches per minute as an alternative to 20 inches per minute. The tensile strength shall be calculated in accordance with ASTM D 412. Specimens shall break between the gauge marks, and the tensile strength shall be calculated on the area of the unstretched specimen. Specimen length, gauge mark distance, and jaw speed shall be recorded with the results.

## 6.6 TENSILE STRESS TEST

The tensile stress test shall be made in conjunction with the tensile strength test by recording the load when the gauge marks indicate that the specimen is at its prescribed elongation. The tensile stress shall be calculated in accordance with ASTM D 412.

## 6.7 ELONGATION TEST

Elongation at rupture shall be determined simultaneously with the test for tensile strength and on the same specimen. The elongation shall be taken as the distance between gauge marks at rupture less the original gauge length of the test specimen. The percentage of elongation at rupture is the elongation divided by the original gauge length and multiplied by 100.

## 6.8 SET TEST

The set test shall be made on 6 inch long test specimens which have been prepared, marked with 2 inch gauge marks, and stretched in accordance with 6.6 until the gauge marks are 6 inches apart. The test specimen shall be held in the stretched position for five seconds and then released. The distance between gauge marks shall be determined one minute after the release of tension. The set is the difference between this distance and the original 2 inch gauge length, expressed as a percentage of the original gauge length.

## 6.9 AGING TESTS

### 6.9.1 Test Specimens

Test specimens of similar size and shape shall be prepared in accordance with 6.4.1.

When the entire cross section of insulation is used, the insulation shall be subjected to the aging condition with the conductor removed. Simultaneous aging of different compound should be avoided. (This sentence has been approved by NEMA as Authorized Engineering Information.)

The test specimens shall be suspended vertically in such a manner that they are not in contact with each other or with the sides of the container.

The aged specimens shall have a rest period at room temperature of not less than 16 hours nor more than 96 hours between the completion of the aging tests and the determination of tensile strength and elongation.

### 6.9.2 Air Oven Test

The test specimens shall be heated at the required temperature for the specified period in an oven having forced circulation of fresh air. The oven temperature shall be controlled to within ±1 °C and recorded continuously.

### 6.9.3 Oil Immersion Test

The test specimens shall be immersed in ASTM Oil No. 2 [described in Table I of ASTM D 471] for the specified time and at the specified temperature. At the end of this period the specimen shall be removed from the oil, blotted lightly, and allowed to rest at room temperature for 4 ± ½ hours before being tested for tensile strength and elongation. The calculations for tensile strength shall be based on the cross sectional area of the specimen obtained before immersion in oil. The elongation shall be based on gauge marks applied to the specimen before immersion in oil.

### 6.9.4 Hot Creep

See ICEA T-28-562.

### 6.9.5 Heat Distortion for Insulated Conductors

See ICEA T-27-581/NEMA WC 53.

### 6.9.6 Heat Distortion for Thermoplastic Jackets

See ICEA T-27-581/NEMA WC 53.

### 6.9.7 Heat Shock for Thermoplastic Jackets

A sample of jacketed cable shall be wound tightly around a mandrel having a diameter in accordance with Table 6-1. The specimen shall be held firmly in place and

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**Table 6-1**
**MANDREL DIAMETER FOR HEAT SHOCK OF JACKET**

| Outside Diameter of Cable | Number of Adjacent Turns | Diameter of Mandrel as a Multiple of Outside Cable Diameter |
|---|---|---|
| inch | | inch |
| 0-0.750 | 6 | 3 |
| 0.751-1.500 | 180 degree bend | 8 |
| 1.501 and larger | 180 degree bend | 12 |

shall be subjected to a temperature of 121 °C ± 1 °C for one hour. At the end of the test period the specimen shall be examined for cracking of the jacket.

### 6.9.8 Nylon Wrap Test

The specimen with the nlyon-covered insulated conductor shall be taken from the completed cable and wrapped four turns around a smooth metal mandrel having a diameter not more than six times that of the specimen. The ends of the specimen shall be secured to the mandrel so that four completed turns of the specimen will be exposed to the air between the securing means. The specimen and mandrel shall be suspended for 24 hours in a full-draft circulating air oven at a temperature of 95.0 °C ± 2.0 °C after which the specimen and mandrel shall be removed from the oven and cooled for one hour in a silica-gel desiccator or the equivalent at room temperature. The specimen shall be straightened immediately upon removal from the desiccator and inspected for surface cracks.

## 6.10 OZONE RESISTANCE TEST

The test shall be made in accordance with ASTM D 470. The ozone concentration shall be 0.025 to 0.030 percent by volume.

## 6.11 THICKNESS OF COVERINGS

See ICEA T-27-581/NEMA WC 53.

## 6.12 ENVIRONMENTAL CRACKING

The test shall be made in accordance with ASTM D 1693, Condition I.

## 6.13 ABSORPTION COEFFICIENT

The absorption coefficient of jacket compounds shall be determined in accordance with ASTM D 3349.

## 6.14 ACCELERATED WATER ABSORPTION

### 6.14.1 General

The test shall be performed on one of the insulated conductors from a completed cable with all coverings over the insulation removed. Composite insulations shall be tested with both insulation layers in place over the conductor (see 3.3.7).

Insulated conductors having a nonconducting separator between the insulation and conductor or having a covering which cannot be removed without damaging the insulation, shall not be tested. In that case a representative 22-16 AWG conductor having the same insulation and an insulation thickness applicable to the voltage rating shall be tested.

The gross length of each sample required by the electrical method shall be 15 feet and, by the gravimetric method, 11 inches.

### 6.14.2 Electrical Method (EM-60)

See ICEA T-27-581/NEMA WC 53. Crosslinked insulation shall be tested 48 hours or more after crosslinking. Thermoplastic insulations shall be tested any time after extrusion.

Capacitance (SIC)
See ICEA T-27-581/NEMA WC 53.

Stability Factor
See ICEA T-27-581/NEMA WC 53.

Permittivity (SIC)

The permittivity of the insulation at 60 hertz shall be calculated as follows:

$$\text{Permittivity} = 13600\ C \log_{10} D/d$$

Where: C = Capacitance in microfarads of the 10-foot section
D = Diameter over the insulation
d = Diameter under the insulation

### 6.14.3 Gravimetric Method

See ICEA T-27-581/NEMA WC 53.

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## 6.15 COLD BEND

See ICEA T-27-581/NEMA WC 53. The mandrel shall have a diameter in accordance with Table 6-2.

**Table 6-2**
**MANDREL DIAMETER FOR COLD BEND OF JACKETS**

| Outside Diameter of Wire or Cable | Diameter of Mandrel as a Multiple of the Outside Diameter of Cable |
|---|---|
| inch | inch |
| 0 - 0.800 | 8 |
| 0.801 and larger | 10 |

## 6.16 FLAME TESTING

### 6.16.1 Type A

#### 6.16.1.1 APPARATUS

The test apparatus shall consist of the following:

(1) Test chamber of sheet metal 12 inches wide, 14 inches deep, and 24 inches high, which is open at the top, and which is provided with means for clamping the test specimen at the upper end and supporting it in a vertical position.

(2) Means for adjusting the position of the test specimen.

(3) A suitable means to keep the specimen taut.

(4) Tirrill Burner with an attached pilot light and mounted on a 20-degree angle block. The burner shall have a nominal bore of $^3/_8$ inch and a length of approximately four inches above the primary air inlets.

(5) An adjustable steel angle (jig) attached to the bottom of the chamber to insure the correct location of the burner with relation to the test specimen.

(6) Gas (a supply of ordinary illuminating gas at normal pressure).

(7) Watch or clock with a hand which makes one complete revolution per minute.

(8) Flame indicators consisting of strips of gummed kraft paper having a nominal thickness of 5 mils and a width of ½ inch. (The paper used for the indicators is known to the trade as 60 pound. [This sentence has been approved as NEMA Authorized Engineering Information.])

(9) Untreated Surgical Cotton.

#### 6.16.1.2 PREPARATION

The test shall be made in a room which is generally free from drafts of air, although a ventilated hood may be used if air currents do not affect the flame. One end of the test specimen approximately 22 inches in length shall be clamped tautly in a vertical position. A paper indicator shall be applied to the specimen so that the lower edge is ten inches above the point at which the inner blue cone of the test flame is to be applied. The indicator shall be wrapped once around the specimen, with the gummed side toward the conductor. The ends shall be pasted evenly together and shall project ¾ inch from the specimen on the opposite side of the specimen to that which the flame is to be applied. The paper tab shall be moistened only to the extent necessary to permit proper adhesion. The height of the flame with the burner vertical shall be adjusted to 5 inches, with an inner blue cone 1½ inches high.

The temperature at the tip of the inner blue cone shall be not less than 836°C.

A flat horizontal layer of untreated surgical cotton shall be placed on the floor of the chamber and centered directly under the specimen. The upper surface of the cotton shall be no more than 9½ inches from the point at which the inner blue cone touches the cable surface.

#### 6.16.1.3 PROCEDURE

The burner, with only the pilot lighted, shall be placed in front of the sample so that the vertical plane through the stem of the burner includes the axis of the wire or cable. The angle block shall rest against the jig, which shall be adjusted so that there is a distance of 1½ inches along the axis of the burner stem between the tip of the stem and the surface of the specimen. The value supplying the gas to the burner proper shall then be opened and the flame automatically applied to the sample. This valve shall be held open for 15 seconds and then closed for no less than 15 seconds, then reopened for 15 seconds, closed for no less than 15 seconds, etc., for a total of five 15-second flame applications.

The flame shall not be reapplied until flaming of the specimen ceases of its own accord. During each application of flame, the position of the burner or specimen shall be adjusted, as necessary, so that the tip of the inner blue cone just touches the surface of the specimen.

### 6.16.2 Type B

#### 6.16.2.1 APPARATUS

See 6.16.1.1, except delete item (9).

#### 6.16.2.2 PREPARATION

See 6.16.1.2, except delete cotton layer.

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#### 6.16.2.3 PROCEDURE

See 6.16.1.3, except the gas valve shall be closed for 15 ± 0 seconds after each application, then reopened and the flame reapplied to the specimen regardless if the specimen is flaming or not.

### 6.17 VOLTAGE TESTS

See ICEA T-27-581/NEMA WC 53. The voltage shall be applied between each insulated conductor with all other conductors and any metallic sheath, metallic shield, or metallic armor connected to ground.

### 6.17.1 Alternating Current Voltage Test

See ICEA T-27-581/NEMA WC 53.

### 6.17.2 Direct Current Voltage Test

See ICEA T-27-581/NEMA WC 53. This test shall be made after the insulation resistance test.

### 6.17.3 Alternating Current Spark Test

See ICEA T-27-581/NEMA WC 53.

### 6.18 INSULATION RESISTANCE

See ICEA T-82-552/NEMA WC 55.

### 6.18.1 Determination of Temperature Conversion Factors for Insulation Resistance

See ICEA T-27-581/NEMA WC 53.

### 6.19 SPECIFIC SURFACE RESISTIVITY

See ICEA T-27-581/NEMA WC 53.

### 6.20 DIELECTRIC STRENGTH RETENTION

Twenty samples, each at least five feet long, shall be cut from a reel or coil.

Ten identified samples shall be immersed, except for the ends, for 14 days in water at the specified temperature. Immediately thereafter, all twenty samples shall be immersed, except for the ends, in water at 20 °C to 30 °C for one hour. At least three feet of each sample shall be immersed.

After the twenty samples have been immersed, an alternating current test voltage, starting at zero, shall be applied across the insulation and increased at the rate of 500 volts per second until breakdown occurs.

The dielectric strength retention shall be calculated as follows:

$$\text{Dielectric strength retention, percent} = B/A \times 100$$

Where: B = Average breakdown voltage of the ten samples immersed for 14 days at the specified temperature.

A = Average breakdown voltage of the ten samples not immersed for 14 days at the specified temperature.

### 6.21 SHIELD ISOLATION

Shield isolation shall be determined using either 6.21.1 or 6.21.2.

### 6.21.1 Insulation Resistance Method

Using the apparatus specified in ICEA T-27-581/NEMA WC 53 the insulation resistance shall be measured between each shield with all other shields and any bare conductor connected to ground potential.

### 6.21.2 Dielectric Method

Using the apparatus specified in ICEA T-27-581/NEMA WC 53 the specified voltage shall be applied for one minute between each shield with all other shields and any bare conductor connected to ground potential.

### 6.22 SHIELD CONTINUITY

Shield continuity shall be determined using any suitable method, such as a low voltage buzzer, light circuit, or dc resistance.

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# Part 7

# SPECIAL CONSTRUCTIONS

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# Part 8
# APPENDICES

## Appendix A
## INDUSTRY STANDARD REFERENCES

**(Appendix A is classified by NEMA as Authorized Engineering Information.)**

| | |
|---|---|
| ANSI MC 96.1-1982 | *Temperature Measurement Thermocouples* |
| ANSI/NFPA 70-1993* | *National Electrical Code* |
| ASTM A 90-81 | *Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles* |
| ASTM A 411-86 | *Zinc Coated (Galvanized) Low Carbon Steel Armor Wire* |
| ASTM A 459-71 (1980) | *Zinc Coated Flat Stell Armoring Tape* |
| ASTM B 3-74 (1985) | *Soft or Annealed Copper Wire* |
| ASTM B 5-83a | *Electrolyte Tough-pitch Copper Refinery Shapes* |
| ASTM B 8-86 | *Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft* |
| ASTM B 33-81 (1985) | *Tinned Soft or Annealed Copper Wire for Electrical Purposes* |
| ASTM B 189-81 (1985) | *Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes* |
| ASTM B 193-87 | *Resistivity of Electrical COnductor Materials* |
| ASTM B 263-58 (1981) | *Cross-Sectional Area of Stranded Conductors* |
| ASTM D 257-78 (1983) | *dc Resistance of Plastics and Electrical Insulating Materials* |
| ASTM D 412-87 | *Rubber Properties in Tension* |
| ASTM D 470-82 | *Testing of Thermosetting Insulations and Jackets for Wire and Cable* |
| ASTM D 471-79 | *Rubber Property—Effect of Liquids* |
| ASTM D 1248-84 | *Polyethylene Plastics Molding and Extrusion Materials* |
| ASTM D 1693-70 (1980) | *Environmental Stress-Cracking of Ethylene Plastics* |
| ASTM D 2765-84 | *Degree of Crosslinking in Crosslinked Ethylene Plastics* |

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## Appendix A (continued)

| | |
|---|---|
| ASTM D 3349-86 | *Absorption Coeffictient of Carbon Black Pigmented Ethylene Film* |
| ICEA T-26-465/ NEMA WC 54-1990 | *Guide for Frequency of Sampling Extruded Dielectric Power, Control, Instrumentation, and Portable Cables for Tests* |
| ICEA T-27-581/ NEMA WC 53-1990 | *Standard Test Methods for Extruded Dielectric Power, Control, Instrumentation and Portable Cables* |
| ICEA T-28-562 (1983) | *Test Methods for Measurement of Hot Creep of Polymeric Insulations* |
| NBS Handbook 100 (2/21/66) | *Copper Wire Tables* |

Copies of the above documents may be obtained from the appropriate source as follows:

**American National Standards Institute (ANSI)**
11 West 42nd Street
New York, NY 10036

**American Society for Testing and Materials (ASTM)**
1916 Race Street
Philadelphia, PA 19103

**Insulated Cable Engineers Association Inc.**
P.O. Box 440
South Yarmouth, MA 02664

**National Bureau of Standards (NBS)**
The *NBS Handbook 100* is sold by
the National Technical Information Service
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# Appendix B

## ADDITIONAL CONDUCTOR INFORMATION
## (Appendix B is classified by NEMA as Authorized Engineering Information.)

**Table B-1**
**APPROXIMATE DIAMETERS OF STRANDED CLASS B AND C COPPER CONDUCTORS**

| Conductor Size | Diameter |
|---|---|
| AWG | inch |
| 22 | 0.029 |
| 20 | 0.036 |
| 19 | 0.041 |
| 18 | 0.046 |
| 17 | 0.052 |
| 16 | 0.058 |

**Table B-2**
**APPROXIMATE WEIGHTS OF COPPER CONDUCTORS IN LBS/1000 FT**

| Conductor Size | Conductor Weight | |
|---|---|---|
| AWG | Solid | Stranded |
| 22 | 1.94 | 1.98 |
| 20 | 3.10 | 3.15 |
| 19 | 3.90 | 3.97 |
| 18 | 4.92 | 5.02 |
| 17 | 6.21 | 6.32 |
| 16 | 7.81 | 7.97 |

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# Appendix C

## REPRESENTATIVE VALUES OF TENSILE STRENGTH AND ELONGATION FOR NON-MAGNETIC ARMOR MATERIALS

**(Appendix C is classified by NEMA as Authorized Engineering Information.)**

### Table C-1
### NON-MAGNETIC ARMOR MATERIALS

| Metal | Tensile Strength psi | Elongation 2-Inch Length, Percent |
|---|---|---|
| Aluminum | 13000-45000 | 15-45 |
| Ambrac* | 50000-70000 | 20-40 |
| Brass | 40000-50000 | 40-50 |
| Bronze | 35000-42000 | 40 |
| Monel* | 75000 | 45 |
| Stainless Steel | 82000-90000 | 50 |
| Zinc | 20000 | 60 |

*Trade names—The listing of these materials implies no endorsement; rather it shows them as being typical of materials commercially available at the time of printing.

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# Appendix D

# OTHER TEST METHODS

**(Appendix D is classified by NEMA as Authorized Engineering Information.)**

When mutually agreed upon between the user and manufacturer, other tests to determine specific electrical characteristics should be conducted.

*These tests should take into account cable construction and applications.*

For information only, the following test methods are given:

## D 1 Capacitance

The capacitance of 2/C shielded cables shall be measured to three significant figures, at a frequency of 1000 ± 100 Hz and reported in micromicrofarads (°F) per foot. An electrically short piece, i.e. less than $^1/_{40}$ of a wavelength of cable, should be used for this test. For twin-conductor cables, the capacitance between the two inner conductors shall be determined by the following formula:

$$\text{Capacitance} = [2(Ca+Cb)-Cc]/4$$

Where: Ca = Capacitance between the No. 1 conductor and the No. 2 conductor connected to shield.

Cb = Capacitance between No. 2 conductor and the No. 1 conductor connected to shield.

Cc = Capacitance between No. 1 and No. 2 conductors connected together and the shield.

## D 2 Capacitance Unbalance

The coefficient of asymmetry of a shielded twin-conductor cable expressed in percent shall be determined by the following formula:

$$\text{Coefficient of Asymmetry} = [400\,(Ca-Cb)]/2\,[(Ca+Cb)-Cc]$$

Where: Ca = Capacitance between No. 1 conductor and the No. 2 conductor connected to shield.

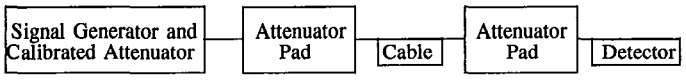
Cb = Capacitance between No. 2 conductor and the No. 1 conductor connected to shield.

Cc = Capacitance between the No. 1 and No. 2 conductors connected together and the shield.

The coefficient shall be determined at a frequency of 1000 ± 100 Hz on a specimen of cable not exceeding ten feet in length.

## D 3 Attenuation

Attenuation per unit length is defined as the logarithmic decrement in transmitted power. The attenuation, expressed in decibel (db) per 100 feet, shall be measured at a sufficiently low-power level that the resulting temperature rise will be negligible. An acceptable method for measuring attenuation is as follows:




In the block diagram shown above, a suitable length of cable with an attenuation of at least 3 db is inserted between the connectors. The signal generator and calibrated attenuator are adjusted to produce a reasonable indication at the detector, when the detector is tuned. The detector reading is noted, and the calibrated attenuator output level is recorded. The cable under test is then withdrawn and the circuit completed with the connectors (or a very short length of cable). With the detector tuned, the calibrated attenuator is readjusted to reproduce the original reading at the detector, and the attenuator output level is again recorded. Attenuation is then computed as follows:

A = 100/L (Difference in Calibrated Attenuator Readings in db)

Where: A = Attenuation in db per 100 feet.
L = Length of cable under test in feet.

For measurements at frequencies of 400 MHz or less, the characteristic impedance of the attenuator pads and connectors shall preferably be the same as that of the cable under test. Both pads shall be high enough in attenuation value to minimize the error caused by any mismatch of the signal generator and detector.

For the majority of measurements, it is recommended that the attenuation of each pad be approximately 10 db. Tuning stubs may be used in the circuit for impedance-matching purposes.

## D 4 Impedance

The characteristic impedance of twin-conductor cables shall be determined preferably by calculation from the capacitance measurement specified in D1 and the velocity of propagation measurement specified in D5, using the following formula:

$$Zo \text{ in Ohms} = 101600/[(\text{Percent Velocity})\,(\text{Capacitance in F/ft})]$$

## D 5 Velocity

The velocity of propagation is determined in terms of the percentage of the velocity of wave propagation along the cable to the velocity of an electromagnetic wave in

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## Appendix D (*continued*)

free space. The velocity of propagation in the cable may be found by resonating a length of cable at a frequency between 10 and 200 MHz with one end short-circuited or open-circuited.

Percent Velocity = [Fr × L]/2.46 N

Where: Fr = Resonant frequency in MHz
L = Length of cable under test, in feet
N = Number of quarter wavelengths in the cable

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# Appendix E

## CONDUCTOR AND CIRCUIT IDENTIFICATION

**(Appendix E is classified by NEMA as Authorized Engineering Information.)**

This appendix contains recommendations for conductor and circuit identification when such identification is used.

### E 1 INSTRUMENTATION CABLES—*National Electrical Code* Applications

The *National Electrical Code* specified that conductors colored white be used only as grounded conductors and that conductors colored green or green/yellow be used only as grounding conductors and that neither white nor green be used in any manner on ungrounded conductors. Table E-1 provides a color sequence which does not include white or green conductors. If grounded and/or grounding conductors are used in the cable, they should be colored white or green, respectively, and inserted as the second and/or third designated conductor in the first sequence of circuit identification only. Grounding conductors or grounded conductors or both, when required, should be specified.

### E 1.1 Individual Color Coding Without Braids

Where color coding of individual conductors is required by other than colored marker braids or wraps, Methods 1, 1A, 1B, 3, 3A, or 3B should be used.

#### E 1.1.1 METHODS 1, 1A, AND 1B

Colored Compounds with Tracers. These methods use base colors with tracers in accordance with Tables E-1 or E-2. Base and tracer colors should be recognizable as the color combinations given in Tables E-1 or E-2 and should approximately match the color shades specified in Table E-3.

Base colors may be obtained by color coatings applied to the insulation or jacket surface or by colored insulation or jacket compound.

Tracers should be colored stripes or bands marked on the surface of the insulation or jacket in such a manner as to afford distinctive circuit coding throughout the length of each wire. Tracers may be in continuous or broken lines, such as a series of dots or dashes, and should be applied longitudinally, annularly, spirally, or in other distinctive patterns.

**Table E-1**
**COLOR SEQUENCE FOR INSTRUMENTATION CABLES**

| Conductor Number | Background or Base Color | Tracer Color | Conductor Number | Background or Base Color | Tracer Color |
|---|---|---|---|---|---|
| 1 | Black | — | 19 | Orange | Blue |
| 2 | Red | — | 20 | Yellow | Blue |
| 3 | Blue | — | 21 | Brown | Blue |
| 4 | Orange | — | 22 | Black | Orange |
| 5 | Yellow | — | 23 | Red | Orange |
| 6 | Brown | — | 24 | Blue | Orange |
| 7 | Red | Black | 25 | Yellow | Orange |
| 8 | Blue | Black | 26 | Brown | Orange |
| 9 | Orange | Black | 27 | Black | Yellow |
| 10 | Yellow | Black | 28 | Red | Yellow |
| 11 | Brown | Black | 29 | Blue | Yellow |
| 12 | Black | Red | 30 | Orange | Yellow |
| 13 | Blue | Red | 31 | Brown | Yellow |
| 14 | Orange | Red | 32 | Black | Brown |
| 15 | Yellow | Red | 33 | Red | Brown |
| 16 | Brown | Red | 34 | Blue | Brown |
| 17 | Black | Blue | 35 | Orange | Brown |
| 18 | Red | Blue | 36 | Yellow | Brown |

Note: See E 1 for *National Electrical Code* Applications.

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## Table E-2
## COLOR SEQUENCE FOR INSTRUMENTATION CABLES

| Conductor Number | Background or Base Color | First Tracer Color | Second Tracer Color | Conductor Number | Background or Base Color | First Tracer Color | Second Tracer Color | Conductor Number | Background or Base Color | First Tracer Color | Second Tracer Color |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1* | Black | — | — | 44 | White | White | Blue | 86 | Blue | Green | — |
| 2 | White | — | — | 45 | White | Black | Blue | 87 | Black | Orange | — |
| 3 | Red | — | — | 46 | Red | White | Blue | 88 | White | Orange | — |
| 4 | Green | — | — | 47 | Green | Orange | Red | 89 | Red | Orange | — |
| 5 | Orange | — | — | 48 | Orange | Red | Blue | 90 | Green | Orange | — |
| 6 | Blue | — | — | 49 | Blue | Red | Orange | 91 | Blue | Orange | — |
| 7 | White | Black | — | 50 | Black | Orange | Red | 92 | Black | Blue | — |
| 8 | Red | Black | — | 51 | White | Black | Orange | 93 | White | Blue | — |
| 9 | Green | Black | — | 52 | Red | Orange | Black | 94 | Red | Blue | — |
| 10 | Orange | Black | — | 53 | Green | Red | Blue | 95 | Green | Blue | — |
| 11 | Blue | Black | — | 54 | Orange | Black | Blue | 96 | Orange | Blue | — |
| 12 | Black | White | — | 55 | Blue | Black | Orange | 97 | Yellow | — | — |
| 13 | Red | White | — | 56 | Black | Orange | Green | 98 | Yellow | Black | — |
| 14 | Green | White | — | 57 | White | Orange | Green | 99 | Yellow | White | — |
| 15 | Blue | White | | 58 | Red | Orange | Green | 100 | Yellow | Red | — |
| 16 | Black | Red | — | 59 | Green | Black | Blue | 101 | Yellow | Green | — |
| 17 | White | Red | — | 60 | Orange | Green | Blue | 102 | Yellow | Orange | — |
| 18 | Orange | Red | — | 61 | Blue | Green | Orange | 103 | Yellow | Blue | — |
| 19 | Blue | Red | — | 62 | Black | Red | Blue | 104 | Black | Yellow | — |
| 20 | Red | Green | — | 63 | White | Orange | Blue | 105 | White | Yellow | — |
| 21 | Orange | Green | — | 64 | Red | Black | Blue | 106 | Red | Yellow | — |
| 22 | Black | White | Red | 65 | Green | Orange | Blue | 107 | Green | Yellow | — |
| 23 | White | Black | Red | 66 | Orange | White | Red | 108 | Orange | Yellow | — |
| 24 | Red | Black | White | 67 | Blue | White | Red | 109 | Blue | Yellow | — |
| 25 | Green | Black | White | 68 | Black | Green | Blue | 110 | Black | Yellow | Red |
| 26 | Orange | Black | White | 69 | White | Green | Blue | 111 | White | Yellow | Red |
| 27 | Blue | Black | White | 70 | Red | Green | Blue | 112 | Green | Yellow | Red |
| 28 | Black | Red | Green | 71 | Green | White | Red | 113 | Orange | Yellow | Red |
| 29 | White | Red | Green | 72 | Orange | Red | Black | 114 | Blue | Yellow | Red |
| 30 | Red | Black | Green | 73 | Blue | Red | Black | 115 | Black | Yellow | White |
| 31 | Green | Black | Orange | 74 | Black | Orange | Blue | 116 | Red | Yellow | White |
| 32 | Orange | Black | Green | 75 | Red | Orange | Blue | 117 | Green | Yellow | White |
| 33 | Blue | White | Orange | 76 | Green | Red | Black | 118 | Orange | Yellow | White |
| 34 | Black | White | Orange | 77 | Orange | White | Green | 119 | Blue | Yellow | White |
| 35 | White | Red | Orange | 78 | Blue | White | Green | 120 | Black | Yellow | Green |
| 36 | Orange | White | Blue | 79 | Red | White | Orange | 121 | White | Yellow | Green |
| 37 | White | Red | Blue | 80 | Green | White | Orange | 122 | Red | Yellow | Green |
| 38 | Black | White | Green | 81 | Blue | Black | Green | 123 | Orange | Yellow | Green |
| 39 | White | Black | Green | 82 | Orange | White | — | 124 | Blue | Yellow | Green |
| 40 | Red | White | Green | 83 | Green | Red | — | 125 | Black | Yellow | Blue |
| 41 | Green | White | Blue | 84 | Black | Green | — | 126 | White | Yellow | Blue |
| 42 | Orange | Red | Green | 85 | White | Green | — | 127 | Red | Yellow | Blue |
| 43 | Blue | Red | Green | | | | | | | | |

*This conductor is in the inside of the assembly.

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# Appendix E *(continued)*

### E 1.1.1.1 METHOD 1 ▲

This method uses base colors with tracers in accordance with the first 21 color combinations given in Table E-1. For cables composed of more than 21 conductors, these 21 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all conductors.

### E 1.1.1.2 METHOD 1A

This method uses base colors with tracers in accordance with the first 36 color combinations given in Table E-1. For cables composed of more than 36 conductors, these 36 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all conductors.

### E 1.1.1.3 METHOD 1B

This method uses base colors with tracers in accordance with Table E-2 using color combinations in non-repeating sequence to provide identification of all conductors.

### E 1.1.2 METHODS 3, 3A, AND 3B—NEUTRAL OR SINGLE COLOR COMPOUNDS WITH SURFACE PRINTING OF NUMBERS AND COLOR DESIGNATIONS

This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color designations as given in Tables E-1 or E-2.

For example, for conductors 1 to 7, inclusive:

| | | |
|---|---|---|
| 1-Black | 1-Black | 1-Black, etc. |
| 2-White | 2-White | 2-White, etc. |
| 3-Red | 3-Red | 3-Red, etc. |
| 4-Green | 4-Green | 4-Green, etc. |
| 5-Orange | 5-Orange | 5-Orange, etc. |
| 6-Blue | 6-Blue | 6-Blue, etc. |
| 7-White-Black | 7-White-Black | 7-White-Black, etc. |

### E 1.1.2.1 METHOD 3

This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color designations as given for the first 21 conductor numbers in Table E-2. For cables composed of more than 21 conductors, these color combinations should be repeated in regular sequence to the extent necessary to provide such identification of all conductors.

### E 1.1.2.2 METHOD 3A

This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color designations as given for the first 21 conductor numbers in Table E-1. For cables composed of more than 21 conductors, these 21 color combinations should be repeated in regular sequence to the extent necessary to provide such identification of all conductors.

### E 1.1.2.3 METHOD 3B

This method uses a single color insulation or covering on all conductors with printed conductor numbers and color designations as given in Table E-2 using color combinations in non-repeating sequence to provide identification of all conductors.

### E 1.1.3 METHODS 5, 5A, AND 5B—INDIVIDUAL COLOR CODING WITH BRAIDS ▲

If colored marker braids are required, the color sequence of the conductors in the cable, beginning with black on the inside, should be in accordance with Table E-1 or E-2. When more than one color is required, the first color named in the table should be the background color. The shades of the colors should approximate those identified by the numbers given in Table E-3.

The tracers should consist of three carriers with each carrier composed of a minimum of two ends. Where two tracers are used, they should be crossed.

**Table E-3 ▲**
**SHADES OF COLOR**

| Color | Munsell Notation* | |
|---|---|---|
| Black | N2/ | |
| White | N9/ | |
| Red | 2.5 R | 4/12 |
| Blue | 2.5 PB | 4/10 |
| Green | 2.5 G | 5/12 |
| Orange | 2.5 YR | 6/14 |
| Yellow | 5 Y | 8.5/12 |
| Brown | 2.5 YR | 3.5/6 |

*Munsell Color System published by:
Munsell Color—Macbeth Division
2441 North Calvert Street
Baltimore, MD 21218 USA

▲ Revised 3-1-1989.

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# Appendix E (*continued*)

### E 1.1.3.1 METHOD 5

This method uses colored marker braids in accordance with the first 21 color combinations given in Table E-2. For cables composed of more than 21 conductors, these 21 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all conductors.

### E 1.1.3.2 METHOD 5A

This method uses colored marker braids in accordance with the first 36 color combinations given in Table E-1. For cables composed of more than 36 conductors, these 36 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all conductors.

### E 1.2.3.3 METHOD 5B

This method uses colored marker braids in accordance with Table E-2 using color combinations in non-repeating sequence to provide identification of all conductors.

### E 1.1.4 METHOD 6—LAYER IDENTIFICATION

For cables having braidless or jacketed individual conductors requiring layer-tracer identification, one conductor of each layer of the cable should be covered by a braid or tape, or should be provided with a raised ridge or ridges to function as a tracer, or be otherwise distinctively marked or colored.

### E 1.1.5 METHODS 7, 7A, AND 7B—PAIRED CONDUCTORS

Colored Compounds with Tracers. One conductor of each pair should be colored either "white" or "black." The sequence of coding the "other" conductor of each pair should be in accordance with Tables E-1 or E-2, omitting white or black for Methods 7 and 7B or omitting black for Method 7A.

### E 1.1.5.1 METHOD 7

This method uses base colors and tracers for the "other" conductor in each pair in accordance with the first 21 color combinations given in Table E-2, omitting white or black respectively. For cables composed of more than 20 pairs, these 20 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all pairs.

### E 1.1.5.2 METHOD 7A

This method uses base colors and tracers for the "other" conductor in each pair in accordance with the first 36 color combinations given in Table E-1, omitting black. For cables composed of more than 35 pairs, these 35 color combinations should be repeated in regular sequence to the extent necessary to provide identifications of all pairs.

### E 1.1.5.3 METHOD 7B

This method uses base colors and tracers for the "other" conductor in each pair in accordance with Table E-2 using color combinations in non-repeating sequence, omitting white or black respectively, to provide identification of all pairs.

### E 1.1.6 METHODS 8, 8A, AND 8B—PAIRED CONDUCTORS

Neutral or Single Color Compounds with Surface Printing of Number and Color Designations. This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color designations. One conductor of each pair should be printed "1-black" or "2-white." The sequence for coding the "other" conductor of each pair should be in accordance with Tables E-1 or E-2, omitting 1-black or 2-white for Methods 8 and B or omitting 1-black for Method 8A.For example:

| | (a) | | (b) | | (c) |
|---|---|---|---|---|---|
| Print 1st pair | 1-black, 2-white | or | 2-white, 1-black | or | 1-black, 3-blue |
| Print 2nd pair | 1-black, 3-red | or | 2-white, 3-red | or | 1-black, 4-orange |
| Print 3rd pair | 1-black, 4-green | or | 2-white, 4-green | or | 1-black, 5-yellow |
| Print 4th pair | 1-black, 5-orange | or | 2-white, 5-orange | or | 1-black, 6-brown |

### E 1.1.6.1 METHOD 8

This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color desig-nations as described in examples (a) and (b) for the first 20 pair in accordance with Table E-2. For cables composed of more than 20 pairs, these 20 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all pairs.

### E 1.1.6.2 Method 8A

This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color designations as described in example (c) for the first 35 pairs in accordance with Table E-1. For cables composed of more than 35 pairs, these 35 color combinations should be repeated in regular sequence to the extent necessary to provide identification of all pairs.

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# Appendix E *(continued)*

### E 1.1.6.3 METHOD 8B

This method uses a single-color insulation or covering on all conductors with printed conductor numbers and color designations as described in examples (a) and (b) in accordance with Table E-2 using color combinations in non-repeating sequence to the extent necessary to provide identification of all pairs.

### E 1.1.7 METHODS 9 AND 9A—COLORED COMPOUNDS WITH NUMBERS

One conductor on each pair should be coded "white" or "black" and the other conductor in each pair should be coded with any other contrasting color.

### E 1.1.7.1 METHOD 9

One conductor of each pair should be coded "white" or "black" and the other conductor should be coded with any other contrasting color. Pairs should be identified in sequence by printed numbers on at least one conductor in each pair, beginning with the number 1.

### E 1.1.7.2 METHOD 9A

One conductor of each pair should be coded "white" or "black" and the other conductor should be coded with any other contrasting color. Pairs should be identified in sequence by printed numbers on the jacket or covering over each pair, beginning with the number 1.

## E 2 THERMOCOUPLE EXTENSION CABLES

Color coding of pairs should be in accordance with ANSI MC 96.1. Colors should approximately, but need not necessarily exactly, match the color shades specified in Table E-3.

**Table E-4**
**COLOR CODING OF DUPLEX INSULATED THERMOCOUPLE EXTENSION WIRE**

| Extension Wire Type | | | Color of Insulation | | |
|---|---|---|---|---|---|
| Type | Positive | Negative | Overall | Positive | Negative* |
| T | TPX | TNX | Blue | Blue | Red |
| J | JPX | JNX | Black | White | Red |
| E | EPX | ENX | Purple | Purple | Red |
| K | KPX | KNX | Yellow | Yellow | Red |
| R or S | SPX | SNX | Green | Black | Red |
| B | BPX | BNX | Gray | Gray | Red |

*A tracer having the color corresponding to the positive wire code color may be used on the negative wire color code.

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# Appendix E (*continued*)

## E 2.1 Methods 10 and 10A—Color Coding of Braidless Conductors

Colors may be obtained by suitable color coatings applied to the insulation or jacket surface or by colored insulation or jacket compound.

### E 2.1.1 METHOD 10

This method uses colored compounds in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified in sequence by printed numbers on at least one conductor in each pair, beginning with the number 1.

### E 2.1.2 METHOD 10A

This method uses colored compounds in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified in sequence by printed numbers on the jacket or covering over each pair, beginning with the number 1.

## E 2.2 Methods 11, 11A, 11B, 11C, and 11D—Color Coding with Braids

If colored marker braids are required, the braid may be identified by either solid colors or by colored tracers in a neutral colored braid such as white or light tan. The tracers should consist of three carriers with each carrier composed of a minimum of two ends.

### E 2.2.1 METHOD 11

This method uses solid color braids in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified in sequence by printed numbers on at least one conductor in each pair, beginning with number a.

### E 2.2.2 METHOD 11A

This method uses solid color braids in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified in sequence by printed numbers on the jacket or covering over each pair, beginning with the number 1.

### E 2.2.3 METHOD B

This method uses solid color braids in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified by tracers of a contrasting color (or colors) in at least one of the conductors of each pair.

### E 2.2.4 METHOD 11C

This method uses a neutral colored braid with colored tracers in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified in sequence by printed numbers on at least one conductor in each pair, beginning with the number 1.

### E 2.2.5 METHOD 11D

This method uses a neutral colored braid with colored tracers in accordance with ANSI MC 96.1 and Table E-4. Pairs should be identified in sequence by printed numbers on the jacket or covering over each pair, beginning with the number 1.

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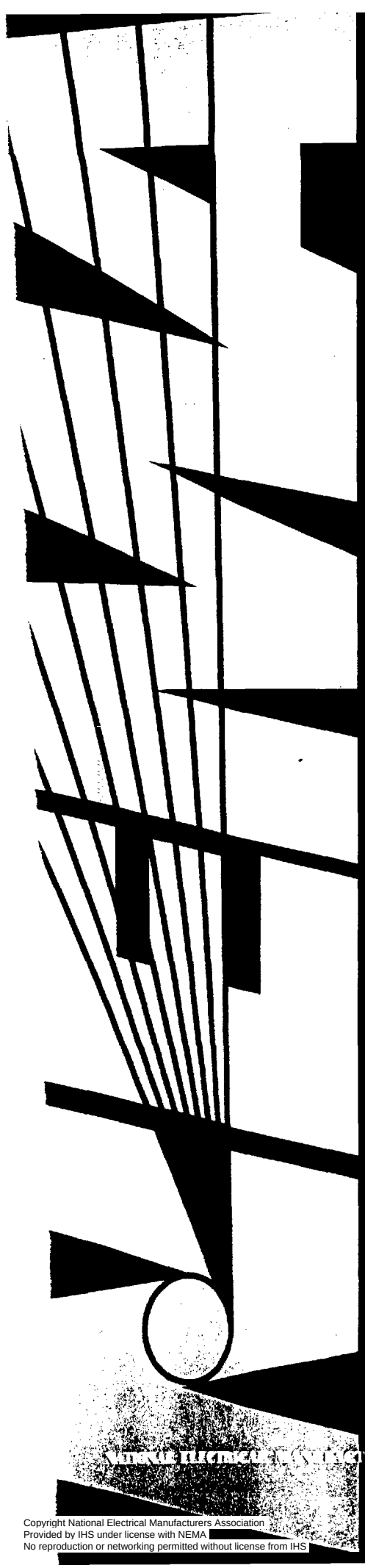

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