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Standard for Safety

UL 1072

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Medium-Voltage Power Cables

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Underwriters Laboratories Inc.®

Standard

Underwriters Laboratories Inc.®
A not-for-profit organization dedicated to public safety
and committed to quality service

May 26, 1995

Standard for

Medium-Voltage Power Cables

UL 1072, Second Edition

Accompanying this transmittal notice is a copy of the Second edition of UL 1072.

THIS EDITION OF THE STANDARD IS NOW IN EFFECT.

The requirements in this standard are substantially in accordance with UL's bulletin on this subject dated July 6, 1994. This bulletin is now obsolete and may be discarded.

Revised and/or additional pages may be issued from time to time.

UL 1072

Standard for

Medium-Voltage Power Cables

First Edition – August, 1986

Second Edition

May 26, 1995

An effective date included as a note immediately following certain requirements is one established by Underwriters Laboratories Inc.

Revisions of this standard will be made by issuing revised or additional pages bearing their date of issue. A UL Standard is current only if it incorporates the most recently adopted revisions, all of which are itemized on the transmittal notice that accompanies the latest published set of revision pages.

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FOREWORD

A. This Standard contains basic requirements for products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product employing materials or having forms of construction differing from those detailed in the requirements of this Standard may be examined and tested according to the intent of the requirements and, if found to be substantially equivalent, may be judged to comply with the Standard.

E. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

F. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

INTRODUCTION

1 Scope

1.1 These requirements cover the shielded and nonshielded medium-voltage power cables that are described in Tables 1.1 (single-conductor) and 1.2 (multiple-conductor). Multiple-conductor cables may include one or more individually jacketed nonconductive optical-fiber members. These electrical and hybrid electrical and optical-fiber cables are for use (optical and electrical functions associated in the case of a hybrid cable) in accordance with Article 326 and other applicable parts of the National Electrical Code (NEC).

1.2 These cables have one or more stranded copper or aluminum conductors that are insulated with a solid, extruded dielectric. Cables that have a metal sheath or interlocked armor incorporate an effective grounding path. A grounding conductor is optional in other cables. Cables for direct burial are so marked and have an overall covering (see 1.4 for direct-burial cables that are not covered). Cables that are for use in cable trays generally are so marked (see 60.1 and 60.2). Cables that are sunlight-resistant generally are so marked (see 61.1 – 61.3). Cables that are marked "MV-90" or "MV-90 dry" have a maximum operating temperature of 90°C (194°F). Cables that are marked "dry" have insulation for use only in dry locations. All other cables have insulation that is for use in both wet and dry locations. Multiple-conductor cables that include one or more optical-fiber members are surface marked to so indicate. Cables that are marked "oil resistant II" are for exposure to mineral oil at temperatures not in excess of 75°C (167°F). Cables that are marked "oil resistant I" are for exposure to mineral oil at temperatures not in excess of 60°C (140°F).

1.3 A multiple-conductor Type MV cable that has a smooth (other than lead) or corrugated metal sheath or that has interlocked metal armor may be marked for use also as Type MC cable.

1.4 These requirements do not cover power cables that have a concentric neutral. Specifically, they do not cover 2-conductor concentric-neutral power cables for the following uses:

a) URD – Single-phase primary underground residential distribution systems.

b) UD – Three-phase primary underground distribution systems.

1.5 A product that contains features, characteristics, components, materials, or systems new or different from those covered by the requirements in this Standard, and that involves a risk of fire, electric shock, or injury to persons shall be evaluated using the appropriate additional component and end-product requirements as determined necessary to maintain the acceptable level of safety as originally anticipated by the intent of this Standard. A product whose features, characteristics, components, materials, or systems conflict with specific requirements or provisions of this Standard cannot be judged to comply with this Standard. Where considered appropriate, revision of requirements shall be proposed and adopted in conformance with the methods employed for development, revision, and implementation of this Standard.

Table 1.1
Single-conductor Type MV cables

Voltage rating	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Overall covering
5000	8 AWG – 1000 kcmil	90°C (194°F) dry	XLPE or EPCV	–	Column A Table 13.2	Nonshielded	None
		90°C (194°F) dry	XLPE, EPCV, or EP	–	Column B Table 13.2	Nonshielded	Nonconductive jacket Column B Table 25.15
		90°C (194°F) wet or dry	XLPE or EP	–	Column C Table 13.2	Nonshielded	Nonconductive jacket Column C Table 25.15
		90°C (194°F) wet or dry	XLPE or EP	100 or 133	Table 13.1	Shielded	a
8000	8 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100	Column D Table 13.2	Nonshielded	Nonconductive jacket Column D Table 25.15
	6 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100	Table 13.1	Shielded	a
15000	2 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100 or 133	Table 13.1	Shielded	a
25000	1 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100 or 133	Table 13.1	Shielded	a
28000	1 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100	Table 13.1	Shielded	a
35000	1 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100	Table 13.1	Shielded	a

[a] The overall covering consists of one of the following (see Table 24.1 for complete descriptions):

1) Conductive nonmetallic insulation covering (Table 15.3) as part of shielding, with or without nonmagnetic metal sheath or armor over conductive nonmetallic insulation covering as part of shielding, with or without supplementary nonconductive jacket (Table 27.1) over metal sheath or armor.

2) Nonconductive jacket (Table 25.14) over shielding, with or without nonmagnetic metal sheath or armor over nonconductive jacket, with or without supplementary nonconductive jacket (Table 27.1) over metal sheath or armor.

3) Nonmagnetic metal sheath or armor as part of shielding, with or without supplementary nonconductive jacket (Table 27.1) over metal sheath or armor.

Table 1.2
Multiple-conductor Type MV cables

Voltage rating	Circuit conductors							Grounding conductor	Overall covering
	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Individual covering		
5000	8 AWG – 1000 kcmil	90°C (194°F) dry	XLPE or EPCV	–	Column A Table 13.2	Nonshielded	None	Optional Covered 21.1	None – assembly of single-conductor cables
		90°C (194°F) dry	XLPE EPCV or EP	–	Column B Table 13.2	Nonshielded	Nonconductive jacket Column B Table 25.15	Optional Covered 21.1	None – assembly of single-conductor cables
		90°C (194°F) wet or dry	XLPE or EP	–	Column C Table 13.2	Nonshielded	Nonconductive jacket Column C Table 25.15	Optional Covered 21.1	None – assembly of single-conductor cables
		90°C (194°F) wet or dry	XLPE or EP	100 or 133	Table 13.1	Nonshielded or Shielded	None or Nonconductive jacket (Table 17.1)	Optional Bare 21.5	Nonconductive jacket (Table 25.14)
								Required Bare 21.1	Interlocked armor with or without Supplementary jacket
								May be required Bare 21.3 and 21.4	Metal sheath with or without Supplementary jacket
							Nonconductive jacket (Table 25.14) over shield	Optional Covered 21.1	None
							Conductive nonmetallic insulation covering (Table 15.3) as part of shield	Optional Covered 21.1	None
							Metal sheath as part of shield with or without Supplementary jacket	Optional Covered 21.1	None

(Continued)

Table 1.2 (Cont'd)
Multiple-conductor Type MV cables

Voltage rating	Circuit Conductors							Grounding conductor	Overall covering
	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Individual covering		
8000	8 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100	Column D Table 13.2	Nonshielded	Nonconductive jacket Column D (Table 25.15)	Optional Covered 21.1	None – assembly of single-conductor cables
	6 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100 or 133	Table 13.1	Shielded	None or Nonconductive jacket (Table 17.1)	Optional Bare 21.5	Nonconductive jacket (Table 25.14)
								Required Bare 21.1	Interlocked armor with or without Supplementary jacket
15000	2 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100 or 133				May be required Bare 21.3 and 21.4	Metal sheath with or without Supplementary jacket
							Nonconductive jacket (Table 25.14) over shield	Optional Covered 21.1	None
25000	1 AWG – 1000 kcmil	90°C (194°F) wet or dry	XLPE or EP	100 or 133			Conductive nonmetallic insulation covering (Table 15.3) as part of shield	Optional Covered 21.1	None
							Metal sheath as part of shield with or without supplementary jacket	Optional Covered 21.1	None

(Continued)

Table 1.2 (Cont'd)
Multiple-conductor Type MV cables

<table>
<tr><th rowspan="2">Voltage rating</th><th colspan="7">Circuit conductors</th><th rowspan="2">Grounding conductor</th><th rowspan="2">Overall covering</th></tr>
<tr><th>Size</th><th>Use</th><th>Insulation material</th><th>Percent insulation level</th><th>Insulation thickness</th><th>Shield</th><th>Individual covering</th></tr>
<tr><td rowspan="2">28000</td><td rowspan="2">1 AWG – 1000 kcmil</td><td rowspan="2">90°C (194°F) wet or dry</td><td rowspan="2">XLPE or EP</td><td rowspan="2">100</td><td rowspan="2">Table 13.1</td><td rowspan="6">Shielded</td><td rowspan="3">None or Nonconductive jacket (Table 17.1)</td><td>Optional Bare 21.5</td><td>Nonconductive jacket (Table 25.14)</td></tr>
<tr><td>Required Bare 21.2</td><td>Interlocked armor with or without Supplementary jacket</td></tr>
<tr><td rowspan="4">35000</td><td rowspan="4">1/0 AWG – 1000 kcmil</td><td rowspan="4">90°C (194°F) wet or dry</td><td rowspan="4">XLPE or EP</td><td rowspan="4">100</td><td rowspan="4">Table 13.1</td><td>May be required Bare 21.3 and 21.4</td><td>Metal sheath with or without Supplementary jacket</td></tr>
<tr><td>Nonconductive jacket (Table 25.14) over shield</td><td>Optional Covered 21.1</td><td>None</td></tr>
<tr><td>Conductive nonmetallic insulation covering (Table 15.3) as part of shield</td><td>Optional Covered 21.1</td><td>None</td></tr>
<tr><td>Metal sheath as part of shield with or without Supplementary jacket</td><td>Optional Covered 21.1</td><td>None</td></tr>
</table>

2 Units of Measurement

2.1 In addition to being stated in the inch/pound units that are customary in the USA, each of the requirements is also stated in units that make the requirement conveniently usable in countries employing the various metric systems (practical SI and customary). Equivalent – although not necessarily exactly identical – results are to be expected from applying a requirement in USA or metric terms. Equipment calibrated in metric units is to be used when a requirement is applied in metric terms.

3 Terms

3.1 Wherever the designation "UL 1581" is used in this cable standard, reference is to be made to the designated part(s) of the Reference Standard for Electrical Wires, Cables, and Flexible Cords (UL 1581).

CONSTRUCTION

4 Materials

4.1 Only materials that are acceptable for the particular use shall be used in a cable.

4.2 Each material used in a cable shall be compatible with all of the other materials used in the cable.

5 General

5.1 Medium-voltage cable shall be designated as Type MV and shall comply in all respects with the applicable requirements for construction details, test performance, and markings.

CONDUCTOR(S)

6 Materials

6.1 The conductor(s) in a cable shall be of soft-annealed copper or of semi-annealed (1/2 – 3/4 hard) or hard-drawn aluminum. Soft-annealed copper wires (strands) shall comply with ASTM B 3-90. A metal coating that is provided on soft-annealed copper in accordance with 8.1 or 8.2 shall be of tin complying with ASTM B 33-81 or of a tin/lead alloy complying with ASTM B 189-90. The tensile strength of a semi-annealed (1/2 – 3/4 hard) aluminum conductor shall be 18,500 ±3,500 lbf/in^2 or 128 ±24 MN/m^2 or 12,755 ±2,143 N/cm^2 or 13.0 ±2.5 kgf/mm^2. Hard-drawn aluminum wires (strands) shall comply with ASTM B 230-89.

6.2 An individual conductor shall not be smaller than No. 8 AWG (16.51 kcmil or 8.367 mm^2) and shall not be larger than 1000 kcmil or 507 mm^2. The nominal cross-sectional area of a conductor is indicated in Table 6.1 (not a requirement).

Table 6.1
Nominal conductor cross-sectional area
(Information only – not a requirement)

Size of conductor	kcmil	mm^2
8 AWG	16.51	8.367
7	20.82	10.55
6	26.24	13.30
5	33.09	16.77
4	41.74	21.15
3	52.62	26.67
2	66.36	33.62
1	83.69	42.41
1/0	195.6	53.49
2/0	133.1	67.43
3/0	167.8	85.01
4/0	211.6	107.2
250 kcmil	250	127
300	300	152
350	350	177
400	400	203
450	450	228
500	500	253
550	550	279
600	600	304
650	650	329
700	700	355
750	750	380
800	800	405
900	900	456
1000	1000	507

7 Resistance

7.1 The direct-current resistance of any length of conductor in ohms per thousand conductor feet or in ohms per conductor kilometer shall not be higher than the maximum acceptable (nominal x 1.02) resistance indicated in Tables 7.1 – 7.10 at 20°C (68°F) or at 25°C (77°F). If, as provided for in 9.2, metal-coated wires are used in only the outer layer of an uncoated copper conductor, the direct-current resistance of the resulting conductor shall not exceed the value tabulated for an uncoated conductor of the same size and construction. See 7.2 concerning measurement at other temperatures, 7.3 for cabling factors applicable to multiple-conductor cables, and 7.4 and Section 63 for the methods of measurement.

7.2 The resistance of a conductor measured at any temperature other than 20°C (68°F) or 25°C (77°F) is to be adjusted to the resistance at 20°C (68°F) or 25°C (77°F) by means of the applicable multiplying factor from Table 7.11.

7.3 In a finished multiple-conductor cable, the increased resistance of a conductor because of cabling shall not be higher than the applicable value from Tables 7.1 – 7.10 multiplied by the following factor, with the result rounded off to the same number of decimal places as the tabulated value.

a) One layer of conductors: 1.02

b) More than one layer of conductors: 1.03

7.4 The conductor resistance shall be measured by means of a Kelvin double bridge or a potentiometer if the resistance of the specimen is below 1 ohm. If the resistance is 1 ohm or is higher, a Wheatstone bridge is acceptable. In any case, the equipment selected shall be accurate to within 0.5 percent of the value read. The method using a Kelvin double bridge or its equivalent is outlined in Section 63. The method using a potentiometer or a Wheatstone bridge is to be essentially the same.

Table 7.1
Maximum acceptable direct-current resistance of aluminum and uncoated copper conductors: concentric-stranded ASTM Classes B, C, and D and compact-stranded and compressed-stranded aluminum and uncoated copper

Size of conductor	20°C				25°C			
	Aluminum and copper-clad aluminum		Uncoated copper		Aluminum and copper-clad aluminum		Uncoated copper	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	1.07	3.51	0.652	2.14	1.09	3.58	0.665	2.18
7	0.851	2.79	0.519	1.70	0.868	2.85	0.529	1.74
6	0.675	2.21	0.411	1.35	0.689	2.26	0.419	1.38
5	0.534	1.75	0.325	1.07	0.545	1.79	0.332	1.09
4	0.424	1.39	0.258	0.846	0.433	1.42	0.263	0.863
3	0.336	1.10	0.205	0.673	0.343	1.12	0.209	0.686
2	0.266	0.873	0.162	0.532	0.271	0.890	0.165	0.542
1	0.211	0.692	0.129	0.423	0.215	0.706	0.132	0.432
1/0	0.168	0.551	0.102	0.335	0.171	0.562	0.104	0.341
2/0	0.133	0.436	0.0810	0.266	0.136	0.445	0.0826	0.272
3/0	0.105	0.345	0.0642	0.211	0.107	0.351	0.0655	0.215
4/0	0.836	0.274	0.0510	0.167	0.0853	0.280	0.0520	0.171
250 kcmil	0.0707	0.232	0.0431	0.141	0.0721	0.237	0.0440	0.144
300	0.0590	0.194	0.0360	0.118	0.0602	0.195	0.0367	0.121
350	0.0505	0.166	0.0308	0.101	0.0515	0.169	0.0314	0.103
400	0.0442	0.145	0.0269	0.0883	0.0451	0.148	0.0274	0.0900
450	0.0393	0.129	0.0240	0.0787	0.0401	0.132	0.0245	0.0803
500	0.0354	0.116	0.0216	0.0709	0.0361	0.117	0.0220	0.0723
550	0.0321	0.105	0.0196	0.0643	0.0327	0.107	0.0200	0.0656
600	0.0295	0.0968	0.0180	0.0591	0.0301	0.0987	0.0184	0.0602
650	0.0272	0.0892	0.0166	0.0545	0.0277	0.0910	0.0169	0.0556
700	0.0253	0.0830	0.0154	0.0505	0.0258	0.0847	0.0157	0.0515
750	0.0236	0.0774	0.0144	0.0472	0.0241	0.0790	0.0147	0.0482
800	0.0221	0.0725	0.0135	0.0443	0.0225	0.0740	0.0138	0.0452
900	0.0196	0.0643	0.0120	0.0394	0.0200	0.0656	0.0122	0.0402
1000	0.0177	0.0581	0.0108	0.0354	0.0181	0.0592	0.0110	0.0361

Table 7.2
Maximum acceptable direct-current resistance of copper conductors: concentric-stranded ASTM Class B with each strand coated with tin or a tin/lead alloy and compressed-stranded ASTM Class B with each strand coated

Size of conductor	20°C		25°C	
	Ohms based on 1000 feet of conductor	Ohms based on 1 kilometer of conductor	Ohms based on 1000 feet of conductor	Ohms based on 1 kilometer of conductor
8 AWG	0.678	2.22	0.692	2.27
7	0.538	1.77	0.549	1.80
6	0.427	1.40	0.436	1.43
5	0.338	1.11	0.345	1.13
4	0.269	0.883	0.274	0.900
3	0.213	0.699	0.217	0.713
2	0.169	0.554	0.172	0.566
1	0.134	0.440	0.137	0.448
1/0	0.106	0.348	0.108	0.355
2/0	0.0842	0.276	0.0859	0.282
3/0	0.0667	0.219	0.0680	0.223
4/0	0.0524	0.172	0.0535	0.175
250 kcmil	0.0448	0.147	0.0457	0.150
300	0.0374	0.123	0.0382	0.125
350	0.0320	0.105	0.0326	0.107
400	0.0277	0.0909	0.0283	0.0927
450	0.0246	0.0807	0.0251	0.0823
500	0.0222	0.0728	0.0226	0.0743
550	0.0204	0.0669	0.0208	0.0683
600	0.0187	0.0614	0.0191	0.0626
650	0.0171	0.0561	0.0174	0.0572
700	0.0159	0.0522	0.0162	0.0532
750	0.0148	0.0486	0.0151	0.0495
800	0.0139	0.0456	0.0142	0.0465
900	0.0123	0.0404	0.0126	0.0412
1000	0.0111	0.0364	0.0113	0.0372

Table 7.3
Maximum acceptable direct-current resistance of 19-wire combination round-wire unilay-stranded conductors of copper

Metal coating of strands	AWG size of conductor	20°C Ohms based on 1000 feet of conductor	20°C Ohms based on 1 kilometer of conductor	25°C Ohms based on 1000 feet of conductor	25°C Ohms based on 1 kilometer of conductor
Each strand coated	6	0.427	1.41	0.436	1.43
	5	0.339	1.11	0.346	1.13
	4	0.269	0.882	0.274	0.900
	3	0.213	0.700	0.217	0.713
	2	0.169	0.555	0.172	0.566
	1	0.1340	0.4398	0.1367	0.4485
	1/0	0.1063	0.3487	0.1084	0.3556
	2/0	0.08432	0.2766	0.08598	0.2820
	3/0	0.06688	0.2194	0.06820	0.2238
	4/0	0.05248	0.1722	0.05352	0.1755
Each strand uncoated	6	0.4122	1.348	0.4192	1.375
	5	0.3261	1.070	0.3225	1.091
	4	0.2585	0.8481	0.2636	0.8649
	3	0.2050	0.6727	0.2091	0.6860
	2	0.1626	0.5335	0.1659	0.5440
	1	0.1289	0.4230	0.1315	0.4313
	1/0	0.1022	0.3354	0.1042	0.3419
	2/0	0.08108	0.2660	0.08267	0.2712
	3/0	0.06431	0.2110	0.06558	0.2151
	4/0	0.05099	0.1673	0.05200	0.1705

Table 7.4
Maximum acceptable direct-current resistance of 19-wire combination round-wire unilay-stranded conductors of aluminum

AWG size of conductor	20°C		25°C	
	Ohms based on 1000 feet of conductor	Ohms based on 1 kilometer of conductor	Ohms based on 1000 feet of conductor	Ohms based on 1 kilometer of conductor
6	0.6716	2.204	0.6852	2.248
5	0.5326	1.748	0.5436	1.784
4	0.4224	1.386	0.4309	1.414
3	0.3351	1.100	0.3418	1.121
2	0.2656	0.8714	0.2710	0.8892
1	0.2107	0.6913	0.2149	0.7051
1/0	0.1671	0.5483	0.1705	0.5594
2/0	0.1325	0.4347	0.1351	0.4433
3/0	0.1051	0.3448	0.1072	0.3517
4/0	0.08332	0.2734	0.08501	0.2789

Table 7.5
Maximum acceptable direct-current resistance of copper conductors: concentric-stranded ASTM Classes C and D with each strand coated with tin or a tin/lead alloy and compressed-stranded ASTM Classes C and D with each strand coated

Size of conductor	Class C				Class D			
	20°C		25°C		20°C		25°C	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	0.678	2.22	0.692	2.27	0.680	2.23	0.694	2.28
7	0.538	1.77	0.549	1.80	0.538	1.77	0.549	1.80
6	0.427	1.40	0.436	1.43	0.427	1.40	0.436	1.43
5	0.339	1.11	0.364	1.13	0.339	1.11	0.346	1.13
4	0.269	0.883	0.274	0.900	0.269	0.883	0.274	0.900
3	0.213	0.699	0.217	0.713	0.213	0.699	0.217	0.713
2	0.169	0.554	0.172	0.566	0.169	0.554	0.172	0.566
1	0.134	0.440	0.137	0.448	0.134	0.440	0.137	0.448
1/0	0.106	0.348	0.108	0.355	0.106	0.348	0.108	0.355
2/0	0.0842	0.276	0.0859	0.282	0.0842	0.276	0.0859	0.282
3/0	0.0669	0.219	0.0682	0.224	0.0669	0.219	0.0682	0.224
4/0	0.0530	0.174	0.0541	0.177	0.0530	0.174	0.0541	0.177
250 kcmil	0.0448	0.147	0.0457	0.150	0.0448	0.147	0.0457	0.150
300	0.0374	0.123	0.0381	0.125	0.0374	0.123	0.0381	0.125
350	0.0320	0.105	0.0326	0.107	0.0320	0.105	0.0326	0.107
400	0.0280	0.0919	0.0286	0.0937	0.0280	0.0919	0.0286	0.0937
450	0.0249	0.0817	0.0254	0.0833	0.0249	0.0817	0.0254	0.0833
500	0.0224	0.0735	0.0228	0.0750	0.0224	0.0735	0.0228	0.0750
550	0.0204	0.0669	0.0208	0.0683	0.0204	0.0669	0.0208	0.0683
600	0.0187	0.0614	0.0191	0.0626	0.0187	0.0614	0.0191	0.0626
650	0.0172	0.0564	0.0175	0.0576	0.0173	0.0568	0.0176	0.0579
700	0.0160	0.0525	0.0163	0.0535	0.0160	0.0525	0.0163	0.0535
750	0.0149	0.0489	0.0152	0.0499	0.0150	0.0492	0.0153	0.0502
800	0.0140	0.0459	0.0143	0.0469	0.0140	0.0459	0.0143	0.0469
900	0.0126	0.0413	0.0129	0.0422	0.0126	0.0412	0.0129	0.0422
1000	0.0111	0.0364	0.0113	0.0371	0.0112	0.0367	0.0114	0.0375

Table 7.6
Maximum acceptable direct-current resistance of ASTM Class G stranded conductors

Size of conductor	Uncoated copper				Coated copper (each strand coated with tin or a tin/lead alloy)				Aluminum			
	20°C		25°C		20°C		25°C		20°C		25°C	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	0.660	2.17	0.673	2.21	0.701	2.30	0.715	2.35				
7	0.523	1.72	0.533	1.75	0.544	1.78	0.555	1.82	0.858	2.82	0.865	2.87
6	0.415	1.36	0.423	1.39	0.432	1.42	0.441	1.45	0.681	2.23	0.695	2.28
5	0.329	1.08	0.336	1.10	0.342	1.12	0.349	1.14	0.540	1.77	0.551	1.81
4	0.261	0.856	0.266	0.873	0.271	0.889	0.276	0.907	0.428	1.40	0.437	1.43
3	0.207	0.679	0.211	0.693	0.215	0.705	0.219	0.720	0.340	1.12	0.347	1.14
2	0.164	0.538	0.167	0.549	0.171	0.561	0.174	0.561	0.269	0.883	0.274	0.900
1	0.131	0.430	0.134	0.438	0.137	0.449	0.140	0.458	0.216	0.709	0.220	0.723
1/0	0.104	0.341	0.106	0.348	0.108	0.354	0.110	0.361	0.171	0.561	0.174	0.572
2/0	0.0826	0.271	0.0843	0.276	0.0859	0.282	0.0876	0.287	0.136	0.446	0.139	0.455
3/0	0.0655	0.215	0.0668	0.219	0.0682	0.224	0.0696	0.228	0.107	0.351	0.109	0.358
4/0	0.0520	0.171	0.0530	0.174	0.0541	0.178	0.0552	0.181	0.0852	0.280	0.0869	0.285
250 kcmil	0.0442	0.145	0.0451	0.148	0.0460	0.151	0.0469	0.154	0.0725	0.238	0.0740	0.243
300	0.0368	0.121	0.0375	0.123	0.0383	0.126	0.0391	0.128	0.0604	0.198	0.0616	0.202
350	0.0316	0.104	0.0322	0.106	0.0328	0.108	0.0335	0.110	0.0518	0.170	0.0528	0.173
400	0.0276	0.0906	0.0282	0.0924	0.0287	0.0942	0.0293	0.0960	0.0453	0.149	0.0462	0.152
450	0.0246	0.0807	0.0251	0.0823	0.0255	0.0837	0.0260	0.0853	0.0403	0.132	0.0411	0.135
500	0.0221	0.0725	0.0225	0.0740	0.0230	0.0755	0.0235	0.0770	0.0363	0.119	0.0370	0.121
550	0.0202	0.0663	0.0206	0.0676	0.0210	0.0689	0.0214	0.0703	0.0331	0.109	0.0338	0.111
600	0.0185	0.0607	0.0189	0.0619	0.0192	0.0630	0.0196	0.0643	0.0304	0.0997	0.0310	0.102
650	0.0171	0.0561	0.0174	0.0572	0.0178	0.0584	0.0182	0.0596	0.0280	0.0919	0.0286	0.0937
700	0.0159	0.0522	0.0162	0.0532	0.0165	0.0541	0.0168	0.0552	0.0260	0.0853	0.0265	0.0870
750	0.0148	0.0486	0.0151	0.0495	0.0154	0.0505	0.0157	0.0515	0.0243	0.0797	0.0248	0.0813
800	0.0139	0.0456	0.0142	0.0465	0.0144	0.0472	0.0147	0.0482	0.0228	0.0748	0.0233	0.0763
900	0.0123	0.0404	0.0125	0.0412	0.0128	0.0420	0.0131	0.0428	0.0202	0.0663	0.0206	0.0676
1000	0.0111	0.0364	0.0113	0.0371	0.0115	0.0377	0.0117	0.0385	0.0182	0.0597	0.0186	0.0609

Table 7.7
Maximum acceptable direct-current resistance of ASTM Class H stranded conductors

Size of conductor	Uncoated copper				Coated copper (each strand coated with tin or a tin/lead alloy)				Aluminum			
	20°C		25°C		20°C		25°C		20°C		25°C	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	0.666	2.19	0.679	2.23	0.708	2.32	0.722	2.37				
7	0.528	1.73	0.539	1.77	0.561	1.84	0.572	1.88				
6	0.419	1.37	0.427	1.40	0.445	1.46	0.454	1.49				
5	0.332	1.09	0.339	1.11	0.353	0.16	0.360	1.18				
4	0.263	0.863	0.268	0.880	0.280	0.919	0.286	0.937				
3	0.209	0.686	0.213	0.699	0.222	0.728	0.226	0.743				
2 (133 wires)	0.166	0.545	0.169	0.556	0.172	0.564	0.175	0.576	0.272	0.892	0.277	0.910
2 (259 wires)	0.167	0.548	0.170	0.557	0.178	0.584	0.181	0.592				
1	0.132	0.433	0.135	0.442	0.140	0.459	0.143	0.469				
1/0	0.105	0.345	0.107	0.351	0.109	0.358	0.111	0.365	0.172	0.564	0.175	0.576
2/0	0.0830	0.272	0.0847	0.278	0.0863	0.283	0.0880	0.289	0.136	0.446	0.193	0.455
3/0 (259 wires)	0.0659	0.216	0.0672	0.220	0.0685	0.225	0.0699	0.229	0.108	0.354	0.110	0.361
3/0 (427 wires)	0.0662	0.217	0.0675	0.221	0.0703	0.231	0.0717	0.236				
4/0 (259 wires)	0.0522	0.171	0.0532	0.175	0.0543	0.178	0.0554	0.182	0.0857	0.281	0.0874	0.287
4/0 (427 wires)	0.0526	0.173	0.0536	0.176	0.0546	0.179	0.0557	0.183	0.0861	0.282	0.0878	0.288
250 kcmil	0.0444	0.146	0.0453	0.149	0.0462	0.152	0.0471	0.155	0.0728	0.239	0.0743	0.244
300	0.0370	0.121	0.0337	0.124	0.0385	0.126	0.0393	0.129	0.0607	0.199	0.0619	0.203
350	0.0317	0.104	0.0323	0.106	0.0330	0.108	0.0337	0.110	0.0520	0.171	0.0530	0.174
400	0.0278	0.0912	0.0284	0.0930	0.0289	0.0948	0.0295	0.0967	0.0455	0.149	0.0464	0.152
450	0.0247	0.0810	0.0252	0.0827	0.0257	0.0843	0.0262	0.0860	0.0405	0.133	0.0413	0.136
500	0.0222	0.0728	0.0226	0.0743	0.0231	0.0758	0.0236	0.0773	0.0364	0.119	0.0371	0.122
550	0.0204	0.0669	0.0208	0.0683	0.0212	0.0696	0.0216	0.0709	0.0334	0.110	0.0341	0.112
600	0.0187	0.0614	0.0191	0.0626	0.0194	0.0637	0.0198	0.0649	0.0306	0.100	0.0312	0.102
650	0.0172	0.0564	0.0175	0.0576	0.0179	0.0587	0.0183	0.0599	0.0283	0.0929	0.0289	0.0947
700	0.0168	0.0551	0.0171	0.0562	0.0167	0.0548	0.0170	0.0559	0.0263	0.0863	0.0268	0.0880
750	0.0149	0.0489	0.0152	0.0499	0.0155	0.0509	0.0158	0.0519	0.0245	0.0804	0.0250	0.0820
800	0.0140	0.0459	0.0143	0.0469	0.0146	0.0479	0.0149	0.0489	0.0230	0.0755	0.0235	0.0770
900	0.0125	0.0410	0.0128	0.0418	0.0130	0.0427	0.0133	0.0435	0.0204	0.0669	0.0208	0.0683
1000	0.0112	0.0367	0.0114	0.0375	0.0117	0.0384	0.0119	0.0392	0.0184	0.0604	0.0188	0.0616

Table 7.8
Maximum acceptable direct-current resistance of ASTM Class I stranded conductors

Size of conductor	Uncoated copper				Coated copper (each strand coated with tin or tin/lead alloy)				Aluminum			
	20°C		25°C		20°C		25°C		20°C		25°C	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	0.653	2.14	0.666	2.19	0.679	2.23	0.693	2.27	1.07	3.51	1.09	3.58
7	0.518	1.70	0.528	1.73	0.539	1.77	0.550	1.80	0.850	2.79	0.867	2.84
6	0.419	1.37	0.427	1.40	0.436	1.43	0.445	1.46	0.687	2.25	0.701	2.30
5	0.332	1.09	0.339	1.11	0.346	1.14	0.353	1.16	0.545	1.79	0.556	1.82
4	0.263	0.863	0.268	0.880	0.274	0.899	0.279	0.917	0.432	1.42	0.441	1.45
3	0.209	0.686	0.213	0.699	0.217	0.712	0.221	0.726	0.343	1.13	0.350	1.15
2	0.166	0.545	0.169	0.556	0.172	0.564	0.175	0.576	0.272	0.892	0.277	0.910
1	0.131	0.430	0.134	0.438	0.137	0.449	0.140	0.458	0.216	0.709	0.220	0.723
1/0	0.105	0.345	0.107	0.351	0.109	0.358	0.111	0.365	0.172	0.564	0.175	0.576
2/0	0.0834	0.274	0.0851	0.279	0.0868	0.285	0.0885	0.290	0.137	0.449	0.140	0.458
3/0	0.0662	0.217	0.0675	0.222	0.0688	0.226	0.0702	0.230	0.109	0.358	0.111	0.365
4/0	0.0525	0.172	0.0536	0.176	0.0546	0.179	0.0557	0.183	0.0861	0.282	0.0878	0.288
250 kcmil	0.0448	0.147	0.0457	0.150	0.0466	0.153	0.0475	0.156	0.0735	0.241	0.0750	0.246
300	0.0374	0.123	0.0381	0.125	0.0389	0.128	0.0397	0.130	0.0613	0.201	0.0625	0.205
350	0.0320	0.105	0.0326	0.107	0.0333	0.109	0.0340	0.111	0.0525	0.172	0.0536	0.176
400	0.0280	0.0919	0.0286	0.0937	0.0291	0.0955	0.0297	0.0964	0.0460	0.151	0.0469	0.154
450	0.0249	0.0817	0.0254	0.0833	0.0259	0.0850	0.0264	0.0867	0.0409	0.134	0.0417	0.137
500	0.0224	0.0735	0.0228	0.0750	0.0233	0.0764	0.0238	0.0780	0.0368	0.121	0.0375	0.123
550	0.0204	0.0669	0.0208	0.0683	0.0212	0.0696	0.0216	0.0709	0.0334	0.110	0.0341	0.112
600	0.0187	0.0614	0.0191	0.0626	0.0194	0.0637	0.0198	0.0649	0.0306	0.100	0.0312	0.102
650	0.0174	0.0571	0.0177	0.0582	0.0181	0.0594	0.0185	0.0606	0.0286	0.0938	0.0292	0.0957
700	0.0162	0.0532	0.0165	0.0542	0.0168	0.0551	0.0171	0.0562	0.0265	0.0869	0.0270	0.0887
750	0.0151	0.0495	0.0154	0.0505	0.0157	0.0515	0.0160	0.0525	0.0247	0.0810	0.0252	0.0827
800	0.0141	0.0463	0.0144	0.0472	0.0147	0.0482	0.0150	0.0492	0.0232	0.0761	0.0237	0.0776
900	0.0126	0.0413	0.0129	0.0422	0.0131	0.0430	0.0134	0.0438	0.0206	0.0676	0.0210	0.0689
1000	0.0113	0.0371	0.0115	0.0378	0.0118	0.0387	0.0120	0.0395	0.0186	0.0610	0.0190	0.0622

Table 7.9
Maximum acceptable direct-current resistance of ASTM Class K stranded conductors

Size of conductor	Uncoated copper				Coated copper (each strand coated with tin or a tin/lead alloy)			
	20°C		25°C		20°C		25°C	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	0.666	2.19	0.679	2.23	0.715	2.35	0.729	2.39
7	0.528	1.73	0.539	1.76	0.567	1.86	0.578	1.90
6	0.419	1.37	0.427	1.40	0.450	1.48	0.459	1.51
5	0.332	1.09	0.339	1.11	0.357	1.17	0.364	1.19
4	0.263	0.863	0.268	0.880	0.283	0.929	0.289	0.947
3	0.211	0.692	0.215	0.706	0.227	0.745	0.232	0.760
2	0.167	0.548	0.170	0.559	0.180	0.591	0.184	0.602
1	0.133	0.436	0.136	0.445	0.142	0.466	0.145	0.475
1/0	0.105	0.345	0.107	0.351	0.113	0.371	0.115	0.378
2/0	0.0842	0.276	0.0859	0.282	0.0904	0.297	0.0922	0.303
3/0	0.0668	0.219	0.0681	0.224	0.0717	0.235	0.0731	0.240
4/0	0.0530	0.174	0.0541	0.177	0.0569	0.187	0.0580	0.190
250 kcmil	0.0448	0.147	0.0457	0.150	0.0481	0.158	0.0491	0.161
300	0.0374	0.123	0.0381	0.125	0.0401	0.132	0.0409	0.134
350	0.0323	0.106	0.0329	0.108	0.0347	0.114	0.0354	0.116
400	0.0283	0.0929	0.0289	0.0947	0.0304	0.0997	0.0310	0.102
450	0.0251	0.0824	0.0256	0.0840	0.0270	0.0886	0.0275	0.0904
500	0.0226	0.0742	0.0231	0.0756	0.0243	0.0797	0.0248	0.0813
550	0.0206	0.0676	0.0210	0.0689	0.0221	0.0725	0.0225	0.0740
600	0.0189	0.0620	0.0193	0.0633	0.0203	0.0666	0.0207	0.0679
650	0.0174	0.0571	0.0177	0.0582	0.0187	0.0614	0.0191	0.0626
700	0.0162	0.0532	0.0165	0.0542	0.0174	0.0571	0.0177	0.0582
750	0.0151	0.0495	0.0154	0.0505	0.0162	0.0532	0.0165	0.0542
800	0.0141	0.0463	0.0144	0.0472	0.0152	0.0499	0.0155	0.0509
900	0.0126	0.0413	0.0129	0.0422	0.0135	0.0443	0.0138	0.0452
1000	0.0113	0.0371	0.0115	0.0378	0.0122	0.0400	0.0124	0.0408

Table 7.10
Maximum acceptable direct-current resistance of ASTM Class M stranded conductors

Size of conductor	Uncoated copper				Coated copper (each strand coated with tin or a tin/lead alloy)			
	20°C		25°C		20°C		25°C	
	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km	Ohms per 1000 feet	Ohms per km
8 AWG	0.666	2.19	0.679	2.23	0.715	2.35	0.729	2.39
7	0.533	1.75	0.544	1.78	0.573	1.88	0.584	1.92
6	0.423	1.39	0.431	1.42	0.454	1.49	0.463	1.52
5	0.336	1.10	0.343	1.12	0.360	1.18	0.367	1.20
4	0.266	0.873	0.271	0.890	0.286	0.938	0.292	0.957
3	0.213	0.699	0.217	0.713	0.227	0.745	0.232	0.760
2	0.169	0.554	0.172	0.556	0.181	0.594	0.185	0.606
1	0.134	0.440	0.137	0.448	0.144	0.472	0.147	0.482
1/0	0.106	0.348	0.108	0.355	0.114	0.374	0.116	0.382
2/0	0.0850	0.279	0.0867	0.284	0.0913	0.300	0.0931	0.306
3/0	0.0674	0.221	0.0687	0.226	0.0724	0.238	0.0738	0.242
4/0	0.0535	0.176	0.0546	0.179	0.0574	0.188	0.0585	0.192
250 kcmil	0.0453	0.149	0.0462	0.152	0.0486	0.159	0.0496	0.163
300	0.0377	0.124	0.0385	0.126	0.0405	0.133	0.0413	0.136
350	0.0323	0.106	0.0329	0.108	0.0347	0.114	0.0354	0.116
400	0.0283	0.0929	0.0289	0.0947	0.0304	0.0997	0.0310	0.102
450	0.0251	0.0824	0.0256	0.0840	0.0262	0.0860	0.0276	0.0877
500	0.0226	0.0742	0.0231	0.0756	0.0243	0.0797	0.0248	0.0813
550	0.0206	0.0676	0.0210	0.0689	0.0221	0.0725	0.0225	0.0740
600	0.0189	0.0620	0.0193	0.0633	0.0202	0.0663	0.0206	0.0676
650	0.0174	0.0571	0.0177	0.0582	0.0187	0.0614	0.0191	0.0626
700	0.0162	0.0532	0.0165	0.0542	0.0174	0.0571	0.0177	0.0582
750	0.0151	0.0495	0.0154	0.0505	0.0162	0.0532	0.0165	0.0542
800	0.0141	0.0463	0.0144	0.0472	0.0152	0.0499	0.0155	0.0509
900	0.0126	0.0413	0.0129	0.0422	0.0135	0.0443	0.0138	0.0452
1000	0.0113	0.0371	0.0115	0.0378	0.0121	0.0397	0.0123	0.0405

Table 7.11
Factors for adjusting direct-current resistance of conductors[a]

Temperature of conductor		Multiplying factors for adjustment to resistance at			
		25°C (77°F)		20°C (68°F)	
°C	°F	Copper	Aluminum and copper-clad aluminum	Copper	Aluminum and copper-clad aluminum
0	32.0	1.107	1.110	1.085	1.088
1	33.8	1.102	1.105	1.081	1.083
2	35.6	1.098	1.100	1.076	1.078
3	37.4	1.093	1.095	1.072	1.074
4	39.2	1.089	1.090	1.067	1.069
5	41.0	1.084	1.085	1.063	1.064
6	42.8	1.079	1.081	1.059	1.060
7	44.6	1.075	1.076	1.054	1.055
8	46.4	1.070	1.072	1.050	1.051
9	48.2	1.066	1.067	1.045	1.046
10	50.0	1.061	1.063	1.041	1.042
11	51.8	1.057	1.059	1.037	1.038
12	53.6	1.053	1.054	1.033	1.033
13	55.4	1.048	1.050	1.028	1.029
14	57.2	1.044	1.045	1.024	1.024
15	59.0	1.040	1.041	1.020	1.020
16	60.8	1.036	1.037	1.016	1.016
17	62.6	1.032	1.033	1.012	1.012
18	64.4	1.028	1.028	1.008	1.008
19	66.2	1.024	1.024	1.004	1.004
20	68.0	1.020	1.020	1.000	1.000
21	69.8	1.016	1.016	0.996	0.996
22	71.6	1.012	1.012	0.992	0.992
23	73.4	1.008	1.008	0.989	0.989
24	75.2	1.004	1.004	0.985	0.984
25	77.0	1.000	1.000	0.981	0.980
26	78.8	0.996	0.996	0.977	0.976
27	80.6	0.992	0.992	0.973	0.972
28	82.4	0.989	0.989	0.970	0.969
29	84.2	0.985	0.985	0.966	0.965
30	86.0	0.981	0.981	0.962	0.961
31	87.8	0.977	0.977	0.958	0.957
32	89.6	0.974	0.973	0.955	0.954
33	91.4	0.970	0.970	0.951	0.950
34	93.2	0.976	0.966	0.948	0.947
35	95.0	0.963	0.962	0.944	0.943
36	96.8	0.959	0.958	0.941	0.939
37	98.6	0.956	0.955	0.937	0.936
38	100.4	0.952	0.951	0.934	0.932
39	102.2	0.949	0.948	0.930	0.929
40	104.0	0.945	0.944	0.927	0.925
41	105.8	0.942	0.941	0.924	0.922
42	107.6	0.938	0.937	0.921	0.918
43	109.4	0.935	0.934	0.917	0.915
44	111.2	0.931	0.930	0.914	0.911

(Continued)

Table 7.11 (Cont'd)
Factors for adjusting direct-current resistance of conductors[a]

Temperature of conductor		Multiplying factors for adjustment to resistance at			
		25°C (77°F)		20°C (68°F)	
°C	°F	Copper	Aluminum and copper-clad aluminum	Copper	Aluminum and copper-clad aluminum
45	113.0	0.928	0.927	0.911	0.908
46	114.8	0.925	0.924	0.908	0.905
47	116.6	0.922	0.920	0.905	0.902
48	118.4	0.918	0.917	0.901	0.898
49	120.2	0.915	0.913	0.898	0.895
50	122.0	0.912	0.910	0.895	0.892
51	123.8	0.909	0.907	0.892	0.889
52	125.6	0.906	0.904	0.889	0.886
53	127.4	0.902	0.900	0.885	0.882
54	129.2	0.889	0.897	0.882	0.879
55	131.0	0.896	0.894	0.879	0.876
56	132.8	0.893	0.891	0.876	0.873
57	134.6	0.890	0.888	0.873	0.870
58	136.4	0.887	0.884	0.870	0.867
59	138.2	0.884	0.881	0.867	0.864
60	140.0	0.881	0.878	0.864	0.861
61	141.8	0.878	0.875	0.861	0.858
62	143.6	0.875	0.872	0.858	0.855
63	145.4	0.872	0.869	0.856	0.852
64	147.2	0.869	0.866	0.853	0.849
65	149.0	0.866	0.863	0.850	0.846
66	150.8	0.863	0.860	0.847	0.843
67	152.6	0.860	0.857	0.844	0.840
68	154.4	0.858	0.855	0.842	0.838
69	156.2	0.855	0.852	0.839	0.835
70	158.0	0.852	0.849	0.836	0.832
71	159.8	0.849	0.846	0.833	0.829
72	161.6	0.846	0.843	0.830	0.826
73	163.4	0.844	0.841	0.828	0.824
74	165.2	0.841	0.838	0.825	0.821
75	167.0	0.838	0.835	0.822	0.818
76	168.8	0.835	0.832	0.819	0.815
77	170.6	0.833	0.829	0.817	0.813
78	172.4	0.830	0.827	0.814	0.810
79	174.2	0.828	0.824	0.812	0.808
80	176.0	0.825	0.821	0.809	0.805
81	177.8	0.822	0.818	0.807	0.802
82	179.6	0.820	0.816	0.804	0.800
83	181.4	0.817	0.813	0.802	0.797
84	183.2	0.815	0.811	0.799	0.795
85	185.0	0.812	0.808	0.797	0.792
86	186.8	0.810	0.806	0.794	0.790
87	188.6	0.807	0.803	0.792	0.787
88	190.4	0.805	0.801	0.789	0.785
89	192.2	0.802	0.798	0.787	0.782
90	194.0	0.800	0.796	0.784	0.780

[a] No referee resistance measurement is to be made at a temperature outside the range of 15 – 30°C (59 – 86°F). See 63.6.

8 Stranding

8.1 Each conductor shall be concentric-lay-stranded (in this standard, this term includes compressed-stranded and compact-stranded), with at least the number of strands indicated in Table 8.1, or shall be rope-lay-stranded. Copper wires (strands) smaller than No. 36 AWG (0.005 inch or 0.127 mm in diameter) and aluminum wires (strands) smaller than No. 22 AWG (0.0253 inch or 0.642 mm in diameter) shall not be used.

Table 8.1
Conductor stranding

Conductor size	Number of strands in combination unilay	Minimum acceptable number of strands	
		Compact stranded	All others
8, 7	–	7	7
6 – 2	19	7	7
1 – 4/0	19	18	19
250 – 500 kcmil	–	35	37
550 – 1000	–	58	61

8.2 A compact-stranded conductor shall be a round conductor consisting of a central core wire (strand) surrounded by one or more layers of helically laid wires (strands). A compact-stranded aluminum conductor shall have all layers with the same direction of lay (unidirectional). A compact-stranded uncoated copper conductor shall be unidirectional or shall have the direction of lay reversed in adjacent layers (concentric-lay-stranded) and with each layer rolled, drawn, or otherwise compressively formed to change the originally round strands to various shapes that achieve almost complete filling of the spaces originally present between the strands. Each layer shall be compacted before the next layer is applied, and each compacted layer – including the outermost layer – shall have an essentially smooth, round outer surface. The overall diameter of the finished, compacted conductor shall not be larger than indicated in column C or D of Table 8.2, and shall not be smaller than indicated in column A or B of Table 8.2 when the diameter of the conductor is determined as described in 8.8.

Table 8.2
Diameters over round compact-stranded aluminum and copper conductors

Conductor size	Minimum acceptable diameter		Maximum acceptable diameter	
	in A	mm B	in C	mm D
8 AWG	0.133	3.38	0.141	3.58
7	0.150	3.81	0.158	4.01
6	0.167	4.24	0.178	4.52
5	0.189	4.80	0.200	5.08
4	0.211	5.36	0.225	5.72
3	0.236	5.99	0.252	6.40
2	0.265	6.73	0.283	7.19
1	0.296	7.52	0.322	8.18
1/0	0.333	8.46	0.361	9.17
2/0	0.372	9.45	0.406	10.31
3/0	0.419	10.64	0.456	11.58
4/0	0.470	11.94	0.512	13.00
250 kcmil	0.515	13.08	0.558	14.17
300	0.564	14.33	0.611	15.52
350	0.610	15.49	0.661	16.79
400	0.652	16.56	0.706	17.93
450	0.693	17.60	0.749	19.02
500	0.729	18.52	0.789	20.04
550	0.767	19.48	0.829	21.06
600	0.805	20.45	0.866	22.00
650	0.837	21.26	0.901	22.89
700	0.868	22.05	0.935	23.75
750	0.899	22.83	0.968	24.59
800	0.929	23.60	1.000	25.40
900	0.989	25.12	1.061	26.95
1000	1.049	26.64	1.117	28.37

8.3 A compressed-stranded conductor shall be a round conductor consisting of a central core wire (strand) surrounded by one or more layers of helically laid wires (strands) with, for the No. 6 AWG – 1000 kcmil sizes, the direction of lay reversed in successive layers. The direction of lay of the outer layer shall be left-hand in all cases. The strands of one or more layers shall be slightly compressed by rolling, drawing, or other means to change the originally round strands to various shapes that achieve filling of some of the spaces originally present between the strands. A finished compressed-stranded ASTM Class B conductor shall not be larger in overall diameter than indicated in column C or D of Table 8.3 and shall not be smaller in overall diameter than indicated in column A or B of Table 8.3 (see note [a] to Table 8.3), when the diameter of the conductor is determined as described in 8.8.

8.4 A 19-wire combination round-wire unilay-stranded soft-annealed copper or an acceptable aluminum alloy conductor shall be round and shall consist of a straight central wire, an inner layer of six wires of the same diameter as the central wire with the six wires having identical lengths of lay, and an outer layer consisting of six wires of the same diameter as the central wire alternated with six smaller wires having a diameter of 0.732 times the diameter of the central wire and with all twelve wires of the outer layer having the same length of lay and direction of lay as the six wires of the inner layer. An assembled 19-wire combination unilay-stranded conductor shall not be larger in overall diameter than indicated in column H or I of Table 8.4 and shall not be smaller in overall diameter than indicated in column F or G of Table 8.4, when the diameter of the finished conductor is determined as described in 8.8.

Table 8.3
Diameters over compressed concentric-lay-stranded ASTM Classes B, C, and D aluminum, uncoated copper, and coated copper conductors

Conductor size	Minimum acceptable diameter[a]		Maximum acceptable diameter	
	in A	mm B	in C	mm D
8 AWG	0.141	3.58	0.146	3.71
7	0.158	4.01	0.164	4.17
6	0.178	4.52	0.184	4.67
5	0.200	5.08	0.206	5.23
4	0.225	5.72	0.232	5.89
3	0.252	6.40	0.260	6.60
2	0.283	7.19	0.292	7.42
1	0.322	8.18	0.332	8.43
1/0	0.361	9.17	0.372	9.45
2/0	0.406	10.31	0.418	10.62
3/0	0.456	11.58	0.470	11.94
4/0	0.512	13.00	0.528	13.41
250 kcmil	0.558	14.17	0.575	14.61
300	0.611	15.52	0.630	16.00
350	0.661	16.79	0.681	17.30
400	0.706	17.93	0.728	18.49
450	0.749	19.02	0.772	19.61
500	0.789	20.04	0.813	20.65
550	0.829	21.06	0.855	21.72
600	0.866	22.00	0.893	22.68
650	0.901	22.89	0.929	23.60
700	0.935	23.75	0.964	24.49
750	0.968	24.59	0.998	25.35
800	1.000	25.40	1.030	26.16
900	1.061	26.95	1.094	27.79
1000	1.117	28.37	1.152	29.26

[a] In no case is the diameter determined as described in 8.8 to be more than 3 percent smaller than the diameter of the conductor determined (as described in 8.8) after the conductor is assembled but before it is compressed.

Table 8.4
Nominal strand and conductor dimensions for 19-wire combination round-wire unilay-stranded copper or aluminum conductors

AWG conductor size	Nominal strand dimensions								Nominal conductor diameter		Minimum acceptable conductor diameter		Maximum acceptable conductor diameter	
	Large strand				Small strand									
	Diameter		Cross-sectional area		Diameter		Cross-sectional area							
	in A	mm	cmil B	mm²	in C	mm	cmil D	mm²	in E=3A+2C	mm	in F=0.95xE	mm G	in H=1.05xE	mm I
6	0.0402	1.0	1616	0.818	0.0294	0.7	864	0.437	0.179	4.55	0.170	4.32	0.188	4.78
5	0.0452	1.1	2043	1.034	0.0331	0.8	1096	0.555	0.202	5.13	0.192	4.88	0.212	5.38
4	0.0507	1.3	2570	1.301	0.0371	0.9	1376	0.696	0.226	5.74	0.215	5.46	0.237	6.02
3	0.0570	1.4	3249	1.644	0.0417	1.1	1739	0.880	0.254	6.45	0.241	6.12	0.267	6.78
2	0.0640	1.6	4096	2.073	0.0468	1.2	2190	1.108	0.286	7.26	0.272	6.91	0.300	7.62
1	0.0718	1.8	5155	2.609	0.0526	1.3	2767	1.400	0.321	8.15	0.305	7.75	0.337	8.56
1/0	0.0807	2.1	6512	3.296	0.0591	1.5	3493	1.768	0.360	9.14	0.342	8.69	0.378	9.60
2/0	0.0906	2.3	8208	4.154	0.0663	1.7	4396	2.225	0.404	10.26	0.384	9.75	0.424	10.77
3/0	0.1017	2.6	10343	5.234	0.0745	1.9	5550	2.809	0.454	11.53	0.431	10.95	0.477	12.12
4/0	0.1142	2.9	13042	6.600	0.0836	2.1	6989	3.537	0.510	12.95	0.485	12.32	0.536	13.61

8.5 Conductors that are not combination unilay, compacted, or compressed shall be either reverse-lay or unidirectional. A finished ASTM Class B, C, or D stranded conductor shall not be larger or smaller than indicated in the applicable columns of Table 8.5 (Class B), Table 8.6 (Class C), or Table 8.7 (Class D) when the diameter of the conductor is determined as described in 8.8.

Table 8.5
Diameters over round concentric-lay-stranded ASTM Class B aluminum, uncoated copper, and coated copper conductors

Conductor size	Minimum acceptable diameter		Nominal diameter		Maximum acceptable diameter	
	in A	mm B	in C	mm D	in E	mm F
8 AWG	0.139	3.53	0.146	3.71	0.153	3.89
7	0.156	3.96	0.164	4.17	0.172	4.37
6	0.175	4.45	0.184	4.67	0.193	4.90
5	0.196	4.98	0.206	5.23	0.216	5.49
4	0.220	5.59	0.232	5.89	0.244	6.20
3	0.247	6.27	0.260	6.60	0.273	6.93
2	0.277	7.04	0.292	7.42	0.307	7.80
1	0.315	8.00	0.332	8.43	0.349	8.86
1/0	0.353	8.97	0.372	9.45	0.391	9.93
2/0	0.397	10.08	0.418	10.62	0.439	11.15
3/0	0.447	11.35	0.470	11.94	0.494	12.55
4/0	0.502	12.75	0.528	13.41	0.544	14.07
250 kcmil	0.546	13.87	0.575	14.61	0.604	15.34
300	0.599	15.21	0.630	16.00	0.662	16.81
350	0.647	16.43	0.681	17.30	0.715	18.16
400	0.692	17.58	0.728	18.49	0.764	19.41
450	0.733	18.62	0.772	19.61	0.811	20.60
500	0.772	19.61	0.813	20.65	0.854	21.69
550	0.812	20.62	0.855	21.72	0.898	22.81
600	0.848	21.54	0.893	22.68	0.938	23.83
650	0.883	22.43	0.929	23.60	0.975	24.77
700	0.916	23.27	0.964	24.49	1.012	25.70
750	0.948	24.08	0.998	25.35	1.048	26.62
800	0.979	24.87	1.030	26.16	1.082	27.48
900	1.039	26.39	1.094	27.79	1.149	29.18
1000	1.094	27.79	1.152	29.26	1.210	30.73

Table 8.6
Diameters over round concentric-lay-stranded ASTM Class C aluminum, uncoated copper, and coated copper conductors

Conductor size	Minimum acceptable diameter		Nominal diameter		Maximum acceptable diameter	
	in A	mm B	in C	mm D	in E	mm F
8 AWG	0.141	3.58	0.148	3.76	0.155	3.94
7	0.158	4.01	0.166	4.22	0.174	4.42
6	0.177	4.50	0.186	4.72	0.195	4.95
5	0.198	5.03	0.208	5.28	0.218	5.54
4	0.222	5.64	0.234	5.94	0.246	6.25
3	0.250	6.35	0.263	6.68	0.276	7.01
2	0.281	7.14	0.296	7.52	0.311	7.90
1	0.316	8.03	0.333	8.46	0.350	8.89
1/0	0.355	9.02	0.374	9.50	0.393	9.98
2/0	0.399	10.13	0.420	10.67	0.441	11.20
3/0	0.447	11.35	0.471	11.96	0.495	12.57
4/0	0.503	12.78	0.529	13.44	0.555	14.10
250 kcmil	0.547	13.89	0.576	14.63	0.505	12.83
300	0.599	15.21	0.631	16.03	0.663	16.84
350	0.647	16.43	0.681	17.30	0.715	18.16
400	0.693	17.60	0.729	18.52	0.765	19.43
450	0.734	18.64	0.773	19.63	0.812	20.62
500	0.773	19.63	0.814	20.68	0.855	21.72
550	0.812	20.62	0.855	21.72	0.898	22.81
600	0.848	21.59	0.893	22.68	0.938	23.83
650	0.884	22.45	0.930	23.62	0.977	24.82
700	0.917	23.29	0.965	24.51	1.013	25.73
750	0.949	24.10	0.999	25.37	1.049	26.64
800	0.980	24.89	1.032	26.21	1.084	27.53
900	1.038	26.37	1.093	27.76	1.148	29.16
1000	1.095	27.81	1.153	29.29	1.211	30.76

Table 8.7
Diameters over round concentric-lay-stranded ASTM Class D aluminum, uncoated copper, and coated copper conductors

Conductor size	Maximum acceptable diameter		Nominal diameter		Maximum acceptable diameter	
	in	mm	in	mm	in	mm
8 AWG	0.141	3.58	0.148	3.76	0.155	3.94
7	0.158	4.01	0.166	4.22	0.174	4.42
6	0.177	4.50	0.186	4.72	0.195	4.95
5	0.199	5.05	0.209	5.31	0.219	5.56
4	0.223	5.66	0.235	5.97	0.247	6.27
3	0.251	6.38	0.264	6.71	0.277	7.04
2	0.282	7.16	0.297	7.54	0.312	7.92
1	0.316	8.03	0.333	8.46	0.350	8.89
1/0	0.355	9.02	0.374	9.50	0.393	9.98
2/0	0.399	10.13	0.420	10.67	0.441	11.20
3/0	0.448	11.38	0.472	11.99	0.496	12.60
4/0	0.504	12.80	0.530	13.46	0.557	14.14
250 kcmil	0.547	13.89	0.576	14.63	0.605	15.37
300	0.599	15.21	0.631	16.03	0.663	16.84
350	0.648	16.46	0.683	17.32	0.716	18.19
400	0.693	17.60	0.729	18.52	0.765	19.43
450	0.734	18.64	0.773	19.63	0.812	20.62
500	0.774	19.66	0.815	20.70	0.856	21.74
550	0.812	20.62	0.855	21.72	0.898	22.81
600	0.848	21.54	0.893	22.68	0.938	23.83
650	0.884	22.45	0.930	23.62	0.977	24.82
700	0.917	23.29	0.965	24.51	1.013	25.73
750	0.948	24.08	0.998	25.35	1.048	26.62
800	0.980	24.89	1.032	26.21	1.084	27.53
900	1.040	26.42	1.095	27.81	1.150	29.21
1000	1.095	27.81	1.153	29.29	1.211	30.76

8.6 Concentric-lay-stranded coated or uncoated annealed copper conductors (including compressed conductors) shall comply with the applicable parts of ASTM B 8-93. Compact round concentric-lay-stranded uncoated copper conductors shall comply with the applicable parts of ASTM B 496-92.

8.7 Concentric-lay-stranded aluminum conductors (including compressed conductors) shall comply with the applicable parts of ASTM B 231-90. Compact stranded aluminum shall comply with the applicable parts of ASTM B 400-92.

8.8 Measurements of the diameter of a conductor are to be made at one end of the finished conductor by means of a machinist's micrometer caliper that has a flat surface on the anvil and also on the end of the spindle and is calibrated to read directly to at least 0.001 inch or 0.01 mm. Each division is to be of a width that facilitates estimation of each measurement to 0.0001 inch or 0.001 mm. The diameter is to be measured at three points in a plane that is perpendicular to the longitudinal axis of the conductor, the points being spaced approximately 60° apart around the circumference of the conductor. At each point, the measurement is to be made on a straight line that extends through the center of the conductor and through the centers of two wires (strands) that are 180° apart around the circumference of the conductor. The three readings are to be recorded to the nearest 0.0001 inch or 0.001 mm, added together, and divided by 3, with the result rounded off to the nearest 0.001 inch or 0.01 mm. The diameter of the finished conductor is not acceptable if the rounded average of the three micrometer readings is larger than the maximum diameter or smaller than the minimum diameter indicated for the conductor in the applicable Table 8.2, 8.3, 8.5, 8.6, or 8.7.

8.9 The length of lay in only the outer layer of a No. 1 AWG – 1000 kcmil round compact-stranded conductor shall neither be less than 8 nor more than 16 times the overall diameter of that layer. The length of lay of the strands in the outer layer of a No. 8 – 2 AWG compact-stranded conductor shall be 8.0 – 17.5 times the overall diameter of that layer. The direction of lay of the outer layer shall be left-hand.

8.10 Every stranded conductor other than a compact-stranded conductor shall comply with the following:

a) The direction of lay of the strands, members, or ropes in a No. 6 AWG – 1000 kcmil conductor other than a combination unilay conductor shall be reversed in successive layers.

b) For a bunch-stranded member of a rope-lay-stranded conductor, the length of lay of the individual strands in a member shall not be more than 30 times the outside diameter of that member.

c) For a concentric-stranded member of a rope-lay-stranded conductor, the length of lay of the individual strands in a member shall be 8 – 16 times the outside diameter of that layer.

d) The length of lay of the strands in both layers of a 19-wire combination round-wire unilay-stranded copper or aluminum conductor shall be 8 – 16 times the outside diameter of the completed conductor. Otherwise, the length of lay of the strands in every layer of a concentric-lay-stranded conductor consisting of fewer than 37 strands shall be 8 – 16 times the outside diameter of that layer.

e) The length of lay of the strands in the outer two layers of a concentric-lay-stranded conductor consisting of 37 or more strands shall be 8 – 16 times the outside diameter of that layer.

f) The length of lay of the members or ropes in the outer layer of a rope-lay-stranded conductor shall be 8 – 16 times the outside diameter of that layer.

9 Metal Coating

9.1 If the insulation or other material adjacent to a copper conductor corrodes unprotected copper in the test in 30.1, each of the individual strands of that conductor shall be separately covered with a metal coating that complies with 6.1.

9.2 In the case of a copper conductor on whose wires a coating is not needed for corrosion protection but is used, it is acceptable to coat only the wires of the outer layer (see 7.1) or to coat all of the wires. The metal coating used shall comply with 6.1.

10 Joints

10.1 A joint in one of the individual wires (strands) shall be made in a workmanlike manner, shall not change the diameter of the wire (strand) or of the overall conductor, and shall not lessen the mechanical strength or impair the flexibility of the overall conductor. A joint shall not be made in the stranded conductor as a whole but, for other than a rope-lay-stranded conductor (see 10.2) shall be made by separately joining each individual wire (strand) in a manner that does not increase the overall diameter of the entire stranded conductor. A joint in a compact-stranded or compressed-stranded conductor shall be made before compacting or compressing. A joint in any conductor shall be made before the conductor-stress-relief material, the insulation, and other coverings are applied.

10.2 In a rope-lay-stranded conductor consisting of a central core surrounded by one or more layers of stranded members (primary groups), each member may be considered to be equivalent to a solid wire and, as such, may be spliced as a unit. These joints are to be dispersed throughout the length of the conductor so that the diameter and configuration of the completed conductor are not substantially affected, and so that the flexibility of the completed conductor is not adversely affected thereby. In no case shall these joints be closer together than two lay lengths.

CONDUCTOR STRESS RELIEF (CONDUCTOR SHIELDING)

11 Details

11.1 Conductor stress relief shall be provided on each circuit conductor. It shall be readily removable from the conductor and shall be bonded to the insulation (the tension necessary to remove the stress relief from the insulation is not specified). The conductor stress relief shall be of conductive nonmetallic material and shall comply with Tables 11.1 (form), 11.2 (thicknesses), and 11.3 (material).

11.2 The thickness(es) of a conductive tape used alone, of a conductive extrusion used alone, or of a conductive extrusion plus a conductive tape are to be determined on a full cross section of the conductor shielding produced by cutting a specimen of the finished conductor through perpendicular to its longitudinal axis. All measurements are to be made over the tops of strands or at the impressions left by strands. In the case of a conductive tape used alone, the minimum thickness is to be measured directly by means of one of the following:

a) A dead-weight dial micrometer having a presser foot 0.250 $\pm$0.010 inch or 6.4 $\pm$0.2 mm in diameter and exerting a total of 3.0 $\pm$0.1 ozf or 85 $\pm$3 gf or 0.84 $\pm$0.02 N on the specimen – the load being applied by means of a weight, or

b) An optical device that is accurate to at least 0.001 inch or 0.01 mm.

In all other cases, the maximum and minimum thicknesses are each to be measured directly by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm and the two are then to be averaged to determine the average thickness.

11.3 The volume resistivity of the finished conductor shielding taken as a unit shall comply with 41.1.

Table 11.1
Conductor shielding

Voltage ratings	Acceptable construction of conductor stress relief
5000, 8000, and 15000	A conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25 directly on the conductor or Overlapping[a] conductive tape covered by a conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25 or Overlapping[a] conductive tape alone
25000, 28000, and 35000	A conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25 directly on the conductor or Overlapping[a] conductive tape covered by a conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25

[a] The amount of overlap is not specified.

Table 11.2
Thicknesses of conductor stress relief

Material	On a compact-stranded conductor		On any other conductor	
	Minimum acceptable average thickness[a]	Minimum acceptable thickness at any point[a]	Minimum acceptable average thickness[a]	Minimum acceptable thickness at any point[a]
Conductive tape of any convenient width applied with an unspecified overlap directly to the conductor	Not specified	2.5 mils or 0.06 mm	Not specified	2.5 mils or 0.06 mm
A conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25 over the above-mentioned tape or directly on the conductor. The properties of the material used shall comply with Table 11.3 when specimens are prepared and tested as indicated in the method to which reference is made in Table 11.3	8 mils or 0.20 mm	5 mils or 0.13 mm	15 mils or 0.38 mm	12 mils or 0.30 mm

[a] Where both tape and extruded material are used, no reduction is acceptable in any of the specified thicknesses of the tape or extruded material

Table 11.3
Properties of extruded conductor stress relief

Property	Acceptable value
I. Ultimate elongation (see Section 28 for method) using 1-inch or 25-mm bench marks on specimens that first are die-cut from a specially molded slab that is not more than 0.1 inch or 2.5 mm thick and then are aged as follows in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	100 percent (minimum)
II. Brittleness temperature by the Acceptance Impact Procedure B described in ASTM D 746-79 (R1987) using five die-punched specimens that are 0.25 ±0.02 inch or 6.35 ±0.51 mm wide	−10°C (+14°F) (maximum)
III. Cold – see Section 36 for method	No damage shall result

INSULATION

12 Material, Application, and Centering

12.1 Each circuit conductor shall be insulated for its entire length with a thermoset insulation that complies with Table 12.1 (XLPE) or Table 12.4 (EP). The insulation shall be applied directly to the outer surface of the conductor stress relief and shall be bonded thereto (see 11.1). The insulation shall not have any repairs or joints and shall not have defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification.

12.2 The insulation in 5-kV nonshielded single-conductor cables constructed as indicated in columns A and B of Table 13.2 is not required to be for use in wet locations. Insulation that is for use in wet locations shall be used in all other single-conductor cables and in all multiple-conductor cables other than those consisting of an assembly of the 5-kV nonshielded single-conductor cables constructed without any overall covering as indicated in column A or B of Table 13.2.

12.3 The insulation shall have a circular cross section and shall be applied concentrically about the conductor and the conductor stress relief.

Table 12.1
Properties of XLPE[a] insulation from 90°C (194°F) cable

Property	Acceptable value
I. Physical properties – see Section 29 for method	See Table 12.2
II. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 62 for method	
Maximum elongation	Filled – 100 percent[b] Unfilled – 175 percent[b]
Maximum set	Filled – 5 percent[b] Unfilled – 10 percent[b]
III. Cold bend – see Section 36 for method	No damage shall result
IV. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 32 for method	
8 – 4/0 AWG conductors (round specimens)	25 percent
250 – 1000 kcmil conductors (flat, rectangular specimens)	15 percent
V. Insulation resistance at 60.0°F (15.6°C)	See Table 12.3
VI. Accelerated water absorption, electrical method – see Section 37 for method[c]	
Maximum dielectric constant after 24 h	3.5
Maximum increase in capacitance	1 – 14 d: 3.0 percent 7 – 14 d: 1.5 percent
Maximum stability factor after 14 d[d]	1.0 percent
Maximum stability factor difference[d]	1 – 14 d: 0.5 percent
VII. Specific inductive capacity – see Section 39 for method[e]	Maximum – 3.5
VIII. Power factor – see Section 39 method[e]	Maximum – 2.0 percent

[a] XLPE designates a cross-linked compound whose characteristic constituent is cross-linked polyethylene. For 5-kV cables only, the compound may be pigmented by the addition of carbon black.

[b] Greater elongation or set is acceptable if the loss of weight does not exceed 30 percent in a solvent extraction test made as described in ASTM D 2765-90.

[c] Not required for dry-locations cable (nonshielded 5-kV single-conductor cable insulated as indicated in column A or B of Table 13.2).

[d] Only one of these tests is required [see 37.1(d)].

[e] Not required for 5-kV cable.

Table 12.2
Physical properties of XLPE[a] insulation from 90°C (194°F) cable

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1800 lbf/in^2 or 12.4 MN/m^2 or 1240 N/cm^2 or 1.27 kgf/mm^2
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant insulation from nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column A of Table 13.2 and marked "oil resistant II" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant insulation from nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column A of Table 13.2 and marked "oil resistant I" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] XLPE designates a cross-linked compound whose characteristic constituent is cross-linked polyethylene. For 5-kV cables only, the compound may be pigmented by the addition of carbon black.

Table 12.3
Insulation resistance of XLPE[a] insulation from 90°C (194°F) cable

Property	Acceptable value
V. Insulation resistance at 60.0°F (15.6°C)	
1) Insulation and individual nonconductive circuit-conductor jacket tested together – see Section 58 for method	
On jacketed nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column B of Table 13.2 On jacketed nonshielded wet-or-dry- locations 5-kV single-conductor cable insulated as indicated in column C of Table 13.2 On jacketed nonshielded wet-or-dry- locations 8-kV cable insulated as indicated in column D of Table 13.2 In nonshielded multiple-conductor cable insulated as indicated in Table 13.2 without a nonconductive jacket on each circuit conductor	Minimum K: 12,000 megohms based on 1000 conductor feet or Minimum K: 3650 megohms based on a conductor kilometer
2) Insulation alone	
In nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column A of Table 13.2 – see Section 58 for method In shielded single-conductor cable insulated as indicated in Table 13.1 – see Section 57 for method In shielded multiple-conductor cable insulated as indicated in Table 13.1 – see Section 57 for method In nonshielded multiple-conductor cable insulated as indicated in Table 13.1 without a nonconductive jacket on each circuit conductor – see Section 58 for method	Minimum K: 20,000 megohms based on 1000 conductor feet or Minimum K: 6100 megohms based on a conductor kilometer

[a] XLPE designates a cross-linked compound whose characteristic constituent is cross-linked polyethylene. For 5-kV cables only, the compound may be pigmented by the addition of carbon black.

Table 12.4
Properties of EP[a] insulation from 90°C (194°F) cable

Property	Acceptable value
I. Physical properties – see Section 29 for method	See Table 12.5
II. Cold bend – see Section 36 for method	No damage shall result
III. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 62 for method	
Maximum elongation	50 percent
Maximum set	5 percent
IV. Insulation Resistance at 60.0°F (15.6°C)	See Table 12.6
V. Accelerated water absorption[b]	
Electrical method – see Section 37 for method	
Maximum dielectric constant after 24 h	4.0
Maximum increase in capacitance	1 – 14 d: 3.5 percent 7 – 14 d: 1.5 percent
Maximum stability factor after 14 d[c]	1.0 percent
Maximum stability factor difference[c]	1 – 14 d: 0.5 percent
VI. Relative permittivity – see Section 39 for method[d]	Maximum: 4.0
VII. Power factor – see Section 39 for method[d]	Maximum: 2.0 percent

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of nonconjugated diene.

c) A blend of EPM and EPDM.

[b] Not required for dry-locations cable (nonshielded 5-kV single-conductor cable insulated as indicated in column A or B of Table 13.2.

[c] Only one of these test is required [see 37.1(d)].

[d] Not required for 5-kV cable.

Table 12.5
Physical properties of EP[a] insulation from 90°C (194°F) cable

Condition of specimens at time of measure	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	200 percent (2 inches or 50 mm)	700 lbf/in^2 or 4.83 MN/m^2 or 483 N/cm^2 or 0.492 kgf/mm^2
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of nonconjugated diene.

c) A blend of EPM and EPDM.

Table 12.6
Insulation resistance of EP[a] insulation from 90°C (194°F) cable

Property	Acceptable value
IV. Insulation resistance at 60°F (15.6°C)	
Insulation and individual nonconductive circuit-conductor jacket tested together – see Section 58 for method	
On jacketed nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column B of Table 13.2	Minimum K: 12,000 megohms based on 1000 conductor feet
On jacketed nonshielded wet-or-dry-locations 5-kV single-conductor cable insulated as indicated in column C of Table 13.2	or
On jacketed nonshielded wet-or-dry-locations 8-kV single-conductor cable insulated as indicated in column D of Table 13.2	Minimum K: 3650 megohms based on a conductor kilometer
In nonshielded multiple-conductor cable insulated as indicated in Table 13.1 with a nonconductive jacket on each circuit conductor	
Insulation alone	
In nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column A or Table 13.2 – see Section 58 for method	Minimum K: 20,000 megohms based on 1000 conductor feet
In shielded single-conductor cable insulated as indicated in Table 13.1 – see Section 57 for method	
In shielded multiple-conductor cable insulated as indicated in Table 13.1 – see Section 57 for method	or
In nonshielded multiple-conductor cable insulated as indicated in Table 13.1 without a nonconductive jacket on each circuit conductor – see Section 58 for method.	Minimum K: 6100 megohms based on a conductor kilometer

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of nonconjugated diene.

c) A blend of EPM and EPDM.

Table 12.7
Properties of EPCV[a] insulation from 90°C (194°F) 5-kV dry-locations cable

Property	Acceptable value
I. Physical properties – see Section 29 for method	See Table 12.8
II. Cold bend – see Section 36 for method	No damage shall result
III. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 62 for method	
Maximum elongation	50 percent
Maximum set	5 percent
IV. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 32 for method	
8 – 4/0 AWG conductors (round specimens)	25 percent
250 – 1000 kcmil conductors (flat, rectangular specimens)	15 percent
V. Insulation resistance at 60.0°F (15.6°C)	See Table 12.9

[a] EPCV designates a cross-linked compound whose characteristic constituent is a covulcanizate of ethylene propylene (EP) and polyethylene (PE).

Table 12.8
Physical properties of EPCV[a] insulation from 90°C (194°F) 5-kV dry-locations cable

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	200 percent (2 inches or 50 mm)	1500 lbf/in^2 or 10.3 MN/m^2 or 1034 N/cm^2 or 1.05 kgf/mm^2
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

[a] EPCV designates a cross-linked compound whose characteristic constituent is a covulcanizate of ethylene propylene (EP) and polyethylene (PE).

Table 12.9
Insulation resistance of EPCV[a] insulation from 90°C (194°F) 5-kV dry-locations cable

Property	Acceptable value
V. Insulation resistance at 60°F (15.6°C)	
Insulation and individual nonconductive circuit-conductor jacket tested together – on jacketed nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column B of Table 13.2 – see Section 58 for method	Minimum K: 12,000 megohms based on 1000 conductor feet or Minimum K: 3650 megohms based on a conductor kilometer
Insulation in nonshielded dry-locations 5-kV single-conductor cable insulated as indicated in column A of Table 13.2 – see Section 58 for method	Minimum K: 20,000 megohms based on 1000 conductor feet or Minimum K: 6100 megohms based on a conductor kilometer

[a] EPCV designates a cross-linked compound whose characteristic constituent is a covulcanizate of ethylene propylene (EP) and polyethylene (PE).

13 Thicknesses

13.1 The average thickness of the insulation and the minimum thickness at any point of the insulation shall not be less than indicated in Table 13.1 (shielded single-conductor cable and shielded and nonshielded multiple-conductor cables) or Table 13.2 (nonshielded single-conductor 5- and 8-kV cables) when determined as described in 13.2 (removal of bonded components damages the insulation) or 13.3 (insulation separable without being damaged).

13.2 In the case of a circuit conductor in which a bonded component (bonding to the insulation is required in 11.1 for conductor shielding and optional in 15.2 for extruded insulation shielding) cannot be removed without damage to the insulation, the thicknesses of the insulation are to be determined on a full cross section of the insulation produced by cutting a specimen of the finished conductor through perpendicular to its longitudinal axis. All measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The maximum and minimum thicknesses are to be measured directly and the two are then to be averaged to determine the average thickness.

13.3 The thicknesses of insulation from which all bonded and other components can be removed without damage to the insulation are to be determined as described in 13.2 (basic optical method) or by one of the following methods:

a) DIFFERENCE METHOD – Measurements are to be made by means of a machinist's micrometer caliper having a flat surface both on the anvil and on the end of the spindle and calibrated to read directly to at least 0.001 inch or 0.01 mm. All measurements are to be made on a length of the finished conductor from which all components over the insulation have been removed without damage to the insulation. The average thickness of the insulation is to be taken as half of the difference between the mean of the maximum and minimum diameters over the insulation at one point and the average diameter over the conductor and the insulation shielding measured at the same point. The minimum thickness of the insulation is to be taken as the difference between a measurement (first measurement) made over the conductor and the conductor shielding plus the thinnest insulation wall, and the diameter over the conductor and the conductor shielding. The first measurement is to be made after slicing off the thicker side of the insulation. None of the thickness of the conductor shielding is to be included in the thickness of the insulation.

b) DIRECT MEASUREMENT – Measurements are to be made by means of the machinist's micrometer caliper described in (a) or by means of a dead-weight dial micrometer that exerts 10 ± 2 gf or 0.10 ± 0.02 N on a specimen through a flat, rectangular presser foot 0.078 inch by 0.375 inch or 1.98 mm by 9.52 mm. The anvil of the instrument is to be of the same dimensions as the presser foot. The instrument is to be calibrated as indicated in (a). The insulation is to be removed from a length of the finished conductor without damage to the insulation, and the maximum and minimum points are to be determined by direct measurement using the micrometer caliper or dial micrometer. The average of these determinations is to be taken as the average thickness of the insulation.

c) REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 13.2 or in (a) or (b) above are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 in or 0.001 mm is to be used. The insulation is to be removed from a length of the finished conductor without damage to the insulation and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The average of these determinations is to be taken as the average thickness of the insulation. The results of this optical procedure are to be taken as conclusive.

Table 13.1
Thicknesses of XLPE or EP insulation in 5 – 35 kV shielded single-conductor cable and in 5 – 35 kV shielded and 5 kV nonshielded multiple-conductor cables

Voltage rating of cable (phase-to-phase circuit voltage)	Size of conductor	100 percent insulation level (grounded neutral)[a]				133 percent insulation level (ungrounded neutral)[a]			
		mils		mm		mils		mm	
		Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
5000	8 AWG – 1000 kcmil	90	81	2.29	2.06	90	81	2.29	2.06
8000	6 – 1000	115	104	2.92	2.64	140	126	3.56	3.20
15000	2 – 1000	175	158	4.45	4.01	215	194	5.46	4.93
25000	1 – 1000	260	234	6.60	5.94	345	311	8.76	7.90
28000	1 – 1000	280	252	7.11	6.40	–	–	–	–
35000	1/0 – 1000	345	311	8.76	7.90	–	–	–	–

[a] The selection of the cable insulation level to be used in a particular installation is made on the basis of the applicable phase-to-phase voltage of the circuit and of the general system category (expressed as a percent insulation level) as outlined below:

100 PERCENT LEVEL – Cables in this category are intended for use where the system is provided with relay protection such that ground faults clear as rapidly as possible but, in any case, within 1 min. While these cables are applicable to the great majority of cable installations that are on grounded systems, these cables also are installed for use on other systems for which the application of cables is acceptable (see next paragraph), provided that the above clearing requirements are met in completely de-energizing the faulted section.

In common with other electrical equipment, the use of cables is not recommended on systems where the ratio of the zero to positive phase reactance of the system at the point of cable application lies between −1 and −40 because excessively high voltages may be encountered in the case of ground faults.

133 PERCENT LEVEL – This insulation level corresponds to that formerly designated for undergrounded systems. Cables in this category are intended for use in situations in which the clearing-time requirements of the 100 percent level category cannot be met, and yet there is reason to expect that the faulted section is de-energized in a time not exceeding 1 h. Also, they may be used when additional insulation strength over the 100 percent level category is desirable.

Table 13.2
Thicknesses of insulation in nonshielded single-conductor cables rated 5000 or 8000 V

	5000 V Cables							
	Dry locations							
	XLPE or EPCV insulation without any covering over the insulation		XLPE, EPCV, or EP insulation with a nonconductive jacket over the insulation		Wet-or-dry-locations XLPE or EP insulation with a nonconductive jacket over the insulation		8000-V cable with wet-or-dry-locations XLPE or EP insulation (100 percent insulation level) with a nonconductive jacket over the insulation	
	A		B		C		D	
Size of conductor	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
	mils							
8 – 4/0 AWG	110	99	90	81	125	113	180	162
213 – 500 kcmil	120	108	90	81	140	126	210	189
501 – 750	130	117	90	81	155	140	235	212
751 – 1000	130	117	90	81	155	140	250	225
	mm							
8 – 4/0 AWG	2.79	2.51	2.29	2.06	3.18	2.87	4.57	4.11
213 – 500 kcmil	3.05	2.74	2.29	2.06	3.56	3.20	5.33	4.80
501 – 750	3.30	2.97	2.29	2.06	3.94	3.56	5.97	5.38
751 – 1000	3.30	2.97	2.29	2.06	3.94	3.56	6.35	5.72

INSULATION SHIELDING

14 General

14.1 Insulation shielding (electrostatic) shall be provided over the insulation on each circuit conductor in the following cables:

a) Single-conductor cables insulated as indicated in Table 13.1.

b) 8 – 35 kV cables insulated as indicated in Table 13.1.

Insulation shielding is optional in 5-kV multiple-conductor cables that are insulated as indicated in Table 13.1. Insulation shielding is not acceptable in single-conductor cables that are insulated as indicated in Table 13.2.

14.2 Insulation shielding shall consist of both of the following elements:

a) A conductive nonmetallic covering (see 15.1 – 15.8) directly over and in intimate contact with the insulation, and

b) A nonmagnetic metal component (see 16.1) embedded in or directly over and in intimate contact with the conductive nonmetallic covering.

14.3 The insulation shielding on all of the individual conductors of a multiple-conductor cable shall be of the same physical makeup and construction.

15 Conductive Nonmetallic Covering

15.1 The conductive nonmetallic covering shall consist of a conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25, a conductive nonmetallic tape, or a conductive nonmetallic tape over a conductive nonmetallic coating. The covering shall be directly over and in intimate contact with the insulation. The covering shall enclose the insulation throughout the length of the circuit conductor. A supplementary conductive nonmetallic tape may be provided over a conductive extrusion. The covering shall be removable when the conductor is terminated or spliced (see marking requirement in 67.1).

15.2 An extruded covering that is not bonded to the insulation (see stripping-tension test in Section 31), a tape covering, and a coating-plus-tape covering shall be readily removable. An extruded covering may be bonded to the insulation (the means for removing a bonded covering from the insulation is not specified but typically is by means of a solvent, hot air, or a flame.)

15.3 The volume resistivity of the finished extruded, tape, or coating-plus-tape covering taken as a unit shall comply with 42.1.

15.4 The properties of an extruded covering shall comply with Table 15.1 when specimens from the finished cable are prepared and tested as described in the paragraphs referenced in the table.

15.5 The thicknesses of an extruded covering shall not be less than indicated in Table 15.3 when measured as described in 15.6 (covering bonded to the insulation) or 15.7 (covering not bonded to the insulation).

15.6 The thicknesses of an extruded covering that is bonded to the insulation are to be determined on a full cross section of the covering produced by cutting a specimen of the finished conductor through perpendicular to its longitudinal axis. All measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The maximum and minimum thicknesses are to be measured directly and the two are then to be averaged to determine the average thickness.

15.7 The thicknesses of an extruded covering that is not bonded to the insulation are to be determined either optically as described in 15.6 or from measurements made on the covering removed from the finished conductor. In the latter case, direct measurements of the maximum and minimum thicknesses are to be made by means of a machinist's micrometer caliper having a flat surface both on the anvil and on the end of the spindle and calibrated to read directly to at least 0.001 inch or 0.01 mm. The average of these measurements is to be taken as the average thickness.

15.8 Conductive tape may be of any convenient width, and shall be at least 2.5 mils or 0.06 mm in thickness at any point when removed from the finished conductor and measured using either of the following:

a) A dead-weight dial micrometer that exerts 10 ±2 gf or 0.10 ±0.02 N on a specimen through a flat, rectangular presser foot 0.078 inch by 0.375 inch or 1.98 mm by 9.52 mm and having a flat anvil of the same dimensions as the presser foot, or

b) A machinist's micrometer caliper having a flat surface both on the anvil and on the end of the spindle.

Each instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The tape shall be applied helically with an overlap of at least 10 percent of the tape width. The tape shall be applied either directly over the insulation or over a conductive nonmetallic coating on the insulation.

Table 15.1
Properties of extruded conductive covering

Property	Acceptable value(s)
I. Physical properties – see note [b] to Table 25.11 and Section 29 for method	See Table 15.2
II. Brittleness temperature by the Acceptance Impact Procedure B described in ASTM D 746-79(R1987) using five die-punched specimens that are 0.25 ±0.02 inch or 6.35 ±0.51 mm wide	Maximum −10°C (+14°F)
III. Cold bend – see Section 36 for method	No damage shall result

Table 15.2
Properties of extruded conductive covering

Condition of specimens at time of measurement	From cable in which the metal component of the insulation shielding is embedded in the extruded covering A		From cable in which the metal component of the insulation shielding is not embedded in the extruded covering B	
	Minimum acceptable ultimate elongation (1 inch or 25 mm bench marks)	Minimum acceptable tensile strength	Minimum acceptable ultimate elongation (1 inch or 25 mm bench marks)	Minimum acceptable tensile strength
Unaged	100 percent (1 inch or 25 mm)	1200 lbf/in^2 or 8.27 MN/m^2 or 827 N/cm^2 or 0.844 kgf/mm^2	Not measured	Not measured
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	100 percent (1 inch or 25 mm)	85 percent of the result with unaged specimens	100 percent (1 inch or 25 mm)	Not measured
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 68.1(h): Aged in ASTM oil No. 2 (see 28.8) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens		Oil resistance is not applicable	
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 68.1(h) Aged in ASTM oil No. 2 (see 28.8) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	65 percent of the result with unaged specimens		Oil resistance is not applicable	

Table 15.3
Thicknesses of extruded conductive nonmetallic covering

Calculated minimum[c] diameter over insulation	On single-conductor cable in which the metal component of the insulation shielding is embedded in the extruded covering[a] A		In jacketed multiple-conductor cable in which the metal component of the insulation shielding is embedded in the extruded covering[b] B		In single-and multiple-conductor cable in which the metal component of the insulation shielding is not embedded in the extruded covering C
	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable thickness at any point
inch	mils				
0 – 0.425	45	36	30	24	24
Over 0.425 but not over 0.700	60	48	30	24	24
Over 0.700 but not over 1.000	80	64	50	40	24
Over 1.000 but not over 1.500	80	64	50	40	32
Over 1.500 but not over 2.500	110	88	80	64	40
Over 2.500	140	112	–	–	–
mm	mm				
0 – 10.80	1.14	0.91	0.76	0.61	0.51
Over 10.80 but not over 17.78	1.52	1.22	0.76	0.61	0.61
Over 17.78 but not over 25.40	2.03	1.62	1.27	1.02	0.61
Over 25.40 but not over 38.10	2.03	1.62	1.27	1.02	0.81
Over 38.10 but not over 63.50	2.79	2.24	2.03	1.63	1.02
Over 63.50	3.56	2.84	–	–	–

[a] Acceptable as the overall cable jacket.

[b] Acceptable as an individual jacket (conductive insulation covering serving as a jacket as well as part of the insulation shielding) on the insulated conductor (see 17.1 – 17.4).

[c] The minimum diameter over the insulation is to be the sum of the minimum acceptable conductor diameter, twice the minimum acceptable thickness at any point of the conductor stress relief, and twice the minimum acceptable average thickness of the insulation.

16 Nonmagnetic Metal Component

16.1 The metal component shall be nonmagnetic, shall be electrically continuous throughout the length of the insulated conductor, and shall consist of one or a combination of the constructions detailed in Table 16.1.

Table 16.1
Construction of metal component of insulation shielding

Form	Material and dimensions[a]	Application	
		Manner	Placement throughout the length of the insulated conductor
Tape or tapes	Copper of any convenient width and at least 2.5 mils or 0.06 mm thick or Other nonmagnetic metal of any convenient width and of a thickness that results in a conductance at least that of copper that is 2.5 mils or 0.06 mm thick	Helically applied or Corrugated and longitudinally applied with an unspecified overlap	Directly over and in intimate contact with the conductive nonmetallic covering
Straps	Copper having an effective cross-sectional area of at least 5000 circular mils (0.004 square inch) per inch of diameter over the insulation or of at least 0.01 square millimeter per millimeter of diameter over the insulation or Other nonmagnetic metal having an effective cross-sectional area that results in a conductance at least that of the copper mentioned above	Helically or longitudinally applied	Directly over and in intimate contact with the conductive nonmetallic covering
Wires		Helically applied	Directly over and in intimate contact with the conductive nonmetallic covering
		Corrugated and longitudinally applied	Embedded (0.005 inch or 0.13 mm minimum thickness at any point) in extruded insulation shielding (see 15.2, 15.4, and 15.5) with none of the metal exposed at either the inner or outer surface of the extruded insulation shielding before and after the cold-bend test in 36.1
Wire[b] braid		Applied around the underlying construction	Directly over and in intimate contact with the conductive nonmetallic covering

(Continued)

Table 16.1 (Cont'd)
Construction of metal component of insulation shielding

Form	Material and dimensions[a]	Application	
		Manner	Placement throughout the length of the insulated conductor
Sheath	Smooth aluminum or lead sheath complying with 26.2 and 26.4 – 26.6 or Welded and corrugated aluminum, bronze, or copper sheath complying with 26.2, 26.3, 26.7, and 26.8 or Extruded and corrugated aluminum sheath complying with 26.2, 26.3, 26.9, and 26.10 The sheath in any form shall have an effective cross-sectional area that results in a conductance at least that of the copper wires or straps mentioned above	Tightly formed around the underlying construction	Directly over and in intimate contact with the conductive nonmetallic covering

[a] Additional conductance in the metal component may be necessary to meet circuit needs. This additional conductance is to be provided by adding additional area, by using metal of a higher conductivity, or be using more than one of the constructions described.

[b] In a wire braid, the individual wires shall not be smaller in diameter than 6.3 mils or 0.160 mm (No. 34 AWG).

JACKET ON INDIVIDUAL CIRCUIT CONDUCTORS FOR MULTIPLE-CONDUCTOR CABLE

17 Details

17.1 A jacket shall be provided on each shielded circuit conductor intended for use in a multiple-conductor cable that does not have any overall covering. A jacket is acceptable but is not required on each shielded or nonshielded circuit conductor intended for use in a multiple-conductor cable that has an overall covering. A jacket is required on each nonshielded single-conductor cable, other than the construction covered in column A of Table 13.2, intended for assembly into a multiple-conductor cable that does not have any overall covering.

17.2 A circuit-conductor jacket that is provided, whether required or not, shall be of one of the nonconductive materials indicated in Table 25.1, or shall be one of the conductive materials covered in Section 15 if the functions of insulation shielding and circuit-conductor jacket are combined. A circuit-conductor jacket shall not have defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. A nonconductive circuit-conductor jacket that is provided shall be applied directly over the insulation of a nonshielded circuit conductor and directly over the shielding of a shielded circuit conductor. The insulation or shield shall be completely covered and shall be well centered in the nonconductive jacket throughout the length of the circuit conductor. A nonconductive circuit-conductor jacket shall be removable without damage to any part(s) of the cable beneath the jacket.

17.3 Specimens prepared from samples of a circuit-conductor jacket taken from the finished cable shall exhibit properties that comply with Table 15.1 (conductive material), or the applicable table referenced in Table 25.1 (nonconductive jacket) when tested as described in Section 29.

17.4 The average thickness and the minimum thickness at any point of a nonconductive circuit-conductor jacket shall not be less than indicated in Table 17.1 (for a multiple-conductor cable having an overall covering) or in Table 25.14 (for a multiple-conductor cable not having any overall covering) when measured as described in 17.5 (basic optical method) or 17.6 (direct measurement) or, in case of doubt, by the referee method described in 17.7. For thicknesses of a conductive circuit-conductor jacket (functions of insulation shielding and circuit-conductor jacket combined), see 15.5, Table 15.3, and the notes to Table 15.3.

Table 17.1
Thicknesses of nonconductive jacket on each shielded or nonshielded circuit conductor in a multiple-conductor cable having an overall covering and insulated in the thicknesses indicated in Table 13.1

Calculated diameter under jacket		mils		mm	
in	mm	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
0 – 0.425	0 – 10.80	25	20	0.64	0.51
Over 0.425 but not over 0.700	Over 10.80 but not over 17.78	30	24	0.76	0.61
Over 0.700 but not over 1.500	Over 17.78 but not over 38.1	50	40	1.27	1.02
Over 1.500 but not over 2.500	Over 38.10 but not over 63.50	80	64	2.03	1.63
Over 2.500	Over 63.50	–	–	–	–

17.5 BASIC OPTICAL METHOD – Measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The nonconductive circuit-conductor jacket is to be removed from a length of the finished conductor without damage to the jacket. The maximum and minimum points are to be measured directly and the two are to be averaged to determine the average thickness.

17.6 DIRECT MEASUREMENT – Measurements are to be made by means of a dead-weight pin-gauge dial micrometer that exerts 25 ±2 gf or 0.25 ±0.02 N on a specimen through a flat, rectangular presser foot measuring 0.043 inch by 0.312 inch or 1.09 mm by 7.92 mm. The pin is to be 0.437 inch or 11.10 mm long and 0.020 inch or 0.51 mm in diameter. The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The nonconductive circuit-conductor jacket is to be removed from a short length of the finished conductor without damage to the jacket. A 3/8-inch or 10-mm slice is to be cut from the center of the resulting hollow length of the jacket with each cut perpendicular to the longitudinal axis of the hollow length. The maximum and minimum points are to be determined by direct measurement with the entire length of the pin contacting the inside surface of the jacket during each measurement. The average of these determinations is to be taken as the average thickness of the jacket.

17.7 REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 17.5 or 17.6 are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 inch or 0.001 mm is to be used. The nonconductive circuit-conductor jacket is to be removed from a length of the finished conductor without damage to the jacket and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The average of these determinations is to be taken as the average thickness of the jacket. The results of this optical procedure are to be taken as conclusive.

OPTICAL-FIBER MEMBER(S)

18 Construction

18.1 An overall jacket shall be part of and shall enclose each individual optical-fiber member. A member may include one or more glass fibers with their requisite individual coverings and may also include one or more strength elements. A member shall not include any metal or other conductive material but, otherwise, neither the jacket nor the underlying construction of the member is specified.

ASSEMBLY OF MULTIPLE-CONDUCTOR CABLE

19 Optical-Fiber Member(s)

19.1 One or more optical-fiber members(s) may be included in a multiple-conductor cable. Optical-fiber members may be grouped with or without electrical conductors. Optical-fiber members shall be cabled individually or as a group with the same direction and length of lay as the electrical conductors. In the performance of the cable, each optical-fiber member is to be considered as a filler. A group of optical-fiber members with or without any electrical conductor(s) in it shall not include any non-current-carrying metal parts such as a metal strength element or a metal vapor barrier, and shall not include any other conductive parts. A nonconductive strength element may be included; its construction is not specified.

20 Circuit Conductors

20.1 A multiple-conductor cable shall contain two or more circuit conductors, each of which shall be insulated and all of which shall be of the same size. All of the circuit conductors shall be insulated with the same material in one of the thicknesses indicated in Table 13.1 or 13.2. All shall have the same insulation level. All shall be shielded (see 14.3) or nonshielded and all shall be individually jacketed or not jacketed in accordance with 17.1. All shall have the same temperature, wet or dry, and voltage ratings. All of the circuit conductors in a given cable shall be of the same metal (see 21.7 for grounding-conductor metal).

20.2 The circuit conductors shall be cabled with a length of lay that is not greater than indicated in Table 20.1. 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 several (typically 10) complete twists (full 360° cycles) shall have the insulated conductors cabled with a length of lay that is not greater than indicated in Table 20.1, and

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 indicated in Table 20.1.

If the direction of lay is not reversed in a cable containing layers of conductors, the outer layer of conductors shall have a left-hand lay and the direction of lay for the inner layers of conductors is not specified. If the direction of lay is not reversed in a single-layer cable, the conductors shall have a left-hand lay.

20.3 A left-hand lay is defined as a counterclockwise twist away from the observer.

Table 20.1
Length of lay of circuit conductors

Number of circuit conductors in cable	Maximum acceptable length of lay	
	With an overall covering on cable	Without an overall covering on cable
2	30 times conductor diameter[a]	60
3	35 times conductor diameter[a]	times
4	40 times conductor diameter[a]	conductor
5 or more	15 times the calculated diameter over the assembly of circuit conductors but, in a multiple-layer cable, the length of lay of the circuit conductors in each of the inner layers in not specified (governed by the construction of the cabling machine)	diameter[a]

[a] "Conductor diameter" is the calculated diameter over one finished circuit conductor.

21 Grounding Conductor

21.1 COVERED – One covered grounding conductor of the size indicated in column A (copper) or column B (aluminum) of Table 21.1 for the size of circuit conductors used in the cable may be provided unsectioned (in one location) in a triplex or other multiple-conductor cable that does not have an overall nonconductive jacket or an overall metal covering and in which the circuit conductors comply with column A, B, C, or D of Table 13.2 (nonshielded single-conductor cable) or are individually shielded (see Table 1.2). The covering on the grounding conductor may be for corrosion or other protection but shall not be credited as insulation. The covering shall be colored as indicated in 66.4 and 66.5.

21.2 BARE – Cable having interlocked aluminum or steel armor shall contain a grounding conductor that is not smaller in size or lower in resistance than indicated in Table 21.1 for the size of circuit conductors used in the cable. See 21.6.

21.3 Cable having a corrugated or smooth metal sheath with a resistance greater than indicated in one of the last four columns of Table 21.1 for the size of circuit conductors used in the cable shall contain a grounding conductor that is of a size such that the measured resistance (see 21.8) of the grounding conductor in parallel with the sheath is not higher than indicated in one of the last four columns of Table 21.1 for the size of the circuit conductors used in the cable. See 21.6.

21.4 Cable having a corrugated or smooth metal sheath with a resistance equal to or lower than indicated in one of the last four columns of Table 21.1 for the size of the circuit conductors used in the cable may contain a grounding conductor. See 21.6.

21.5 Cable having an overall nonconductive jacket but not having any metal sheath or interlocked armor may contain a grounding conductor. See 21.6.

21.6 Whether required or not, any grounding conductor provided in a cable covered in 21.2, 21.3, 21.4, or 21.5 shall be bare and shall be cabled with the circuit conductors as a single conductor (one section) or divided into two or more equal parts with each such part or section cabled separately. The grounding conductor shall not be smaller in overall size than No. 14 AWG if of copper or No. 12 AWG if of aluminum. No part of a sectioned grounding conductor shall be smaller than No. 14 AWG if of copper or No. 12 AWG if of aluminum.

21.7 ALL – A grounding conductor shall not be laid straight and shall not be distributed helically (concentric). A grounding conductor of copper is acceptable with aluminum circuit conductors in a multiple-conductor cable without an overall covering but, otherwise, a grounding conductor shall be of the same metal as the circuit conductors.

21.8 RESISTANCE – The resistance of the smooth or corrugated metal sheath, and any grounding conductor taken in parallel with the metal sheath, is to be determined by placing a sample of the finished cable in a wooden, V-shaped trough having stud-type wire connectors at the ends (spaced 10 ft or 3048 mm between centers) as shown in Figure 21.1. The sample of cable under test is not to be under any mechanical tension in the trough. The ends of the metal sheath and any grounding conductor are to be secured firmly in the wire connectors. The grounding conductor is to be folded around each end of the metal sheath and gripped against the sheath by the wire connectors. The wires of a stranded grounding conductor are to be spread out somewhat to result in maximum contact. Leads are to be brought out to a Kelvin double-bridge ohmmeter that has a range of 0.001 – 11 ohms and is accurate to within 2 percent of the value read. The resistance of the smooth or corrugated metal sheath and any grounding conductor is to be read directly in ohms.

Figure 21.1
Apparatus for measuring resistance of metal sheath and any grounding conductor

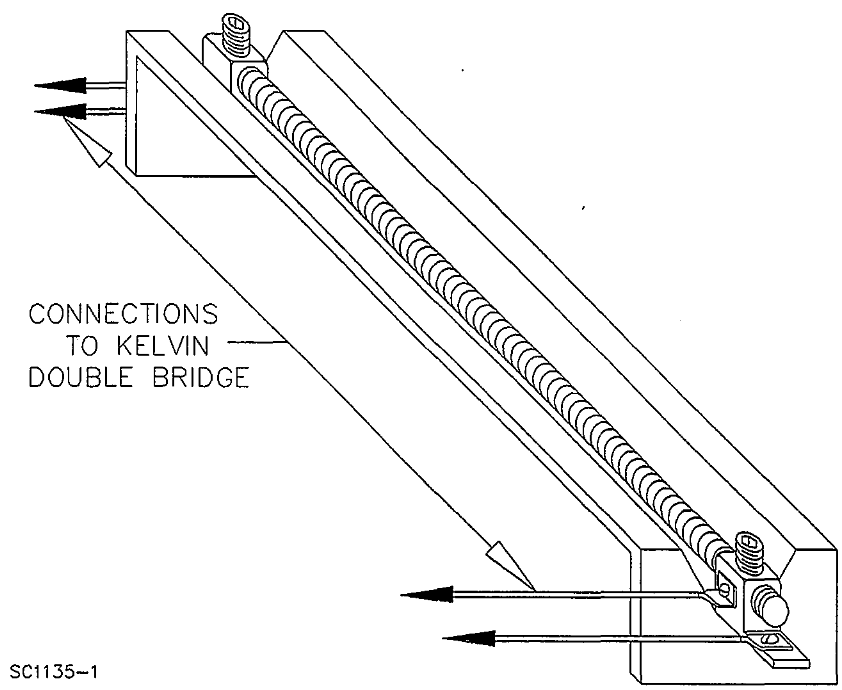


Table 21.1
Smallest acceptable grounding conductor

Size of circuit conductors		Grounding conductor						Maximum acceptable direct-current resistance of corrugated or smooth sheath in cable without a grounding conductor, and of the parallel combination of grounding conductor and sheath in cable having a corrugated or smooth sheath of higher resistance than indicated in these 4 columns			
		Copper			Aluminum			20°C (68°F)		25°C (77°F)	
		Smallest acceptable AWG size of unsectioned grounding conductor	Smallest acceptable total cross-sectional area of sectioned grounding conductor[a]		Smallest acceptable AWG size of unsectioned grounding conductor	Smallest acceptable total cross-sectional area of sectioned grounding conductor[a]		Ohms based on 1000 feet of sheath	Ohms based on 1 kilo-meter of sheath	Ohms based on 1000 feet of sheath	Ohms based on 1 kilo-meter of sheath
Copper	Aluminum	A	cmil[b]	mm^2	B	cmil[c]	mm^2				
8 AWG	8 – 6 AWG	8	16180	8.20	6	25715	13.03	0.6795	2.230	0.6929	2.274
6 – 2	4 – 1/0	6	25715	13.03	4	40905	20.73	0.4276	1.403	0.4359	1.430
1 – 2/0	2/0 AWG – 250 kcmil	4	40905	20.73	2	65033	32.95	0.2689	0.8820	0.2742	0.8993
3/0 AWG – 250 kcmil	300 – 400	3	51568	26.14	1	82016	41.56	0.2132	0.6996	0.2175	0.7133
300 – 400	450 – 600	2	65033	32.95	1/0	103488	52.42	0.1691	0.5548	0.1724	0.5657
450 – 600	750 – 900	1	82016	41.56	2/0	130438	66.08	0.1340	0.4398	0.1367	0.4485
750 – 1000	1000	1/0	103488	52.42	3/0	164444	88.31	0.1063	0.3487	0.1084	0.3556

[a] Resistance is the criterion of size but the area in this column is included for use if area is more convenient. A conductor having less than the tabulated area is acceptable if the resistance of the conductor complies with one of the last four columns.

[b] 0.98 times the nominal area in circular mils of the AWG conductor size in column A.

[c] 0.98 times the nominal area in circular mils of the AWG conductor size in column B.

22 Fillers

22.1 Fillers shall be used where necessary to give a substantially circular cross section to a completed multiple-conductor cable that has an overall covering. Fillers may be separate or may be integral with any nonconductive jacket. Fillers shall be cabled with the conductors or, if applicable to the construction, may be in the center of the cable. Fillers shall be of nonconductive nonmetallic material but otherwise are not specified.

23 Assembly Covering

23.1 In a multiple-conductor cable on which there is a metal sheath (of any variety) or interlocked armor (with or without a supplementary jacket over the sheath or armor), the assembly of circuit conductors (with or without a jacket on each), any grounding conductor, and any fillers shall be enclosed either in a nonconductive jacket that complies with 23.3 – 23.5 or by a tape separator that complies with 23.6.

23.2 In a multiple-conductor cable on which there is an overall jacket but no metal sheath or interlocked armor, the assembly of circuit conductors, any grounding conductor, and any fillers may be enclosed in a nonmetallic separator or binder whose material and construction are not specified.

23.3 An assembly jacket shall be of one of the materials (nonconductive) indicated in Table 25.1. An assembly jacket shall not have any defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. An assembly jacket shall be applied directly over the underlying assembly. The underlying assembly shall be completely covered and shall be well centered in the assembly jacket.

23.4 Specimens prepared from samples of an assembly jacket taken from the finished cable shall exhibit properties that comply with the applicable one of the tables referenced in Table 24.1 when tested as described in Section 29.

23.5 The average thickness and the minimum thickness at any point of an assembly jacket shall not be less than indicated in Table 25.14 when measured as described in 23.7 (basic optical method) or 23.8 (direct measurement) or, in case of doubt, by the referee optical method described in 23.9.

23.6 A separator shall consist of a rubber-filled cloth tape or a treated-paper, polyester, polypropylene, or similar tape. The tape shall be applied to keep any grounding conductor from physical contact with the metal sheath or armor but, otherwise, the construction of the tape and the manner of its application are not specified. An open binder or skeleton arrangement is not acceptable for this purpose.

23.7 BASIC OPTICAL METHOD – Measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The nonconductive assembly jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be measured directly and the two are to be averaged to determine the average thickness.

23.8 DIRECT MEASUREMENT – Measurements are to be made by means of a dead-weight pin-gauge dial micrometer that exerts 25 ±2 gf or 0.25 ±0.02 N on a specimen through a flat, rectangular presser foot measuring 0.043 inch by 0.312 inch or 1.09 mm by 7.92 mm. The pin is to be 0.437 inch or 11.10 mm long and 0.020 inch or 0.51 mm in diameter. The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The nonconductive assembly jacket is to be removed from a short length of the finished cable without damage to the jacket. A 3/8-inch or 10-mm slice is to be cut from the center of the resulting hollow length of the jacket with each cut perpendicular to the longitudinal axis of the hollow length. The maximum and minimum points are to be determined by direct measurement with the entire length of the pin contacting the inside surface of the jacket during each measurement. The average of these determinations is to be taken as the average thickness of the jacket.

23.9 REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 23.7 or 23.8 are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 inch or 0.001 mm is to be used. The nonconductive assembly jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The average of these determinations is to be taken as the average thickness of the jacket. The results of this optical procedure are to be taken as conclusive.

OVERALL COVERING(S)

24 General

24.1 An overall covering(s) shall be provided on each single-conductor and multiple-conductor cable in accordance with Table 24.1. The finished cable shall in each case be round.

Table 24.1
Overall coverings

Cable	Acceptable covering(s)			
	Type	Material(s)	Properties	Thicknesses
Nonshielded single-conductor cables insulated in the thicknesses indicated in columns B, C, and D of Table 13.2	Nonconductive jacket	Any in Table 25.1	Tables 25.2 – 25.12 as applicable	Table 25.15
Shielded single-conductor cables	Option 1: Conductive nonmetallic insulation covering that is part of shielding	Conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25	Column A of Table 15.2	Column A of Table 15.3
	Option 2: Nonconductive jacket over shielding	Any in Table 25.1	Tables 25.2 – 25.12 as applicable	Table 25.14
	Option 3: Nonmagnetic metal covering as part of shielding	a		
	Option 4: Supplementary nonconductive jacket	Any in Table 25.1	Tables 25.2 – 25.12 as applicable	Table 27.1
	over			
	Nonmagnetic metal covering that is part of shielding	a		

(Continued)

Table 24.1 (Cont'd)
Overall coverings

Cable	Acceptable covering(s)			
	Type	**Material(s)**	**Properties**	**Thicknesses**
Shielded single-conductor cables	Option 5: Nonmagnetic metal covering	a		
	over			
	Nonconductive jacket that is over shielding	Any in Table 25.1	Tables 25.2 – 25.12 as applicable	Table 25.14
	Option 6: Nonmagnetic metal covering that is part of shielding	a		
	over			
	Conductive nonmetallic insulation covering that is part of shielding	Conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25	Column A of Table 15.2	Column A of Table 15.3
	Option 7: Supplementary nonconductive jacket	Any in Table 25.1	Tables 25.2 – 25.12 as applicable	Table 27.1
	over			
	Nonmagnetic metal covering that is part of shielding	a		
	over			
	Conductive nonmetallic insulation covering that is part of shielding	Conductive extrusion of any insulation or jacketing material mentioned in Section 12 or 25	Column A of Table 15.2	Column A of Table 15.3

(Continued)

Table 24.1 (Cont'd)
Overall coverings

Cable	Acceptable covering(s)			
	Type	Material(s)	Properties	Thicknesses
Shielded single-conductor cables	Option 8: Supplementary nonconductive jacket	Any in Table 25.1	Tables 25.2 – 25.12 as applicable	Table 27.1
	over			
	Nonmagnetic metal covering	a		
	over			
	Nonconductive jacket that is over shielding	Any in Table 25.1	Table 25.2 – 25.15 as applicable	Table 25.14
Multiple-conductor cable in which 5-kV nonshielded circuit conductors insulated in the thicknesses indicated in Table 13.1 are used with or without a nonconductive jacket of the thicknesses indicated in Table 17.1 on each circuit conductor	Option A: Nonconductive jacket	Any in Table 25.1	Tables 25.2 – 25.15 as applicable	Table 25.14
Multiple-conductor cable in which shielded circuit conductors insulated in the thicknesses indicated in Table 13.1 are used that are not individually jacketed or have an individual nonconductive jacket of the thicknesses indicated in Table 17.1	Option B: Metal sheath or steel or aluminum armor	Section 26		
	over			
	Assembly covering consisting of nonconductive jacket	Any in Table 25.1	Tables 25.2 – 25.15 as applicable	Table 25.24
	or			
	Tape separator	23.6		
	Option C: Supplementary nonconductive jacket over option B	Any in Table 25.1	Tables 25.2 – 25.15 as applicable	Table 27.1

(Continued)

Table 24.1 (Cont'd)
Overall coverings

Cable	Acceptable covering(s)			
	Type	Material(s)	Properties	Thicknesses
Multiple-conductor cable in which shielded circuit conductors insulated in the thicknesses indicated in Table 13.1 are used and have either an individual jacket of the thicknesses indicated in column A of Table 15.3 or an individual nonconductive jacket of the thicknesses indicated in Table 25.14	None required but any used shall comply with option A, B, or C above			
Multiple-conductor cable assembled of nonshielded single-conductor cables that are as indicated in column A, B, C, or D of Table 13.2	None acceptable			

[a] Smooth or corrugated metal sheath or interlocked aluminum armor complying with Section 26 (interlocked steel armor is not acceptable because it is magnetic).

25 Jacket

25.1 MATERIAL AND APPLICATION – An overall jacket shall be of one of the nonconductive materials indicated in Table 25.1, or shall be of one of the conductive materials covered in Section 15 if the functions of the insulation shielding and overall single-conductor cable jacket are combined. An overall jacket shall not have any defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. An overall jacket shall be applied directly over the underlying assembly or over the optional binder or separator mentioned in 23.2. The underlying assembly shall be completely covered and shall be well centered in the jacket. The outer surface of the overall jacket may show impressions of the underlying assembly but shall not show depressions caused by unfilled spaces beneath the overall jacket.

Table 25.1
Nonconductive jacket

Jacket material[a]	Table of properties requirements
CP	25.2
CPE	25.4
NBR/PVC	25.6
Neoprene	25.8
PE	25.10
PVC	25.12

[a] An overall jacket of material that is generically different from any material covered in this table is acceptable if applicable for the use. A pull-out test is to be part of the evaluation. In the test, an outlet bushing is to be secured to the finished cable as intended using the tightening torque tabulated below. Then, 50 lbf or 22.7 kgf is to be exerted for 5 min along the longitudinal axis of the bushing to tend to pull the cable out of the bushing. To be acceptable, the cable is not to move more than 1/8 inch or 3 mm in the bushing.

Trade size of fitting in inches	Tightening torque		
	lbf-inch	N-m	kgf-m
3/8	200	22.6	2.30
1/2	300	33.9	3.46
3/4	500	56.5	5.76
1	700	79.1	8.06
1-1/4	1000	113	11.5
1-1/2	1200	136	13.8
2 and larger	1600	181	18.4

25.2 PROPERTIES – Specimens prepared from samples of an overall jacket taken from the finished cable shall exhibit properties that comply with Table 15.1 (conductive material), or with the applicable table referenced in Table 25.1 (nonconductive jacket) when tested as described in Section 29.

25.3 THICKNESSES – The average thickness and the minimum thickness at any point of a nonconductive jacket shall not be less than indicated in Table 25.14 (overall jacket on shielded single-conductor cable or on multiple-conductor cable) or Table 25.15 (overall jacket on nonshielded single-conductor 5- and 8-kV cables) when measured as described in 25.4 (basic optical method) or 25.5 (direct measurement) or, in case of doubt, by the referee optical method described in 25.6. For the thicknesses of a conductive overall jacket (functions of insulation shielding and the overall cable jacket combined), see 15.5, Table 15.3, and the notes to Table 15.3.

Table 25.2
Properties of nonconductive CP[a] jacket

Property	Acceptable value
I. Physical Properties – see Section 29 for method	See Table 25.3
II. Set using 1-inch or 25-mm bench marks – Maximum at room temperature using unaged specimens – see Section 34 for method	30 percent
III. Cold bend – see Section 36 for method	No damage shall result
IV. Relative permittivity after 24 h in water at room temperature – Only for jacket on nonshielded 8-kV single-conductor cable – see Section 38 for method	Maximum: 10.0 Minimum: 6.00

[a] CP designates a cross-linked compound whose characteristic constituent is chlorosulfonated polyethylene.

Table 25.3
Physical properties of nonconductive CP[a] jacket

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1500 lbf/in^2 or 10.3 MN/m2 or 1034 N/cm^2 or 1.05 kgf/mm^2
Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] CP designates a cross-linked compound whose characteristic constituent is chlorosulfonated polyethylene.

Table 25.4
Properties of nonconductive CPE[a] jacket

Property	Acceptable value	
	Thermoplastic	Thermoset
I. Physical properties – see Section 29 for method	See Table 25.5	
II. Cold bend – see Section 36 for method	No damage shall result	
III. Heat distortion – Maximum reduction in thickness at 121 ±1.0°C (249.8 ±1.8°F) – see Section 33 for method	25 percent	Test not applicable
IV. Set using 1-inch or 25-mm bench marks – Maximum at room temperature using unaged specimens – see 34.1 for method	Test not applicable	30 percent
V. Relative permittivity after 24 h in water at room temperature – only for jacket on nonshielded 8-kV single-conductor cable – see Section 38 for method	Maximum: 10.0 Minimum: 6.00	

[a] CPE designates a thermoplastic or cross-linked compound whose characteristic constituent is chlorinated polyethylene.

Table 25.5
Physical properties of nonconductive CPE[a] jacket

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)		Minimum acceptable tensile strength	
	Thermoplastic	Thermoset	Thermoplastic	Thermoset
Unaged	150 percent (1-1/2 inches or 38 mm)	250 percent (2-1/2 inches or 62.5 mm)	1400 lbf/in^2 or 9.65 MN/m^2 or 965 N/cm^2 or 0.984 kgf/mm^2	1500 lbf/in^2 or 10.3 NM/m^2 or 1034 N/cm^2 or 1.05 kgf/mm^2
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	50 percent of the result with unaged specimens	60 percent of the result with unaged specimens	85 percent of the result with unaged specimens	
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 68.1(h):				
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens		65 percent of the result with unaged specimens	
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 68.1(h):				
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens		50 percent of the result with unaged specimens	

[a] CPE designates a thermoplastic or cross-linked compound whose characteristic constituent is chlorinated polyethylene.

Table 25.6
Properties of nonconductive NBR/PVC[a] jacket

Property	Acceptable value
I. Physical properties – see Section 29 for method	See Table 25.7
II. Set using 1-inch or 25-mm bench marks – Maximum at room temperature using unaged specimens – see 34.1 for method	30 percent
III. Cold bend – see Section 36 for method	No damage shall result
IV. Relative permittivity after 24 h in water at room temperature – only for jacket on nonshielded 8-kV single-conductor cable – see Section 38 for method	Maximum: 10.0 Minimum: 6.00

[a] NBR/PVC designates a cross-linked compound whose characteristic constituents are acrylonitrile butadiene rubber and polyvinyl chloride.

Table 25.7
Physical properties of nonconductive NBR/PVC[a] jacket

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1500 lbf/in^2 or 10.3 MN/m^2 or 1034 N/cm^2 or 1.05 kgf/mm^2
Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of result with unaged specimens

[a] NBR/PVC designates a cross-linked compound whose characteristic constituents are acrylonitrile butadiene rubber and polyvinyl chloride.

Table 25.8
Properties of nonconductive neoprene[a] jacket

Property	Acceptable value
I. Physical properties – see Section 29 for method	See Table 25.9
II. Set using 1-inch or 25-mm bench mark – Maximum at room temperature using unaged specimens – see 34.1 for method	20 percent
III. Cold bend – see Section 36 for method	No damage shall result
IV. Relative permittivity after 24 h in water at room temperature – only for jacket on nonshielded 8-kV single-conductor cable – see Section 38 for method	Maximum 10.0 Minimum 6.00

[a] Neoprene designates a cross-linked compound whose characteristic constituent is polychloroprene.

Table 25.9
Physical properties of nonconductive neoprene[a] jacket

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1500 lbf/in^2 or 10.3 MN/m^2 or 1034 N/cm^2 or 1.05 kgf/mm^2
Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil-resistant II" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil-resistant I" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] Neoprene designates a cross-linked compound whose characteristic constituents is polychloroprene.

Table 25.10
Properties of nonconductive PE[a] jacket

Property	Acceptable value
I. Physical properties – see note [b] to Table 25.11 and Section 28 for method	See Table 25.11
II. Heat distortion – Maximum reduction in thickness at 90.0 ±1.0°C (194.0 ±1.8°F) – see Section 33 for method	25 percent
III. Cold bend – see Section 36 for method	No damage shall result
IV. Environmental cracking – see Section 40 for method	No cracks shall result
V. Relative permittivity after 24 h in water at room temperature – only for jacket on nonshielded 8-kV single-conductor cable – see Section 38 for method	Maximum: 10.0 Minimum: 6.00

[a] PE designates a compound whose characteristic constituent is thermoplastic polyethylene having a nominal density of 0.910 – 0.925 g/cm^3 and a high molecular weight. The compound may be filled or unfilled.

Table 25.11
Physical properties of nonconductive PE[a] jacket

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)[b]	Minimum acceptable tensile strength[b]
Unaged	350 percent (3-1/2 inches or 87.5 mm)	1400 lbf/in^2 or 9.65 MN/m^2 or 965 N/cm^2 or 0.984 kgf/mm^2
Aged in a full-draft circulating-air oven for 48 h at 100.0 ±1.0°C (212.0 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil-resistant II" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil-resistant I" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] PE designates a compound whose characteristic constituent is polyvinylene having a nominal density of 0.910 – 0.925 g/cm^3 and a high molecular weight. The compound may be filled or unfilled.

[b] PE is to be tested at a speed of 20 ±1 in/min or 500 ±25 mm/min.

Table 25.12
Properties of nonconductive PVC[a] jacket

Property	Acceptable value
I. Physical properties – see Section 29 for method	See Table 25.13
II. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 33 for method	50 percent
III. Heat shock – see 35.1 for method	No cracking shall result
IV. Cold bend – see Section 36 for method	No damage shall result
V. Relative permittivity after 24 h in water at room temperature – only for jacket on nonshielded 8-kV single-conductor cable – see Section 38 for method	Maximum: 10.0 Minimum: 6.00

[a] PVC designates a thermoplastic compound whose characteristic constituent is polyvinyl chloride or a copolymer of vinyl chloride and vinyl acetate.

Table 25.13
Physical properties of nonconductive PVC[a] jacket

Conditions of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum acceptable tensile strength
Unaged	100 percent (1 inch or 25 mm)	1500 lbf/in^2 or 10.3 MN/m^2 or 1034 N/cm^2 or 1.05 kgf/mm^2
Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 68.1(h):		
Aged in ASTM oil No. 2 (see 29.2.5.3) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] PVC designates a thermoplastic compound whose characteristic constituent is polyvinyl chloride or a copolymer of vinyl chloride and vinyl acetate.

Table 25.14
Thicknesses of nonconductive jacket:
1) overall jacket on shielded single-conductor cable
2) circuit-conductor jacket on each shielded circuit conductor in a multiple-conductor cable not having any overall covering
3) overall jacket on multiple-conductor cable having an overall covering
4) assembly jacket under metal covering on multiple-conductor cable

Calculated diameter under jacket		Mils		mm	
in	mm	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
0 – 0.425	0 – 10.80	45	36	1.14	0.91
Over 0.425 but not over 0.700	Over 10.80 but not over 17.78	60	48	1.52	1.22
Over 0.700 but not over 1.500	Over 17.78 but not over 38.10	80	64	2.03	1.63
Over 1.500 but not over 2.500	Over 38.10 but not over 63.50	110	88	2.79	2.24
Over 2.500	Over 63.50	140	112	3.56	2.84

Table 25.15
Thicknesses of nonconductive jacket on nonshielded single-conductor cables rated 5000 or 8000 V

Size of conductor	5000-V cables: Dry-locations cables with XLPE, EPCV, or EP insulation in the thicknesses indicated in column B of Table 13.2 (B)		5000-V cables: Wet-or-dry-locations cable with XLPE or EP insulation in the thicknesses indicated in column C of Table 13.2 (C)		8000-V cable with wet-or-dry-locations XLPE or EP insulation (100 percent insulation level) in thicknesses indicated in column C of Table 13.2 (D)	
	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
	mils					
8 – 6 AWG	30	24	80	64	80	64
4 – 2/0	45	36	80	64	95	76
3/0 – 4/0	65	52	95	76	110	88
213 – 500 kcmil	65	52	110	88	110	88
501 – 750	65	52	125	100	125	100
751 – 1000	65	52	125	100	140	112
	mm					
8 – 6 AWG	0.76	0.61	2.03	1.63	2.03	1.63
4 – 2/0	1.14	0.91	2.03	1.63	2.41	1.93
3/0 – 4/0	1.65	1.32	2.41	1.93	2.79	2.24
213 – 500 kcmil	1.65	1.32	2.79	2.24	2.79	2.24
501 – 750	1.65	1.32	3.18	2.54	3.18	2.54
751 – 1000	1.65	1.32	3.18	2.54	3.56	2.84

25.4 BASIC OPTICAL METHOD – Measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The nonconductive overall or supplementary jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be measured directly and averaged to determine the average thickness.

25.5 DIRECT MEASUREMENT – Measurements are to be made by means of a dead-weight pin-gauge dial micrometer that exerts 25 ±2 gf or 0.25 ±0.02 N on a specimen through a flat, rectangular presser foot measuring 0.043 inch by 0.312 inch or 1.09 mm by 7.92 mm. The pin is to be 0.437 inch or 11.10 mm long and 0.020 inch or 0.51 mm in diameter. The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The nonconductive overall or supplementary jacket is to be removed from a short length of the finished cable without damage to the jacket. A 3/8-inch or 10-mm slice is to be cut from the center of the resulting hollow length of the jacket with each cut perpendicular to the longitudinal axis of the hollow length. The maximum and minimum points are to be determined by direct measurement with the entire length of the pin contacting the inside surface of the jacket during each measurement. The average of these determinations is to be taken as the average thickness of the jacket.

25.6 REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 24.4 or 24.5 are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 inch or 0.001 mm is to be used. The nonconductive overall or supplementary jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The average of these determinations is to be taken as the average thickness of the jacket. The results of this optical procedure are to be taken as conclusive.

26 Metal Covering

26.1 GENERAL – A metal covering shall consist of one of the following:

a) A smooth sheath complying with 26.4 – 26.6.

b) A welded and corrugated sheath complying with 26.7 and 26.8.

c) An extruded and corrugated sheath complying with 26.9 and 26.10.

d) Interlocked armor complying with 26.11 – 26.20.

26.2 The sheath, or the strip forming the armor, shall be continuous throughout the length of the cable. A sheath shall not have flaws that affect its integrity – that is, a sheath shall not have any weld openings, cracks, splits, foreign inclusions, or the like. The strip from which armor is formed may be spliced (see 26.13) but there shall not be any cut or broken ends. In a multiple-conductor cable, a metal covering shall be applied over the assembly covering (nonconductive assembly jacket or a tape separator) required in 23.1. In a shielded single-conductor cable, a metal covering shall constitute the nonmagnetic metal component of the insulation shielding and shall comply with the conductance and application requirements in Table 16.1 (applied directly over the conductive nonmetallic covering portion of the insulation shielding). A metal covering shall not be used on a nonshielded single-conductor cable.

26.3 The number of corrugations per unit length of a welded or extruded corrugated metal sheath is not specified but is to be judged on the basis of the performance of the finished cable in the tests specified in this standard.

26.4 SMOOTH METAL SHEATH – A smooth metal sheath shall be of an aluminum-base alloy having a copper content of 0.40 percent or less, of commercially pure lead, or of an alloyed lead. The sheath shall be tightly formed around the underlying cable.

26.5 The average thickness and the minimum thickness at any point of the smooth sheath shall not be less than indicated in Table 26.1 (lead) or Table 26.2 (aluminum). The thicknesses of the smooth sheath are to be determined by means of a machinist's micrometer caliper that has a hemispherical surface on the anvil, has a flat surface on the end of the spindle, and is calibrated to read directly to at least 0.001 inch or 0.01 mm. The spindle shall be round.

26.6 A smooth sheath that does not comply with the requirements in this standard may be stripped from the entire length of the cable and the cable may be resheathed.

26.7 WELDED AND CORRUGATED METAL SHEATH – A welded and corrugated metal sheath shall be of an aluminum-base alloy having a copper content of 0.40 percent or less, of bronze, or of electrolytic copper. The sheath shall be tightly formed around the underlying cable and shall be welded and corrugated.

26.8 The minimum thickness at any point of the unformed metal tape from which the welded and corrugated sheath is made shall not be less than indicated in Table 26.3. The thickness of the unformed tape is to be determined by means of a machinist's micrometer caliper having an anvil and spindle that are round and are not larger than 0.200 inch or 5.1 mm in diameter, with flat surfaces on each.

26.9 EXTRUDED AND CORRUGATED METAL SHEATH – An extruded and corrugated metal sheath shall be of an aluminum-base alloy having a copper content of 0.40 percent or less. The sheath shall be tightly formed around the underlying cable.

26.10 The minimum thickness at any point of the unformed metal tape from which the extruded and corrugated sheath is made shall not be less than indicated in Table 26.3 when determined as indicated in the second sentence of 26.8.

26.11 INTERLOCKED ARMOR – Armor shall consist of interlocked steel or aluminum strip and shall comply with 26.2 and 26.11 – 26.19. Dimensions of the metal strip shall comply with 26.20.

26.12 The strip shall be made of steel or of an aluminum-base alloy with a copper content of 0.40 percent or less. Steel strip shall be protected against corrosion by a coating of zinc on all surfaces, including edges and splices. The coating on each surface shall be evenly distributed, shall adhere firmly at all points, and shall be smooth and free from blisters and all other defects that can diminish the protective value of the coating.

26.13 The steel or aluminum strip shall be uniform in width, thickness, and cross section and shall not have any burrs, sharp edges, pits, scars, cracks, or other flaws that can damage the underlying cable or any supplementary jacket. Splices shall not materially increase the width or thickness of the strip nor shall they lessen the mechanical strength of the strip or adversely affect the formed armor.

26.14 Zinc-coated steel strip shall have a tensile strength of not less than 40,000 lbf/in^2 or 276 MN/m^2 or 27,600 N/cm^2 or 28.1 kgf/mm^2 and not more than 70,000 lbf/in^2 or 483 MN/m^2 or 48,300 N/cm^2 or 49.2 kgf/mm^2. The tensile strength shall be determined on longitudinal specimens consisting of the full width of the strip when practical and otherwise on a straight specimen slit from the center of the strip. The test shall be made prior to application of the strip to the cable.

Table 26.1
Thicknesses of smooth lead sheath

Calculated diameter under lead	Lead over which there is no supplementary jacket		Lead over which there is a supplementary jacket	
	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
inch	mils			
0 – 0.425	45	41	45	41
Over 0.425 but not over 0.700	65	59	55	50
Over 0.700 but not over 1.050	80	72	70	63
Over 1.050 but not over 1.500	95	86	85	77
Over 1.500 but not over 2.000	110	99	95	86
Over 2.000 but not over 3.000	125	113	110	99
Over 3.000	140	126	125	113
mm	mm			
0 – 10.80	1.14	1.04	1.14	1.04
Over 10.80 but not over 17.30	1.65	1.50	1.40	1.27
Over 17.30 but not over 26.70	2.03	1.83	1.78	1.60
Over 26.70 but not over 38.10	2.41	2.18	2.16	1.96
Over 38.10 but not over 50.80	2.79	2.51	2.41	2.18
Over 50.80 but not over 76.20	3.18	2.87	2.79	2.51
Over 76.20	3.56	3.20	3.18	2.87

Table 26.2
Thicknesses of smooth aluminum sheath with or without a supplementary jacket over the sheath

Calculated diameter under aluminum		mils		mm	
inch	mm	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
0 – 0.400	0 – 10.16	35	32	0.89	0.81
Over 0.400 but not over 0.740	Over 10.16 but not over 18.80	45	41	1.14	1.04
Over 0.740 but not over 1.050	Over 18.80 but not over 26.67	55	50	1.40	1.27
Over 1.050 but not over 1.300	Over 26.67 but not over 33.02	65	59	1.65	1.50
Over 1.300 but not over 1.550	Over 33.02 but not over 39.37	75	68	1.90	1.73
Over 1.550 but not over 1.800	Over 39.37 but not over 45.72	85	77	2.16	1.96
Over 1.800 but not over 2.050	Over 45.72 but not over 52.07	95	86	2.41	2.18
Over 2.050 but not over 2.300	Over 52.07 but not over 58.42	105	95	2.67	2.41
Over 2.300 but not over 2.500	Over 58.42 but not over 64.77	115	104	2.92	2.64
Over 2.550 but not over 2.800	Over 64.77 but not over 71.12	125	113	3.18	2.87
Over 2.800 but not over 3.050	Over 71.12 but not over 77.47	135	122	3.43	3.10
Over 3.050 but not over 3.300	Over 77.47 but not over 83.82	145	131	3.68	3.33
Over 3.300 but not over 3.550	Over 83.82 but not over 90.17	155	140	3.94	3.56
Over 3.550 but not over 3.800	Over 90.17 but not over 96.52	165	149	4.19	3.78
Over 3.800 but not over 4.050	Over 96.52 but not over 102.9	175	158	4.45	4.01
Over 4.050	Over 102.9	–	–	–	–

Table 26.3
Minimum acceptable thickness at any point of unformed metal tape from which corrugated sheath is welded or extruded

Metal	Calculated diameter under sheath		Thickness of unformed metal tape	
	inch	mm	mils	mm
Aluminum	0 – 2.180	0 – 55	22	0.56
	Over 2.180 but not over 3.190	Over 55 but not over 81	29	0.74
	Over 3.190 but not over 4.200	Over 81 but not over 107	34	0.87
Bronze or electrolytic copper	0 – 2.365	0 – 60	17	0.43
	Over 2.365 but not over 3.545	Over 60 but not over 90	21	0.53
	Over 3.545 but not over 4.200	Over 90 but not over 107	25	0.64

26.15 Zinc-coated steel strip shall have an elongation of not less than 10 percent in 10 inches or not less than 10 percent in 254 millimeters. The elongation shall be determined as the permanent increase in length of a marked section of the strip (originally 10 inches or 254 mm in length) measured after the specimen has fractured. The test shall be made prior to application of the strip to the cable.

26.16 Unformed zinc-coated steel strip shall comply with the test for weight of zinc coating described in 47.1 – 47.7.

26.17 Finished zinc-coated steel strip, prior to being applied to the cable, shall have a zinc coating that remains adherent without flaking or spalling when the strip is subjected to a 180° bend over a mandrel that is 1/8 inch or 3.2 mm in diameter. The zinc coating is to be considered as complying with this requirement if, when the strip is bent around the specified mandrel, the coating does not flake and none of it can be removed from the strip by rubbing with the fingers.

26.18 Neither loosening or detachment during the adherence test nor superficial (small) particles of zinc formed by mechanical polishing of the surface of the zinc-coated steel strip is to constitute reason for rejection.

26.19 Unformed and formed zinc-coated steel strip shall comply with the copper sulphate test of the zinc coating described in Copper Sulphate Test of Zinc Coating on Steel Strip for and from Steel Armor, Section 46.

26.20 The width of unformed aluminum strip or of unformed zinc-coated steel strip shall not be greater than indicated in Table 26.4. The minimum thickness at any point of the formed metal strip removed from the finished cable shall not be less than indicated in Table 26.4 when measured by means of a machinist's micrometer caliper having an anvil and spindle that are round and are not larger than 0.020 inch or 5.1 mm in diameter, with flat surfaces on each.

Table 26.4
Dimensions of metal strip

Calculated diameter under armor	Maximum acceptable width of unformed strip[a]	Minimum acceptable thickness at any point of the formed strip removed from the finished cable	
		Steel	Aluminum
inch	mils		
0 – 0.500	500	17	22
Over 0.500 but not over 1.000	750	17	22
Over 1.000 but not over 1.500	875	17	22
Over 1.500 but not over 2.000	875	22	27
Over 2.000	1000	22	27
mm	mm		
0 – 12.7	12.7	0.43	0.55
Over 12.7 but not over 25.4	19.0	0.43	0.56
Over 25.4 but not over 38.1	22.2	0.43	0.56
Over 38.1 but not over 50.8	22.2	0.56	0.69
Over 50.8	25.4	0.56	0.69

[a] The acceptable tolerances for the width of steel strip are plus 10 mils and minus 5 mils or plus 0.2 mm and minus 0.1 mm. The acceptable tolerances for the width of aluminum strip are plus and minus 10 mils or plus and minus 0.2 mm.

27 Supplementary Jacket over Metal Covering

27.1 A supplementary covering is required over a metal sheath or armor on a cable that is marked [see 71.1 (a), (b), (c), and (d)] for direct burial. A supplementary covering is acceptable but not required over a metal sheath or armor on other cables. A supplementary covering that is provided shall consist of a nonconductive jacket that is of one of the materials indicated in Table 25.1 and has properties that comply with 25.2. A supplementary jacket shall not have any defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. A supplementary jacket shall be tight and shall be applied directly over the sheath or armor. The sheath or armor shall be completely covered and shall be well centered in the supplementary jacket. The outer surface of a supplementary jacket may show impressions of the sheath corrugations or of the armor convolutions but shall not show depressions caused by unfilled spaces beneath the supplementary jacket.

27.2 The average thickness of a supplementary jacket and the minimum thickness at any point of a supplementary jacket shall not be less than indicated in Table 27.1 when measured as described in 25.4 (basic optical method) or 25.5 (direct measurement) or, in case of doubt, by means of the referee method described in 25.6.

Table 27.1
Thicknesses of supplementary jacket over a metal sheath or armor

Calculated diameter under lead	Jacket over smooth metal sheath		Jacket over corrugated metal sheath of interlocked armor	
	Minimum acceptable average thickness	Minimum acceptable thickness at any point	Minimum acceptable average thickness	Minimum acceptable thickness at any point
inch	mils			
0 – 0.750	50	35	50	35
Over 0.750 but not over 1.500	65	46	50	35
Over 1.500 but not over 2.250	80	56	60	42
Over 2.250 but not over 3.000	95	67	75	52
Over 3.000	110	77	85	60
mm	mm			
0 – 19.05	1.27	0.89	1.27	0.89
Over 19.05 but not over 38.10	1.65	1.17	1.27	0.89
Over 38.10 but not over 57.15	2.03	1.42	1.52	1.07
Over 57.15 but not over 76.20	2.41	1.70	1.90	1.32
Over 76.20	2.79	1.96	2.16	1.52

PERFORMANCE

28 Test or Examination for Integrity and Continuity of Nonconductive Jacket over Insulation Shielding or over a Metal Sheath or Armor

28.1 A visual examination is specified in 28.2 for jackets for which a spark test is inappropriate. Otherwise, the integrity and continuity of nonconductive jacket over insulation shielding or over a metal sheath or over armor shall be demonstrated by the finished jacket withstanding, without electrical breakdown, the application of a 50, 60, 100, 400, 1000, 3000, or 4000 Hz essentially sinusoidal rms test potential of the magnitude indicated in Table 27.1. The a-c spark test is to be made as described in 28.3 – 28.11. One hundred percent of production shall be tested by the cable manufacturer at the cable factory.

28.2 The following finished jackets shall be examined for physical defects (bubbles, open spots, rips, tears, cuts, and foreign material) that are visible with normal or corrected vision without magnification:

a) A conductive jacket combining the functions of insulation shielding and overall single-conductor jacket.

b) An overall jacket of nonconductive neoprene of any dielectric strength.

c) An overall jacket of any nonconductive material having a dielectric strength too low to withstand the spark potential specified in Table 28.1.

d) An overall jacket (of any nonconductive material) applied over an assembly jacket of any material or over a polyester, polypropylene, or similar nonconductive binder tape having a dielectric strength greater than that of the overall jacket.

The visual examination that is required after the jacket is applied serves this purpose and need not be repeated.

28.3 A spark tester shall include a voltage source, an electrode, a voltmeter, a fault-signal device or system, and the necessary electrical connections. The ability of the equipment to comply with the requirements in 28.4 – 28.10 shall be certified at least annually by an accredited independent calibration service or its equivalent, such as checking the test potential with a voltmeter whose calibration is traceable. Calibration shall be traceable to a National Institute of Standards and Technology (USA) Standard or to other national physical measures recognized as equivalent by NIST.

28.4 The voltage source of a spark tester shall maintain the test voltage indicated in Table 28.1 under all normal conditions of leakage current. The voltage source shall not be connected to more than one electrode.

28.5 The electrode shall be of a link-chain or bead-chain or other acceptable type and shall make intimate contact throughout its entire length with the surface of the jacketed construction being tested.

28.6 The bottom of the metal electrode enclosure shall be U- or V-shaped, the chains shall have a length appreciably greater than the depth of the enclosure, and the width of the trough shall be approximately 1-1/2 inches or 40 mm greater than the diameter of the largest-diameter construction that is being tested.

28.7 For a bead-chain electrode, the longitudinal and transverse spacings of the chains and the diameter of each bead shall comply with Table 28.2.

Table 28.1
A-C spark-test potential in kilovolts for a nonconductive jacket over insulation shielding, a metal sheath, or armor

Specified average thickness of jacket		Jacket[a] of CP, thermoset CPE, or NBR/PVC	Jacket[b] of PE, thermoplastic CPE, or PVC
mils	mm		
25	0.64	1.0	2.0
30	0.76	1.5	2.5
45	1.14	2.0	4.0
50	1.27	2.0	4.5
60	1.52	2.5	5.5
65	1.65	2.5	6.0
75	1.90	3.0	6.5
80	2.03	3.0	7.0
85	2.16	3.5	7.5
95	2.41	4.0	8.5
110	2.79	4.5	10.0
140	3.56	5.5	12.5

[a] For a thermoset jacket of a thickness that is not shown, the test voltage is to be calculated on the basis of 40 kilovolts per inch of jacket thickness or 1.575 kilovolts per millimeter of jacket thickness, rounded to the nearest 0.5 kV.

[b] For a thermoplastic jacket of a thickness that is not shown, the test voltage is to be calculated on the basis of 90 kilovolts per inch of jacket thickness or 3.543 kilovolts per millimeter of jacket thickness, rounded to the nearest 0.5 kV.

Table 28.2
Maximum acceptable center-to-center spacings of bead chains

Diameter of a bead[a]		Longitudinal spacing[a]		Transverse spacing[a] Chains staggered		Transverse spacing[a] Chains not staggered	
inch	mm	inch	mm	inch	mm	inch	mm
3/16	5.0	1/2	13	1/2	13	3/8	10
3/32	2.5	The chains shall be staggered and shall touch one another in the longitudinal and transverse directions.					

[a] A diameter and spacings other than indicated are acceptable if investigation shows that the chains contact an equal or greater area of the outer surface of the insulated conductor.

28.8 The electrode shall be provided with an earth-grounded metal screen or another guard that protects operating personnel against electric shock from the electrode and associated parts.

28.9 The voltmeter shall be connected to the circuit to indicate the actual test potential at all times.

28.10 The spark-test equipment shall include a light, counter, or other device or system that gives a visible signal in the event of a fault. When a fault is detected, the signal shall be maintained until the indicator is reset manually.

28.11 The length of the electrode is not specified, but the rate of speed at which the jacketed construction travels through the electrode shall result in every point on the jacketed construction being in contact with the electrode for not less than a total of 18 positive and negative crests of the supply voltage (the equivalent of 9 full cycles of the supply voltage). The maximum acceptable speed of the jacketed construction is to be determined by means of whichever of the following formulas is applicable:

feet per minute = 5/9 x frequency in hertz x electrode length in inches,

or

meters per minute = 1/150 x frequency in hertz x electrode length in millimeters.

For convenience, Table 28.3 shows the formulas for each of the frequencies mentioned in 27.1.

Table 28.3
Formula for maximum acceptable speed of jacketed construction in terms of electrode length L

Nominal supply frequency in hertz	Formula for feet per minute (L in inches)	Formula for millimeters per minute (L in millimeters)
50	$27.8L_{in}$	$0.333L_{mm}$
60	$33.3L_{in}$	$0.400L_{mm}$
100	$55.6L_{in}$	$0.667L_{mm}$
400	$222L_{in}$	$2.67L_{mm}$
1000	$556L_{in}$	$6.67L_{mm}$
3000	$1667L_{in}$	$20.0L_{mm}$
4000	$2222L_{in}$	$26.7L_{mm}$

28.12 The metal component of the insulation shielding or the metal sheath or armor of the jacketed construction and the conductor or conductors shall be earth-grounded during the spark test. An earth-ground connection shall be made at either or both the pay-off and take-up reels. In any case, a reel at which an earth-ground connection is made shall be bonded directly to the earth ground on the transformer or other voltage source in the spark tester.

29 Physical Properties Tests

29.1 General

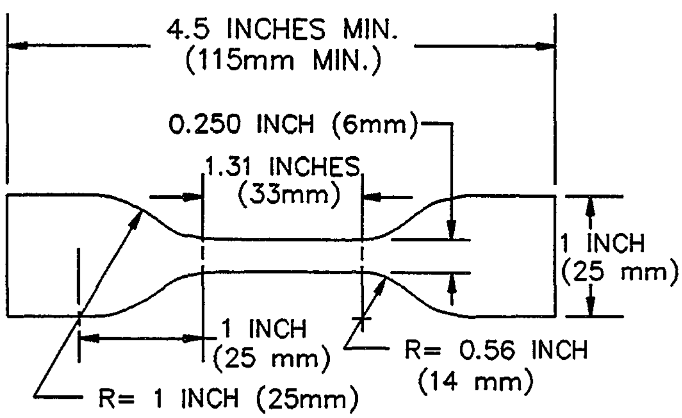
29.1.1 The descriptions of test equipment and methods in Section 29 apply to the determination of the physical properties (tensile strength and ultimate elongation) of unaged and aged specimens of extruded materials that are employed as conductor shielding, conductor insulation, insulation shielding, and jackets. All specimens shall be die-cut; tubular specimens shall not be used. Specific limits for individual materials are in Tables 11.3 (conductor shielding), 12.1 – 12.4 (insulation), 15.1 and 15.2 (insulation shielding), and 25.2 – 25.13 (jackets). Each tensile and elongation result that is compared with the limit in the applicable table is to be the average of the individual results from three specimens.

29.2 Apparatus for making physical tests

29.2.1 Power-driven testing machine

29.2.1.1 Elongation and tensile-strength measurements are to be made on a power-driven machine provided with a device that indicates the actual maximum load at which a specimen breaks. The machine shall be such that the movable grip can be stopped instantly if used in the test for set of nonconductive thermoset jackets (see 34.2). If a machine of the spring-balance type is used, provision is to be made to keep the spring from recoiling. The speed of the power-actuated grip is to be approximately 20 ±1 in/min or 500 ±25 mm/min (This speed applies to all materials, including PE – see notes [a] and [b] to Table 12.5, which define low-density PE and state that it is to be tested at this speed. See also 40.2). The applied tension as indicated by a dial or scale is to be accurate to 2 percent or less of the value read, and a set of weights is to be provided for calibrating the machine. A method for calibrating the machine is given in the American Society for Testing and Materials "Standard Test Methods for Rubber Properties in Tension" (ASTM D 412-92).

Figure 29.1
Die-cut specimen



NT160

29.2.2 Die-cut specimens

29.2.2.1 The die (ASTM die C) for cutting specimens is to produce specimens that have the form and dimensions shown in Figure 29.1. If the dimensions of the sample make the use of this shape impractical, a die having a constricted portion 0.125 inch wide, plus 0.002 inch, minus 0.000 inch or 3.00 mm wide, plus 0.05 mm, minus 0.00 mm (ASTM die D) is to be used.

29.2.3 Specimen marker

29.2.3.1 The specimen marker is to consist of a stamp with parallel metal blades capable of marking fine lines (bench marks) with ink on a specimen without damaging the specimen. The lines are to be 1 inch or 25 mm apart, are to be applied at right angles to the longitudinal axis of the specimen, and are to be centrally located on the constricted portion of the specimen. Because the width of a mark increases while a specimen is being stretched, measurement of elongation is to be made with reference to the center of each mark – that is, with reference to a point halfway between the edges of each mark.

29.2.4 Splitting, skiving, and buffing machines

29.2.4.1 A power-driven buffing machine (grinding wheel) may be used for buffing irregularities from the samples from which die-cut specimens are to be prepared. The abrasive wheel is to be of about No. 36 grit (particle size of 0.486 mm or 0.019 inch). The diameter and rotary velocity of the wheel are to make the wheel have a peripheral speed of 4000 – 5000 ft/min or 20 – 25 m/s. The machine is to be provided with a slow feed that removes very little compound at one cut, thereby not overheating the specimen. A power-driven splitting or skiving machine is to consist of an adjustable upper pressure roller, a band knife or a rotary bell knife, and a power-driven feed roller that passes a sample across the knife blade thereby separating or slicing the sample into layers, with no resulting heating of the sample material from which die-cut specimens are to be prepared. The machine may be used:

a) To produce a strip of insulation from a conductor or a strip of jacketing material, and

b) To remove irregularities from samples of insulation, shielding, or jacket that are approximately 30 mils or 0.76 mm and thicker.

29.2.5 Apparatus for aging

29.2.5.1 GENERAL – The apparatus for the accelerated aging of specimens is to include the equipment described in 29.2.5.2 and 29.2.5.3. In each type of apparatus, provision is to be made for suspending the specimens vertically within the chamber without touching the sides of the chamber or other specimens.

29.2.5.2 AIR-OVEN AGING – The apparatus for the air-oven aging of specimens is to be essentially as indicated in ASTM D 573-88 and D 2436-85 and is to circulate the air within the aging chamber at high velocity. A portion of the air may be recirculated, but a substantial amount of fresh air is to be admitted continuously to maintain an essentially normal oxygen content in the air surrounding the specimens. The exhaust ports of the oven are to be adjusted to achieve 100 – 200 complete fresh-air changes per hour. The blower, fan, or other means for circulating the air is to be located entirely outside the aging chamber. The oven is to maintain the specified temperature within $\pm 1.0^\circ C$ ($\pm 1.8^\circ F$).

29.2.5.3 OIL IMMERSION – The immersion vessel is to be of a size capable of containing the die-cut specimens of the overall covering. The vessel is to be filled with ASTM oil No. 2 and is then to be placed in a bath that maintains the specimens at the specified temperature. The specimens are to be suspended vertically in the oil and are to remain in the oil for the specified time. ASTM oil No. 2 is medium-swelling and of a petroleum base. Measured at 210.0°F (98.9°C), its Saybolt Universal viscosity is 100 ±5 s (443 – 490 m^2 s at 310K). Its aniline point is 93.0 ±3.0°C (199.4 ±5.4°F). Its open-cup flash point is 475.0 ±10.0°F (246.1 ±5.6°C).

29.3 Specimens for physical tests

29.3.1 General

29.3.1.1 Samples for the physical tests of unaged and aged specimens may be taken from a coil or reel of finished cable and/or may be taken from the cable during manufacture at any point following the cross-linking process in the case of thermosets, except that conductor-shielding materials intended for extrusion onto the conductor are to be molded into a slab from which specimens are to be die-cut approximately 6 inches or 150 mm long and not larger in cross-sectional area than 0.025 in^2 or 16 mm^2. The physical tests are to be conducted in still air at an ambient temperature of 24.0 ±8.0°C (75.2 ±14.4°F).

29.3.1.2 A sample of the insulation or insulation shielding material is to be cut longitudinally from the cable. Any irregularities are to be removed by means of a splitting or skiving machine or a slow-feed grinding machine (see 29.2.4.1). A strip of the insulation or of the insulation shielding material is to be prepared with smooth, parallel surfaces by machine splitting or skiving by machine planing for XLPE and PE only (see 29.3.1.3). The strip is then to be laid out flat to form a rectangle from which a test specimen is to be cut with a die (see 29.2.2.1).

29.3.1.3 A test specimen of a jacket is to be die-cut from a sample cut longitudinally and removed from the finished cable and then prepared as indicated for the insulation or insulation shielding. The test specimen is not to be larger than 0.025 in^2 or 16 mm^2 in cross section and is not to have any surface incisions or imperfections.

29.3.2 Splitting, skiving, buffing, and planing

29.3.2.1 When removing fabric impressions or other unevenness, the splitting or skiving or buffing is not to be carried beyond the point at which the unevenness just disappears. If it is necessary to reduce the thickness of the sample for the preparation of the test specimens, it is acceptable to split or skive the insulation or insulation shielding to the required thickness or to slice the material nearly to the required thickness and then finish by buffing. In any case, the final split or skived surface(s) or the final buffed surface is (are) to be smooth. Specimens of XLPE or PE material die-cut from strips of the material produced by machine planing may be used if the planed surfaces are flat, parallel, and smooth. Any splitting, skiving, planing, or buffing is to be done at least 30 min prior to testing of the specimens.

29.3.3 Die-cut specimens

29.3.3.1 A sample of the insulation, insulation shielding, or jacket is to be cut into 7-inch or 180-mm specimens and the components that are not of interest are to be cut through longitudinally and removed. The section of insulation, insulation shielding, or jacket being tested is to be from as close to the conductor as possible and is to be split or skived or buffed to remove any irregularities caused by the stranding. A sample of conductor shielding is to be molded into a slab not thicker than 0.1 inch or 2.5 mm. From this section, a test specimen is to be cut with a die as described in 29.2.2.1 and is to be marked with two lines (bench marks) 1 inch or 25 mm apart. The width of the specimen between the two marks is to be checked.

29.3.3.2 The use of a press for operating the die reduces variations between specimens but, if the die is struck with a mallet, all points of the cutting edges of the die are to be in contact with the material before the die is struck. The cutting is to be done on a smooth surface of a material that does not damage the cutting edges of the die.

29.3.3.3 The thickness T of the specimen is to be taken as the minimum of four measurements to 0.001 inch or 0.01 mm, two of which are to be made at 1/2-inch or 13-mm intervals between the bench marks on one edge and beginning 1/4 inch or 6 mm from either mark. The other two measurements are to be made at corresponding points on the opposite edge. These measurements are to be made with a dead-weight dial micrometer having a presser foot 0.250 ±0.010 inch or 6.4 ±0.2 mm in diameter and exerting a total of 3.0 ±0.1 ozf or 85 ±3 gf or 0.84 ±0.02 N on the specimen – the load being applied by means of a weight. The presser foot is to be at least 1/16 inch or 2 mm onto the edge of the specimen for each measurement. If the results of measurements by this method are in doubt, referee measurements are to be made by means of an optical device accurate to at least 0.0002 inch or 0.005 mm. The results of referee measurements are to be taken as conclusive.

29.4 Ultimate elongation and tensile strength

29.4.1 General

29.4.1.1 Ultimate-elongation and tensile-strength tests are to be conducted simultaneously, using specimens that have not been subjected previously to any test. Each die-cut specimen (tubular or die-cut) is to be clamped in position with both 1-inch or 25-mm bench marks outside of and between the grips. The movable grip is to be adjusted to make the specimen taut but not under tension. The grips are then to be separated at a rate of approximately 20 ±1 in/min or 500 ±25 mm/min until the specimen ruptures. During separation, the distance between the bench marks is to be observed continuously, so that the distance at the instant of rupture can be recorded with an accuracy of at least 0.1 inch or 2 mm. The percent ultimate elongation is to be taken as 100 times the increase in distance between the bench marks, which originally were 1 inch or 25 mm apart. The temperature of the ambient air is to be recorded.

29.4.1.2 After rupture of the specimen, the maximum load in pounds force, meganewtons, newtons, or kilograms force is to be noted from the dial or scale and recorded, together with the original dimensions of the specimen for use in calculating the tensile strength. If a specimen breaks within either jaw at a value below that specified as the minimum that is acceptable, the test results are to be disregarded and the test is to be repeated with another specimen.

29.4.2 Tensile strength

29.4.2.1 The tensile strength of a die-cut specimen is then to be computed by means of the formula

$$S = \frac{P}{WT}$$

in which:

S is the tensile strength in pounds force per square inch, meganewtons per square meter, newtons per square centimeter, or kilograms force per square millimeter;

P is the maximum load in pounds force, meganewtons, newtons, or kilograms force;

W is the width of the specimen in inches, meters, centimeters, or millimeters; and

T is the thickness of the specimen in inches, meters, centimeters, or millimeters.

29.4.3 Accelerated aging

29.4.3.1 All splitting, skiving, buffing, planing, and die-cutting operations are to be completed at least 30 min before the specimens are placed in the chamber for aging or are immersed in oil. Thickness measurements for use as T in the formula in 29.4.2.1 (for determining the cross-sectional area WT) are to be made as described in 29.3.3.3 after the 30-min recovery period and before the specimens are placed in the oven or oil. The marks for the determination of elongation are to be placed on the specimens after the specimens are removed from the oven in which they were aged. For oil immersion, the marks are to be placed on the specimens before they are immersed in oil.

29.4.3.2 Physical tests are to be made on both unaged and aged specimens in close succession and at an ambient temperature of 24.0 ±8.0°C (75.2 ±14.4°F). Unaged specimens are to be maintained at this room temperature for at least 30 min prior to their being tested. Specimens that have been subjected to oil immersion are to be blotted lightly to remove any excess oil and are then to be suspended in air at the ambient temperature mentioned above for 3.5 – 4.5 h before being subjected to the physical tests. Specimens that have been subjected to air-oven aging are to have a rest period of not less than 16 h, and not more than 96 h, at this room temperature following their removal from the oven, and prior to their being tested. Specimens are to be suspended vertically so that they cannot touch one another or the sides of the chamber. Specimens having widely different properties or composition are to be aged in separate ovens.

29.4.4 Air-oven aging

29.4.4.1 The specimens are to be heated at the required temperature for the specified time in an air oven complying with 29.2.5.2, and oven temperatures are to be recorded throughout the time of heating.

30 Test for Corrosion of Uncoated Copper Conductors

30.1 Uncoated copper conductors are to be removed from one unaged specimen of the finished cable and from one specimen aged at the elevated temperature for the length of time indicated in Table 11.3 for the ultimate-elongation test of the conductor-shielding material used in the cable. None of the two specimens of the uncoated copper shall show any evidence of corrosion in a close visual examination with normal or corrected vision without magnification. Normal oxidation or discoloration that is not caused by the conductor-shielding material is to be disregarded.

31 Adhesion (Stripping-Tension) Test of Extruded Insulation Shielding That Is Not Bonded to the Insulation

31.1 The tension necessary to remove extruded insulation shielding that is not bonded to the insulation shall not be less than 4 lbf or 17.8 N or 1.74 kgf when samples from the finished cable are tested as described in 31.2 – 31.5. Removal of the shielding shall not damage the insulation and the insulation shall not retain any conductive material that cannot readily be removed.

31.2 This test is to be made on conductors from finished cable that contains insulation shielding whose conductive nonmetallic covering consists of an extrusion that is not bonded to the insulation. On each of three samples of the conductor(s) from such cable, the metal component of the insulation shielding and any jacket over it are to be removed.

31.3 Two parallel longitudinal cuts 1/2 inch or 13 mm apart and not less than 12 inches or 305 mm long are to be made through the extruded insulation shielding at one end of each sample starting at the end of the sample. Each sample is then to be rotated 180° and two additional, identical cuts are to be made starting from the same end. Starting tabs are to be made by peeling back both of the two resulting 1/2-inch or 13-mm strips from the starting end of each sample for a distance of 2 inches or 50 mm.

31.4 A sample is to be held securely at both of its ends. The free end of one of the starting tabs is to be gripped firmly so that the 1/2-inch or 13-mm strip can be pulled at an angle of 90° to the longitudinal axis of the conductor. The strip is to be peeled from the insulation at a rate of approximately 1/2 in/s or 13 mm/s for a distance of not less than 10 inches or 254 mm. The angle of pull is to be maintained as close as possible to 90° throughout the test. The tension necessary to remove the strip is to be monitored continuously and the minimum value is to be recorded.

31.5 The test is to be repeated with the second strip on the first sample. If none of the following occur with either of the two strips on the first sample, the extruded insulation shielding is acceptable and the two remaining samples need not be tested:

a) The minimum peeling tension is less than 4 lbf or 17.8 N or 1.74 kgf.

b) The insulation is damaged by the peeling.

c) Conductive material remains on the insulation and cannot readily be removed.

If (a), (b), or (c) occur singly or in any combination with either of the two strips on the first sample, the test is to be repeated on each of the two remaining samples for a total of four additional strips tested. The extruded insulation shielding is not acceptable if any of the four additional strips experience (a), (b), or (c) singly or in any combination.

32 Heat Distortion Test of 90°C (194°F) EPCV or XLPE Insulation

32.1 EPCV or XLPE insulation (the insulation plus the conductor shielding in the case of conductors that are too small to provide for flat, rectangular specimens) from finished 90°C (194°F) cable shall not decrease more in thickness than the following percentage (this is indicated for the conductor size and round or flat specimen style in Table 12.7(IV) (for EPCV) or in Table 12.1(IV) (for XLPE) when specimens are subjected to the load indicated in Table 32.1 while being maintained at a temperature of 121.0 ±1.0°C (249.8 ±1.8°F):

Round specimens with conductor in place from No. 8 – 4/0 AWG conductors	25 percent maximum acceptable distortion
Flat, rectangular specimens from 250 – 1000 kcmil conductors	15 percent maximum acceptable distortion

Table 32.1
Specimen load

Size of conductor	Load[a] exerted on a specimen by the foot of the rod[a]	
	gf	N
8 AWG	500	4.90
7 – 1	750	7.35
1/0 – 4/0	1000	9.81
250 – 1000 kcmil	2000	19.61

[a] The specified load is not the weight to be added to each rod in the test apparatus but rather the total of the weight added and the weight of the rod. Because the weight of the rod varies from one apparatus to another, specifying the exact weight to be added to a rod to achieve the specified load on a specimen is impractical in all cases except for an individual apparatus.

32.2 Finished XLPE-insulated circuit conductors are to be removed from the finished cable, and any insulation shielding and other coverings over the insulation are to be removed without damage to the insulation.

32.3 The diameter D_1 over the XLPE insulation and the conductor shielding on each of five 1-inch or 25-mm specimens of No. 8 – 4/0 AWG circuit conductors is to be measured to the nearest 0.001 inch or 0.01 mm. In each case, the measurement is to be made at a marked position by means of a dead-weight dial micrometer whose presser foot puts a load of 85 ±3 gf or 0.84 ±0.02 N or 3.0 ±0.1 ozf on the specimen. The presser foot is to have a flat, round face whose diameter is 0.250 ±0.010 inch or 6.4 ±0.2 mm. The anvil of the instrument is to be round, is to be at least 1.5 inches or 38 mm in diameter, and is to be parallel to the face of the presser foot. In each case, the diameter d over the conductor is to be measured by means of the same dial micrometer. The original thickness T_1 of the insulation and conductor shielding is then to be calculated to the nearest 0.001 inch or 0.01 mm from the following formula.

$$T_1 = \frac{D_1 - d}{2}$$

32.4 For 250 – 1000 kcmil circuit conductors, five samples approximately 8 inches or 200 mm long are to be prepared with a thickness of 0.050 ±0.010 inch or 1.27 ±0.25 mm, with both surfaces smooth. From each of these samples, a flat, rectangular test specimen of the insulation 1 inch long and 9/16 inch wide or 25 mm by 14 mm is to be prepared. At a marked position, the original thickness T_1 of each of these specimens of insulation is to be measured to the nearest 0.001 inch or 0.01 mm by means of the dead-weight dial micrometer described in 32.3. The entire surface of the presser foot is to be in contact with the rectangular specimen during measurement.

32.5 The apparatus for this test is illustrated in Figure 32.1. The apparatus is to be of brass and is to consist of three rods that can move vertically in a support frame. The assembly is to be constructed for use in a heated oven. Each rod is to be straight and 0.750 ±0.010 inch or 19.0 ±0.2 mm in diameter. The weight of each rod is to be 250 g. The lower end of each rod is to be reduced in diameter to 0.375 ±0.010 inch or 9.5 ±0.2 mm for the final 3/4-inch or 19-mm length of the rod. The lower end of the reduced-diameter section is to be flat, round, without sharp edges, and both concentric with and perpendicular to the longitudinal axis of the rod. The lower end of the reduced section is to serve as the foot that presses on a specimen during a test. The force on the specimen is to be the sum of the force exerted by the rod (250 g or 2.45 N) plus that of any weight that needs to be placed on the upper end of the rod to make the total force equal the load specified in Table 32.1. Each weight is to be indent stamped with its exact weight.

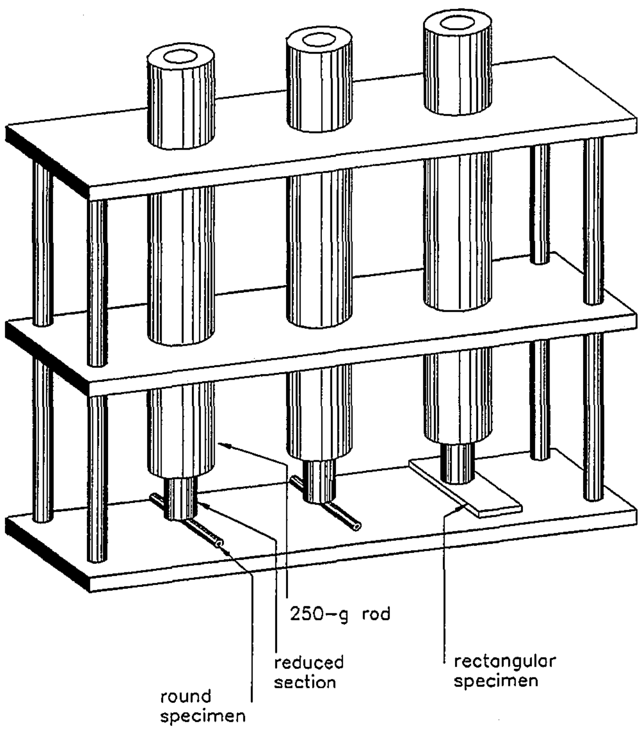
32.6 The frame is to consist of three flat, rectangular plates spaced approximately 2-1/4 inches or 57 mm apart (vertical separation) and parallel to one another in a rigid assembly. The dimensions of the plates are not specified but are to be the same (plates measuring 8-1/2 inches by 2-3/4 inches by 1/4 inch or 216 mm by 70 mm by 6 mm are typical). The upper surface of the lower plate is to be the surface against which each rod presses a specimen during a test. That surface is to be horizontal during a test. That surface is to be smooth (refinishing is necessary as repeated testing indents the surface or makes it rough to the touch). Identically located holes are to be provided through the center and upper plates to serve as guides and supports for the rods, which are to be free to move vertically but not otherwise. The diameter of each hole is to be larger than the 3/4-inch-diameter or 19-mm-diameter portion of a rod but only large enough to provide clearance allowing vertical movement of a rod in the hole. Sufficient horizontal separation (2-3/4 inches or 70 mm is typical) is to be provided between the rods to enable weights to be in place on all three rods at the same time with a clearance of approximately 1/4 inch or 6 mm between the weights. Each rod is to project a distance above the upper plate that enables a weight to be placed on the upper end of the rod without the weight touching the upper plate while the rod is resting on the lower plate (no specimen under the rod). Means is to be provided integral with the frame for keeping the frame raised approximately 3/8 inch or 9.5 mm above the floor of the oven during a test.

32.7 With the applicable weight (if any is needed) in place on each rod that is to be used for a test, the apparatus is to be placed beside the five test specimens in a full-draft circulating-air oven that complies with 29.2.5.2 and has been preheated to a temperature of 121.0 ±1.0°C (249.8 ±1.8°F) for all specimens. The five specimens and the loaded apparatus are to remain side by side in the oven for 60 min of preliminary heating at full draft. At the end of the 60 min, one rod is to be lifted and a specimen is to be centered under it. The loaded rod is to be lowered and gently allowed to bear on the specimen at the marked position. The rod is to continue to bear on the specimen while the apparatus and the specimen remain in the oven for an additional 60 min at full draft. The entire surface of the foot of the rod is to be in contact with any specimen that is rectangular.

32.8 At the end of the second 60 min, the rod is to be lifted and the specimen under it is to be removed. The specimen diameter (round specimen of insulation and conductor shielding on a No. 8 – 4/0 AWG conductor) or thickness (rectangular specimen of insulation from a 250 – 1000 kcmil conductor) is to be measured for determination of the final specimen thickness T_2 to the nearest 0.001 inch or 0.01 mm. The measurement is to be made at the marked position in the same way as the specimen was measured for determining T_1. In the case of a round specimen, the diameter d over the conductor need not be remeasured – that is, in the calculation of T_2, it is acceptable to use the measured value of d that was used in calculating T_1. To minimize the time that the specimen has to recover before its reduced diameter or thickness is measured, measurement is to be made in as short a time as possible after the rod is lifted. If more than 15 s elapses between the time at which the rod is lifted and the time of measurement, the specimen is to be discarded and the test is to be repeated with one of the four remaining specimens.

Figure 32.1
Deformation test apparatus
with specimens in place

Added weights are not shown



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32.9 The percent distortion is to be calculated from the following formula.

$$\text{Percent distortion} = \frac{100 \times (T_1 - T_2)}{T_1}$$

The XLPE insulation (or insulation plus conductor shielding in the case of a round specimen) is acceptable if the distortion calculated for the first specimen does not exceed the percentage indicated for the conductor size and round or flat specimen style in Table 12.1(IV). If the distortion calculated for the first specimen exceeds this percentage, the test is to be repeated on each of three of the remaining specimens. At the end of the second 60 min for these three specimens, the specimens are not to be removed from under the rods at the same time. Instead, the procedure of lifting the rod, removing the specimen, and quickly making the measurement is to be followed for each of the three specimens in turn. The XLPE insulation (or insulation plus conductor shielding in the case of the round specimens) is not acceptable if, for any of the three additional specimens, the calculated distortion exceeds the percentage indicated for the conductor size and round or flat specimen style in Table 12.1(IV).

33 Heat Distortion Test of Nonconductive Thermoplastic Jackets

33.1 Each circuit-conductor, assembly, overall, and supplementary jacket that is of a nonconductive thermoplastic material and is taken from the finished cable shall not decrease more in thickness than the following percentage (this and the test temperature are indicated for the particular material in the applicable properties table) when specimens are subjected to a load of 2000 gf or 19.61 N while being maintained at the following temperature:

Nonconductive thermoplastic CPE	25 percent maximum acceptable distortion	121.0 ±1.0°C (249.8 ±1.8°F)	item III Table 25.4
Nonconductive PE	25 percent maximum acceptable distortion	90.0 ±1.0°C (194.0 ±1.8°F)	item II Table 25.10
Nonconductive PVC	50 percent maximum acceptable distortion	121.0 ±1.0°C (249.8 ±1.8°F)	item II Table 25.12

33.2 Each circuit-conductor, assembly, overall, and supplementary jacket of nonconductive thermoplastic CPE, nonconductive PE, and nonconductive PVC is to be removed from the finished cable without damage to the jacket. Five samples of each jacket approximately 8 inches or 200 mm long are to be prepared with a thickness of 0.050 ±0.010 inch or 1.27 ±0.25 mm, with both surfaces smooth. From each of these samples, a flat, rectangular test specimen 1 inch long and 9/16 inch wide or 25 mm by 14 mm is to be prepared.

33.3 At a marked position, the thickness T_1 of each of these original specimens is to be measured by means of a dead-weight dial micrometer whose presser foot puts a load of 85 ±3 gf or 0.84 ±0.02 N or 3.0 ±0.1 ozf on the specimen. The presser foot is to have a flat, round face whose diameter is 0.250 ±0.010 inch or 6.4 ±0.2 mm. The anvil of the instrument is to be round, is to be at least 1.5 inches or 38 mm in diameter, and is to be parallel to the face of the presser foot. The entire surface of the presser foot is to be in contact with the rectangular specimen during measurement.

33.4 The apparatus for this test is illustrated in Figure 33.1. The apparatus is to be of brass and is to consist of three rods that can move vertically in a support frame. The assembly is to be constructed for use in a heated oven. Each rod is to be straight and 0.750 ±0.010 inch or 19.0 ±0.2 mm in diameter. The weight of each rod is to be 250 g. The lower end of each rod is to be reduced in diameter to 0.375 ±0.010 inch or 9.5 ±0.2 mm for the final 3/4-inch or 19-mm length of the rod. The lower end of the reduced-diameter section is to be flat, round, without sharp edges, and both concentric with and perpendicular to the longitudinal axis of the rod. The lower end of the reduced section is to serve as the foot that presses on a specimen during a test. The force on the specimen is to be the sum of the force exerted by the rod (250 g or 2.45 N) plus that of any weight that needs to be placed on the upper end of the rod to make the total force equal the load specified in 33.1. Each weight is to be indent stamped with its exact weight.

33.5 The frame is to consist of three flat, rectangular plates spaced approximately 2-1/4 inches or 57 mm apart (vertical separation) and parallel to one another in a rigid assembly. The dimensions of the plates are not specified but are to be the same (plates measuring 8-1/2 inches by 2-3/4 inches by 1/4 inch or 216 mm by 70 mm by 6 mm are typical). The upper surface of the lower plate is to be the surface against which the rod presses a specimen during a test. That surface is to be horizontal during a test.

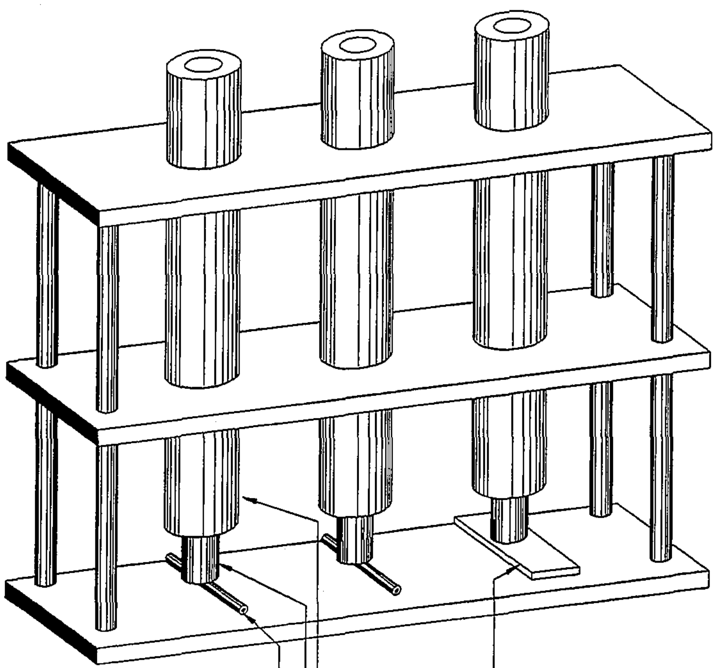
That surface is to be smooth (refinishing is necessary as repeated testing indents the surface or makes it rough to the touch). Identically located holes are to be provided through the center and upper plates to serve as guides and supports for the rods, which are to be free to move vertically but not otherwise. The diameter of each hole is to be larger than the 3/4-inch-diameter or 19-mm-diameter portion of a rod but only large enough to provide clearance allowing vertical movement of a rod in the hole. Sufficient horizontal separation (2-3/4 inches or 70 mm is typical) is to be provided between rods to enable weights to be in place on all three rods at the same time with a clearance of approximately 1/4 inch or 6 mm between the weights. Each rod is to project a distance above the upper plate that enables a weight to be placed on the upper end of the rod without the weight touching the upper plate while the rod is resting on the lower plate (no specimen under the rod). Means is to be provided integral with the frame for keeping the frame raised approximately 3/8 inch or 9.5 mm above the floor of the oven during a test.

33.6 With the applicable weight (if any is needed) in place on each rod that is to be used for a test, the apparatus is to be placed beside the five test specimens in a full-draft circulating-air oven that complies with 29.2.5.2 and has been preheated to a temperature of 121.0 ±1.0°C (249.8 ±1.8°F) for all specimens. The five specimens and the loaded apparatus are to remain side by side in the oven for 60 min of preliminary heating at full draft. At the end of the 60 min, one rod is to be lifted and a specimen is to be centered under it. The loaded rod is to be lowered and gently allowed to bear on the specimen at the marked position. The rod is to continue to bear on the specimen while the apparatus and the specimen remain in the oven for an additional 60 min at full draft. The entire surface of the foot of the rod is to be in contact with any specimen that is rectangular.

33.7 At the end of the second 60 min, the rod is to be lifted and the specimen under it is to be removed. The specimen thickness is to be measured for determination of the final specimen thickness T_2 to the nearest 0.001 inch or 0.01 mm. The measurement is to be made at the marked position in the same way as the specimen was measured for determining T_1. To minimize the time that the specimen has to recover before its reduced thickness is measured, measurement is to be made in as short a time as possible after the rod is lifted. If more than 15 s elapses between the time at which the rod is lifted and the time of measurement, the specimen is to be discarded and the test is to be repeated with one of the four remaining specimens.

Figure 33.1
Deformation test apparatus
with specimens in place

Added weights are not shown



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33.8 The percent distortion is to be calculated from the following formula.

$$\text{Percent distortion} = \frac{100 \times (T_1 - T_2)}{T_1}$$

A nonconductive thermoplastic jacket is acceptable if the distortion calculated for the first specimen does not exceed 25 percent for nonconductive PE or nonconductive thermoplastic CPE and 50 percent for nonconductive PVC. If the distortion calculated for the first specimen exceeds this percentage, the test is to be repeated on each of three of the remaining specimens of that jacket. At the end of the second 60 min for these three specimens, the specimens are not to be removed from under the rods at the same time. Instead, the procedure of lifting the rod, removing the specimen, and quickly making the measurement is to be followed for each of the three specimens in turn. That jacket is not acceptable if, for any of the three additional specimens, the calculated distortion exceeds 25 percent for nonconductive PE or nonconductive thermoplastic CPE and 50 percent for nonconductive PVC.

34 Test for Set of Nonconductive Thermoset Jackets

34.1 Each circuit-conductor, assembly, overall, and supplemental jacket that is of a nonconductive thermoset material and is taken from the finished cable shall not exhibit a set greater than the following (this is indicated for the particular material in the applicable properties table) when specimens are tested as described in 34.2 – 34.6:

Nonconductive CP, Nonconductive thermoset CPE, Nonconductive NBR/PVC	30 percent maximum acceptable set (0.30 inch or 7.5 mm)	item II Table 25.2 item IV Table 25.4 item II Table 25.6
Nonconductive neoprene	20 percent maximum acceptable set (0.20 inch or 5.0 mm)	item II Table 25.8

34.2 The set test is to be made at room temperature by means of the power-driven testing machine described in 29.2.1.1. The machine shall be such that the movable grip can be stopped instantly.

34.3 The set test is to be made using four unaged specimens that have not been stretched or subjected previously to any test. The specimens are to be taken from the finished cable. The specimens are to be die-cut and marked with lines 1 inch or 25 mm apart (bench marks) as described for the physical-properties tests in 29.2.2.1 – 29.2.4.1 and 29.3.1.1 – 29.3.3.2. One specimen is to be clamped in position with both of the bench marks visible between the grips. The grips are to be adjusted symmetrically to distribute the tension uniformly over the cross section of the specimen. The movable grip is to be adjusted to make the test piece taut but not under tension. The temperature of the ambient air is to be recorded.

34.4 The grips are to be separated at a rate of 20 ±1 in/min or 500 ±25 mm/min until the bench marks are 3 inches or 75 mm apart. The test specimen is to be held in the stretched position for 5 s, released immediately without snapping back, and rested for 1 min. The distance between the marks is then to be measured to the nearest 0.01 inch or 0.1 mm and is to be recorded. Just before releasing the specimen, the distance R between the marks is to be observed again and, if it has decreased below the 3 inches or 75 mm because of slipping of the specimen in the grips, the specimen that slipped is to be discarded and the test is to be repeated with a fresh specimen.

34.5 Set is the difference between the distance R measured between bench marks after release and rest and the original bench-mark separation of 1 inch or 25 mm, expressed as a percentage of the original separation:

$$\text{Set} = \frac{[R - (1\text{ in or } 25\text{ mm})] \times 100}{(1\text{ in or } 25\text{ mm})}$$

34.6 A nonconductive thermoset jacket is acceptable if, for the first specimen of that jacket, the calculated set does not exceed 30 percent (0.30 inch or 7.5 mm) for nonconductive CP, nonconductive thermoset CPE, or nonconductive NBR/PVC and 20 percent (0.20 inch or 5.0 mm) for nonconductive neoprene. If the set calculated for the first specimen exceeds this value, the test is to be repeated on each of the three remaining specimens of that jacket. That jacket is not acceptable if, for any of the three additional specimens, the calculated set exceeds 30 percent (0.30 inch or 7.5 mm) for nonconductive CP, nonconductive thermoset CPE, or nonconductive NBR/PVC and 20 percent (0.20 inch or 5.0 mm) for nonconductive neoprene.

35 Heat Shock Test of Nonconductive PVC Jackets

35.1 Each circuit-conductor, assembly, overall, and supplementary jacket that is of nonconductive PVC and is taken from the finished cable shall not show any cracks either on the surface or internally when samples are wound around the mandrel indicated in Table 35.1 and then are subjected to a temperature of 121.0 ±1.0°C (249.8 ±1.8°F) in a full-draft circulating-air oven for 1 h. This test is indicated in Table 25.12(III).

Table 35.1
Mandrel diameter and number of turns for heat-shock test

Calculated outside diameter of jacketed sample (cable, assembly, or circuit conductor)		Diameter of metal mandrel as a multiple of the calculated outside diameter of the jacketed sample (cable, assembly, or circuit conductor)	Number of turns
in	mm		
0 – 0.750	0 – 19.05	3	6
Over 0.750 but not over 1.500	Over 19.05 but not over 38.10	8	180° bend
Over 1.500	Over 38.10	12	180° bend

35.2 This test is to be made using four sample lengths of the finished cable with an overall or supplementary jacket of PVC and each PVC-jacketed assembly and circuit conductor from the finished cable. One sample is to be tightly wound for six complete turns, or for a 180° bend as indicated in Table 35.1, around a metal mandrel having a diameter that complies with Table 35.1. Where six turns are used, successive turns are to be in contact with one another. Both ends of the sample are to be securely held in place by friction tape or another means. After heating to a temperature of 121.0 ±1.0°C (249.8 ±1.8°F) for 1 h in a full-draft circulating-air oven, the sample is to be examined for surface and internal cracks. Internal cracks can be detected as circumferential depressions in the outer surface.

35.3 A PVC jacket is acceptable if, for the first sample of that jacket, there isn't any evidence of cracking. If the first sample having a particular jacket cracks, the test is to be repeated on each of the three remaining samples having that jacket. That jacket is not acceptable if there is evidence of cracking of any of the three additional samples having that jacket.

36 Cold Bend Test of Complete Cable

36.1 While at a temperature of −35.0 ±2.0°C (−31.0 ±3.6°F), finished cable shall be capable of being wound around a right-circular mandrel of the diameter indicated in Table 36.1 without damage to any of its parts.

36.2 Four essentially straight test lengths of the finished cable are to be cooled for 1 h in circulating air precooled and maintained at a temperature of −35.0 ±2.0°C (−31.0 ±3.6°F). At the end of the hour, one specimen is to be removed from the cold chamber and bent for 180° around a wooden mandrel of the diameter indicated in Table 36.1 without any more tension than is necessary to keep the surface of the cable in contact with the mandrel. The bend is to be made at a uniform rate in the direction opposite to any curvature in the specimen, and the time taken to remove the test length from the cold chamber and to complete the bend is not to exceed 30 s.

Table 36.1
Multiplying factor for determining mandrel diameter for cold bend test

Cable	Calculated outside diameter of the cable		Diameter of wooden mandrel as a multiple of the calculated outside diameter of the cable
	in	mm	
Without a metal covering	0 – 0.800 Over 0.800	0 – 20.32 Over 20.32	x8 x10
With armor or a smooth or corrugated metal sheath	–	–	x14

36.3 With a minimum of handling and flexing, the test length is then to be removed from the mandrel and placed on a horizontal surface where it is to remain undisturbed for at least 4 h before being examined for surface damage and then is to be disassembled and examined further for damage. The cable is acceptable if, for the first test length, there aren't any cracks, splits, tears, or other openings in any part of the cable. Adjacent convolutions of any interlocked armor may separate somewhat but none of the cable inside the armor is to be visible. Internal cracking of an extruded part can be detected as circumferential depressions in the outer surface of the part. If the first test length has any of these faults, the test is to be repeated on each of the three remaining test lengths. The cable is not acceptable if any of the three additional test lengths has one or more of these faults.

37 Accelerated Water Absorption – Electrical Method – Tests of EP and XLPE Insulations

37.1 EP and XLPE insulations on circuit conductors shall have the effect that specimens of the insulated conductor that are immersed continuously in tap water at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F) for 14 d comply with all four of the following requirements when tested as described in 37.2 – 37.10. These tests are not required for dry-locations cable – that is, they are not required for nonshielded 5-kV single-conductor cable insulated as indicated in column A or B of Table 13.2. All of these tests are to be made on the insulated conductor. For nonshielded 8-kV single-conductor cable insulated as indicated in column D of Table 13.2, see Section 38 for an additional test to determine the relative permittivity (ϵ_r) of the overall jacket on that cable.

a) ϵ_r, the relative permittivity or dielectric constant of the insulation determined with 48 – 62 Hz current at an average stress of 80 volts per mil or 3150 volts per millimeter, after immersion of the specimens for 24 h, shall be 4.0 or less for EP insulation [Table 12.4(V)(A)(l)] and 3.5 or less for XLPE insulation [Table 12.1(VII)].

b) The capacitance determined after immersion for 14 d shall, for EP insulation, not be more than 3.5 percent higher than the capacitance measured after the 24-h immersion [Table 12.4(V)(A)(2)(a)] and shall, for XLPE insulation, not be more than 3.0 percent higher than the capacitance measured after the 24-h immersion [Table 12.1(VI)(2)(a)].

c) The capacitance determined after immersion for 14 d shall, for EP and XLPE insulations, not be more than 1.5 percent higher than the capacitance measured after immersion for 7 d [Table 12.4(V)(A)(2)(b) and Table 12.1(VI)(2)(b)].

d) EP and XLPE insulations shall comply with one of the following requirements:

1) The stability factor (the numerical difference between the percentage power factors measured with 48 – 62 Hz current at average stresses of 80 and 40 volts per mil or 3150 and 1575 volts per millimeter) determined after the fourteenth day of immersion shall be 1.0 percent or less [Table 12.4(V)(A)(3) and Table 12.1(VI)(3)], or

2) The stability factor determined after the first day subtracted from the stability factor determined after the fourteenth day shall be 0.5 percent or less [Table 12.4(V)(A)(4) and Table 12.1(VI)(4)].

37.2 Each of these tests is to be made on two specimens. If either of these specimens shows any unacceptable result, two additional specimens are to be tested. The insulation is not acceptable if one or both of the two additional specimens show any unacceptable result.

37.3 To determine whether or not EP or XLPE insulation complies with the requirements in 37.1 (each requirement is also stated in the item of the properties table for the material indicated in parentheses in 37.1), tests are to be made using a 15-ft or 5-m specimen of the insulated circuit conductor taken after cross-linking and before the application of any insulation shielding or other covering over the insulation. After not less than 48 h from the time of cross-linking, the specimen is to be dried for 24 h in air at 70.0 ±1.0°C (158.0 ±1.8°F) before being immersed in water.

37.4 The center 120-inch or 3048-mm portion of the specimen is to be immersed continuously in tap water at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F) for 14 d. The 30-inch or 976-mm portion at each end of the specimen is to be kept dry above the water as leakage insulation. A tight-fitting cover for the tank is to be placed directly above the surface of the water, the level of which is to be kept constant.

37.5 The capacitance of the specimen is to be measured with 48 – 62 Hz current at an average stress of 80 volts rms per mil of measured insulation thickness or 3150 volts rms per millimeter of measured insulation thickness with bridge apparatus after 1 d, 7 d, and 14 d of immersion. The voltage applied during each measurement is to be between the conductor in the specimen and an electrode that is earth-grounded and is in contact with the water in which the specimen is immersed. Each result is to be expressed to the nearest picofarad. For use in the calculation of the jacket relative permittivity ϵ_r in 38.5, the designation C_I is to be assigned to the value of capacitance obtained for the specimen of the insulated conductor for overall-jacketed nonshielded 8-kV single-conductor cable insulated as indicated in column D of Table 13.2. The increases in capacitance from 1 d to 14 d and from 7 d to 14 d are to be expressed as percentages of the 1-d and 7-d values, respectively.

37.6 The power factor of the specimen is to be measured as specified in of 37.1(d)(1) after 1 d and 14 d of immersion, and each result is to be expressed to the nearest 0.1 percent. The stability factor of the specimen is then to be computed and expressed to the nearest 0.1 percent.

37.7 The stability-factor difference is then to be computed for the specimen. This value is the numerical difference between the stability factors determined after 1 d and 14 d and is to be expressed to the nearest 0.1 percent.

37.8 For determination of the relative permittivity ϵ_r, the capacitance of the EP or XLPE insulation is to be determined after immersion of the specimen for 24 h, 7 d, and 14 d. The temperature of the water is to be 75.0 ±1.0°C (167.0 ±1.8°F).

37.9 For the relative permittivity ϵ_r determination, measurements of the capacitance of the EP or XLPE insulation are to be made at a frequency of either 1000 or 60 Hz by means of a capacitance bridge. If measured at 1000 Hz, the rms potential impressed upon the insulation is not to exceed 10 V. If measured at 60 Hz, the potential impressed upon the insulation is to result in an average stress of the insulation at 80 volts rms per mil of measured insulation thickness or 3150 volts rms per millimeter of measured insulation thickness.

37.10 The test is to be made on a 15-ft or 5-m specimen of the EP- or XLPE-insulated conductor from which any insulation shielding or other covering over the insulation has been removed, or the specimen of insulated conductor is to be selected from production after cross-linking and prior to the application of any insulation shielding or other covering. The center 120-inch or 3048-mm portion of the specimen is to be immersed in tap water for 14 d, with a 30-inch or 976-mm portion at each end kept dry above the water as leakage insulation. The water temperature and the depth of immersion of the specimen are to be the same whenever readings are taken. ϵ_r, the relative permittivity or dielectric constant of the insulation is to be determined after 1 d, 7 d, and 14 d by means of the formula

$$\epsilon_r = 0.0136 \times C \times \log_{10} \frac{DIA}{dia}$$

in which:

C is the capacitance in picofarads of the immersed 120 inches or 3048 mm of the specimen,

DIA is the measured diameter over the EP or XLPE insulation in inches or millimeters, and

dia is the measured diameter over the conductor shielding in inches or millimeters.

38 Elevated-Temperature Relative Permittivity Test of Jacket on Nonshielded 8-kV Single-Conductor Cable

38.1 The jacket on nonshielded 8-kV single-conductor cable that is insulated as indicated in column D of Table 13.2 shall be such that specimens of the finished jacketed, insulated cable that are immersed in tap water at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F) have a relative permittivity or dielectric constant determined for the jacket with 48 – 62 Hz current at an average stress of 80 volts per mil or 3150 volts per millimeter, after immersion of the specimens for 24 h, no higher than 10.0 and no lower than 6.00 for any jacketing material. This is indicated for each material as the final item (dielectric constant) in the properties table for the material – see Tables 25.2, 25.4, 25.6, 25.8, 25.10, and 25.12.

38.2 To determine whether or not the overall jacket complies with the requirement in 38.1, tests are to be made using four 15-ft or 5-m specimens of the finished cable with the overall jacket in place. After not less than 48 h from the time of cross-linking of a CP, thermoset CPE, NBR/PVC, or neoprene jacket or from application of a thermoplastic CPE, PE of a high molecular weight, or PVC jacket, two specimens are to be dried for 24 h in air at 70.0 ±1.0°C (158.0 ±1.8°F) before being immersed in water.

38.3 The center 120-inch or 3048-mm portion of each specimen is to be immersed in tap water at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F) for 24 h. The 30-inch or 976-mm portion at each end of each specimen is to be kept dry above the water as leakage insulation. A tight-fitting cover for the tank is to be placed directly above the surface of the water.

38.4 The capacitance of each jacketed, insulated specimen is to be measured with 48 – 62 Hz current at an average stress of 80 volts rms per mil of measured insulation thickness (not insulation plus jacket thickness) or 3150 volts rms per millimeter of insulation thickness (not insulation plus jacket thickness) with bridge apparatus after 24 h of immersion. The voltage applied during each measurement is to be between the conductor in the specimen and an electrode that is earth-grounded and is in contact with the water in which the jacketed, insulated specimen is immersed. Each result is to be expressed to the nearest picofarad and is to be designated as C_T.

38.5 ϵ_r, the relative permittivity or dielectric constant of the overall jacket is to be determined by means of the formula

$$\epsilon_r = \frac{0.0136 \times C_I \times C_T}{C_I - C_T} \log_{10} \frac{DIA}{dia}$$

in which:

> C_I *is the capacitance in picofarads of the immersed 120 inches or 3048 mm of one insulated but not-yet-jacketed specimen from 36.5,*
>
> C_T *is the capacitance in picofarads of the immersed 120 inches or 3048 mm of one insulated and jacketed specimen from 38.4,*
>
> *DIA is the measured diameter over the overall jacket in inches or millimeters, and dia is the measured diameter in inches or millimeters over the insulation under the overall jacket on the specimen from 38.4. The overall jacket is acceptable if, for each of the first two specimens,* ϵ_r *is not over 10.0 or under 6.00. If for either specimen,* ϵ_r *is over 10.0 or under 6.00, the test is to be repeated on each of the two remaining specimens. The overall jacket is not acceptable if, for either of the two additional specimens,* ϵ_r *is over 10.0 or under 6.00.*

39 Room-Temperature Relative Permittivity and Power Factor Tests at Rated Voltage for EP and XLPE Insulations on 8 – 35-kV Circuit Conductors

39.1 EP and XLPE insulations on circuit conductors rated over 5 kV shall have the effect that specimens of the insulated conductor immersed in tap water at a temperature of 24.0 ±8.0°C (75.2 ±14.4°F) comply with both of the following requirements when tested as described in 39.2 – 39.6. These tests are not required for any 5-kV cable.

a) ϵ_r, the relative permittivity or dielectric constant determined with 48 – 62 Hz current at rated voltage to ground for the cable under test, after immersion of the specimens for at least 24 h, shall be 4.0 or less for EP insulation [Table 12.4(VI)] and 3.5 or less for XLPE insulation [Table 12.1(VII)(A)].

b) PF, the power factor measured with 48 – 62 Hz current at rated voltage to ground for the cable under test, after immersion of the specimens for at least 24 h, shall be 2.0 percent or less for EP and XLPE insulations [Table 12.4(VII) and Table 12.1(VIII)(A)].

39.2 To determine whether or not EP or XLPE insulation complies with the requirements in 38.1 (each requirement is also stated in the item of the properties table for the material indicated in parentheses in 38.1), tests are to be made using four 13-ft or 4.0-m specimens of 8- and 15-kV circuit conductors and 17-ft or 5.2-m specimens of 25-, 28-, and 35-kV circuit conductors. The specimens of insulated conductor are to be taken after cross-linking and before application of any insulation shielding or other covering over the insulation. After not less than 48 h from the time of cross-linking, two specimens are to be dried for 24 h in air at a temperature of 70.0 ±1.0°C (158.0 ±1.8°F) before being immersed in water.

39.3 The center 120-inch or 3048-mm portion of each specimen is to be immersed in tap water at a temperature of 24.0 ±8.0°C (75.2 ±14.4°F) for 24 h or longer. The remaining portions at the ends of each specimen are to be kept dry above the water as leakage insulation. A tight-fitting cover for the tank is to be placed directly above the surface of the water.

39.4 The capacitance and power factor of each specimen are to be measured with 48 – 62 Hz current after at least 24 h of immersion. During each measurement, the test voltage indicated in Table 39.1 is to be applied between the conductor in the specimen and an electrode that is earth-grounded and is in contact with the water in which the specimen is immersed. Each capacitance measurement is to be expressed to the nearest picofarad.

Table 39.1
Test voltage for room-temperature ϵ_r and PF test of insulation

Voltage rating of cable (phase-to-phase circuit voltage)	Test voltage[a]
5000	2890
8000	4620
15000	8660
25000	14435
28000	16165
35000	20210

[a] The test voltage is the rated voltage to ground for the cable under test, which is the phase-to-phase circuit voltage divided by the square root of 3 (1.732) and rounded off to the nearest 5 V.

39.5 ϵ_r, the relative permittivity or dielectric constant of the insulation is to be determined for each specimen after a 24 h or longer immersion by means of the formula

$$\epsilon_r = 0.0136 \times C \times \log_{10}\frac{DIA}{dia}$$

in which:

C is the capacitance in picofarads of the immersed 120 inches or 3048 mm of the specimen,

DIA is the measured diameter over the EP or XLPE insulation in inches or millimeters,and

dia is the measured diameter over the conductor shielding in inches or millimeters.

39.6 The circuit-conductor insulation is acceptable if, for each of the first two specimens, the power factor (PF) after 24 h is not over 2.0 percent for EP or XLPE and the relative permittivity (ϵ_r) after 24 h is not over 4.0 for EP or is not over 3.5 for XLPE. If any of these limits is exceeded for either specimen, the test is to be repeated on each of the two remaining specimens. The insulation is not acceptable if, for either of the two additional specimens, any of these limits is exceeded.

40 Environmental Cracking Test of Nonconductive PE Jacket

40.1 A nonconductive PE jacket shall not show any evidence of cracking when three specimens are prepared and tested as described in ASTM D 1693-70 (R1988) with the modifications noted in 40.2, 40.3, and 40.4. This is indicated for nonconductive PE jackets in Table 25.10(IV).

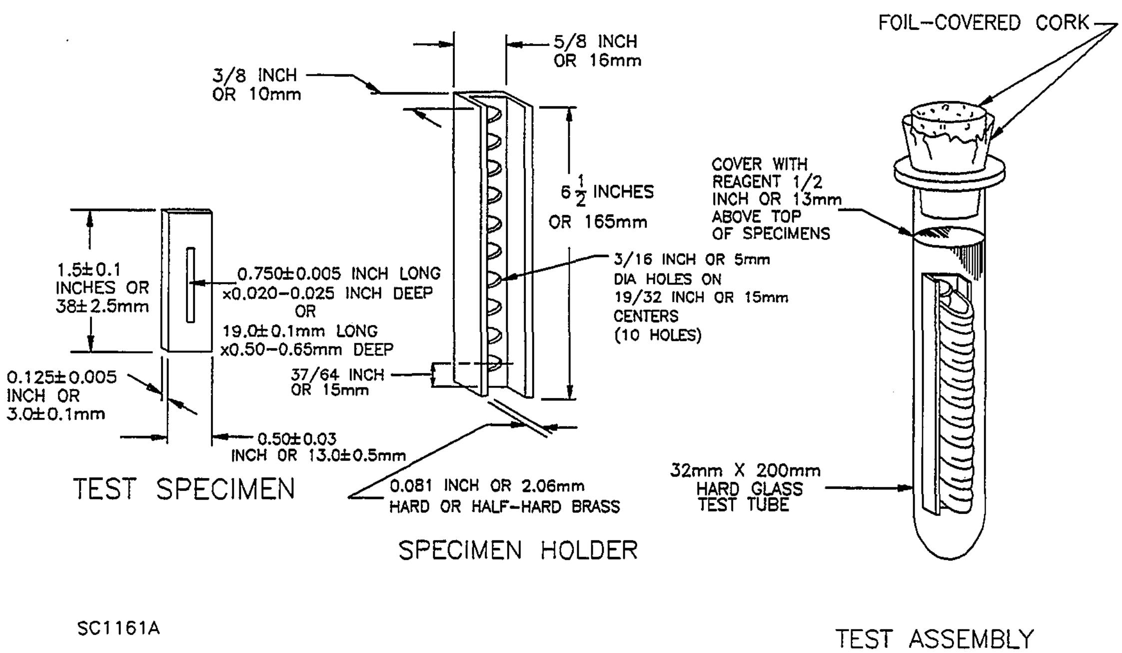
40.2 Six test specimens measuring approximately 1.5 inches by 0.5 inch by 0.125 inch or 38 mm by 13 mm by 3 mm are to be prepared from samples of the nonconductive PE jacket taken from the finished cable. The specimens are to be prepared by the compression and heat molding process that is described as Procedure C in ASTM D 1928-90 except that the temperature of each newly molded specimen may be lowered at any convenient rate. Note that, according to Table 1 of ASTM D 1248-84 (R1989), uncolored and unfilled PE resin is typed by density (g/cm^3) as follows. Note also that only Type I PE is used in Type MV cable.

Type I	0.910 – 0.925
Type II	0.926 – 0.940
Type III	0.941 – 0.959
Type IV	over 0.959

40.3 The controlled imperfection on each of three specimens is to be made with a fresh razor or knife blade and is to consist of a rectangular groove or notch having dimensions within the limits indicated in the left-hand part of the illustration in Figure 40.1. The notch is to be centrally located on one of the surfaces of the specimen that measure 1.5 inches by 0.5 inch or 38 mm by 13 mm. The condition of the edges of the notch is to be as specified in D 1693.

40.4 Each of the three specimens is to be bent, with the notch to the outside of the bend, and is to be placed in the brass specimen holder as illustrated in Figure 40.1. The holder with the three specimens in it is to be placed in a hard-glass test tube that is 200 mm long and 32 mm in diameter. Cracking agent consisting of full-strength Igepal CO-630 (Antarox CO-630) made by the Dyestuff and Chemical Division of the GAF Corporation, 140 West 51 Street, New York, NY 10020 or its equivalent (CO-630 is the referee material) is to be added to the test tube to completely immerse the specimens. The test tube is to be closed by a nonreactive means such as a foil-covered cork and is then to be kept for 48 h in an oil or water bath or air oven operating at a temperature of 50.0 ±1.0°C (122.0 ±1.8°F). At the end of this time, the specimens are to be removed from the cracking agent, cooled to room temperature in still air, and are then to be examined for cracks as detailed in D 1693. The nonconductive PE jacket is acceptable if there are no cracks in any of the three specimens. If any of the first three specimens crack, the test is to be repeated on each of the three remaining specimens. The jacket is not acceptable if there are cracks on any of the three additional specimens.

Figure 40.1
Test assembly for environmental cracking of PE jacket



41 Test for Volume Resistivity of Conductor Shielding

41.1 Finished extruded, tape, or extrusion-over-tape conductor shielding taken as a unit shall have a volume resistivity that does not exceed 100,000 ohm-centimeters at the rated temperature of the insulation when tested as described in ASTM D 257-93 with the modifications noted in 41.2 – 41.4. This is indicated in 11.3.

41.2 The insulation is to be removed from four 10-inch or 250-mm sample lengths of the finished circuit conductor(s) taken from the completed cable, or four 10-inch or 250-mm sample lengths are to be taken of the conductor shielding on the conductor before the insulation is applied. In either case, the conductor shielding is to be cut through to the conductor on opposite sides (180° apart) of the conductor and the conductor is to be removed to produce half-cylinder lengths of the conductor shielding alone. Two such lengths that are not damaged are to be prepared as specimens by applying conductive-paint electrodes to each as described in Section 6.1.3 of D 257. On each specimen, two potential electrodes at least 2 inches or 50 mm apart are to be applied and either a current electrode is to be applied at least 1 inch or 25 mm outside each of the potential electrodes, or the current electrodes may be eliminated if the measured volume resistivity is less than 90,000 ohm-centimeters for each of the two specimens.

41.3 The power in the test circuit is not to exceed 100 mW. The test is to be made at the rated temperature of the insulation (90°C or 194°F for EP and XLPE) with either alternating- or direct-current voltage. The volume resistivity is to be calculated from whichever of the following formulas applies:

If the dimensions are in inches, $P = \frac{R(D^2 - d^2)}{L}$

If the dimensions are in millimeters, $P = \frac{0.039R(D^2 - d^2)}{L}$

in which:

P is the volume resistivity in ohm-centimeters,

R is the measured resistance in ohms,

D is the diameter over the conductor shielding in inches or millimeters,

d is the diameter over the conductor in inches or millimeters, and

L is the distance between potential electrodes in inches or millimeters.

41.4 The conductor shielding is acceptable if, for either of the two specimens, the volume resistivity is not over 100,000 ohm-centimeters. If this limit is exceeded for either specimen, the test is to be repeated on each of the two remaining specimens. The conductor shielding is not acceptable if this limit is exceeded for either of the two additional specimens.

42 Test for Volume Resistivity of Insulation Shielding

42.1 The finished conductive nonmetallic covering portion of any insulation shielding (extruded, tape, or coating-plus-tape covering) taken as a unit shall have a volume resistivity that does not exceed 50,000 ohm-centimeters at the rated temperature of the insulation when tested as described in ASTM D 257-93 with the modifications noted in 42.2 – 42.4. This is indicated in 15.3.

42.2 Any covering over the insulation shielding is to be removed from four 10-inch or 250-mm sample lengths of the finished circuit conductor(s) taken from the finished cable, or four 10-inch or 250-mm sample lengths are to be taken of the conductive nonmetallic covering on the insulated conductor(s) before any covering is applied over the conductive nonmetallic covering. Two such lengths that are not damaged are to be prepared as specimens by applying conductive-paint electrodes to each as described in section 6.1.3 of D 257. On each specimen, two potential electrodes at least 2 inches or 50 mm apart are to be applied and either:

a) A current electrode is to be applied at least 1 inch or 25 mm outside each of the potential electrodes, or

b) The current electrodes may be eliminated if the measured volume resistivity is less than 45,000 ohm-centimeters for each of the two specimens.

42.3 The power in the test circuit is not to exceed 100 mW. The test is to be made at the rated temperature of the insulation (90°C or 194°F for EP and XLPE) with either alternating- or direct-current voltage. The volume resistivity is to be calculated from whichever of the following formulas applies.

If the dimensions are in inches, $P = \frac{2R(D^2 - d^2)}{L}$

If the dimensions are in millimeters, $P = \frac{0.079R(D^2 - d^2)}{L}$

in which:

P is the volume resistivity in ohm-centimeters,

R is the measured resistance in ohms,

D is the diameter over the insulation shielding in inches or millimeters,

d is the diameter over the insulation in inches or millimeters, and

L is the distance between potential electrodes in inches or millimeters.

42.4 The conductive nonmetallic covering portion of the insulation shielding is acceptable if, for each of the two specimens, the volume resistivity is not over 50,000 ohm-centimeters. If this limit is exceeded for either specimen, the test is to be repeated on each of the two remaining specimens. The insulation shielding is not acceptable if this limit is exceeded for either of the two additional specimens.

43 Test for Specific Surface Resistivity of Nonshielded Single-Conductor Cable

43.1 Finished nonshielded single-conductor cable shall have a specific surface resistivity of 200,000 megohms or more when three specimens are prepared and tested as described in ASTM D 257-93 with the modifications noted in 43.2 and 43.3.

43.2 Sample 24-inches or 610-mm or longer lengths of finished nonshielded single-conductor cable insulated as indicated in column A, B, C, or D of Table 12.2 are to be immersed, except at their ends, in tap water at room temperature for 48 h. At the end of this time, the samples are to be removed from the water and the excess moisture is to be blotted off (not wiped). Each sample is to be cut into specimens that are 12 inches or 305 mm long without damaging the surface of the cable. Six specimens are to be prepared. Three of these undamaged specimens are then to be kept in still air at room temperature for 10 min. Two foil electrodes as described in section 6.1.6 of D 257 or two conductive-paint electrodes as described in section 6.1.3 of D 257 are to be applied to each of the three specimens. The electrodes are to be applied around the cable circumference with a distance of 6 inches or 152 mm between the electrodes. Each electrode is to be 1 inch or 25 mm wide. A direct-current potential of 250 – 500 V is to be applied between the two electrodes, and the resistance is to be measured as described in D 257. The specific surface resistivity is to be calculated from the resistance by means of whichever of the following formulas applies:

If the dimensions are in inches, $P = 0.524 \times R \times D$

If the dimensions are in millimeters, $P = 0.0206 \times R \times D$

in which:

P is the specific surface resistivity in megohms,

R is the measured surface resistance in megohms for a 6-inch or 152-mm spacing between electrodes, and

D is the measured diameter of the finished cable in inches or millimeters.

43.3 The cable is acceptable if, for each of the three specimens, the specific surface resistivity is at least 200,000 megohms. If this value is not reached for any of the three specimens, the test is to be repeated on each of the three remaining specimens. The cable is not acceptable if, for any of the three additional specimens, the specific surface resistivity is less than 200,000 megohms.

44 Alternative Tests for Resistance to Tracking of Nonshielded Dry-Locations 5-kV Single-Conductor Cable Insulated with EPCV or XLPE

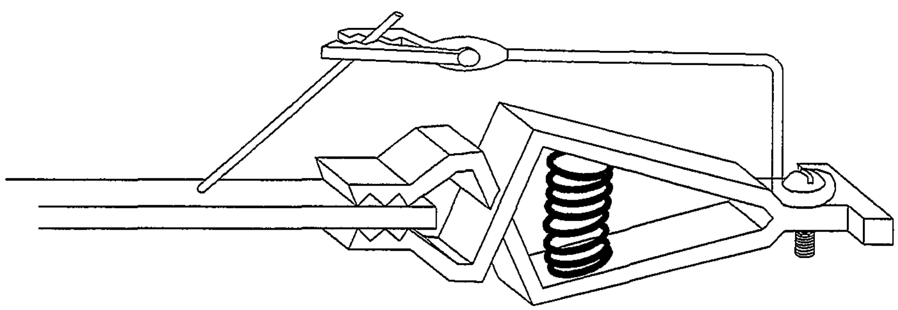
44.1 The EPCV or XLPE insulation of nonshielded dry-locations 5-kV single-conductor cable that is insulated in the thicknesses indicated in column A of Table 13.2 shall not show evidence of tracking when specimens of the insulation from the finished cable are tested either by the dust-and-fog method described in ASTM D 2132-89 with the modifications noted in 44.2 – 44.4, or by the ammonium chloride dip method described in 44.5 – 44.8.

44.2 DUST-AND-FOG METHOD – For the ASTM dust-and-fog method, six specimens of the insulated conductor taken from the finished cable are to be prepared. Each specimen is to be 5-1/2 inches or 140 mm long and is to have seven electrodes applied to it with a distance of 3/4 inch or 19 mm between the electrodes. Each electrode is to consist of one or more turns of a solid round No. 12 AWG metal-coated copper wire wrapped around the insulated conductor. The metal-coated copper is to be firmly in contact with the insulation at all points around the circumference of the insulation. Each electrode is to be tight enough to remain in place on the insulation but is not to damage the insulation.

44.3 One specimen with the electrodes in place is to be placed in a horizontal position in the test chamber with the longitudinal axis of the specimen perpendicular to the axis of the spray. The end electrodes, each alternate electrode, and the conductor are to be earth-grounded. The top side of the specimen is to be dusted as specified for the full length of the specimen between the end electrodes, and then the dust is to be removed from bands approximately 1/32 inch or 0.8 mm wide on both sides of each of the three ungrounded electrodes.

44.4 After the break-in period, the 48 – 62 Hz rms potential applied to the three ungrounded electrodes of the specimen is to be raised to 1500 V with a current of 4 – 10 mA being maintained until the circuit breaker trips at the 2-A setting because of tracking (not because of erosion or excessive moisture or circuit malfunction). The insulation is acceptable if there is no visual evidence of tracking on the specimen. If there is evidence of tracking on the first specimen, the test is to be repeated on each of three additional specimens. If the three specimens are tested simultaneously, the specimens are to be placed in the test chamber so that they are equidistant from the nozzle. The insulation is not acceptable if there is visual evidence of tracking on any of the three additional specimens.

Figure 44.1
Holder for ammonium chloride dip method



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44.5 DIP METHOD – For the ammonium chloride dip method, ten or more specimens are to be tested. Each specimen is to be a strip that is of any convenient width, has a length of approximately 2 inches or 50 mm, and has a thickness of at least 0.060 inch or 1.5 mm. The strips are to be taken from the outside of the insulation and are to be tested with the natural curve of the insulation. The conductor and the conductor shielding are to be removed. The specimens are to be cleaned with an organic solvent, then washed with soap and water to remove traces of the solvent, rinsed with ethyl alcohol, and finally air dried. The surface of the specimens that was the outside of the insulation is not to be touched by the hands or anything else that can damage or contaminate the EPCV or XLPE. The holder for a specimen and electrode is to be made of a battery clip and an alligator clip arranged as shown in Figure 44.1. The electrode is to be a straight length of oxidation-resistant wire such as nickel/chromium resistance wire and is to be 0.04 inch or 1 mm in diameter. As shown in the illustration, the electrode is to contact the longitudinal center line of the specimen at a 45° angle on the surface of the specimen that was the outside surface of the insulation. There is to be at least 1-1/2 inches or 38 mm of specimen length between the contact point of the electrode and the free end of the specimen.

44.6 A 48 – 62 Hz rms potential of 1000 V or less is to be applied between the electrode and an 0.1 percent solution of the American Chemical Society (ACS) reagent grade of ammonium chloride (NH_4Cl) in distilled water in an open-top beaker or other glass container with 0.02 percent of Triton X-100 or an equivalent nonionic wetting agent added. The solution is to be earth-grounded through a carbon rod immersed in the solution. The apparatus is to dip each specimen vertically into the solution with the free end of the specimen entering the solution first and the action reversed as the electrode becomes immersed about 1/16 inch or 1-1/2 mm below the surface of the solution and then reversed again as the specimen is withdrawn to 1 inch or 25 mm of its length measured from the electrode to the surface of the solution. This procedure of immersion to the electrode and withdrawal to 1 inch or 25 mm is to be continuous at the rate of 15 s for each cycle of immersion and withdrawal.

44.7 Tracking occurs when the current in the circuit does not return to zero as the specimen is withdrawn to 1 inch or 25 mm of its length. If this does not occur at the initial voltage, the potential is to be increased slowly or in steps (steps of 200 V are convenient) until, ultimately, 2000 V is applied to the specimen with or without the tracking current but without a visible arc. If a visible arc appears at any point in the procedure, the potential is to be decreased until there is no visible arc as the specimen is withdrawn. The potential is then to be raised again until 2000 V is reached with or without the tracking current but without a visible arc. The foregoing constitutes break-in of a specimen and is to be achieved in 10 or fewer cycles.

44.8 After break-in, the immersion and withdrawal procedure is to continue at 2000 V for a total of 50 cycles (including the 10 or fewer cycles of break-in), or fewer cycles if arcing is visible between the electrode and the solution across the full 1-inch or 25-mm length of the insulation. The insulation is not acceptable if, during the 50-cycle testing of each of any five consecutive specimens, visible arcing occurs through two or more successive cycles on any specimen at 2000 V or a lower potential. The insulation also is not acceptable if, during the 50-cycle testing of each of ten consecutive specimens, any two specimens have visible arcing for less than two successive cycles at 2000 V or a lower potential.

45 U-Bend Discharge Test of Nonshielded Single-Conductor Cable

45.1 Finished nonshielded single-conductor cable shall not break down electrically and shall not crack, erode, or track on its outside surface when two or four specimens are prepared and tested as described in 45.2 and 45.3.

45.2 Sample lengths of the finished nonshielded single-conductor cable, each at least 5 ft or 1525 mm long, are to be tested. Four sample lengths are to be prepared for a dry-locations cable, and eight sample lengths are to be prepared for a dry-or-wet-locations cable. For a cable that is insulated as indicated in column A or B of Table 13.2 (cable for dry locations), two of these lengths are to be tested unconditioned. For a cable that is insulated as indicated in column C or D of Table 13.2 (cable for dry or wet locations), two of these lengths are to be immersed for 14 d, except for their ends, in tap water that is maintained at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F). At the end of this time, the two lengths are to be removed from the water and given 24 h to dry in still air that is at room temperature. These two immersion-conditioned lengths and two additional unconditioned lengths (two unconditioned lengths and no additional conditioned lengths in the case of a dry-locations cable) are then each to be bent at their midpoints for 180° around a mandrel of the diameter indicated in Table 45.1. The sides (legs) of each U are to be straight and parallel to one another.

Table 45.1
Multiplying factor for determining mandrel diameter for U-bend discharge test

Size of conductor	Diameter of mandrel as a multiple of the calculated outside diameter of the cable
8 – 2 AWG	6
1 – 3/0	8
4/0 AWG – 500 kcmil	10
550 – 1000	12

45.3 Each of the U-bend specimens is to be supported separately with its bend down and the legs of the U extending upward in a vertical plane. The center of each bend is to rest on a flat, horizontal metal plate that is earth grounded. A 48 – 62 Hz essentially sinusoidal rms test potential of the magnitude indicated in Table 45.2 is to be applied between the conductor in each specimen and the metal plate. In each case, the voltage is to be applied for the number of hours indicated in Table 45.2. The cable is acceptable if, for either of the two dry-locations specimens or for any of the four dry-or-wet-locations specimens, there is no electrical breakdown and there is no visible cracking, erosion, or tracking of the outside surface. A change in color or glossiness or other appearance is not cause for rejection. If any of the first two or four specimens break down or show cracking, erosion, or tracking, the test is to be repeated on each of the two or four remaining specimens. The cable is not acceptable if any of the two or four additional specimens break down or show cracking, erosion, or tracking.

Table 45.2
Test voltage and time for U-bend discharge test

Cable	Test potential in kilovolts		Test period in hours
	Unconditioned specimens	Specimens conditioned in water	
Dry-locations 5-kV cable insulated as indicated in column A or B of Table 13.2	13	none	6
Wet-or-dry-locations 5-kV cable insulated as indicated in column C of Table 13.2	20	15	100
Wet-or-dry-locations 8-kV cable insulated as indicated in column D of Table 13.2	27	20	100

46 Copper Sulphate Test of Zinc Coating on Steel Strip for and from Steel Armor

46.1 The coating of zinc on steel strip for and from steel armor shall enable specimens of the strip to comply with all of the following requirements. This is indicated in 26.19.

a) A specimen of the zinc-coated steel strip tested before forming shall not show a bright, adherent deposit of copper on any surface, including edges, after two 60-s immersions in a solution of copper sulphate.

b) A specimen of the partially uncoiled steel armor from finished cable:

1) Shall not show a bright, adherent deposit of copper after one 60-s immersion in a solution of copper sulphate, and

2) Shall not show a bright, adherent deposit of copper on more than 25 percent of any surface, including edges, after two 60-s immersions in the copper sulphate solution.

46.2 The solution of copper sulphate is to be made from distilled water and the American Chemical Society (ACS) reagent grade of cupric sulphate ($CuSO_4$). In a copper container or in a glass, polyethylene, or other chemically nonreactive container in which a bright piece of copper is present, a quantity of the cupric sulphate is to be dissolved in hot distilled water to obtain a solution that has a specific gravity slightly higher than 1.186 after the solution is cooled to a temperature of 18.3°C (65.0°F). Any free acid that might be present is to be neutralized by the addition of approximately 1 gram of cupric oxide (CuO) or 1 gram of cupric hydroxide [$Cu(OH)_2$] per liter of solution. The solution is to be diluted with distilled water to obtain a specific gravity of exactly 1.186 at a temperature of 18.3°C (65.0°F). The solution is then to be filtered.

46.3 At one end of a sample length of finished cable that has armor formed of zinc-coated steel strip, the armor is to be unwound from the outside to expose the edges and the inner surface of the formed strip, and also to facilitate working cheesecloth between the turns onto the inner surface to dry that surface during the test. To reduce the damage to the zinc coating, the strip is not to be straightened as it is unwound but is to remain in the helical form with a diameter that is not larger than about three times the cable diameter. Three 6-inch or 150-mm (axial measurement) specimens are to be cut from the partially uncoiled armor. Additionally, three straight 6-inch or 150-mm specimens are to be cut from a sample length of the zinc-coated steel strip before forming.

46.4 With prudent attention to the risks to health and to the risk of fire, the six specimens are to be cleaned with an organic solvent. Each specimen is to be examined for evidence of damage to the zinc coating, and only specimens that are not damaged are to be selected for use in the test. One specimen of the unformed strip and one specimen of the armor are to be tested.

46.5 The two selected specimens are to be rinsed in water, and all of their surfaces are to be dried with clean cheesecloth. As much of the water as possible is to be removed in the drying operation because water slows the reaction between the zinc and the solution, thereby adversely affecting the test results. The surface of the zinc is to be dry and clean before a specimen is immersed in the solution of copper sulphate. The specimens are not to be touched by the hands or anything else that can contaminate or damage the surfaces.

46.6 A glass, polyethylene, or other chemically nonreactive beaker having a diameter approximately equal to twice the diameter measured over the specimen of partially uncoiled armor is to be filled with the solution of copper sulphate to a depth of not less than 3 inches or 76 mm. The temperature of the solution is to be maintained at 18.3 $\pm$1.1°C (65.0 $\pm$2.0°F).

46.7 One of the selected specimens is to be immersed in the solution and is to be supported on end in the center of the beaker with at least half of its axial length immersed. The specimen is to remain in the solution for 60 s, during which time it is not to be moved nor is the solution to be stirred.

46.8 At the end of the 60 s period, the specimen is to be removed from the beaker, rinsed immediately in running tap water, rubbed with clean cheesecloth (a clean soft-bristle test-tube or bottle brush in good condition and of applicable size may be used to rub the interior surfaces of the specimen of partially uncoiled armor, but cheesecloth is to be used on the other surfaces of this specimen and on the unformed strip) until any loosely adhering deposits of copper are removed, and is then to be dried with clean cheesecloth. The turns of the specimen of partially uncoiled armor are not to be separated farther during this process. Again, the hands and other damaging and contaminating objects and substances are not to touch the surfaces that were immersed. The part of the specimen that was immersed is to be examined, considering each edge and broad surface separately and disregarding the portion of the specimen within 1/2 inch or 13 mm of its immersed end.

46.9 If the part of the specimen that was immersed has any deposit of bright, firmly adhering copper outside the 1/2-inch or 13-mm end portion, an estimate is to be made and recorded of the percentage of each edge and broad surface that is covered with copper.

46.10 Regardless of whether the first dip results in a bright, adherent deposit of copper, the immersion, washing, rubbing, drying, examining, estimating, and recording operations are to be repeated once using the same specimen and beaker of solution. After the second dip, the solution in the beaker is to be discarded.

46.11 The remaining specimen is to be subjected to the 2-dip procedure described in 46.7 – 46.10.

46.12 Neither the armor nor the unformed strip is acceptable if there is any bright, adherent copper showing outside the 1/2-inch or 13-mm end portion of the immersed part of the specimen of unformed strip after the first or second dip. Even if the unformed strip is acceptable, the armor is not acceptable if the specimen of partially uncoiled armor shows any bright, adherent copper after the first dip or more than 25 percent coverage after the second dip. If, after any dip there is adherent copper that is dull or dark rather than being bright and shiny, contamination is to be considered to be present. In each such instance, the results are to be disregarded and the test is to be repeated on a new specimen.

47 Test for Weight of Zinc Coating on Steel Strip for Steel Armor

47.1 The amount of zinc per unit area, including edges, that coats steel strip intended for use in steel armor shall be 0.35 oz/ft^2 or more or shall be 0.11 kg/m^2 or more when one specimen of the unformed, zinc-coated steel strip is tested as described in 47.2 – 47.8. This is indicated in 26.16.

47.2 Three 3-inch or 75-mm straight lengths of the unformed zinc-coated steel strip are to be prepared. Each specimen is to be undamaged and is to be cleaned with an organic solvent, rinsed in ethyl alcohol, and dried by exposure to still air at room temperature. One specimen is to be selected for use in the test.

47.3 The stripping solution for this test is to be prepared by mixing 500 mL of the American Chemical Society (ACS) reagent grade of HCl having a specific gravity of 1.19 with 500 mL of distilled water and giving the resulting solution time to cool to room temperature.

47.4 A clean, zinc-coated specimen whose weight is 125 g or less is to be weighed W_1 to the nearest 0.01 g. A clean, zinc-coated specimen whose weight is over 125 g is to be weighed W_1 to the nearest 0.1 g. After being weighed for W_1, the specimen is to be immersed alone in the stripping solution to a depth that covers the specimen and is to remain immersed until the violent evolution of hydrogen ceases (see caveat in 47.5) and only a few bubbles are being evolved (approximately 15 – 30 s). The same stripping solution may be used for successive specimens until the time required for stripping the zinc from the steel becomes inconveniently long. The temperature of the stripping solution is not at any time to exceed 100°F (38°C). After being stripped, the specimen is to be scrubbed under running water, dipped in hot water, and wiped or blown dry. The dry, clean, stripped specimen then is to be weighed W_2 to the same accuracy as in the weighing for W_1.

47.5 DANGER – Hydrogen is an extremely flammable gas that is lighter than air and forms explosive mixtures with air.

Use forced ventilation.

Keep heat, sparks, open flame, and non-explosion-proof electrical equipment away.

Do not smoke.

Do not inhale the gas.

47.6 The total surface area A of the specimen, including edges, that was coated with zinc is to be determined to the nearest 0.01 $inch^2$ or to the nearest 5 mm^2. Alternatively, the average thickness G of the stripped specimen is to be determined to the nearest 0.001 in or 0.025 mm.

47.7 If the surface area is known, the weight of zinc coating is to be calculated for the specimen using whichever of the following formulas applies:

$$\text{If A is in square inches, } C = \frac{(W_1 - W_2) \times 5.08}{A}$$

$$\text{If A is in square millimeters, } C = \frac{(W_1 - W_2) \times 2.280}{A}$$

in which:

C is the weight of zinc coating in ounces per square foot of coated surface or in grams per square meter of coated surface;

W_1 is the weight of the clean, coated specimen in grams;

W_2 is the weight of the dry, clean, stripped specimen in grams; and

A is the coated surface area of the specimen in square inches or in square millimeters.

47.8 If only the thickness is known, the weight of the zinc coating may be calculated using whichever of the following formulas applies:

$$\text{If G is in inches, } C = \frac{(W_1 - W_2) \times G \times 328}{W_1}$$

$$\text{If G is in millimeters, } C = \frac{(W_1 - W_2) \times G \times 0.0129}{W_1}$$

in which:

C is the weight of zinc coating in ounces per square foot of coated surface or in grams per square meter of coated surface;

W_1 is weight of the clean, coated specimen in grams;

W_2 is the weight of the dry, clean, stripped specimen in grams; and

G is the thickness of the stripped specimen in inches or millimeters.

47.9 The zinc-coated steel strip is not acceptable if the calculation for the single specimen shows that there is less zinc on the steel than 0.35 oz/ft^2 or 0.11 kg/m^2.

48 Tension Test of Interlocked Armor

48.1 Interlocked armor shall be capable of withstanding for 5 min, without opening up at any point or pulling out of a connector of the applicable size, an axial tension imparted by a weight that exerts 150 lbf or 667 N or 68 kgf.

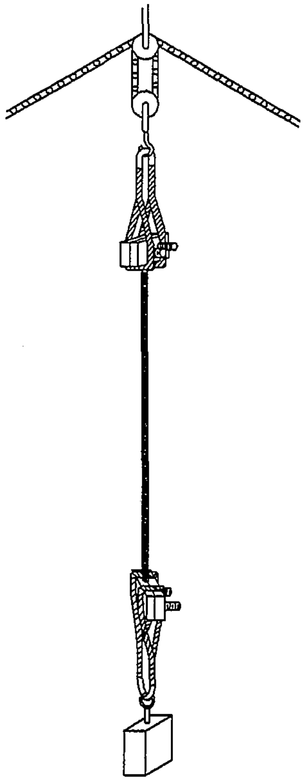
48.2 The apparatus is to consist of a pair of clamps, a weight that exerts 150 lbf or 667 N or 68 kgf, and a secure means for suspending the weight from a support. See Figure 48.1.

48.3 The clamps are to be made of hardwood, and the two pieces comprising each clamp are to be fastened together by two bolts by means of which the connector or the armor is to be clamped tightly between the jaws without being crushed. Two clamps constructed as shown in Figure 48.2 are to be provided. The weight is to be equipped with a secure means for attachment to one of the clamps. A block and tackle or a differential pulley is to be used to lift the sample, clamps, and weight.

48.4 One end of a 48-inch or 1220-mm sample length of the finished cable from which any jacket over the armor (see 27.1) has been removed is to be secured in a cable connector of the applicable size. The connector screw is to be tightened with a torque of 35 lbf-in or 47.5 N · m or 4.84 kgf-m if the head of the screw is slotted and with a torque of 160 lbf-in or 216.9 N · m or 22.1 kgf-m if the head of the screw is not slotted (hexagonal). The connector is then to be fastened in one of the clamps, and the armor at the other end of the cable is to be fastened in the second clamp with the armor gripped by the full 2 inch or 50 mm width of the clamp. The clamps are to be tightened to keep the sample from slipping but not any farther.

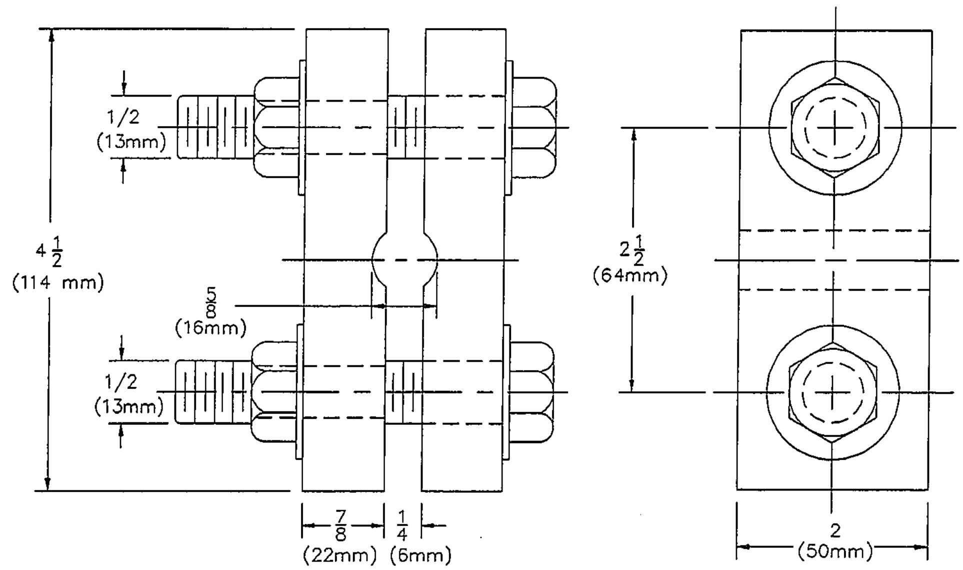
48.5 The clamp engaging the armor is to be uppermost. The sample is to be suspended by the upper clamp with a loop of rope passing over the hook of a block and tackle or a differential pulley hung from a secure support, and the weight is to be attached to the lower clamp – that is, the clamp engaging the connector. The sample is to hang vertically for its full length and at right angles to the faces of the clamps. The sample, clamps, and weight are then to be raised gently so that it takes at least 45 s to apply the tension to the sample (a rate of not more than 200 lbf/min or 890 N/min or 91 kgf/min) until the weight just clears the floor and hangs free in the air. The weight is to be kept from rotating by hand. The weight is to be supported by the sample for 5 min, is then to be let down to the floor, and the weight and clamps are to be removed. Observation is then to be made to determine whether or not the edges of adjacent convolutions of the armor have separated to expose the interior of the cable. The cable is acceptable if there is no exposure of the cable interior and the cable does not pull out of the connector because of opening or other deformation of the armor. Pull out caused by the connector breaking is to be disregarded and a new sample is to be tested. If the armor opens or pulls out of the connector, the test is to be repeated on one additional sample. The cable is not acceptable if the additional sample opens or pulls out of the connector.

Figure 48.1
Apparatus for tension test



SC0685

Figure 48.2
Clamp for tension test



SB1078

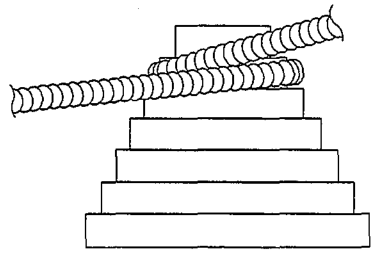
49 Flexibility Test for Cable Having Interlocked Armor or a Smooth or Corrugated Metal Sheath

49.1 Finished cable in which there is interlocked armor or a smooth or corrugated metal sheath shall be capable of being wound around a circular mandrel having a diameter equal to 14 times the diameter measured over the metal armor or sheath without damage to the armor or sheath, to the jacket or separator (see 23.1) under the armor or sheath, or to the conductor or conductor assembly.

49.2 The apparatus is to consist either of a stepped cone as shown in Figure 49.1 (each step is to be a right-circular cylinder about 2 inches or 50 mm high) or of rods or cylinders of applicable diameter.

49.3 Any jacket over the armor or sheath (see 27.1) is to be removed from two test lengths of finished cable having armor or a smooth metal sheath and from six test lengths of finished cable having a welded and corrugated metal sheath. One test length of a cable having armor or a smooth metal sheath and three test lengths of a cable having a welded and corrugated metal sheath are then to be wound around the mandrel for 180° without any more tension than is necessary to keep the armor or sheath in contact with the mandrel throughout the turn. Each length is to be tested separately. In the case of a welded and corrugated metal sheath, one sample is to be bent with the weld line located at the inner edge of the bend, a second sample is to be bent with the weld line at the outer edge of the bend, and a third sample is to be bent with the weld line midway between the inner and outer edges of the bend. While a sample is in position on the mandrel, observation is to be made to determine whether or not the jacket or separator under the armor or sheath and the conductor or conductor assembly are damaged, and the armor or sheath is to be examined for damage. Cable having a smooth or corrugated sheath is acceptable if there are no weld openings, cracks, splits, tears, or other openings in a smooth or corrugated metal sheath. Adjacent convolutions of interlocked armor may separate somewhat but cable having interlocked armor is acceptable if no part of the cable inside the armor or metal sheath is visible. If any of these faults occur on the initial specimen or specimens, the test is to be repeated on the remaining one or three specimens. The cable is not acceptable if any of these faults occur on any of the additional specimens.

Figure 49.1
Stepped cone for flexibility test



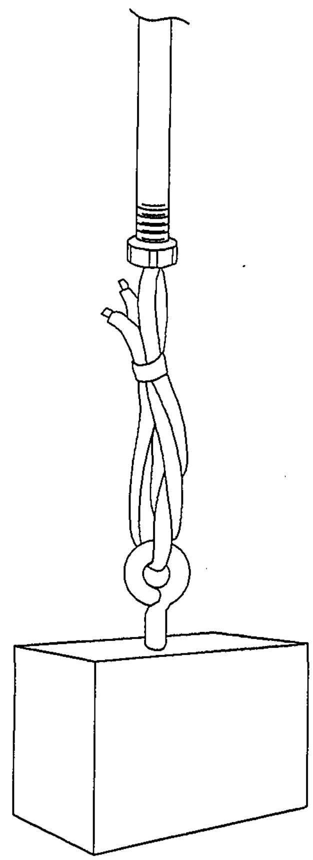
50 Test for Tightness of Armor or Metal Sheath

50.1 Any interlocked armor or smooth or corrugated metal sheath in a cable shall grip the underlying construction to keep it from being withdrawn from a 10-ft or 3-m sample of the finished cable by the application of a weight that exerts a pull of 30 lbf or 133 N or 13.6 kgf.

50.2 The apparatus is to consist of a 10 ft or 3 m length of pipe with an inside diameter that enables the cable sample to be pulled through the pipe, pipe caps with holes slightly larger in diameter than the inside diameter of the armor or metal sheath to be tested, and a weight that exerts a pull of 30 lbf or 133 N or 13.6 kgf. The pipe is to be used to keep a test sample approximately straight, and is to be supported in a vertical position with the pipe cap attached to the lower end. The pipe cap is to be used to provide a shoulder against which the armor or metal sheath of the sample can rest. The edges of the hole are to be rounded.

50.3 Two samples of the finished cable are to be cut to a length of 10-1/2 ft or 3150 mm and the armor or metal sheath is to be removed for 6 inches or 150 mm at one end of each sample. The ends of the armor or metal sheath are to be cut square and all burrs of metal are to be removed. One sample is then to be drawn into the pipe with the exposed 6 inch or 150 mm section of the conductor(s) projecting through the hole in the cap at the lower end of the pipe. The weight is to be attached to the conductor or assembly of conductors projecting through the hole, with the conductor or assembly not rubbing on the sides of the hole in the cap. The pipe in its vertical position is to be raised gently so that the weight just clears the floor and then hangs free for 60 s (see Figure 50.1). The cable is acceptable if the end(s) of the conductor(s) do not recede into the armor or metal sheath at the upper end a distance greater than 1/2 inch or 13 mm. If the conductor(s) of the first sample recede more than 1/2 inch or 13 mm, the test is to be repeated with the remaining sample. The cable is not acceptable if the conductor(s) of the additional sample recede more than 1/2 inch or 13 mm.

Figure 50.1
Test for tightness of
armor or metal sheath



SB1133

51 Test for Partial Discharge (Corona) Level of Each Circuit Conductor Having Insulation Shielding

51.1 Requirement

51.1.1 The partial-discharge extinction level shall be at least the voltage indicated in Table 51.1 when the discharge falls below 5 pC in a test of each shielded circuit conductor in every length of finished cable. This test is to be made as described in 51.2.1 – 51.6.2. This test is to be made before the dielectric-withstand and insulation-resistance tests described in Sections 52, 53, 55, and 57.

Table 51.1
Partial-discharge extinction level

Voltage rating of cable (phase-to-phase circuit voltage)	Minimum partial-discharge extinction level in kilovolts	
	100 percent insulation level (grounded neutral)	133 percent insulation level (ungrounded neutral)
5000	4[a]	5[a]
8000	6	8
15000	11	15
25000	19	26
28000	21	–
35000	26	–

[a] For the 5000-V rating, the insulation thicknesses are the same for the 133 percent insulation level as for the 100 percent insulation level and so insulation thickness is not an indication of the insulation level as it is for all of the other ratings (see thicknesses in Table 13.1). Unless the higher level is indicated by one of the following markings as covered in 68.1(b)(1), a 5000-V shielded circuit conductor is to be tested as being of the 100 percent insulation level (4-kV extinction level):

ungrounded neutral	133 percent insul. level	100 or 133 percent insul. level	grounded or ungrounded neutral
	133 percent insulation level	100 or 133 percent insulation level	

51.2 Definitions

51.2.1 PARTIAL DISCHARGE LEVEL – The partial discharge level of the shielded conductor under test is the maximum continuous or repetitious apparent charge transfer, measured in picocoulombs, occurring at the test voltage.

51.2.2 PARTIAL-DISCHARGE EXTINCTION LEVEL – The partial-discharge extinction level is the voltage at which the apparent charge transfer falls to 5 pC or less when measured in the manner described in this test, as the applied voltage is decreased from the prescribed initial value.

51.3 Test apparatus

51.3.1 The test apparatus is to consist of:

a) An alternating-current power supply having a kilovolt-ampere capacity for the length of shielded conductor under test. For the purposes of this test procedure, filters, inductors, and other necessary equipment up to the point at which the shielded conductor under test is connected are to be considered part of the power supply. The high-voltage circuits, the conductor terminations, and the test facility are to be designed and operated in such a manner that the basic interference level indicated on the measuring device corresponds to a charge transfer of not more than 4 pC.

b) A voltage-measuring device connected directly to the test conductor in such a manner that it corresponds to the voltage impressed across the dielectric.

c) A partial-discharge measuring device consisting of a primary detection circuit, an amplifier, and an oscilloscope. The amplifier output is to be displayed on an oscilloscope using a power-frequency time base.

d) A partial-discharge calibrator consisting of a pulse generator and a capacitor. The charge-transfer method (in which the charge transfer in coulombs is equal to the product of the coupling capacitance of the calibrating capacitor in farads and the calibrating pulse amplitude in volts: $Q = CV$) is to be used to calibrate the test equipment.

e) Supplementary partial-discharge meters and graphic recorders may be used to monitor the amplifier or oscilloscope output of the partial-discharge measuring device. Supplementary meters may be used as a primary display.

51.4 Calibration of test equipment

51.4.1 CALIBRATION SCHEDULE – The test equipment is to be calibrated at the beginning of each working shift by testing according to 51.4.2 – 51.4.6. In addition, the test equipment is to be recalibrated at any time that the shielded conductor being tested is not of the same general construction as the shielded conductor used for the most recent calibration, or at any time that the length of the shielded conductor being tested differs by more than 25 percent from the length of the shielded conductor used for the most recent calibration.

51.4.2 CALIBRATION PROCEDURE – The partial-discharge calibrator is to be connected to the conductor at the end opposite that of the partial-discharge detection circuitry. The calibrator ground is to be connected to the metal component of the insulation shielding at the end opposite to that of the partial-discharge detection circuitry. For test lengths that are shorter than 100 ft or 30.5 m, the calibrator may be connected to either end of the shielded conductor.

51.4.3 With one end of the shielded conductor connected to the high-voltage power source and to the partial-discharge detection circuit, the amplifier gain is to be adjusted so that the following minimum primary-display sensitivity requirements are complied with:

a) If the primary display is an oscilloscope, each scale division is to represent not more than 10 pC. Scale divisions of approximately 10 mm are to be used. For meters and recorders, 10 pC is to represent not less than 10 percent of full scale.

b) A detector response is to be obtainable for a charge transfer of 5 pC or less.

c) The display range is to extend through at least 55 pC.

51.4.4 The gain and response of supplementary measuring devices used for recording the test results or for conducting the test are to be adjusted to meet the minimum primary-display requirements.

51.4.5 The scale used for indicating partial discharge is to be linear between zero and an end point that is not less than 50 pC. The display deflection for 50 pC (or the nearest value obtainable with the calibrator being used) is to be determined using the partial-discharge calibrator. If the equipment being used is not linear, the scale is to be calibrated at values of approximately 5, 25, and 50 pC, or at three values throughout the range that are the nearest obtainable with the partial-discharge calibrator being used.

51.4.6 A means of displaying the calibration signal is to be provided. The amplifier gain is to be adjusted only while the calibration signal is displayed. The sensitivity of displays used to conduct the test or record data is not to be less than given in 51.4.3 – 51.4.5. The calibrating signal is to be provided by one of the following:

a) A calibrating capacitor that is rated for the full voltage and forms part of the primary calibration circuit so that it need not be disconnected while the power supply is energized.

b) A secondary calibrating pulse that is injected across the detection impedance by means of a capacitor that is not larger than 2000 pF. In this case, the amplitude of the secondary pulse response is to be calibrated against the primary calibrating circuit before the power supply is energized.

51.5 Items to be tested

51.5.1 Every conductor having insulation shielding in each of the following finished cables shall be tested. One hundred percent of production shall be tested by the cable manufacturer at the cable factory. A cable is not acceptable if any shielded conductor in it has an extinction level lower than specified in 51.1.1.

a) Shielded single-conductor cable.

b) Multiple-conductor cable consisting of an assembly of shielded single-conductor cables.

c) Multiple-conductor cable with individually shielded circuit conductors within an overall covering.

51.6 Test procedure

51.6.1 TEST VOLTAGE – A sinusoidal rms test voltage having a frequency of 49 – 61 Hz is to be applied between the conductor and the metal component of the insulation shielding. The applied voltage is to be raised to a value at least 20 percent greater than the minimum partial-discharge extinction level indicated in Table 51.1 but is not to exceed the a-c test voltage specified for the dielectric withstand test in 52.1 or 53.1. The voltage is then to be lowered to determine the partial-discharge extinction level as described in 51.3.1.

51.6.2 VOLTAGE APPLICATION – The applied voltage is not to be maintained for more than 3 min during any single test.

52 A-C Dielectric Withstand Test of Each 5-kV Conductor Having Insulation Shielding

52.1 The insulation (100 and 133 percent insulation levels) in each shielded conductor in every length of finished 5-kV cable shall withstand for 5 min without breakdown a 23 – 62 Hz essentially sinusoidal rms test potential of 13 kV. This test is to be made as described in 52.2 – 52.6. It is to be conducted after the test described in Test for Partial Discharge (Corona) Level of Each Circuit Conductor Having Insulation Shielding, Section 51, for partial discharge level and before the test for insulation resistance described in Test for Insulation Resistance of Each Conductor Having Insulation Shielding, Section 57.

52.2 The test apparatus is to consist of a means (such as a circuit breaker) connected in series with the conductor under test for indicating a heavy flow of current in the test circuit, and a testing transformer that complies with the following. The test potential is to be supplied by a 23 – 62 Hz isolation transformer whose output potential is continuously variable from near zero to at least the specified rms test potential. With a test conductor in the circuit, the output potential is to have a crest factor (peak voltage divided by rms voltage) equal to 95 – 100 percent of the crest factor of a pure sine wave over the upper half of the output range. The output voltage is to be monitored continuously by a voltmeter that:

a) If of the analog rather than digital type, shall have a response time that does not introduce a lagging error greater than 1 percent of full scale at the specified rate of increase in voltage, and that

b) Has an overall accuracy that does not introduce an error exceeding 5 percent.

The maximum current output of which the transformer is capable shall enable routine testing of full reels of the cable without tripping of the circuit breaker by the charging current but in no case shall the transformer have a capacity lower than 5 kVA. One end of the output winding of the transformer is to be bonded to the core of the transformer. The core shall be earth-grounded.

52.3 Each 5-kV conductor having insulation shielding in each of the following finished cables shall be tested. One hundred percent of production shall be tested by the cable manufacturer at the cable factory.

a) Shielded single-conductor cable.

b) Multiple-conductor cable consisting of an assembly of shielded single-conductor cables.

c) Multiple-conductor cable with individually shielded circuit conductors within an overall covering.

52.4 The metal components of all insulation shielding in the cable and any metal sheath or armor shall be connected together and to the point of earth grounding on the core of the transformer. The test potential is to be applied in turn between each circuit conductor and the earth-grounded metal component(s) of the insulation shielding.

52.5 The initially applied rms potential may be anywhere in the range of near zero to 5000 V. The initially applied voltage is to be increased at an essentially uniform rate that:

a) Is not less than 100 percent of the voltage rating for the conductor in 60 s, and

b) Is not more than 100 percent in 10 s (the rate of increase is not to exceed 500 V/s in any case).

The increase is to continue in this manner until the rms test potential reaches 13,000 V. If this level is reached without breakdown, the voltage is to be held constant at 13,000 for 5 min and then is to be reduced to near zero at the rate mentioned above. The cable is not acceptable if, for any circuit conductor in the cable, breakdown occurs at less than 13,000 V as the voltage is being increased or decreased or if breakdown occurs in less than 300 s (5 min) at 13,000 V.

52.6 During the period of application of the test voltage, observation is to be made to determine whether there is any current leakage or rupture of the insulation as indicated by tripping of the circuit breaker or other means. After the test, the test leads are to be connected together and the circuit is to be closed to make certain that the current-indicating means is functioning as intended.

53 A-C Dielectric Withstand Test of Each 8 – 35 kV Conductor Having Insulation Shielding

53.1 The insulation (100 and 133 percent insulation levels) in each shielded conductor in every length of finished 8 – 35 kV cable shall withstand for 5 min without breakdown a 23 – 62 Hz essentially sinusoidal rms test potential of the magnitude indicated in Table 53.1. This test is to be made as described in 52.2 – 52.6 with the "5000 V" in 52.3 and 52.5 replaced by 8000, 15000, 25000, 28000, or 35000 V as applicable to the rating of the shielded conductor(s) under test and with the "13,000 V" in 52.5 replaced by the applicable test voltage for the rating and percent insulation level from Table 53.1. This test is to be conducted after the test described in Section 51 for partial discharge level and before the tests for insulation resistance described in Section 57, which is to be followed by the d-c dielectric withstand test described in Section 55.

Table 53.1
A-C dielectric withstand rms test potential in kilovolts for 8-35 kV shielded conductors

Voltage rating of cable (phase-to-phase circuit voltage)	100 percent insulation level (grounded neutral)	133 percent insulation (ungrounded neutral)
8000	18	22
15000	27	33
25000	38	49
28000	42	–
35000	49	–

54 A-C Dielectric Withstand Test of Each Nonshielded Conductor

54.1 The insulation in each nonshielded conductor for and in every length of cable that is not, at the cable manufacturer's option (see 54.2), alternatively subjected to the tests for insulation resistance described in Test for Insulation Resistance of Each Nonshielded Conductor, Section 58, followed by the d-c dielectric withstand test described in D-C Dielectric Withstand Test of Each 8 – 35 kV Conductor Having Insulation Shielding, Section 55, shall withstand for 5 min without breakdown a 23 – 62 Hz essentially sinusoidal rms test potential of 13 kV for 5-kV cable and 18 kV for 8-kV cable followed by the tests for insulation resistance described in Section 58. The a-c dielectric withstand test is to be made as described in 54.3 – 54.5.

54.2 This alternative of a-c dielectric withstand followed by insulation resistance or the other alternative (see 56.1) of insulation resistance followed by d-c dielectric withstand shall be chosen by the cable manufacturer. The alternative chosen for a given size and construction at a given factory shall be applied to 100 percent of production of that size and construction at that factory. Within a factory, different alternatives may be chosen for different sizes of the same construction. The same alternative shall be chosen for testing the individual conductors of a multiple-conductor cable before and after they are assembled into the cable.

54.3 The test apparatus for the a-c dielectric withstand test is to be as described in 52.2.

54.4 Each nonshielded conductor shall be tested before assembly into a multiple-conductor cable, and every nonshielded conductor in each of the following finished cables shall be tested:

a) Nonshielded single-conductor 5-kV cables as indicated in columns A, B, and C of Table 13.2, and nonshielded single-conductor 8-kV cable (100 percent insulation level) as indicated in column D of Table 13.2.

b) Multiple-conductor cable without an overall covering and with nonshielded conductors as indicated in columns A, B, C (5 kV), and D (8 kV – 100 percent insulation level) of Table 13.2.

c) Multiple-conductor 5-kV cable with an overall covering and with individual nonshielded conductors insulated (100 and 133 percent insulation levels) as indicated in Table 13.1 with or without a nonconductive jacket on each conductor.

54.5 Any metal sheath or armor in a multiple-conductor cable shall be connected to the point of earth grounding on the core of the transformer. In such cable, the test potential is to be applied in turn between each circuit conductor and the earth-grounded metal sheath or armor, with any other circuit conductors connected together and to the metal sheath or armor. All other multiple-conductor cable (multiple-conductor cable without a metal sheath or armor and with or without an overall nonconductive jacket), each individual conductor of a multiple-conductor cable before assembly into the cable, and all single-conductor cable shall be immersed (see 54.6) for at least 6 h in tap water that is at any one temperature in the range of 40.0 – 85.0°F (4.4 – 29.4°C) and shall be tested while still immersed. The ends of all conductors that are immersed in water are to extend well away from the water and are to be dry and clean. For water-immersed cable, the test potential is to be applied in turn between each circuit conductor and an electrode that is earth-grounded and is in contact with the water in which the cable is immersed, with any other circuit conductors connected together and to the electrode. In all cases, the test potential is to be applied and the results judged as indicated in 52.5 and 52.6, with the 5000 V and 13,000 V mentioned in 52.5 being used for a 5-kV conductor and with these potentials changed to 8000 V and 18,000 V for the 8-kV (100 percent insulation level) construction in column D of Table 13.2.

54.6 If at the time of immersion the temperature of any part of the coil or reel differs by more than 5.0°F (2.8°C) from the temperature of the water, one of the following is to be done to make certain that the water and each insulated conductor are at the same temperature at the time that the insulation resistance is measured:

a) An insulated conductor is to be considered to be at the same temperature as the water in which it is immersed whenever the same d-c resistance of the conductor is obtained in each of three successive measurements made at 30-min intervals by means of the equipment mentioned in 7.4.

b) The water is to be heated or cooled, as necessary, to within 5.0°F (2.8°C) of the temperature of the insulated conductor(s) before the coil or reel is immersed.

55 D-C Dielectric Withstand Test of Each 8 – 35 kV Conductor Having Insulation Shielding

55.1 The insulation (100 and 133 percent insulation levels) in each shielded conductor in every length of finished 8 – 35 kV cable shall withstand for 15 min without breakdown a d-c test potential of the magnitude indicated in Table 55.1. This test is to be conducted after three other tests have been completed – the test described in Test for Partial Discharge (Corona) Level of Each Circuit Conductor Having Insulation Shielding, Section 51, for partial-discharge level, followed by the a-c dielectric withstand test described in 53.1, and then the test for insulation resistance described in Test for Insulation Resistance of Each Conductor Having Insulation Shielding, Section 57. This test for d-c dielectric withstand is to be made as described in 55.2 – 55.6.

Table 55.1
D-C dielectric withstand test potential in kilovolts for 8-35 kV shielded conductors

Voltage rating of cable (phase-to-phase circuit voltage)	100 percent insulation level (grounded neutral)	133 percent insulation level (ungrounded neutral)
8000	45	45
15000	70	80
25000	100	125
28000	105	–
35000	125	–

55.2 The test apparatus is to consist of a means (such as a circuit breaker) connected in series with the conductor under test for indicating a heavy flow of current in the test circuit, and a supply of direct current that complies with the following. The test potential is to be continuously variable from near zero to at least the specified test potential and is to be obtained from a battery or generator or from a-c supplied rectifying equipment. The test potential from a battery or generator is to be monitored continuously by an electrostatic voltmeter. The test potential from rectifying equipment is to be monitored continuously either directly by an electrostatic voltmeter or indirectly by a low-voltage indicator that is connected to make its readings independent of any test load. Rectifying equipment shall include a resistive load and capacitors that keep the ripple component of the d-c output potential from exceeding 4 percent whether or not a test load is connected. The maximum current of which the d-c supply is capable shall enable routine testing of full reels of cable without tripping of the circuit breaker by the charging current but in no case shall the supply have a capacity lower than 2.5 kVA. The negative side of the d-c output of any generator or rectifying equipment used shall be bonded to the frame of the generator or to the metal enclosure of the rectifying equipment. The frame of a generator or the metal enclosure of rectifying equipment shall be earth-grounded.

55.3 Every 8 – 35 kV conductor having insulation shielding in each of the following finished cables shall be tested. One hundred percent of production shall be tested by the cable manufacturer at the cable factory.

a) Shielded single-conductor cable.

b) Multiple-conductor cable consisting of an assembly of shielded single-conductor cables.

c) Multiple-conductor cable with individually shielded conductors within an overall covering.

55.4 The metal components of all insulation shielding in the cable and any metal sheath or armor shall be connected together and to the point of earth grounding of the negative side of the d-c supply. The test potential is to be applied in turn between each conductor and the earth-grounded metal component(s) of the insulation shielding.

55.5 The initially applied d-c potential may be anywhere in the range of near zero to 3 times the applicable a-c voltage rating in the first column of Table 55.1. The initially applied voltage is to be increased at an essentially uniform rate that is not less than 100 percent of the a-c voltage rating for the conductor in 60 s, and is not more than 100 percent in 10 s (the rate of increase is not to exceed 500 V/s in any case). The increase is to continue in this manner until the d-c test potential reaches the test voltage in Table 55.1 that is applicable to the rating and percent insulation level. If this voltage is reached without breakdown, the voltage is to be held constant for 15 min and then is to be reduced to near zero at the rate mentioned above. The cable is not acceptable if, for any conductor in the cable, breakdown occurs at less than the specified test potential as the voltage is being increased or decreased or if breakdown occurs in less than 900 s (15 min) at the specified test potential.

55.6 During the period of application of the test voltage, observation is to be made to determine whether there is any current leakage or rupture of the insulation as indicated by tripping of the circuit breaker or other means. After the test, the test leads are to be connected together and the circuit is to be closed to make certain that the current-indicating means is functioning as intended.

56 D-C Dielectric Withstand Tests of Each Nonshielded Conductor

56.1 The insulation in each nonshielded conductor for and in every length of cable that is not, at the cable manufacturer's option (see 56.2), alternatively subjected to the a-c dielectric withstand test described in Section 54 followed by the test for insulation resistance described in Section 57 – 59, shall first be subjected to the test for insulation resistance described in Section 57 – 59 and shall then withstand for 5 min without breakdown a d-c test potential of 35 kV for 5-kV cable and 45 kV for 8-kV cable. The d-c dielectric withstand test is to be made as described in 56.2 – 56.4.

56.2 This alternative of insulation resistance followed by d-c dielectric withstand or the other alternative (see 54.1) of a-c dielectric withstand followed by insulation resistance shall be chosen by the cable manufacturer. The alternative chosen for a given size and construction at a given factory shall be applied to 100 percent of production of that size and construction at that factory. Within a factory, different alternatives may be chosen for different sizes of the same construction. The same alternative shall be chosen for testing the individual conductors of a multiple-conductor cable before and after they are assembled into the cable.

56.3 The test apparatus for the d-c dielectric withstand is to be as described in 55.2.

56.4 All of the conductors noted in 54.4 shall be tested.

56.5 Any metal sheath or armor in a multiple-conductor cable shall be connected to the point of earth grounding of the negative side of the d-c supply. In such cable, the test potential is to be applied in turn between each circuit conductor and the earth-grounded metal sheath or armor, with any other circuit conductors connected together and to the metal sheath or armor. All other multiple-conductor cable (multiple-conductor cable without a metal sheath or armor and with or without an overall nonconductive jacket), each individual conductor of a multiple-conductor cable before assembly into the cable, and all single-conductor cable shall be immersed (see 54.6) for at least 6 h in tap water that is at any one temperature in the range of 40.0 – 85.0°F (4.4 – 29.4°C) and shall be tested while still immersed. For water-immersed cable, the test potential is to be applied in turn between each circuit conductor and an electrode that is earth-grounded and is in contact with the water in which the cable is immersed, with any other circuit conductors connected together and to the electrode. In all cases, the test potential is to be applied and the results judged as indicated in 52.5 and 52.6, with the "5000 V" and "13,000 V" mentioned in 52.5 changed to 5000 V and 35,000 V for a 5-kV conductor and with these potentials changed to 8000 V and 45 kV for the 8-kV (100 percent insulation level) construction in column D of Table 13.2.

57 Test for Insulation Resistance of Each Conductor Having Insulation Shielding

57.1 The insulation (100 and 133 percent insulation levels) in each shielded conductor in every length of finished 5 – 35 kV cable shall have an insulation-resistance constant K at a temperature of 60.0°F (15.6°C) that is not less than the number of megohms (based on 1000 conductor feet or based on a conductor kilometer) indicated for the particular insulation material in item V of Table 12.3 for XLPE or item IV of Table 12.6 for EP when the insulation resistance is measured and K is calculated as described in 57.2 – 57.6. For 5-kV conductors, the insulation resistance is to be measured after the a-c dielectric withstand test described in Section 52. For 8 – 35 kV conductors, the insulation resistance is to be measured after the a-c dielectric withstand test described in 53.1 and before the d-c dielectric withstand test described in Section 55.

57.2 All production of the conductors noted in 52.3 shall be tested.

57.3 The measuring equipment and test procedure shall be applicable but otherwise are not specified. A megohm bridge used for these measurements shall be of applicable range and calibration, shall present readings that are accurate to 10 percent or less of the value indicated by the meter, and shall have a 125-V or higher open-circuit potential.

57.4 Each conductor being tested is to be in thermal equilibrium with its surroundings at any one temperature in the range of 40.0 – 85.0°F (4.4 – 29.4°C) at the time that the insulation resistance is measured. If the temperature of the cable at the time of measurement differs from 60.0°F (15.6°C), the insulation resistance is to be adjusted to the insulation resistance at 60.0°F (15.6°C) by multiplying the measured value by the factor M taken from the applicable column of Table 59.1 at the measurement temperature. The column that applies to the particular insulation is to be determined as described in Section 59.

57.5 Shielded single-conductor cables are to be tested between the conductor and the shielding. Shielded multiple-conductor cables are to be tested between each conductor and its shielding. In each case, the metal conductor is to be connected to the test equipment and the reading of insulation resistance is to be taken after electrification for 60 s. The constant K at a temperature of 60.0°F (15.6°C) is to be calculated from the formula

$$K = \frac{L \times R}{1000 \times \log_{10}\frac{D}{d}}$$

in which:

R is the measured insulation resistance in megohms adjusted to 60.0°F (15.6°C) (see 57.4 and Table 59.1),

K is the constant for the insulation (specified in the insulation properties requirements),

L is the length of circuit conductor being tested in feet or meters,

D is the measured diameter over the insulation, and

d is the measured diameter under the insulation.

57.6 A test at 60.0°F (15.6°C) is to be made for a coil or reel that does not show acceptable results when the temperature of the insulation is other than 60.0°F (15.6°C).

57.7 If coils or reels are connected together for the insulation-resistance test and acceptable results are not obtained, the coils or reels are to be retested individually to determine which ones have at least the minimum K.

58 Test for Insulation Resistance of Each Nonshielded Conductor

58.1 The insulation in and any individual nonconductive jacket on each nonshielded conductor for and in every length of cable shall have an insulation-resistance constant K at a temperature of 60.0°F (15.6°C) that is not less than the number of megohms (based on 1000 conductor feet or based on a conductor kilometer) indicated for the particular insulation material in item V of Table 12.3 for XLPE or item IV of Table 12.6 for EP when the insulation resistance is measured and K is calculated as described in 58.2 – 58.4. For conductors that the cable manufacturer chooses to subject to an a-c dielectric withstand test (see 54.1 and 54.2), the insulation resistance is to be measured after the a-c dielectric withstand test described in Section 54. For conductors that the cable manufacturer chooses to subject to a d-c dielectric withstand test (see 56.1 and 56.2), the insulation resistance is to be measured after at least 6 h of immersion but before the d-c dielectric withstand test described in Section 56.

58.2 All production of the conductors noted in 54.4 shall be tested.

58.3 The test apparatus and temperature are to be as described in 57.3 and 57.4.

58.4 Nonshielded single-conductor cables are to be tested between the conductor and water while still immersed either after the a-c dielectric withstand procedure described in 54.5, or after immersion (see 54.6) for at least 6 h in tap water that is at any one temperature in the range of 40.0 – 85.0°F (4.4 – 29.4°C). Nonshielded multiple-conductor cables without any overall covering are to be tested while still immersed. Multiple-conductor cables having an overall metal sheath, overall armor, or an overall nonconductive jacket are to be tested between each conductor and all other conductors connected together and to any metal sheath or armor. In each case, the metal conductor is to be connected to the test equipment and the reading of insulation resistance is to be taken after electrification for 60 s. The constant K at a temperature of 60.0°F (15.6°C) is to be calculated from the formula in 57.5. See 57.6 and 57.7.

59 Test Procedure for Determining the Multiplying-Factor Column for Adjusting Insulation Resistance

59.1 Two samples, conveniently of a No. 14, 12, or 10 AWG solid conductor with a 45-mil or 1.14-mm wall of insulation, are to be selected as representative of the insulation under consideration. The samples are to be of a length (at least 200 ft or 60 m) that yields insulation-resistance values that are stable within the calibrated range of the measuring instrument at the lowest water-bath temperature.

59.2 The two samples are to be immersed in a water bath equipped with heating, cooling, and circulating facilities. The ends of the samples are to extend at least 2 ft or 600 mm above the surface of the water to reduce electrical leakage. The samples are to be left in the water at room temperature for 16 h before adjusting the bath temperature to 50.0°F (10.0°C) or before transferring the samples to a 50.0°F (10.0°C) bath.

59.3 The d-c resistance of the metal conductor is to be measured at applicable intervals of time until the temperature remains unchanged for at least 5 min. The insulation is then to be considered as being at the temperature of the bath indicated on the bath thermometer.

59.4 Each of the two samples is to be exposed (59.3 applies) to successive water temperatures of 50.0, 61.0, 72.0, 82.0, and 95.0°F (10.0, 16.1, 22.2, 27.8, and 35.0°C) and returning, 82.0, 72.0, 61.0, and 50.0°F (27.8, 22.2, 16.1, and 10.0°C). Insulation-resistance readings are to be taken at each temperature after equilibrium is established.

59.5 The two sets of readings (four readings in all) taken at the same temperature are to be averaged for the two samples. These four average values and the average of the single readings at 95.0°F (35.0°C) are to be plotted on semilog paper. A continuous curve (usually a straight line) is to be drawn through the five points. The value of insulation resistance at 60.0°F (15.6°C) is then to be read from the graph.

59.6 The resistivity coefficient C for a 1.0°F (0.55°C) change in temperature is to be calculated to two decimal places by dividing the insulation resistance at 60.0°F (15.6°C) read from the graph by the insulation resistance at 61.0°F (16.1°C). C heads the column of multiplying factors M that applies to the particular insulation.

Table 59.1
Multiplying factor M[a] for adjusting insulation resistance to 60.0°F (15.6°C)

Temperature		Resistivity coefficient C for 1.0°F (0.55°C)									
°F	°C	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12
40	4.4	0.55	0.46	0.38	0.31	0.26	0.22	0.18	0.15	0.12	0.10
41	5.0	0.57	0.48	0.40	0.33	0.28	0.23	0.19	0.16	0.14	0.12
42	5.6	0.59	0.49	0.42	0.35	0.30	0.25	0.21	0.18	0.15	0.13
43	6.1	0.60	0.51	0.44	0.37	0.32	0.27	0.23	0.20	0.17	0.15
44	6.7	0.62	0.53	0.46	0.39	0.34	0.29	0.25	0.22	0.19	0.16
45	7.2	0.64	0.56	0.48	0.42	0.36	0.32	0.28	0.24	0.21	0.18
46	7.8	0.66	0.58	0.50	0.44	0.39	0.34	0.30	0.26	0.23	0.20
47	8.3	0.68	0.60	0.53	0.47	0.42	0.37	0.33	0.29	0.26	0.23
48	8.9	0.70	0.62	0.56	0.50	0.44	0.40	0.36	0.32	0.29	0.26
49	9.4	0.72	0.65	0.59	0.53	0.48	0.42	0.39	0.35	0.32	0.29
50	10.0	0.74	0.68	0.61	0.56	0.51	0.46	0.42	0.39	0.35	0.32
51	10.6	0.77	0.70	0.64	0.59	0.54	0.50	0.46	0.42	0.39	0.36
52	11.1	0.79	0.73	0.68	0.63	0.58	0.54	0.50	0.47	0.43	0.40
53	11.7	0.81	0.76	0.71	0.67	0.62	0.58	0.55	0.51	0.48	0.45
54	12.2	0.84	0.79	0.75	0.70	0.67	0.63	0.60	0.56	0.54	0.51
55	12.8	0.86	0.82	0.78	0.75	0.71	0.68	0.65	0.62	0.59	0.57
56	13.3	0.89	0.86	0.82	0.79	0.76	0.74	0.71	0.68	0.66	0.64
57	13.9	0.92	0.89	0.86	0.84	0.82	0.79	0.77	0.75	0.73	0.71
58	14.4	0.94	0.93	0.91	0.89	0.87	0.86	0.84	0.83	0.81	0.80
59	15.0	0.97	0.95	0.94	0.95	0.94	0.93	0.92	0.91	0.90	0.89
60	15.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
61	16.1	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12
62	16.7	1.06	1.08	1.10	1.12	1.14	1.17	1.19	1.21	1.23	1.25
63	17.2	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.33	1.37	1.40
64	17.8	1.13	1.17	1.22	1.26	1.31	1.36	1.41	1.46	1.52	1.57
65	18.3	1.16	1.22	1.28	1.34	1.40	1.47	1.54	1.61	1.69	1.76
66	18.9	1.19	1.27	1.34	1.42	1.50	1.59	1.68	1.77	1.87	1.97
67	19.4	1.23	1.32	1.41	1.50	1.61	1.71	1.83	1.95	2.08	2.21
68	20.0	1.27	1.37	1.48	1.59	1.72	1.85	1.99	2.14	2.20	2.48
69	20.6	1.30	1.42	1.55	1.69	1.84	2.00	2.17	2.36	2.56	2.77
70	21.1	1.34	1.48	1.63	1.79	1.97	2.16	2.37	2.59	2.84	3.11
71	21.7	1.38	1.54	1.71	1.90	2.10	2.33	2.58	2.85	3.15	3.48
72	22.2	1.43	1.60	1.80	2.01	2.25	2.52	2.81	3.14	3.50	3.90
73	22.8	1.47	1.67	1.89	2.13	2.41	2.72	3.07	3.45	3.88	4.36
74	23.3	1.51	1.73	1.98	2.26	2.58	2.94	3.34	3.80	4.31	4.89
75	23.9	1.56	1.80	2.08	2.40	2.76	3.17	3.64	4.18	4.78	5.47

(Continued)

Table 59.1 (Cont'd)
Multiplying factor M[a] for adjusting insulation resistance to 60.0°F (15.6°C)

Temperature		Resistivity coefficient C for 1.0°F (0.55°C)									
°F	°C	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12
76	24.4	1.60	1.87	2.18	2.54	2.95	3.43	3.97	4.59	5.31	6.13
77	25.0	1.65	1.95	2.29	2.69	3.16	3.70	4.33	5.05	5.90	6.87
78	25.6	1.70	2.03	2.41	2.85	3.38	4.00	4.72	5.56	6.54	7.69
79	26.1	1.75	2.11	2.53	3.03	3.62	4.32	5.14	6.12	7.26	8.61
80	26.7	1.81	2.19	2.65	3.21	3.87	4.66	5.60	6.73	8.06	9.65
81	27.2	1.86	2.28	2.79	3.40	4.14	5.03	6.11	7.40	8.95	10.8
82	27.8	1.92	2.37	2.93	3.60	4.43	5.44	6.66	8.14	9.93	12.1
83	28.3	1.97	2.46	3.07	3.82	4.74	5.87	7.26	8.95	11.0	13.6
84	28.9	2.03	2.56	3.23	4.05	5.07	6.34	7.91	9.85	12.2	15.2
85	29.4	2.09	2.67	3.39	4.29	5.43	6.85	8.62	10.8	13.6	17.0

[a] Calculated from the formula $M = C^{(t - 60)}$ in which C is determined as described in Section 59 and t is the temperature of the cable in °F.

60 Vertical-Tray Flame Test

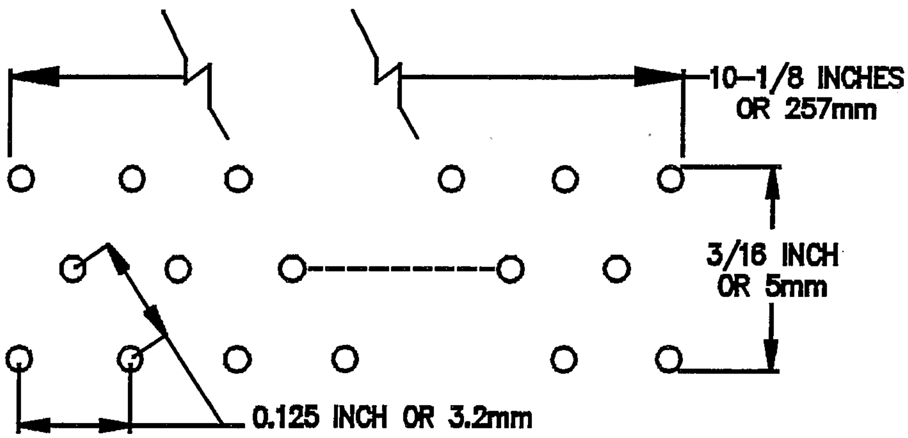
60.1 Single-conductor (No. 1/0 AWG – 1000 kcmil) and multiple-conductor (No. 8 AWG – 1000 kcmil) Type MV cables that are of any construction that includes an overall metal sheath or armor without a supplementary jacket over the metal covering are acceptable for use in cable trays without being subjected to the vertical-tray flame test described in 60.2 – 60.10. These cables may be marked for use in cable trays [68.1(g)] but are not required to be so marked. Single-conductor Nos. 8 – 1 AWG Type MV cables are not acceptable for use in cable trays. See caveat in 60.11.

60.2 Single-conductor (No. 1/0 AWG – 1000 kcmil) or multiple-conductor (No. 8 AWG – 1000 kcmil) Type MV cable that is of a given construction including either an overall jacket, or a supplementary jacket of nonconductive material over an overall metal sheath or armor, and also has the outer jacket marked [68.1(g)] to indicate that the cable is for use in cable trays if the insulation and outer jacket on that construction in the No. 1/0 AWG single-conductor cable or in the 3-conductor No. 2 AWG multiple-conductor cable rated 15 kV do not exhibit damage that reaches the upper end of any sample when two sets of samples of either cable are separately installed in a vertical ladder type of cable tray and subjected to 20 min of flame as indicated in 60.3 – 60.11.

60.3 The test flame is to be supplied by means of a strip or ribbon type of propane-gas burner[a] whose flame-producing surface consists essentially of a flat metal plate 13-7/16 inches long and 1-5/32 inches wide or 341 mm by 30 mm through which 242 holes that are 52.0 mils or 1.32 mm (No. 55 drill) in diameter are drilled on 0.125-inch or 3.2-mm centers in three staggered rows of 81, 80, and 81 holes each to form an array measuring 10-1/8 inches by 3/16 inch or 257 mm by 4.8 mm centered on the plate (see Figure 60.1).

[a] A burner (catalog No. 10L 11-55) and venturi mixer (catalog No. 14-18 that can be used to effect compliance with the requirements in 60.3 are available from the American Gas Furnace Company, Spring Street, Elizabeth, New Jersey 07201.

Figure 60.1
Burner holes



242 round holes 52.0 mils or 1.32 mm (No. 55 drill) in diameter, on 0.125-inch or 3.2-mm centers, staggered in three rows of 81 and 80 and 81, and centered on face of burner – see 60.3.

60.4 A steel ladder type of cable tray is to be securely mounted in a vertical position. The tray is to be 12 inches wide, 3 inches deep, about 96 inches long or is to measure 300 mm by 76 mm by 2400 mm. The tray is to have channel rungs that:

a) Measure approximately 1 inch or 25 mm in the direction parallel to the length of the tray and approximately 1/2 inch or 13 mm in the direction of the depth of the tray,

b) Are spaced approximately 9 inches or 230 mm apart (measured center to center), and

c) Are tack welded to the side rails.

60.5 Five sample 96-inch or 2438-mm lengths of the 250 kcmil size of the finished single-conductor cable or three such lengths of the 3-conductor No. 2 AWG multiple-conductor cable rated 15 kV are to be fastened in a single layer in the tray by means of steel wire at their upper and lower ends and at two other equally spaced points along their lengths, with each sample vertical and separated from adjacent cable(s) by an air spacing of half the measured diameter of the sample. The samples are to be centered between the side rails of the tray.

60.6 The unlit burner is to be positioned behind the cable tray containing the samples, with the flame-producing surface of the burner vertical and its long dimension horizontal and with the 10-1/8-inch or 257-mm dimension of the array of holes spaced 3 inches or 76 mm from the samples in the tray and centered midway between the side rails of the tray. The centerpoint of the array of holes is to be 18 inches or 457 mm above the bottom end of the tray and samples and midway between two rungs. The swivel arm or other support for the burner is to be arranged to enable the burner to be quickly removed from and precisely returned to the position just described. The flame-producing surface of the burner is to remain vertical and its long dimension is to remain horizontal while the burner is away from the samples. Provision is to be made for collection, removal, and nonpolluting disposal of the smoke produced during this test.

60.7 With prudent attention to the risks inherent in handling, mixing, and igniting air and propane under pressure and in the size of the flame necessary for this test, propane gas is to be entrained by air through the mixer. While the burner is positioned away from the samples and before any test is started, the burner is to be lit and its flame is to be adjusted. The rate at which the gas flows into the mixer is to be adjusted as follows:

a) Air flowing to the mixer is to be controlled at the rate of 163 ±10 SCFH (standard cubic feet per hour) or 1280 ±80 cm^3/s. This should result in a nominal air pressure of 1.7 ±0.2 inH_20 or 43 ±5 mmH_20 or 421 ±49 Pa at a temperature of (60.0°F) 15.6°C.

b) Gas flowing to the mixer is to be controlled at the rate of 28 ±1 SCFH (standard cubic feet per hour) or 220 ±8 cm^3/s using propane gas with a nominal heating value of 2500 Btu (thermochemical) per cubic foot or 93 MJ/m^3 or 22.2 kilocalories (thermochemical) per cubic meter.

60.8 While the samples, the cable tray, and the surrounding air are in thermal equilibrium with one another at a temperature of 20 ±10°C (68 ±18°F) and the air in the vicinity of the cable tray is still, the burner with its flame adjusted as indicated in 60.7 is to be moved into position behind the cable tray and samples and is to apply flame to the samples for 20 min, after which time the burner flame is to be extinguished by simultaneously closing the gas and air supply valves. Note is to be taken and records kept of both of the following:

a) The time in seconds that the samples continue to flame following removal of the burner flame, and

b) The total length of damage to the insulation in each sample and of damage to the outer jacket on each sample.

The maximum height of damage to the cable is to be determined by measuring the blistering, char, and other damage (b) upward from the bottom of the vertical tray but ignoring soot that can be removed with a cloth after the samples and tray have cooled to room temperature. Note is to be taken of any flaming run-out or drip.

60.9 The procedures outlined in 60.4 – 60.8 are to be repeated with a second set of five samples of the No. 1/0 AWG size of the single-conductor cable or with a second set of three samples of the 3-conductor No. 2 AWG multiple-conductor cable rated 15 kV.

60.10 The results of this test of a given construction using No. 1/0 AWG single-conductor samples or the 3-conductor No. 2 AWG multiple-conductor cable rated 15 kV are to be considered representative of the performance of the finished single-conductor cable of that construction in all of the sizes No. 1/0 AWG – 1000 kcmil or of the finished multiple-conductor cable of that construction in all of the sizes No. 8 AWG – 1000 kcmil. No size of a cable of a given construction is acceptable for use in cable trays if any of the samples tested exhibits damage to the outer jacket or to the insulation that reaches the upper end of the sample.

60.11 The results obtained using this test do not imply that cables of similar construction will necessarily perform the same way in other cable arrangements, other cable-tray configurations, and other environments.

61 Test for Sunlight Resistance

61.1 The EPCV or XLPE insulation of a nonshielded single-conductor cable that is insulated as indicated in column A of Table 13.2 and the nonconductive jacket of a nonshielded single-conductor cable that is insulated and jacketed as indicated in column B, C, or D of Table 13.2 are required to be sunlight resistant and so shall comply with the test requirement in 61.4 – 61.10. These single-conductor cables and any multiple-conductor cable that does not have an overall covering and is an assembly of one of these single-conductor cables shall not be marked [68.1(j)] to indicate that the cable is resistant to sunlight.

61.2 Shielded single-conductor and multiple-conductor cables that have a metal sheath or armor as the outermost covering are inherently resistant to sunlight and so shall not be marked [68.1(j)] to indicate that the cable is resistant to sunlight.

61.3 Sunlight resistance is acceptable but not required for any other outermost jacket – a conductive or nonconductive jacket or a supplementary nonconductive jacket on a shielded single-conductor cable, a nonconductive overall jacket or a supplementary nonconductive jacket on a multiple-conductor cable having an overall covering, and a conductive or nonconductive individual jacket on a circuit conductor in a multiple-conductor cable not having an overall covering. Any such jacket that is marked [68.1(j)] to indicate that the cable of which that outermost jacket is a part is resistant to sunlight shall comply with the test requirement in 61.4 – 61.10.

61.4 The EPCV or XLPE insulation mentioned in 61.1 and the marked outermost jacket mentioned in 61.3 are acceptable for use where exposed to sunlight if the ratio of the average tensile strength and ultimate elongation of five conditioned specimens of the insulation or jacket to the average tensile strength and ultimate elongation of five unaged specimens of the same insulation or jacket is 0.80 or higher when the insulation or jacket from the finished cable is tested (720 h of exposure) as outlined in 61.5 – 61.10.

61.5 Five specimens of the insulation or jacket taken from five complete specimens of the finished single- or multiple-conductor cable are to be mounted vertically in the specimen drum of carbon-arc-radiation and water-spray exposure equipment that is similar to the Type D apparatus described in the American Society for Testing and Materials "Standard Recommended Practice for Operating Light-Exposure Apparatus (Carbon-Arc-Type) with and without Water for Exposure of Nonmetallic Materials" (ASTM G 23-93). The specimens are to be centered between the top and bottom of the drum. The drum of the apparatus used is to be 31 inches or 787 mm in diameter (the diameter from the face of a specimen on one side of the drum to the face of a specimen on the opposite side of the drum is to be about 30 inches or 762 mm), 17-3/4 inches or 451 mm high, and is to revolve at the rate of 1 r/min. The apparatus is to have arcs between two sets of vertical carbon electrodes that are 1/2 inch or 13 mm in diameter and are individually enclosed in a clear globe of heat-resistant optical glass (9200-PX Pyrex glass or its equivalent) that is opaque at wavelengths shorter than 2750 angstrom units or 275 nm and whose transmission improves to 91 percent at 3700 angstrom units or 370 nm. The same horizontal plane is to bisect both arcs and is to intersect each specimen at its midpoint. The globes are to be replaced after whichever of the following occurs first: either 2000 h of use or appearance in the globes of pronounced discoloration, milkiness, or both. The globes are to be washed with detergent and water, rinsed thoroughly, and air dried at room temperature immediately before each day's operation.

61.6 Radiation from the arcs is to be kept by positive, nonmake-shift means from reaching persons within sight of the apparatus. Ventilation is to be provided to keep the specimens from being contaminated by the products of combustion in the arcs, and these products and the ozone generated are to be kept from being in any significant concentration in air breathed by persons.

61.7 Means are to be provided to enable each specimen to pass through a fine spray of water once during each revolution of the drum in the cycle of 3 and 17 min repeated as noted in 61.8. The water is to be clean, its pH is to be 6.0 – 8.0, its temperature is to be 16.0 ±5.0°C (60.0 ±9.0°F), and the water is not to be recirculated unless these conditions are maintained. While the arcs are in operation but the spray is off, the equilibrium black-panel temperature of the drum is to be 63 ±5°C (145 ±9°F).

61.8 With the drum revolving continuously at 1 r/min, with the arcs operating continuously and carrying a current of 15 – 17 A apiece at a drop in rms potential of 120 – 145 V, and with prudent attention to the risks to eyesight and to other health risks presented by the arcs, the spray is to be operated for 3 min on and 17 min off. This cycle is to be repeated six times without interruption resulting in operation with each specimen being subjected to radiation from the arcs for a total of 102 min and to the water spray with radiation from the arcs for a total of 18 min. This sequence is to be repeated resulting, in turn, in a total elapsed operating time of 720 h. The apparatus is to be turned off after the total operating time of 720 h. The specimens are to cool to room temperature before being removed from the drum for testing.

61.9 Die-cut specimens are to be prepared from the insulation or jacket conditioned in the apparatus and are to include the portions of the insulation or jacket closest to the arcs. The surfaces facing the arcs are not to be split, skived, buffed, or planed away.

61.10 The five conditioned specimens of insulation or jacket and the five unaged specimens of insulation or jacket are to be tested separately and in close succession for tensile strength and ultimate elongation. The respective averages are to be calculated from the five tensile-strength and ultimate-elongation values obtained for the conditioned specimens and are to be divided by the averages of the five tensile-strength and ultimate-elongation values obtained for the unaged specimens. The cable is not acceptable for sunlight-resistant use if either the tensile-strength or ultimate-elongation ratio is less than 0.80.

62 Hot Creep Tests

62.1 The elongation and set exhibited by EPCV, XLPE, and EP insulations at a temperature of 150.0 ±2.0°C (302.0 ±3.6°F) shall not be greater than the following percentages (this is indicated for the particular material in the applicable properties table) when a specimen(s) are prepared from the finished cable and tested as described in 62.2 – 62.20. Greater elongation or set is acceptable for filled and unfilled XLPE insulations if the loss of weight does not exceed 30 percent in a solvent extraction test made as described in ASTM D 2765-90.

EPCV	50 percent maximum acceptable elongation, item III of Table 12.7 5 percent maximum acceptable set, item III of Table 12.7
Filled XLPE insulation	100 percent maximum acceptable elongation, item II of Table 12.1 5 percent maximum acceptable set, item II of Table 12.1
Unfilled XLPE insulation	175 percent maximum acceptable elongation, item II of Table 12.1 10 percent maximum acceptable set, item II of Table 12.1
EP insulation	50 percent maximum acceptable elongation, item III of Table 12.4 5 percent maximum acceptable set, item III of Table 12.4

62.2 CIRCULATING-AIR OVEN – The oven is to have an interior size that is not smaller than 12 inches or 305 mm in both width and depth and 20 inches or 508 mm in height. The oven is to be equipped with an observation window. The heating medium is to be air that is circulated at atmospheric pressure and maintains a uniform temperature throughout the test chamber. The temperature is to be kept within ±2.0°C or ±3.6°F of the point at which it is set by means of a thermostat.

62.3 SPECIMEN SUPPORT – A specimen is to be suspended vertically by means of a battery clip or other fixed upper jaw, and an unrestrained lower jaw assembly is to be clamped to the lower end of the specimen. The lower jaw assembly is to consist of a battery or other clip that supports a pan or other receptacle in which pellets or other pieces of metal can be placed to add weight in small increments to stress the specimen. See Figure 62.1 for typical apparatus noting that the construction and dimensions are not critical and therefore are not specified. A specimen is not to touch any part of the oven or the support apparatus.

62.4 SPECIMENS – At least three specimens are to be prepared from a sample of the insulation taken from the finished cable. Any shielding is to be removed before the specimens are prepared.

62.5 For a No. 8 AWG circuit conductor having 90 mils or 2.29 mm of insulation, the specimen may be the entire cross section of the insulation (tubular specimen). Such a specimen is not to be cut longitudinally. When a partial cross section is used, the specimen is to be die-cut as indicated in 62.6 or is to be rectangular with a cross section not larger in area than 0.025 inch^2 or 16 mm^2.

62.6 For a No. 8 AWG circuit conductor having insulation thicker than 90 mils or 2.29 mm and for a No. 6 AWG – 1000 kcmil circuit conductor, a die-cut specimen with a uniform cross-sectional area not greater than 0.025 inch^2 or 16 mm^2 throughout the specimen length is to be prepared from the insulation. A die-cut specimen is to be prepared using either:

a) ASTM D 412-92 Die B or E with a specimen length of not less than 6 inches or 150 mm, or

b) ASTM D 412-92 Die C or D with a specimen length of not less than 4.5 inches or 110 mm.

A die-cut specimen is not to have any surface incisions or other imperfections.

62.7 Except when a full cross section is used, all surface irregularities (such as corrugations from stranding) are to be removed to result in a specimen that is smooth and of uniform thickness throughout its length.

62.8 ELONGATION TEST – One specimen is to be tested and the other two specimens are to be held in reserve.

62.9 An unstretched specimen is to be marked with bench marks that are 1 inch or 25 mm apart as described in 29.2.3.1 and is to be placed in the jaws of the support apparatus. The distance between the jaws is not to be greater than 4 inches or 100 mm.

62.10 Weight is to be added to the lower jaw assembly so that the total weight of the lower jaw, weight holder, and added weight provides a stress of 29.0 lbf/in^2 or 0.20 MPa or 20.4 gf/mm^2 on the specimen cross section.

62.11 The total stress weight is to be calculated using one of the following:

a) Stress weight (lbf) = cross-sectional area (in^2) x 29.0 (lbf/in^2) stress

b) Stress weight (gf) = cross-sectional area (mm^2) x 20.4 (gf/mm^2) stress

62.12 The support apparatus with the attached specimen is to be placed in the circulating-air oven, which is to have been preheated to 150.0 ±2.0°C (302.0 ±3.6°F).

62.13 After 15 min, the distance between the bench marks is to be measured using a scale calibrated with divisions of 64ths of an inch or with divisions of 0.5 mm. This distance D_e is to be recorded to the nearest 1/64 inch or 0.5 mm. See 62.16.

62.14 The hot creep elongation is to be calculated as follows:

$$C = \frac{100 \times (D_e - G)}{G}$$

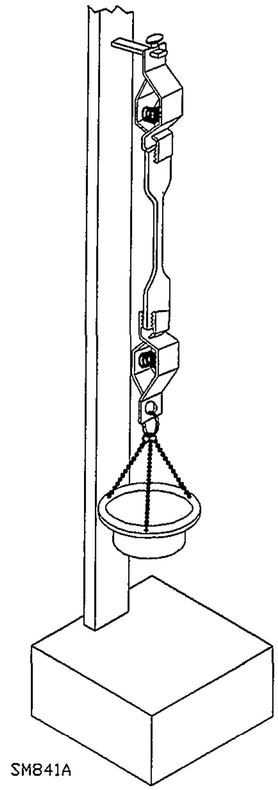
in which:

C is the hot creep elongation in percent,

D_e is the distance between the bench marks obtained in 62.13, and

G is the original distance between the bench marks (1 inch or 25 mm).

Figure 62.1
Typical specimen-support apparatus with die-cut specimen in place



The solid steel base measures 4 inches by 4 inches by 1-1/2 inches or 102 mm by 102 mm by 38 mm. The solid steel vertical support column measures 1/4 inch by 1-1/2 inch es by 17-1/2 inches or 6.4 mm by 38 mm by 445 mm (the 17-1/2-inch or 445-mm length is determined by how tall an apparatus will fit in the oven – see also 62.9). The upper ja w is secured to the vertical support column by a steel rod 1/4 inch or 6.4 mm in diamete r and 2 inches or 51 mm long.

62.15 SET TEST – The set test is to be performed on the same specimen and at the same temperature as the elongation test in 62.8 – 62.14. The set test is to be made immediately following the elongation test without removing the specimen from the oven.

62.16 The lower jaw assembly is to be removed from the specimen immediately after the measurement of D_e in 62.13. The oven door is to be closed as quickly as possible to reduce the heat loss and cooling of the specimen.

62.17 The specimen is to remain in the oven for 5 min and then is to be removed from the oven and kept in still air at room temperature to cool for at least 1 h.

62.18 The distance D_s between bench marks is then to be measured to the nearest 1/64 inch or 0.5 mm and recorded using the scale mentioned in 62.13.

62.19 The hot creep set is to be calculated as follows (the result can be positive or negative):

$$S = \frac{100 \times (D_s - G)}{G}$$

in which:

S is the hot creep set in percent,

D_s is the distance between the bench marks obtained in 62.18, and

G is the original distance between the bench marks (1 inch or 25 mm).

62.20 RESULTS – If either the hot creep elongation or set does not comply with the requirement in 62.1 when one specimen is tested, each test is to be repeated on the two remaining specimens and, for each property, the average value of the three readings is to comply. If the average for three specimens of EP insulation does not comply, the EP insulation is not acceptable. If the average for three specimens of XLPE insulation does not comply, a solvent extraction test as described in ASTM D 2765-90 may be conducted. If specimens of XLPE insulation lose more than 30 percent of their weight in the solvent extraction test, the XLPE insulation is not acceptable.

63 Test Method for D-C Conductor Resistance

63.1 Measurement of the d-c resistance of any length of conductor in ohms per thousand conductor feet or in ohms per conductor kilometer by means of the Kelvin double bridge mentioned in 7.4 is to be made on one specimen using the method described in 63.2 – 63.8. See 7.2 concerning measurement at a temperature other than 25°C (77°F) or 20°C (68°F).

63.2 A determination of the direct-current resistance of a conductor is to be made within an accuracy of 0.5 percent of the value read by means of a general-purpose Kelvin double bridge or its equivalent using one straight specimen of the conductor that is 24 – 48 inches or 610 – 1220 mm long.

63.3 Each general-purpose Kelvin-bridge current electrode is to be attached to the stranded specimen in a way – adjacent strands in mutual contact, each strand of the outer layer in full-length contact with the electrode, no strands damaged or bent, uniform pressure by the electrode at all points of strand contact, and so forth – that results in an essentially uniform distribution of current among the strands.

63.4 The distance between each general-purpose Kelvin-bridge potential electrode and its corresponding current electrode is to equal or exceed 1.5 times the circumference of the conductor specimen. The resistance of the Kelvin-bridge yoke between the reference standard and the specimen is not to be more than 0.1 percent of the resistance of the reference standard or the specimen, whichever is less, unless compensation is made for the potential leads or the coil and lead ratios are balanced.

63.5 Each general-purpose Kelvin-bridge potential electrode shall contact the conductor specimen with a surface that is a sharp knife edge (see 63.8). The length of the conductor specimen between the knife edges is to be measured to the nearest 0.01 inch or 0.2 mm.

63.6 When using the general-purpose Kelvin bridge, the conductor specimen, all equipment, and the surrounding air are to be in thermal equilibrium with one another at one temperature in the range of 15 – 30°C (59 – 86°F). All of the referee resistance measurements are to be made at that one temperature. See 7.2 and note [a] to Table 7.11.

63.7 Because the general-purpose Kelvin-bridge measuring current raises the temperature of the specimen, the magnitude of the current is to be as low as possible and the time of its use is to be brief. Too much current, too much time, or both are being used for a measurement if any change in resistance is detected with the galvanometer in two successive readings.

63.8 The contact surfaces of the general-purpose Kelvin-bridge current electrodes, the surface of the conductor specimen, and the knife edges of the general-purpose Kelvin-bridge potential electrodes are to be clean and undamaged. Contact-potential error is to be eliminated by taking four readings in direct succession: the first with the current flowing in one direction, the second with the current flowing in the other direction, then – after the specimen has been turned end for end – the third with the current flowing in one direction, and the fourth with the current flowing in the other direction. Contact-potential imbalance is to be minimized by having the potential electrodes made of the same material.

64 Test for Durability of Ink Printing

64.1 Indelible-ink printing is acceptable for the identification of the responsible organization(s) [68.1(c) and 68.2 and 68.5] if the printing remains legible after being rubbed repeatedly with a felt-faced weight as described in 64.2 – 64.5.

64.2 Two straight 300-mm or 12-inch specimens are to be cut from a sample length of the insulation or jacket taken from the finished cable, with the ink printing clearly legible. The sample and specimens are to be handled as little as possible and are not to be wiped, scraped, or otherwise cleaned in any way.

64.3 One of the specimens is to be aged in a full-draft, circulating-air oven that complies with ASTM D 573-88 and D 2436-85 (100 – 200 fresh-air changes per hour) operating for the time and at the temperature specified for the insulation or jacketing material whose outer surface is printed and is then to be removed from the oven and kept in still air to cool to room temperature for 60 min before being tested. The one remaining specimen is to rest for at least 24 h in still air at 23.0 ±5.0°C (73.4 ±9.0°F) before being tested.

64.4 The test is to be made using a weight whose lower face is machined to a flat, rectangular surface measuring 25 mm by 50 mm or 1 inch by 2 inches. The height of the weight is to be uniform to ensure even distribution of the weight throughout the area of the lower face. Clamps or other means are to be provided for securing to the lower face of the weight a layer of craft felt (composition not specified) that is approximately 1.2 mm or 0.047 inch thick. Without the felt in place, the weight and the means for securing the felt to the weight are to exert 450 ±5 g or 1 lbf ±0.2 ozf or 4.45 ±0.06 N on a specimen. The felt may be used for several tests but is to be replaced as soon as the fibers flatten or become soiled. While not in use, the weight is to be stored resting on one of its surfaces that is not covered with felt. The apparatus and the specimens are to be in thermal equilibrium with the surrounding air at a temperature of 23.0 ±5.0°C (73.4 ±9.0°F) throughout the test. Each specimen is to be placed on a solid, flat, horizontal surface with the printing up and at the center of the length of the specimen. The ends of each specimen are to be bent around supports or are otherwise to be secured to keep the printed area of the insulation or jacket from rotating out from under the weight.

64.5 The felted surface of the weight is to be placed on the printed area of a specimen with the felted surface horizontal and with the 50 mm or 2 inch dimension of the felted surface parallel to the length of the specimen. With the weight so resting on the specimen, the felt is to be slid lengthwise by hand along the printed area of the specimen for a total of three cycles. Each cycle is to consist of one complete back-and-forth motion covering the entire length of the specimen. The three cycles of rubbing are to be completed at an even pace taking a total time of 5 – 10 s. The procedure is to be repeated on the second specimen. If the printing is illegible on either of the two specimens, the cable is not acceptable.

MARKINGS

65 Intervals

65.1 All printing on the outer surface of a finished cable that has an overall jacket or supplementary jacket and on the conductive nonmetallic covering and any marker tape within a finished cable shall be repeated at the following intervals throughout the entire length of the cable:

a) Markings on the outer surface of the cable:

1) Size shall be repeated at intervals that are not longer than a nominal 24 inches or 610 mm (maximum 25 inches or 635 mm).

2) All information other than size shall be repeated at intervals that are not longer than 40 inches or 1.02 m.

b) Size and all other information on the conductive nonmetallic covering and any marker tape shall be repeated at intervals that are not longer than a nominal 24 inches or 610 mm (maximum 25 inches or 635 mm).

66 Color of Circuit Conductor(s)

66.1 The color or colors of the finished circuit conductor(s) are not specified except that green, green and yellow, or white shall not be used.

66.2 Distinctively coded or identified shields may be used to provide circuit identification or conductor identification.

66.3 The markings covered in 66.1 and 66.2 shall not conflict with or be confusable with any of the other markings required or otherwise covered in this standard.

66.4 The covering on the grounding conductor that is mentioned in 21.1 shall be green throughout the entire length and circumference of its finished outer surface with or without one or more yellow stripes of even or varying width. No other conductor in the cable shall be green or green and yellow. Each yellow stripe shall be unbroken and shall be either straight or helical. The yellow stripe or stripes shall occupy a total width – stripe width shall be measured perpendicular to the longitudinal axis of each stripe, not necessarily around the conductor circumference – of 5 – 70 percent of the calculated circumference of the outer surface of the finished conductor and no less individual width than 5 percent of the calculated circumference of the finished outer surface. See 66.5.

66.5 An NEC-standard 600-V branch-circuit conductor is acceptable as the covered grounding conductor mentioned in 21.1 if the NEC conductor:

a) Does not have any legend other than (optionally) to indicate size and/or to indicate that the conductor is only for grounding, and

b) Is painted or otherwise colored green with or without one or more yellow stripes to comply with 66.4.

67 Identification of Conductive Nonmetallic Covering Portion of Insulation Shielding

67.1 The conductive nonmetallic covering portion of the insulation shielding described in Section 15 shall be plainly identified by "SEMICONDUCTIVE – Remove before terminating or splicing" or other words to the effect that the covering is conductive and is to be removed when the conductor is terminated or spliced. The marking shall be in one of the following forms:

a) Legible ink printing directly on the outer surface of the finished extruded covering in a color or colors that contrast with the color of the covering. This printing need not comply with the durability requirements in the test described in Test for Durability of Ink Printing, Section 64.

b) Legible ink printing directly on the surface of the conductive tape before the tape is applied alone or over a conductive coating on the insulation. If a conductive coating is used under the tape, the coating shall be identified ("SEMICONDUCTIVE – Remove coating and tape before terminating or splicing" or other words to the same effect) in the marking on the conductive tape.

c) A legibly printed marker tape applied longitudinally immediately over the extruded, tape, or tape-over-coating covering. If a conductive coating is used under the conductive tape, the coating shall be identified ("SEMICONDUCTIVE – Remove coating and conductive tape before terminating or splicing" or other words to the same effect) in the wording on the marker tape.

68 On or in the Cable

68.1 The following information (except for the conductor-metal identification specified in (e), the sequence of the items is not specified) shall appear at the intervals indicated in 65.1 throughout the entire length of the finished cable. Other information may be added if it does not confuse or mislead. See also 67.1.

a) The type-letter (use of the word "Type" is optional) and temperature designation of the cable:

1) Nonshielded 5-kV single-conductor cable with EPCV or XLPE insulation without any covering over the insulation as indicated in column A of Table 13.2: "Type MV-90 dry".

2) Nonshielded 5-kV single-conductor cable with XLPE, EPCV, or EP insulation with a nonconductive jacket over the insulation as indicated in column B of Table 13.2: "Type MV-90 dry".

3) Other cables with XLPE or EP insulation: "Type MV-90". See (l).

b) The following circuit information with the voltage rating and insulation level determined by reference to the applicable Table 13.1 or 13.2:

1) SHIELDED SINGLE- AND MULTIPLE-CONDUCTOR CABLE – Maximum working voltage of the cable ("X000 volts" or "XKV") followed by "100% insul. level", "Grounded neutral", or "100% insulation level" for cables with 100 percent insulation level and "ungrounded neutral", "133% insul. level", or "133% insulation level" for cables with 133 percent insulation level. Cables rated 5000 V that comply with the requirements for the 133 percent insulation level may be marked "100 or 133% insul. level", "100 or 133% insulation level", or "grounded or ungrounded neutral".

2) NONSHIELDED SINGLE-CONDUCTOR CABLE RATED 8000 VOLTS – Maximum working voltage of the cable ("X000 volts" or "XKV") followed by "100% insul. level", "grounded neutral", or "100% insulation level" and the word "nonshielded".

3) NONSHIELDED SINGLE- AND MULTIPLE-CONDUCTOR CABLE RATED 5000 VOLTS – Maximum working voltage of the cable ("5000 volts" or "5KV") followed by the word "nonshielded".

c) The name of the cable manufacturer, that manufacturer's trade name for the cable, or both, or any other acceptable distinctive marking by means of which the organization responsible for the cable can readily be identified. If the organization responsible for the cable is different from the actual manufacturer, both the responsible organization and the actual manufacturer shall be identified by name or by acceptable coding such as by trade name, trademark, the assigned electrical reference number, or the assigned combination of colored marker threads. The meaning of any coded identification shall be made available by the organization responsible for the cable. A private labeler may also be identified. See 68.2 and 68.5.

d) The AWG or kcmil or MCM size of each circuit conductor and of any grounding conductor provided. See (e).

e) If the circuit conductors or any grounding conductor are of aluminum, the size designation shall be followed immediately by the word "aluminum" or the letters "AL". See 68.7.

f) The number of circuit conductors if there are more than one.

g) The designation "for CT use" or "for use in cable trays" if the cable complies with the vertical-tray flame-test requirements in 60.2 – 60.10. This marking is optional on cables with an overall metal covering (see 60.1).

h) The designation "oil resistant II" or "oil res II" if the cable jacket complies with the 75°C (167°F) oil-resistance requirements in the physical properties table applicable to the material:

Material	Table
Conductive material	15.2
Nonconductive CP	25.3
Nonconductive CPE	25.5
Nonconductive NBR/PVC	25.7
Nonconductive neoprene	25.9
Nonconductive PE	25.11
Nonconductive PVC	25.13

i) The designation "oil resistant I" or "oil res I" if the cable jacket complies with the 60°C (140°F) oil-resistance requirements in the physical properties table applicable to the material:

Material	Table
Conductive material	15.2
Nonconductive CP	25.3
Nonconductive CPE	25.5
Nonconductive NBR/PVC	25.7
Nonconductive neoprene	25.9
Nonconductive PE	25.11
Nonconductive PVC	25.13

j) The designation "sunlight resistant" or "sun res" if the cable jacket (see 61.3) complies with the sunlight-resistance test requirement in 61.4 – 61.10. This marking is not acceptable on single-conductor nonshielded constructions, on multiple-conductor cables consisting of an assembly of these nonshielded single-conductor cables without an overall covering (see 61.1) or on multiple-conductor cables having metal as the outermost covering (see 61.2).

k) Direct-burial cables are to be marked as indicated in 71.1 and 71.2.

l) Cable with a smooth (other than lead) or corrugated metal sheath or with interlocked metal armor may be marked "MV-90 OR MC" as applicable in (a)(3).

m) Cable with an optical-fiber member(s) shall be marked "Contains optical-fiber member(s)".

68.2 The information required in 68.1 shall appear in the following form:

a) CABLE ON WHICH THE OUTER SURFACE IS A JACKET – Legible ink, raised, or indent printing of the jacket. See 68.3.

b) CABLE ON WHICH THE OUTER SURFACE IS METAL – Legible printing on a marker tape or tapes located anywhere in a single-conductor cable other than between the insulation and the conductor shielding or between the insulation and the insulation shielding, and anywhere in a multiple-conductor cable other than within an insulated conductor.

68.3 Ink printing to identify the organization that is responsible for the cable [68.1(c)] shall be one of the following:

a) Ink printing that complies with the durability requirements in the test described in Test for Durability of Ink Printing, Section 64.

b) Ink printing that either is not tested as described in Test for Durability of Ink Printing, Section 64, or does not comply with the durability requirements in the test. This printing shall be supplemented by a marker thread or threads whose color or combination of colors is assigned. The thread or threads may be located anywhere in a single-conductor cable other than between the insulation and the conductor shielding or between the insulation and the insulation shielding, and anywhere in a multiple-conductor cable other than within an insulated conductor.

68.4 If a glass-fiber thread or threads are used, the length of lay of the filaments in each basic strand shall not be longer than 1/3 inch or 8.5 mm.

68.5 If the organization that is responsible for the cable produces Type MV cable in more than one factory, the marking to identify the organization required in 68.1(c) shall include an identification of the factory. If a colored thread or threads are used, the ply or the material of one or more of the threads used at each factory shall be different from the ply or material of the same color thread or threads used at every other factory. The organization responsible for the cable shall make available the meaning of the different plies and materials.

68.6 Indent printing and embossed printing shall not reduce the thickness of the insulation or jacket below the minimum thickness at any point indicated in the applicable one of the Tables 13.2 (column A), 15.3 (column A), 25.14, 25.15, or 27.1.

68.7 The outer surface of the insulation or covering over the insulation on each insulated aluminum conductor in a cable in which there are any conductors that are not of aluminum shall be durably and legibly ink printed, indent printed, or embossed throughout the entire length of the cable with the word "aluminum" or the abbreviation "AL".

69 Responsibility for the Insulated Conductors

69.1 NO IDENTIFICATION NEEDED – If the circuit conductors are made by or for the organization responsible for the cable in the same factory in which the cable is made, and if the organization responsible for the cable operates no other factory in which these conductors are made, no identification need be provided in or on any length of circuit conductor in a finished cable to mark the circuit conductor as the product of a particular organization or factory.

69.2 ONLY FACTORY IDENTIFICATION NEEDED – If the organization responsible for the cable operates more than one factory in which the circuit conductors are made for the acceptable Type MV cables made by or for the organization responsible for the cable, a durable and distinctive identification shall be provided in or on every length of circuit conductor in all of the organization's acceptable Type MV cables to mark the circuit conductors as the product of a particular factory unless the conductors are made in the same factory in which the cable is made. The organization need not be identified.

69.3 ORGANIZATION AND FACTORY IDENTIFICATION NEEDED – If the circuit conductors are made by or for an organization other than the organization responsible for the cable, a permanent and distinctive identification shall be provided on or in every length of circuit conductor in a finished cable to mark the circuit conductor as the product of a particular organization and factory.

70 On the Tag, Reel, or Carton

70.1 A tag on which the following information (except for the conductor-metal identification specified in (f), the sequence of the items is not specified) is indicated plainly shall be tied to every shipping length of finished cable. However, if the cable is wound on a reel or coiled in a carton, the tag may be glued, tied, stapled, or otherwise attached to the reel or carton instead of to the cable, or the tag may be eliminated and the information may be printed or stenciled directly onto the reel or carton. Other information may be added if it does not confuse or mislead.

a) The maximum voltage for which the cable is acceptable as outlined in 68.1(b)(1), (b)(2), or (b)(3).

b) The name of the cable manufacturer, that manufacturer's trade name for the cable, or both, or any other acceptable distinctive marking by means of which the organization responsible for the cable can readily be identified. If the organization that is responsible for the cable is different from the actual manufacturer, both the responsible organization and the actual manufacturer shall be identified by name or by acceptable coding such as by trade name, trademark, the assigned electrical reference number, or the assigned combination of colored marker threads. The meaning of any coded identification shall be made available by the organization responsible for the cable. A private labeler may also be identified.

c) The date of manufacture by month and year.

d) The type-letter (use of the word "Type" is optional) and temperature designation of the cable:

1) Nonshielded 5-kV single-conductor cable with EPCV or XLPE insulation without any covering over the insulation as indicated in column A of Table 13.2: "Type MV-90 dry".

2) Nonshielded 5-kV single-conductor cable with XLPE, EPCV, or EP insulation with a nonconductive jacket over the insulation as indicated in column B of Table 13.2: "Type MV-90 dry".

3) "Type MV-90".

e) The AWG or kcmil or MCM size of each circuit conductor and of any grounding conductor provided. See (f).

f) If the circuit conductors or any grounding conductor are of aluminum, the size designation shall be followed immediately by the word "aluminum" or the letters "AL". See 68.7.

g) Description of the colored-thread marker assigned to identify the organization responsible for the cable if the thread(s) are used in the cable.

h) For direct-burial cable, the wording delineated in 71.1 (cable marking) or 71.2 (tag, reel, or carton marking), as applicable.

i) For a Type MV cable with a smooth (other than lead) or corrugated metal sheath or interlocked armor "For use also as Type MC cable".

71 Marking of Direct-Burial Cable

71.1 The following cables may be marked "for direct burial", "direct burial", "dir burial", or "dir bur" on the outer surface or on the marker tape in accordance with 68.3:

a) Shielded multiple-conductor cable having a grounding conductor that complies with 20.5 and a sunlight-resistant overall jacket.

b) Nonshielded multiple-conductor 5000-V cable having either a metal sheath or armor; having a grounding conductor complying with 21.2, 21.3, or 21.4.; and having a sunlight-resistant supplementary jacket.

c) Shielded multiple-conductor cable having either a metal sheath or armor; a grounding conductor complying with 21.2, 21.3, or 21.4; and having a sunlight-resistant supplementary jacket (jacket not required over a lead sheath).

d) Shielded single-conductor cable having a lead sheath (jacket not required over the lead) or a smooth or corrugated aluminum sheath; having a grounding conductor complying with 21.3 or 21.4; and having a supplementary jacket over the aluminum sheath.

71.2 The following cables are not to be surface marked for direct burial and are not to contain a marker tape indicating direct burial but the tag, reel, or carton may be marked "For direct burial if installed in a system with a grounding conductor that is in close proximity and conforms with NEC 250-51":

a) Shielded multiple-conductor cable with a sunlight-resistant overall jacket and without a grounding conductor.

b) Shielded single-conductor cable with a sunlight-resistant overall jacket and without a metal sheath or armor.