

IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding

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of the
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Foreword

(This Foreword is not a part of IEEE Std 837-1989, IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.)

This standard has been written to fill a need for standardization of terminology and test requirements for permanent grounding connections.

Many types of connectors are available that may be used as permanent grounding connections even though they were designed for use as power connectors. This standard has been written to provide a meaningful reproducible test program that will enable connector manufacturers to qualify their products as permanent grounding connections. The users can then be reasonably assured that the qualified permanent grounding connection will be capable of performing satisfactorily over the lifetime of the substation or other installation.

This standard addresses the parameters for testing grounding connections on aluminum, copper, steel, copper-clad steel, galvanized steel, stainless steel, and stainless-clad steel.

Comments, corrections, and suggestions for the next revision of this standard are welcome and should be submitted to the Secretary, IEEE Standards Board 345 East 47th Street New York, NY 10017.

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IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding

1. Scope and Purpose

1.1 Scope

This standard provides direction and methods for qualifying permanent connections used for substation grounding. It particularly addresses the connectors used within the grid system, connectors used to join ground leads to the grid system, and connectors used to join the ground leads to equipment and structures.

1.2 Purpose

The purpose of this standard is to give assurance to the user that connectors meeting the requirements of this standard will perform in a satisfactory manner over the lifetime of the installation provided that the proper connectors are selected for the application and that the connectors are installed correctly.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

- [1] ANSI/IEEE Std 100-1988 IEEE Standard Dictionary of Electrical and Electronics Terms.¹
- [2] ASTM A363-83, Specification for Zinc-Coated (Galvanized) Steel Overhead Ground Wire Strand.²
- [3] ASTM A510-82, Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel.
- [4] ASTM A752-83, Specification for General Requirements for Wire Rods and Coarse Round Wire, Alloy Steel.
- [5] ASTM B1-85, Specification for Hard-Drawn Copper Wire.

¹ANSI/IEEE publications are available from the Sales Department of ANSI, 1430 Broadway, New York, NY 10018, or from the Service Center, IEEE, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

²ASTM publications are available from the Sales Department of American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

- [6] ASTM B2-85, Specification for Medium-Hard-Drawn Copper Wire.
- [7] ASTM B3-74 (1985), Specification for Soft or Annealed Copper Wire.
- [8] ASTM B8-86, Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft.
- [9] ASTM B49-78 (1983), Standard Specification for Hot-Rolled Copper Rods for Electrical Purposes.
- [10] ASTM B105-88, Specification for Hard-Drawn Copper Alloy Wires for Electrical Conductors.
- [11] ASTM B117-85, Method of Salt Spray (Fog) Testing.
- [12] ASTM B172-71 (1985), Specification for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors.
- [13] ASTM B173-71 (1985), Specification for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors.
- [14] ASTM B174-71 (1985), Specification for Bunch-Stranded Copper Conductors for Electrical Conductors.
- [15] ASTM B193-87, Test Method for Resistivity of Electrical Conductor Materials.
- [16] ASTM B227-70 (1980), Specification for Hard-Drawn Copper-Clad Steel Wire.
- [17] ASTM B228-88, Specification for Concentric-Lay-Stranded Copper-Clad Steel Conductors.
- [18] ASTM B229-85, Concentric-Lay-Stranded Copper and Copper-Clad Steel Composite Conductors.
- [19] ASTM B230-85, Specification for Aluminum 1350-H19 Wire, for Electrical Purposes.
- [20] ASTM B233-85, Specification for Aluminum 1350 Drawing Stock for Electrical Purposes.
- [21] ASTM B236-88, Specification for Aluminum Bars for Electrical Purposes (Bus Bars).
- [22] ASTM B258-81 (1986), Specification for Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors.
- [23] ASTM B317-88, Specification for Aluminum-Alloy Extruded Bar, Rod, Pipe, and Structural Shapes for Electrical Purposes (Bus Conductors).
- [24] ASTM B396-87, Specification for Aluminum-Alloy 5005-H19 Wire for Electrical Purposes.
- [25] ASTM B397-85, Specification for Concentric-Lay-Stranded Aluminum-Alloy 5005-H19 Conductors.
- [26] ASTM B398-85, Specification for Aluminum-Alloy 6201-T81 Wire for Electrical Purposes.
- [27] ASTM B399-86, Specification for Concentric-Lay-Stranded Aluminum-Alloy 6201-T81 Conductors.
- [28] ASTM B416-88, Specification for Concentric-Lay-Stranded Aluminum-Clad Steel Conductors.
- [29] ASTM B609-85, Specification for Aluminum 1350 Round Wire, Annealed and Intermediate Tempers, for Electrical Purposes.

3. Definitions

General definitions of words or terms of a technical nature not listed in this standard shall be as defined in ANSI/IEEE Std 100-1988 [1].³

³The numbers in brackets correspond to those of the references listed in Section 2.

conductor: A metallic substance that allows a current of electricity to pass continuously along it. As used in this standard, a conductor includes cable (wire), rods (electrodes), and metallic structures.

conductor combination: The various conductors that may be joined by a connector.

connector: A metallic device of suitable electric conductance and mechanical strength used to connect conductors.

connector thermal capacity: The ability of a connector to withstand the amount of current required to produce a specified temperature on the control conductor without increasing the resistance of the connector beyond that specified in this standard.

control conductor: The conductor that is utilized to measure equivalent changes in temperature, size, etc., that are occurring in at least one of the conductors joined by the connector under test.

current cycle loop: The combination of conductors and connectors that carries the current of the circuit under test.

equalizer: A device to provide equipotential planes for resistance measurements.

grid system: A system consisting of interconnected bare conductors buried in the earth or in concrete to provide a common ground for electrical devices and metallic structures.

permanent connection: A grounding connector that will retain its electrical and mechanical integrity for the design life of the conductor within limits established by this standard.

4. Qualification Tests

A listing of the tests to be performed for all types of connectors is given in Table 1. They shall be tested individually and sequentially, as shown in Table 1.

Table 1— Qualification Test Sequence and Quantities

Test	Section	Minimum Number of Samples
		Per Test*
Individual test group-mechanical Mechanical pullout	7.2	4
Individual test group-electromagnetic Electromagnetic force	7.3	4
Sequential test groups-acidic		4
Current-temperature cycling	8.1 through 8.8	
Freeze-thaw	9.1 through 9.6	
Corrosion-nitric acid	10.2	
Fault current	11.1 through 11.9	
Sequential test groups-alkaline		4
Current-temperature cycling	8.1 through 8.8	
Freeze-thaw	9.1 through 9.6	
Corrosion-salt spray	10.3	
Fault current	11.1 through 11.9	

*These are the minimum number of connector samples of each connector design and conductor combination tested.

5. Performance Criteria

5.1 General

When installed and tested in accordance with this standard, all connections shall conform to the performance criteria given in 5.2 and 5.3.

5.2 Mechanical Tests

5.2.1 Pullout Value Criteria

The connector pullout value, when tested in accordance with 7.2, shall meet the minimum pullout values shown in Table 2 with no visible movement of the premarked conductor with respect to the connector.

Table 2— Minimum Pullout Values

Copper or Aluminum Wire Size	Copper-Clad Steel Wire	Steel Wire or Rod*	Minimum Pullout Value	
			(lbf)	(N)
AWG or kcmil	Number/AWG Size of Strands	Diameter (in)		
8	—	—	150	668
6	—	3/16	300	1335
4	—	—	300	1335
3	—	1/4	300	1335
2	7/#10	—	300	1335
1	—	5/16	300	1335
1/0	7/#8	3/8	300	1335
2/0	7/#7	7/16	500	2225
3/0	7/#6	—	500	2225
4/0	—	1/2	500	2225
250	7/#5 & 19/#9	9/16	1000	4450
300	7/#4 & 19/#8	5/8	1000	4450
350	—	—	1000	4450
400	19/#7	3/4	1000	4450
500	19/#6	—	1000	4450
600	19/#5	7/8	2000	8900
750	—	1	2000	8900
1000	—	—	2000	8900

*Steel wire and rod includes copper-clad steel rod, galvanized steel, stainless steel, and stainless-clad steel. For connections involving the combination of wire and rod, use the pullout value of the wire.

5.2.2 Electromagnetic Force Withstand Criteria

When tested in accordance with 7.3, the connection shall remain intact with no visible movement of the premarked conductor with respect to the connector. The resistance of the connection, calculated per 5.3.4 and tested in accordance with Section 7., shall not increase by more than 50%. (The final resistance shall not exceed 1.5 times the initial value.) Resistance measurements shall be recorded in accordance with 5.3.3 and 7.3.6.

5.3 Sequential Tests

5.3.1 Temperature Criteria

The temperature of the connections tested in accordance with Section 8. shall not exceed the temperature of the control conductor.

5.3.2 Resistance Criteria

The resistance of the connection, calculated per 5.3.4 and tested in accordance with Sections 8. through 11., shall not increase more than 150% from the initial resistance value. (The final resistance shall not exceed 2.5 times the initial value.) Resistance measurements shall be recorded in accordance with 8.8.

5.3.3 Initial Resistance

Initial resistance of the test sample is the measurement taken between equalizers, as shown in Fig 1, and shall not be greater than 1.1 times the resistance on an equal length of control conductor.

5.3.4 Connector Resistance Calculation

The resistance of the connectors shall be determined by subtracting the resistance of the control conductor from the resistance of the connection sample tested (see Fig 1).

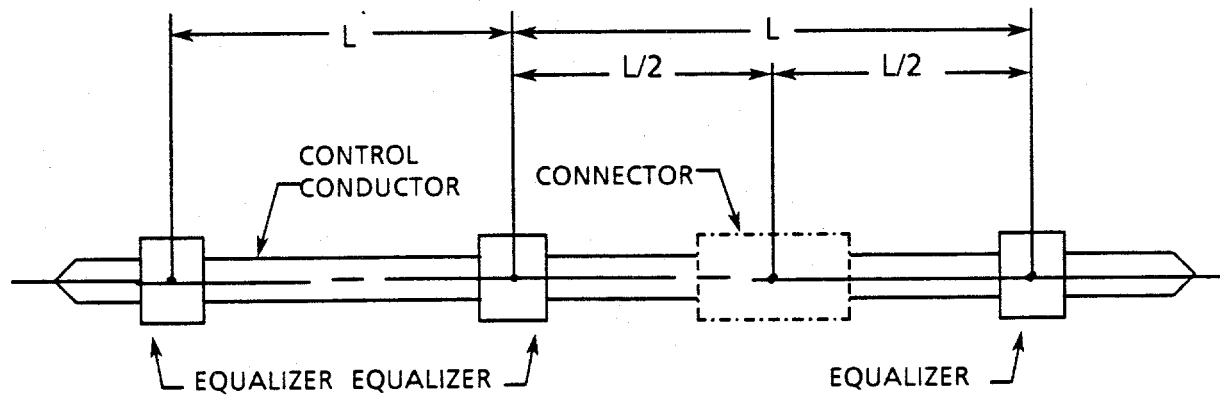


Figure 1— Measurement Points

6. Test Procedures

6.1 General

Mechanical tests are to be conducted on new connectors for pullout strength and electromagnetic withstand strength of the connection in accordance with Section 7.

6.2 Mechanical Test Samples

The samples subjected to mechanical tests shall not be used for the sequential tests.

6.3 Sequential Test Samples

Current-temperature cycling, freeze-thaw, corrosion, and fault-current tests are to be conducted sequentially. Use the same samples for all tests conducted in accordance with Sections 8. through 11. There shall be a separate set of samples used for the sequential acidic test and a separate set for the sequential alkaline test.

6.4 Connector Description

A description adequate for complete identification of the test connectors shall be included in the test report.

6.5 Test Conductors

The conductors shall conform to the applicable ASTM standards: [2], [3], [41], [5], [6], [7], [8], [9], [10], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29].

6.6 Test Assembly Methods

All assembly details not specifically defined in this standard shall be completely described in the test report.

6.7 Connection Preparation

Connections shall be prepared in accordance with the manufacturers' recommendations for field installation.

6.8 Installation

The method of installation and the installation tooling shall be in accordance with the manufacturers' recommendations for field installation. When clamping bolts are employed, they shall be tightened to the torque specified in Table 3, unless otherwise specified by the manufacturers.

Table 3— Clamping Bolt Tightening Torque

Bolt Size (in)	Stainless Steel Galvanized Steel or Silicon Bronze Bolts			Aluminum Bolts (Lubricated)		
	(lbf-in)	(lbf-ft)	(N-m)	(lbf-in)	(lbf-ft)	(N-m)
3/8	240	20	27	168	14	19
13/32	288	24	32	204	17	23
7/16	360	30	41	240	20	27
1/2	480	40	54	300	25	34
9/16	576	48	65	384	32	43
5/8	660	55	75	480	40	54

7. Mechanical Tests

7.1 General

These tests are intended to assure the reliability of grounding systems against mechanical abuse and electromagnetic forces.

Conductor Combination. For a multirange connector, mechanical pullout and electromagnetic force tests shall be performed on the connector joining the largest-to-largest and smallest-to-smallest conductors for which the connector is designed. The conductors used shall be a commercially available hard-drawn type.

NOTE — The selection of a hard-drawn conductor, rather than soft-drawn, will result in a more stringent test.

7.2 Mechanical Pullout Test

7.2.1 Test Samples

A minimum of four samples of each connector and conductor combination required, as described in 7.1.1, shall be subjected to each mechanical pullout test.

7.2.2 Test Conditions

When placing the sample in the tensile testing machine, care shall be taken to ensure that all strands of the conductor are loaded simultaneously and in line with the connector. The length of free conductor between the gripping device and the connector shall not be less than 10 in. If gripping of the connector is necessary, it shall be in a manner that will not influence the pullout value.

7.2.3 Loading Speed

The load shall be applied at a crosshead speed not exceeding 0.25 in (6.35 mm) per minute per foot of sample length.

7.3 Electromagnetic Force Test

7.3.1 Test Samples

A minimum of four samples of each connector and conductor combination, as specified in 7.1.1, shall be subjected to each electromagnetic force test.

7.3.2 Test Configuration

The test loop consisting of one through four test samples shall be mounted in the same plane with the bus connections, as shown in Fig 2. Equalizers shall be used according to 8.2.3, and conductor length shall be as specified in 8.2.4.

The assembled loop may be mounted on an insulated surface of appropriate size. The use of loosely fitted restraining devices is recommended. This is for safety considerations and to simulate buried ground conductors or connections to ground rods, or both. Restraining devices, such as U-bolts, used to fasten the loop to the board shall be as located in Fig 2. Use of alternate restraining devices, which also will allow free movement of the conductor, are at the option of the tester.

7.3.3 Fault Duration

Fault duration shall be 0.2 seconds.

NOTE — The average time required to clear a fault in a high-voltage transmission system is approximately 0.1 second or 6 cycles. The first 0.05 second (3 cycles) is for a protective relay to detect a fault and to operate. The next 0.05 second (3 cycles) is for a breaker to respond and to operate. The total time to clear a fault is therefore 0.1 second (6 cycles). If a primary protective relay fails to operate, then a breaker failure protective relay takes over and an adjacent breaker will trip within the next 0.1 second (6 cycles) for the total time of 0.2 second (12 cycles). During this time, fault current will flow causing a ground connection to be stressed by electromagnetic force.

7.3.4 Fault Current

The magnitude of the short-circuit current for this test shall be the value of an asymmetric current defined as follows:

- (1) Eighty percent of rms symmetrical value of fusing current calculated for the size of the tested conductor for 0.2 second duration. The maximum rms symmetrical value of fusing current shall be limited to 100 000 A. (See Appendix B.)
- (2) The peak value for the first half cycle of the test current shall be 2.7 times one half of the rms value calculated above.
- (3) X/R ratio of the test circuit shall be such that the test current contains a dc component resulting in the first peak of the test current having an asymmetry, and the magnitude as stated above.

NOTE — Using this as a parameter to prove that a connection would survive the most severe forces encountered during a fault, the asymmetrical current value was selected for the test.

The maximum fusing current value of 100 000 A rms symmetrical was chosen because this is the highest value anticipated by utilities.

It is assumed that fault current will divide equally and flow in two directions when entering the ground grid.

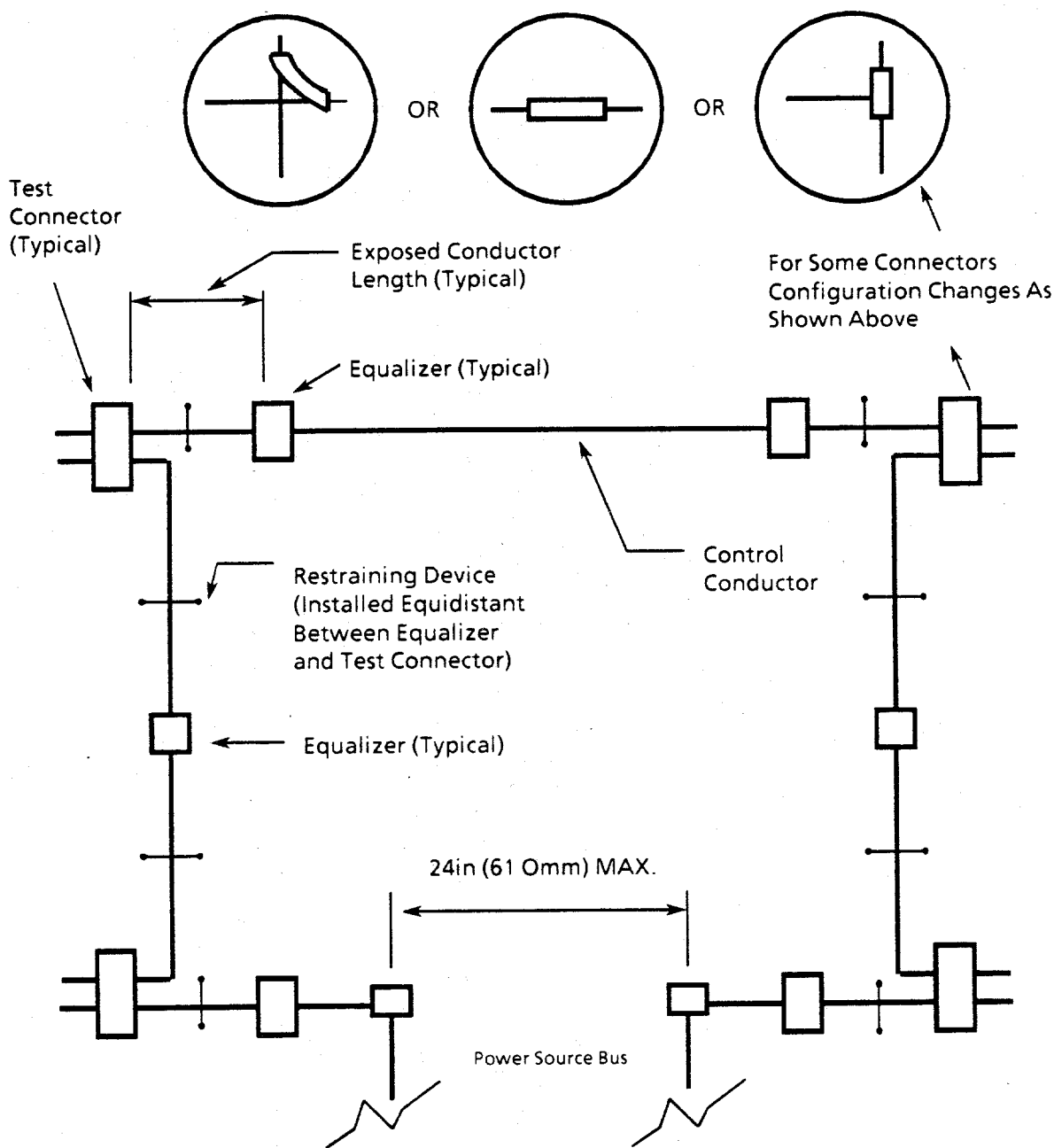


Figure 2— Typical Test Loop

7.3.5 Number of Surges

The test shall consist of three surges. Repeat each surge after the conductor has been allowed to cool to 100 °C or less.

7.3.6 Resistance Measurements

Resistance readings shall be recorded for each sample, in accordance with 8.8 initially, and after the three fault surges when samples have returned to ambient temperature.

8. Current-Temperature Cycling Test

8.1 General

This test is intended to assure the conformance to resistance criteria of connections subjected to temperature changes caused by fluctuating currents.

8.2 Current-Temperature Cycling Test

This test shall be the first test conducted in a series of sequential tests, as listed in Table 1.

8.2.1 Conductor Combinations

When joining different types or sizes of conductors, the selection of the conductor combinations and test current shall be that which results in the highest connector temperature while producing the conductor temperatures specified in Table 5.

Example 1: Connector for 3/4–1 in galvanized steel rod to #6–#2 copper wire. From Table 6, test currents are 3/4 in rod—274 A, 1 in rod—324 A, #6 wire—230 A, #4 wire—320 A, and #2 wire—440 A. Select a 1 in galvanized steel rod and #4 copper wire and use an initial test current of 320 A, which should achieve a 250 °C temperature on the galvanized steel rod.

Example 2: Connector for 1/2–5/8 in stainless-clad steel rod to 350–500 kcmil copper wire. From Table 6, test currents are 1/2 in rod—246 A, 5/8 in rod—285 A, 350 kcmil wire—1441 A, and 500 kcmil wire—1860 A. Select a 5/8 in stainless-clad steel rod and 350 kcmil copper wire and use an initial test current of 285 A, which should achieve a 350 °C temperature on the stainless-clad steel rod.

Example 3: Connector for #1/0–#2/0 copper wire to #4/0–250 kcmil copper wire. From Table 6, test currents are #1/0 wire—620 A, #2/0 wire—725 A, #4/0 wire—1010 A, and 250 kcmil wire—1140 A. Select a #2/0 and #4/0 copper wire and use an initial test current of 725 A, which should achieve a 350 °C temperature on the #2/0 copper wire.

8.2.2 Test Samples

Four connectors of each size and type shall be required for each series of sequential tests.

8.2.3 Equalizer

Equalizers shall be installed on the stranded conductor on each side of each connector. The equalizer provides an equipotential plane for resistance measurements and prevents the influence of one connection on the other in the current-temperature cycling test. Equalizers are not required on solid conductors.

Any form of equalizer that ensures contact of all strands of a conductor for the duration of the current-temperature cycling test may be used.

When the cables to be joined in a current-temperature cycle loop are identical, a continuous piece of cable may be used between the connections. A short compression sleeve centered between the connections will then act as the equalizer.

NOTE — Resistance measurement points on solid conductors shall be the same as those used for conductors requiring equalizers.

8.2.4 Conductor Length

The exposed length of the conductor in the current cycle loop between the connectors and the equalizers shall be as given in Table 4.

Table 4— Conductor Length from Connector to Equalizer

Copper Wire or Cable Size	Aluminum Wire or Cable Size	Steel or Clad Steel Wire or Rod	Current-Temperature Cycling Test Minimum Conductor Length Exposed from Connector to Equalizer	
			(in)	(mm)
Up to 2/0	Up to 4/0	Up to 7/16	12	300
Over 2/0 to 500	Over 4/0 to 795	Over 7/16 to 3/4	24	600
Over 500	Over 795	Over 3/4	36	900

8.3 Ambient Conditions

The current-temperature cycling tests shall be conducted in a space free of drafts at an ambient temperature of 20 °C (68 °F) to 40 °C (104 °F).

8.4 Control Conductor

A control conductor, used for the purpose of obtaining conductor temperature, shall be installed in the current cycle loop between two equalizers. It shall be of the same type and size as the conductor, of those joined by the connector under test, that established the highest temperature. Its length between equalizers shall be the same as the test samples.

8.5 Current Cycling

8.5.1 Current Cycling Period

Each cycle of the current-temperature cycling test shall consist of maintaining the minimum temperature specified in Table 5 on the control conductor for one hour and then cooling to room ambient. For suggested test currents, refer to Table 6.

Table 5— Conductor Temperature

Conductor	Temperature for Current Cycling Test
Aluminum	250 °C
Copper	350 °C
Steel	350 °C
Copper-clad steel	350 °C
Galvanized steel	250 °C
Stainless steel	350 °C
Stainless-clad steel	350 °C

8.5.2 Number of Cycles

The connections shall be subjected to a minimum of 25 current cycles.

8.5.3 Current Cycling Temperature

The current shall be adjusted over the first five cycles to result in a steady-state temperature on the control conductor specified in Table 5, and adjusted every five cycles thereafter as required to attain the specified steady-state temperature for a total of 25 cycles.

8.6 Loop Configuration

Loop configuration shall provide a minimum space of 2 ft (610 mm) between the connected conductor, 2.5 ft (760 mm) from the floor, 4 ft (1220 mm) from the ceiling, and 2 ft (610 mm) from the walls.

The current cycle loop may be bent back on itself in a U or zigzag shape provided the above spacings are used.

8.7 Measurements

Resistance and temperature measurements shall be recorded at the beginning of the test and after every five cycles.

8.7.1 Resistance Measurements

Resistance measurements shall be made during the current-off period and when the conductor temperature has stabilized at ambient. The measurements shall be made across each connector between potential points located in the center of the equalizers adjacent to the connector or at the equivalent points on a solid conductor. For these measurements, a current of a sufficiently low magnitude shall be used to avoid appreciable heating.

8.7.2 Temperature Correction

Ambient temperature shall be recorded concurrently with each set of resistance measurements, and the resistance shall be corrected to 20 °C. The corrected resistance shall be used in evaluating the performance of the connection.

8.7.3 Temperature Measurements

Temperature measurements shall be recorded for the connectors and the control conductor near the end of the current heating period, with current on. The temperature shall be measured by means of thermocouples permanently installed on each connector as close as possible to the point in the current path midway between the two conductors. One thermocouple shall be installed at the midpoint of the control conductor.

Table 6— Applied Current Levels

Current-Temperature Cycling Suggested Test Currents for Conductor Temperature Specified in Table 5						
Copper or Aluminum Wire Size AWG or Kcmil	Copper Wire Amperes	Aluminum Wire Amperes	Copper-Clad Steel Wire			
			Number/AWG Strand Size	30% Conductivity Amperes	40% Conductivity Amperes	
8	165	103	7/#8	280	320	
6	230	143	7/#7	330	375	
4	320	198	7/#6	385	440	
3	375	234	7/#5	450	515	
2	440	276	19/#9	460	520	
1	520	324	7/#4	515	590	
1/0	620	382	19/#8	530	610	
2/0	725	451	19/#7	620	700	
3/0	855	534	19/#6	720	815	
4/0	1010	627	19/#5	835	940	
250	1140	708				
300	1295	806				
350	1441	900				
400	1574	984				
500	1860	1159				
600	2095	1322				
750	2471	1545				
1000	3010	1895				

Diameter		Copper-Clad Steel Rod*	Steel Galvanized Steel Wire and Rod	Stainless Steel Wire and Rod	Stainless-Clad Steel Rod†
(in)	(mm)	Amperes	Amperes	Amperes	Amperes
3/16	4.8	—	77	58	98
1/4	6.4	—	108	83	135
5/16	7.9	—	136	107	168
3/8	9.5	—	162	131	197
7/16	11.1	—	186	153	223
1/2	12.7	350	207	174	246
9/16	14.3	—	226	193	266
5/8	15.9	425	243	210	285
3/4	19.2	570	274	242	318
7/8	22.2	—	300	282	347
7/8	22.2	—	300	282	347
1	25.4	850	324	293	373

*Copper-clad steel rod based on 0.010 in (0.254 mm) copper thickness.

†Stainless-clad steel rod based on 0.020 in (0.508 mm) No. 304 stainless steel over No. 1020 steel core.

9. Freeze-Thaw Test

9.1 General

This test is intended to assure the conformance to resistance criteria of connections subjected to repeated cycles of freezing and thawing in water.

9.2 Freeze-Thaw Test

This test shall be the second test in a series of sequential tests as listed in Table 1.

9.3 Test Samples and Their Configuration

Test connectors are the same test samples subjected to current-temperature cycling test in accordance with Section 8.

Test samples can be tested in a series loop or as individual test samples as shown in Figs 1, 2, and 3.

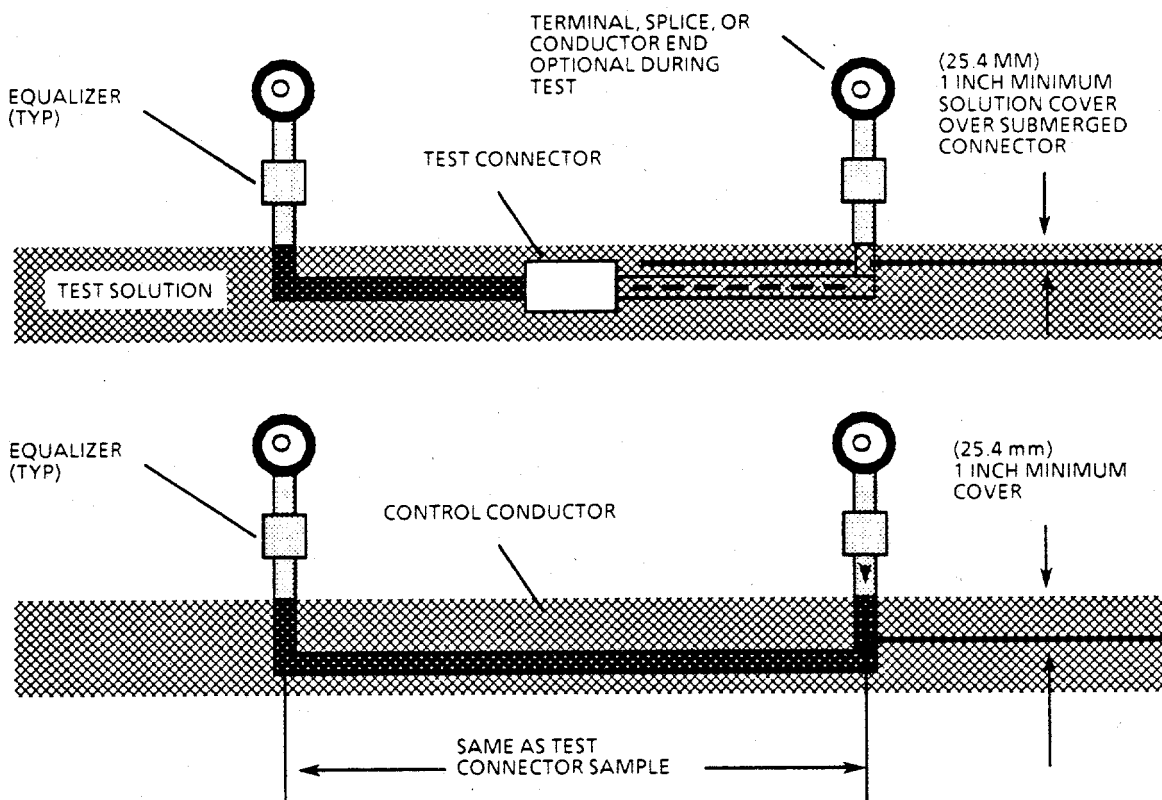


Figure 3— Typical Submerged Test Sample

9.4 Freeze-Thaw Equipment

Containers resistant to freezing and heating temperatures and suitable for holding samples in a series loop configuration or as individual samples shall contain enough water to submerge and cover the connectors by a minimum of 1 in (25.4 mm) of water.

9.5 Freezing and Thawing Cycle

9.5.1 Freezing and Thawing Temperatures

The freezing and thawing cycle shall consist of lowering the temperature of the test connector samples to $-10\text{ }^{\circ}\text{C}$ ($14\text{ }^{\circ}\text{F}$) or lower, and raising the temperature to at least $20\text{ }^{\circ}\text{C}$ ($68\text{ }^{\circ}\text{F}$). The test samples shall remain at both the low and high temperature for at least two hours during each cycle.

9.5.2 Number of Cycles

The connection shall be subjected to a minimum of 10 freeze-thaw cycles.

9.6 Resistance Measurements

Resistance measurements shall be recorded before the initial freeze-thaw cycle and after the final freeze-thaw cycle. Prior to taking resistance measurements, samples shall be heated for one hour at $100\text{ }^{\circ}\text{C}$ to ensure dryness. The connectors shall be returned to ambient. Resistance measurements shall be recorded in accordance with 8.8.

10. Corrosion Tests

10.1 General

These corrosion tests are designed to evaluate the corrosion resistance of connections. However, some conductor types—stainless steel, for example—are resistant to the corrosive environment found in most substations. For corrosion-resistant conductors, the corrosion test is not specified to provide criteria for acceptance or rejections, but only to provide conditioning of the connector for the fault current test. Table 7 specifies the type of corrosion test for the various conductor combinations connected. If the conductor combination connected is listed for both “Below Grade” and “Above Grade” applications, the connector shall be tested using both sequential test groups, acidic and alkaline, as noted in Table 1.

10.2 Nitric Acid Test (HNO_3)

10.2.1 General

The purpose of this test is to standardize as much as possible simple immersion corrosion procedures for the connector and conductors buried in corrosive soils, as shown in Table 7.

10.2.2 Nitric Acid Test

This test shall be the third test in a series of sequential tests as shown in Table 1.

Table 7— Corrosion Tests

Conductor Combination Connected	Application	
	Below Grade Nitric Acid Test	Above Grade Salt Spray Test
Aluminum to aluminum	—	X
Aluminum to steel (uncoated or galvanized)	—	X
Copper to aluminum	—	X
Copper to copper	X	X
Copper to copper-clad steel	X	X
Copper to steel (uncoated or galvanized)	X	X
Copper to stainless steel	X	—
Copper to stainless-clad steel	X	—
Copper-clad steel to aluminum	—	X
Copper-clad steel to copper-clad steel	X	X
Copper-clad steel to steel (uncoated or galvanized)	X	X
Copper-clad steel to stainless steel	X	—
Copper-clad steel to stainless-clad steel	X	—
Stainless steel to stainless steel	X	—
Stainless-steel to stainless-clad steel	X	—
Stainless-clad steel to stainless-clad steel	X	—
Steel (uncoated or galv.) to steel (uncoated to galv.)	X	—

10.2.3 Test Samples

The test connector samples shall be the same connectors tested in accordance with Sections 8. and 9.

10.2.4 Equalizer Attack

If the equalizers are immersed with the test connectors, resistance measurements may be adversely affected. If the resistance measurement exceeds the limits of 5.3.2, no allowance shall be made for the effect of acid attack on the equalizer.

10.2.5 Submerged Lengths

The length of the test sample specimen submerged in the acid solution shall be equal to the length of control conductor submerged in the same solution.

10.2.6 Connector Location

The connector shall be centrally located on the conductor length and a minimum of 80% of the distance between equalizers of exposed conductor shall be submerged in the acid solution.

10.2.7 Ambient Temperature

Ambient temperature shall be 20 °C to 35 °C.

NOTE — 20 °C to 25 °C is the ideal temperature for an acid solution since the rate of reaction doubles with every 10 °C increase of the solution temperature. If the reduction of the conductor is closely monitored, it is reasonable to use 20 °C to 35 °C ambient temperature and obtain the reduction required.

10.2.8 Control Conductor

The control conductor shall be the same one used in Sections 8. and 9.

10.2.9 Copper Control Test Sample

The copper control test sample required by 10.2.14 shall be the same general cross-sectional area and shape as the test conductor samples. The copper control test sample shall be provided with equalizers as specified in 8.2.3.

10.2.10 Acid Solution HNO₃

Acid solution shall be a 10% by volume concentration of nitric acid HNO₃ and distilled water H₂O. See Appendix A.

10.2.11 Solution Volume

Solution volume shall be such to provide a minimum ratio of 1 liter of 10% solution to 25 in² ($1.613 \cdot 10^4$ mm²) of submerged test sample surface area. This surface area shall include the surface of all strands of the conductor submerged in the solution.

10.2.12 Submersion Time for Copper Conductors

The test samples shall be submerged in the 10% acid solution for a time, which will reduce the control conductor to 80% of its original cross-sectional area. The reduction shall be determined by the weight reduction per unit length or resistance increase readings of the control conductor.

10.2.13 Submersion Time for Copper-Clad Steel Conductors

The test samples shall be submerged in the 10% acid solution for a time, which will increase the resistance of the control conductor by 25% above the initial resistance prior to testing.

10.2.14 Submersion Time for Steel, Galvanized Steel, Stainless Steel and Stainless-Clad Steel

The test samples shall be submerged in the 10% acid solution for a time, which will reduce the copper control test sample to 80% of its original cross-sectional area. The reduction shall be determined by the weight reduction per unit length or resistance increase readings of the copper control test sample.

NOTE — The acid solution may not affect the conductors. However, it may affect the connector.

10.2.15 Containers

Containers shall be of a material resistant to nitric acid and of sufficient size to allow the solution to completely cover the specified test sample, as shown in Fig 3.

10.2.16 Resistance Measurements

The test samples shall be removed from the acid and rinsed in fresh water. Prior to taking resistance measurements, samples shall be heated for 1 h at 100 °C to ensure dryness. Samples shall be returned to ambient. Resistance measurements shall be recorded in accordance with 8.8.

10.3 Salt Spray Test

10.3.1 General

This test method covers the procedure for determining the corrosive effects of salt spray (sodium chloride) on connections.

10.3.2 Salt Spray Test

This test shall be the third test in a series of sequential tests, as shown in Table 1.

10.3.3 Test Samples

The test connector samples shall be the same connectors tested in accordance with Sections 8. and 9.

10.3.4 Applicable Standard

The test shall be performed according to ANSI/ASTM B117-85 [11] except Sections 5. and 6. shall be modified to accommodate conductor and connector design combinations being tested.

10.3.5 Length of Test

The test shall be conducted for a minimum of 500 h.

10.3.6 Resistance Measurements

After completion of the salt spray test, the test samples shall be rinsed in fresh water. Prior to taking resistance measurements, samples shall be heated for 1 h at 100 °C to ensure dryness. Samples shall be returned to ambient. Resistance measurements shall be recorded in accordance with 8.8.1.

10.3.7 Visual Evaluation

Connectors and conductors shall be visually inspected for the type of corrosion, if any, and this information shall be recorded in the test data, such as uniform corrosion, pitting, galvanic action, etc.

11. Fault-Current Test

11.1 General

The purpose of this test is to determine if connections conditioned in previous tests will withstand fault-current surges.

11.2 Fault-Current Test

This test shall be the fourth test in a series of sequential tests as shown in Table 1.

11.3 Test Samples

The test samples shall be the same connectors tested in accordance with Sections 8., 9., and 10..

11.4 Configuration

The test samples shall be mounted in a loop as shown in Fig 2 or as individual test samples as shown in Fig 1. Use of a control conductor and fastening devices is at the option of the tester.

11.5 Fault Duration

The fault duration shall be 10 s.

11.6 Fault Current

The symmetrical rms fault current shall be 90% of the fusion current for the remaining cross-sectional area and for a 10 s duration. See Appendix B.

NOTE — Ninety percent of the fusion current is established to prevent loss of the conductor and provide a method of measuring resistance readings after three repeated fault surges.

11.7 Number of Surges

The test shall consist of three surges. Repeat each surge after the conductor has been allowed to cool to 100 °C or less.

11.8 Resistance Measurements

Resistance readings shall be recorded for each sample and control conductor in accordance with 8.8 initially and after the three fault surges when the samples have returned to ambient.

11.9 Visual Evaluation

Connectors shall be taken apart or dissected, or both, and visually inspected for burning or other damaging effects to the connection, and the results shall be recorded.

12. Bibliography

[B1] ANSI/UL 467-1984, Safety Standard for Grounding and Bonding Equipment.

[B2] ANSI/UL 486A-1982, Safety Standard for Wire Connectors and Soldering Lugs for Use with Copper Conductors.

[B3] ANSI/UL 486B-1982, Safety Standard for Wire Connectors for Use with Aluminum Conductors.

[B4] ANSI/IEEE Std 80-1986, IEEE Guide for Safety in AC Substation Grounding.

[B5] NACE TM-01-69 (1976 Revision), Laboratory Corrosion Testing of Metals for the Process Industries.

[B6] NEMA CC1-1984, Electrical Power Connectors for Substations.

[B7] NEMA CC3-1973 (R 1983), Connectors for Use Between Aluminum or Aluminum/Copper Overhead Conductors.

[B8] VDE Standard 0142.64, Regulation for Earthings in AC Installation with Rated Voltages Above 1 kV (Germany).

[B9] MIXON, J. Corrosion Resistance Test for Copper and Copper Alloy Connector Products Used on Grounding Grid Conductors and Electrodes. Harrisburg, PA: AMP, Inc, June 27, 1979.

[B10] MIXON, J. Exploratory Acid Corrosion Tests. Harrisburg, PA: AMP, Inc, Oct 5, 1978.

[B11] SVERAK, J.G. Safe Substation Grounding, Part II. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-101, Oct 1982, pp 4006—4023 (IEEE Paper 82 WM 180-8).

[B12] SVERAK, J.G. Sizing of Ground Conductors Against Fusing. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-100, Jan 1981, pp 51–59 (IEEE Paper F80 256-8).

Annex A Nitric-Acid, Dilution

(Informative)

(These Appendices are not a part of IEEE Std 837-1989, IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.)

NOTE — Nitric acid, HNO_3 , is usually purchased as 70% concentrate and is adjusted to the percentage requirement for the user by the following calculation per liter of solution.

$$\text{volume of } \text{HNO}_3(\text{mL}) = \frac{1000 \text{ mL} \cdot 10\%}{70\%} \text{ per liter}$$

$$\text{volume of } \text{HNO}_3(\text{mL}) = 143 \text{ mL of } \text{HNO}_3 \text{ per liter}$$

$$143 \text{ mL of } 70\% \text{ nitric acid concentrate} + 857 \text{ mL of water} = 1 \text{ L of } 10\% \text{ acid test solution}$$

Annex B Conductor Ampacity Calculation [B4] and [B12]

(Informative)

The following equation can be used to calculate the ampacity for any conductor for which the material constants are known, or can be determined by calculation:

$$I = A \sqrt{\left(\frac{TCAP \cdot 10^{-4}}{t_c \alpha_r \rho_r} \right) \ln \left(\frac{K_o + T_m}{K_o + T_a} \right)}$$

where

- I = rms current in kA
- A = conductor cross section in mm²
- T_m = maximum allowable temperature in °C
- T_a = ambient temperature in °C
- T_r = reference temperature for material constants in °C
- α_o = thermal coefficient of resistivity at 0 °C
- α_r = thermal coefficient of resistivity at reference temperature T_r
- ρ_r = the resistivity of the ground conductor at reference temperature T_r in $\mu\Omega\text{-cm}$
- K_o = $1/\alpha_o$, or $(1/\alpha_r) - T_r$ in °C
- t_c = time of current flow in seconds
- $TCAP$ = thermal capacity factor in joules/cm³/°C

Material constants for conductors used with connectors covered by this standard are listed in Table B.1. Note that α_r and ρ_r are defined for the same reference temperature of r degrees Celsius. Table B.1 provides data for α_r and ρ_r at 20 °C. $TCAP$ is defined as $4.184 \cdot SH \cdot SW$ where SH is the specific heat in cal/gram/°C and SW is the specific weight in gram/cm³.

Introducing a new factor, β , which is defined as

$$\beta = \frac{\alpha_r \cdot \rho_r \cdot 10^4}{TCAP}$$

and rearranging the equation yields the following new equation for conductor ampacity:

$$I = A \sqrt{\frac{\ln \left(\frac{K_o + T_m}{K_o + T_a} \right)}{\beta t_c}} \text{ in kA}$$

NOTE — When calculating fusing current, the fusing temperature in accordance with Table B.1 shall be used for T_m . For bimetallic conductors, the material with the lower fusing temperature is given in Table .

Example solving for the fusing current of 100% conductivity copper, 500 kcmil conductor:

Let:

- $A = 253 \text{ mm}^2$
- $T_m = 1083 \text{ °C}$
- $T_a = 40 \text{ °C}$
- $K_o = 234 \text{ °C}$
- $\beta = 19.8$

$$t = 0.2 \text{ s}$$

$$I = 253 \cdot \sqrt{\frac{\ln\left(\frac{234 + 1083}{234 + 40}\right)}{19.8 \cdot 0.2}}$$

$$I = 159.3 \text{ kA} = 159\,300 \text{ A rms}$$

$$80\% \text{ of } I = 127,400 \text{ A rms}$$

This exceeds the maximum fusing current limit of 100,000 A rms symmetrical referred to in 7.3.4. Therefore, the first peak of the asymmetrical test current = $0.5 \cdot 2.7 \cdot 100\,000 = 135\,000 \text{ A peak}$.

Example solving for I at 1083 °C for #4/0 AWG 100% conductivity copper conductor:

Let

$$\begin{aligned} A &= 107.2 \text{ mm}^2 \text{ for \#4/0 AWG conductor} \\ T_m &= 1083 \text{ }^\circ\text{C} \\ T_a &= 40 \text{ }^\circ\text{C} \\ K_o &= 234 \text{ }^\circ\text{C} \\ \beta &= 19.8 \\ t &= 0.2 \text{ s} \end{aligned}$$

$$I = 107.2 \cdot \sqrt{\frac{\ln\left(\frac{234 + 1083}{234 + 40}\right)}{19.8 \cdot 0.2}}$$

$$I = 67.5 \text{ kA} = 67\,500 \text{ A rms}$$

$$80\% \text{ of } I = 54\,000 \text{ A rms}$$

The first peak of the asymmetrical test current

$$= 0.5 \cdot 2.7 \cdot 54\,000$$

$$= 72\,900 \text{ A peak}$$

Table B.1 —Material Constants

Description	Material Conductivity (%)	α_r Factor @ 20 °C	K_0 ($1/\alpha_0$) @ 0 °C	Fusing Temperature (°C)	ρ_r @ 20 °C ($\mu\Omega\text{-cm}$)	TCAP Factor Effective Value ($\text{J/cm}^3/\text{°C}$)	β Factor @20 °C	
							Before Acid Corrosion Test	After Acid Corrosion Test
Copper, Annealed Soft-drawn	100.0	0.00393	234	1083	1.724	3.422	19.8	19.8
Copper, Commercial Hard-Drawn	97.0	0.00381	242	1084	1.777	3.422	19.8	19.8
Copper-Clad Steel Core, Wire	40.0	0.00378	245	1084	4.397	3.846	43.2	54.0
Copper-Clad Steel Core, Wire	30.0	0.00378	245	1084	5.862	3.846	57.6	72.0
Copper-Clad Steel Core, Rod*	20.0	0.00378	245	1084	8.621	3.846	84.7	105.9
Aluminum, EC Grade	61.0	0.00403	228	657	2.862	2.556	45.1	45.1
Aluminum, 5005 Alloy	53.5	0.00353	263	660	3.223	2.598	43.8	43.8
Aluminum, 6201 Alloy	52.5	0.00347	268	660	3.284	2.598	43.9	43.9
Aluminum-Clad Steel Core	20.3	0.00360	258	660	8.481	2.670	114.3	114.3
Steel, No. 1020	10.8	0.0016	605	1510	15.9	3.284	77.5	77.5
Stainless Steel, No. 304	2.4	0.0013	749	1400	72.0	4.032	232.2	232.2
Stainless-Clad Stainless Core, Rod†	9.8	0.0016	605	1400	17.5	4.443	63.0	63.0
Zinc-Coated Steel Core	8.6	0.0032	293	419	20.1	3.931	163.6	163.6

*Copper-clad steel rod based on 0.010 in (0.264 mm) copper thickness.

†Stainless-clad steel rod based on 0.020 in (0.508 mm) No. 304 stainless steel thickness over No. 1020 steel core.