ANSI/IEEE 576-1989

An American National Standard

IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry

Sponsor

Petroleum and Chemical Industry Committee
of the
Industry Applications Society

Approved January 24, 1989

IEEE Standards Board

Approved June 12, 1989

American National Standards Institute

Foreword

(This Foreword is not a part of ANSI/IEEE Std 576-1989, IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry.)

This document has been generated to provide guidance for installation of electrical cable systems within the Petroleum and Chemical Industry.

It has long been recognized that the majority of cable failures are a result of mechanical damage during installation. The use of this document should reduce the possibility of electrical failure in a cable system.

There are many specific details involved in the installation of cable systems that are subject to differences of opinion. This document covers only the major problem areas.

This document will be revised from time to time to incorporate the latest information available.

This document was prepared by the Cable Installation Working Group of the Petroleum and Chemical Industry Committee of the Industry Applications Society of IEEE, which consisted of the following members:

H. R. Stewart, Jr., *Chair*

H. D. Danner
William F. Ecton
Jim Hunt
Richard Kirby
Layton Tuggle
D. Voltz
Olin Willis

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

D. C. Azbill
R. F. Barrett
W. Beard
B. A. Birkett
W. O. Brown
J. Caroff
J. Demos
J. S. Dudor
M. Durham
J. B. Dwyer
H. B. Dygert
C. J. Erickson
E. J. Fagan
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A. W. Smith
T. B. Smith
H. R. Stewart
J. A. Stewart
F. D. Szachta
A. L. Verhiel
B. Wiseman
J. R. Zahn

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CLAUSE PAGE

CLAUSE PAGE

An American National Standard

IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry

1. General Provisions

1.1 Scope

This recommended practice provides a guide to installation, splicing, termination, and field-proof testing of cable systems for the petrochemical industry. It is not intended to be a design document, although many of the problems of installation can be avoided by designing cable layouts with the installation limits of this recommended practice.

1.2 Purpose

The purpose of this recommended practice is to provide a uniform guide of installation limits that will avoid premature cable failure due to improper installation and mechanical damage during installation. It is intended to provide a reference that can be specified for cable installations.

1.3 References

The following publications shall be used in conjunction with this standard:

[1] ANSI/IEEE Std 404-1986, IEEE Standard for Cable Joints for Use with Extruded Dielectric Cable Rated 5000 V Through 46 000 V and Cable Joints for Use with Laminated Dielectric Cable Rated 2500 Through 500 000 V.[1]

[2] Engineering Data, Copper and Aluminum Conductor Electrical Cables. Ramsey, NJ: The Okonite Company.

[3] IEEE Std 400-1980, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field.[2]

[4] Installation Practices for Cable Raceway Systems. Ramsey, NJ: The Okonite Company.

[5] ANSI/NFPA 70, National Electrical Code. Batterymarch Park, Quincy, MA: National Fire Protection Association, 1986.[3]

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[1]ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 088554-1331.

[2]IEEE publications can be obtained from the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

2. Definitions

sidewall pressure: The pressure exerted on an insulated cable as the result of the cable's being pulled around a bend during installation.

occupancy factor: The factor by which the forces are adjusted due to cable spacing in a conduit. Sometimes called weight correction factor.

jamming: The wedging of cables in a conduit when three cables lie side by side in a fiat plane.

minimum bending radius: The minimum radius that an insulated cable can be bent that will not cause mechanical damage during installation.

electrical connection: The point at which two or more electrical conductors are joined together to establish electrical continuity.

3. Pulling Tensions

3.1 Maximum Pulling Tension on Cable

3.1.1 Pulling Eye Attachment

With pulling eye attached to copper conductors, the maximum pulling strain should not exceed 0.008 times circular-mil area (CM). With pulling eye attached to aluminum conductors, the maximum pulling strain should not exceed 0.006 times circular-mil area (CM).

Tm = $0.008 \times n \times$ CM
Tm = Maximum tension, lbs
n = number of conductors
CM = circular mil area of each conductor

Maximum limitation for this calculation is 5000 lb for single conductor (1/C) cables and 6000 lb for multiple conductor cables.

3.1.2 Cable Grip Over Lead Sheath

With cable grip over lead sheath, the maximum pulling strain should not exceed 1500 lbs/sq in of lead sheath cross-sectional area for commercial lead.

Tm = maximum tension (lbs) = $4712t\,(D - t)$
t = sheath thickness (in)
D = overall diameter of cable (in)

3.1.3 Cable Grip Over Non-Leaded Cable

With cable grip over non-leaded cable, the maximum pulling strain should not exceed 1000 lbs and may not exceed the maximum tension based on 0.008 or 0.006 × total conductor area.

[3]ANSI/NFPA publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

3.2 Maximum Permissible Pulling Length for One Straight Section

$$Lm = \frac{Tm}{fW} \tag{1}$$

where

Lm = pulling length, (ft) [straight section]
Tm = maximum tension (lbs)
W = weight of cable per foot (lbs)
f = Coefficient of friction (usually 0.5)

3.3 Small Conductor Cables

In the case of small conductors where the permissible load is limited by 0.008 times the total circular-mil area of the conductors, the permissible load on the sheath may be added to that permitted on the conductor if the conductor and sheath are joined securely to the pulling eye.

3.4 Pulling Tension Requirements in Ducts and Conduits

3.4.1 Straight Run of Cable

For a straight run of cable, the tension is given by the following equation:

$T = lwfv$

where

T = pulling tension (lbs)
l = length of duct (ft)
w = weight of cable (lb/ft)
f = coefficient of friction (usually 0.5) between cable(s) and duct or conduit surface
v = occupany factor
1 cable per duct v= 1.0
3 cables per duct v= V_c or V_t from Fig 1

3.4.2 Curved Duct Sections

For curved duct sections, the following equation applies:

$T_2 = T_1 e^{fa}$

T_2 = Tension coming out of the bend (lbs)
T_1 = Tension at the end of a straight section entering a bend (lbs)
a = angle of bend in radians
f = coefficient of friction (usually 0.5)

3.4.2.1 Values of e^{fa}.

Values of e^{fa} commonly used are listed below:

Bend Angle in Degrees	Value of e^{fa*}[2]
15	1.14
30	1.30
45	1.48
60	1.70
75	1.94
90	2.20
105	2.50
120	2.86

*NOTE: Coefficient of friction is 0.5.

3.4.2.2 Minimizing Pulling Tension

In order to minimize the pulling tension on the cable(s), the cable should be fed into the duct run from the end nearest the bend.

3.5 Check List Prior to Pulling Cable

1) Be sure there is adequate clearance between duct or conduit diameter and cable diameter. Do not exceed recommended “percent fill” requirements.
2) Use adequate lubrication of the proper type to reduce friction in conduit and duct pulls. The grease and oil type lubricants used on lead sheathed cables should not be used on non-metallic sheathed cables. There are a number of commercially available wire pulling compounds that are suitable for use with non-leaded cables.
3) Avoid sharp bending of the cable at the first pulley in overhead installations by locating the pay-off reel far enough away from the first pulley that the lead-in angle is kept relatively flat.
4) After installation, check to determine that end seals are still intact and have not been damaged to the point where water could enter. Apply plastic or rubber tape to help protect against invisible damage if the cable will be subjected to immersion or rain. This is particularly important if there will be a delay of some time between the pulling operation and splicing and terminating.
5) In installing armored cables on rack, use sufficient rollers to prevent the cable from dragging on the rack, which might result in excessive tension. Avoid sharp bends in the cable by using one 3-sheave pulley at 45 degree bends and multi-roller sheave at 90 degree bends.
6) Keep adequate tension on the messenger in aerial cable installations to prevent sharp bends at pulleys. Do not release the tension on the messenger until it is secured to poles on both ends.

3.6 Methods of Gripping Cables for Pulling

3.6.1 General

In general, insulated cables may be gripped either directly by the conductors or by a basket-weave pulling grip applied over the cables. The method used depends on the anticipated maximum pulling tension. When pulls are relatively light, a basket-weave grip is used. Heavier pulls will require connecting to the conductor either by means of pulling eyes or by forming a loop with the conductor itself. In some instances, it is desirable to use a grip over the outer covering in addition to the conductor connection to prevent any slippage of one with respect to the other.

3.6.2 Non-Metallic Sheathed Cables

The smaller sizes of non-metallic sheathed cables are usually gripped directly by the conductors by forming them into a loop to which the pull wire or rope can be attached. The insulation on each conductor is removed before the loop is formed. Larger sizes are more easily handled by applying a pulling grip over the cable or cables, provided the pull is not too severe. If more than one cable is involved, the ends should be bound together with friction tape before applying the grip overall. Long, hard pulls will necessitate the use of pulling eyes.

3.6.3 Lead Sheathed Cables

Pulling eyes for lead sheathed cables can be applied either at the factory or in the field. They must be wiped to the lead sheath to prevent the entrance of moisture. For shorter pulls a basket-weave grip may be applied over the lead sheath or over the jacket if one is present over the lead sheath.

3.6.4 Interlocked Armor Cables

In pulling interlocked armor cable it is necessary to grip the armor and the conductors. This can be accomplished in a number of ways. One method requires that a portion of the armor be removed. Friction tape is then applied over the armor and down over the conductors, and a long basket weave grip is applied in such a way that it grips both the armor and the conductors. Another method requires that two holes be drilled through the cable (armor and conductors) at right angles to each other and that a loop be formed by passing steel wires through the holes and out over the end of the cable. A third approach would be to use a pulling eye and a grip together, the grip being applied over the armor to prevent its slipping back. The armor is not a tension member. Be certain pulling load is taken by the conductors.

3.6.5 Preassembled Aerial Cable

This type of cable shall always be gripped by the messenger, which is usually attached to a pulling swivel. In addition, a basket grip should be applied over the conductors to prevent any slippage and to facilitate guiding the conductors through the pulley. When pulling pre-assembled aerial cable through sheaves, the conductor bundle should be rotated to position the messenger on the sheave surface to reduce possible crushing damage.

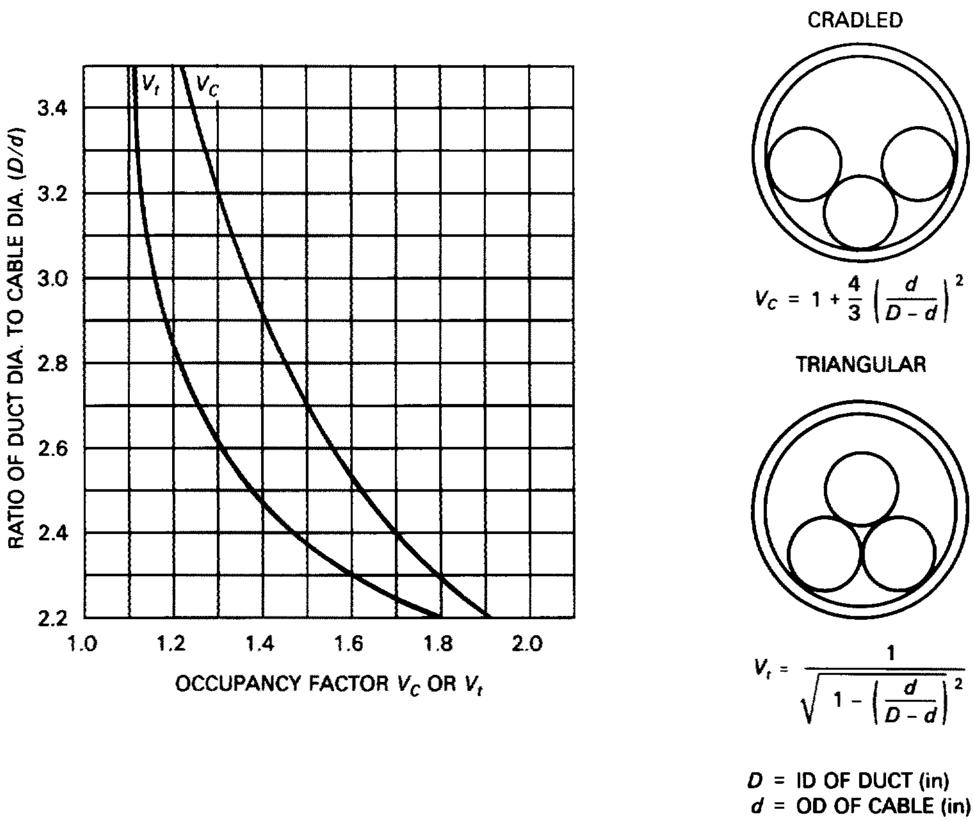

Figure 1—Occupancy Factors

4. Side Wall Pressure

4.1 Side Wall Pressure Limitations

One of the limitations to be considered in the installation of electrical cables is side wall pressure. The side wall pressure is the force exerted on the insulation and sheath of the cable at a bend point when the cable is under tension.

When installing single-conductor cable, three single-conductor cables, or multi-conductor cables per duct or conduit, the sidewall pressure acting on the cable at a bend is the ratio of the pulling tension to the radius of the bend.

However, when installing three single-conductor cables per duct or conduit, a multiplying factor is used to correct for added frictional forces that exist between triangularly or cradle arranged cables resulting in a greater pulling tension. This factor is referred to as the "occupancy factor."

The maximum sidewall pressure per foot of radius is 300 lb/ft. However, in order to minimize cable damage because of excessive sidewall pressure, the installer should check the cable manufacturer's recommendation for each type of cable to be installed.

Although the maximum allowable sidewall pressure is 300 lbs/ft of raceway bend radius, specific installation procedures and specific cable constructions may allow this maximum to be increased.

4.2 Occupancy Factor Calculations

The occupancy factor for one single-conductor cable or one multi-conductor in a duct or conduit is V = 1; for three single-conductor cables in a duct or conduit the equations for determining the occupancy factors are as follows:

1) For a cradle configuration,

$$V_c = 1 + \frac{4}{3}\left(\frac{d}{D-d}\right)^2 \tag{2}$$

2) For a triangular configuration,

$$V_t = \frac{1}{\sqrt{1-\left(\frac{d}{D-d}\right)^2}} \tag{3}$$

D = I.D. of duct (in)
d = O.D. of single conductor cable (in)

A graph of the above occupancy factors is given in Fig 1. The equations for determining the approximate values of sidewall pressure are as follows:

1) For one single-conductor cable in duct or conduit
$P = T/R$
2) For three single-conductor cables in a duct or conduit with a cradle configuration;
$P = 1/3\ (3V_c - 2)\ (T/R)$
3) For three single-conductors in a duct or conduit in a triangular configuration;
$P = V_t/2\ (T/R)$

P = sidewall pressure (lb/ft)
T = tension leaving the bend (lb)
R = inside radius of the bend (ft)
V_c = occupancy factor for cradled formation (see Fig 1)
V_t = occupancy factor for triangular formation (see Fig 1)

4.3 Example Calculations

1) One single conductor cable in duct or conduit.
Assumptions are as follows:
a) T = tension out of bend = 600 lb
b) R = inside radius of bend = 2 ft
c) P = sidewall pressure
P = T/R = 600 lb/2 ft = 300 lb/ft
2) Three single conductor cables in duct or conduit in a cradled configuration.
Assumptions are as follows:
a) T = tension out of bend = 872 lb
b) R = inside radius of bend = 1.87 ft
c) V_c = occupancy factor from Fig 1 = 1.31
d) D = duct inside diameter = 3.068 in
e) d = cable diameter = 1 in
$P = 1/3;\ (3V_c - 2)\ (T/R)$
$= 1/3;\ (3 \times 1.31 - 2)\ (872\ \text{lb}/1.87\ \text{ft}) = 300\ \text{lb/ft}$

3) Three single-conductor cables in duct or conduit in a triangular configuration.
   Assumptions are as follows:
   a) T = tension out of bend = 984 lb.
   b) R = inside radius of bend = 1.87 ft.
   c) V_t = occupancy factor from Fig 1 = 1.14
   d) D = duct inside diameter = 3.068
   e) d = cable diameter = 1 in

   $P = V_t/2\ (T/R) = 1.14/2\ (984/1.87) = 300$ lb/ft

5. Jamming

Jamming can occur with cables in a conduit when three cables lay side by side in a fiat plane. The cables will become wedged in the conduit and pulling damage will occur. This may occur when pulling around bends or when the cable twists. For one or two conductors or for a multi-conductor with an overall jacket, jamming is not applicable. For four or more conductors we still evaluate the cable as three conductors, because this is the pattern into which they will most likely move. Cabling will eliminate jamming.

5.1 Computation of Ratio

A check should be made by computing the ratio between the conduit inside diameter (D) and a single-conductor overall diameter (d) to evaluate the potential for jamming. Because bending a cylinder produces an oval cross-section in the bend, we will use $1.05D$ for the conduit inside diameter in our limitations:

If $1.05D/d$ is larger than 3.0, jamming is impossible.

If $1.05D/d$ is between 2.8 and 3.0, jamming is probable.

If $1.05D/d$ is less than 2.5, jamming is impossible, but check clearance.

D = inside diameter of conduit or duct
d = cable overall diameter

5.2 Jam Ratio

The critical range of the jam ratio to avoid is 2.8 to 3.0 [4].

Jam Ratio = Conduit ID/Cable OD

6. Recommended Bending Radii for Cables

6.1 General

The minimum values for the radii of thermoplastic and thermosetting cable for permanent training during installation are given in this section. These limits do not apply to conduit bends, sheaves, or other curved surfaces around which the cable may be pulled under tension while being installed. Larger radii bends may be required for such conditions (see section 4.1, Side Wall Pressure). In all cases the minimum radii specified refers to the inner surface of the cable and not to the axis of the cable.

Table 1—Minimum Bending Radius of Single- and Multi-Conductor Cable without Metallic Shield or Armor as a Multiple of Cable Diameter

	Overall Diameter of Cable (inches)		
Insulation Thickness (Mils)	**1.00 and Less**	**1.01 to 2.00**	**2.01 and Over**
155 and Less	4	5	6
156 to 315	5	6	7
316 and Over		7	8

Table 2—Minimum Bending Radius of Power and Control Cables with Metallic Sheath or Armor as a Multiple of Cable Diameter*

Type of Cable	Bending Radius
Interlocked Armor	7
Flat-Tape Armor	12
Wire Armor	12
Corrugated Sheath	7
Lead Sheath	12

*(Applies to non-shielded cable only.)

Table 3—Minimum Bending Radius of Single- and Multi-Conductor Non-Metallic Portable Cable as a Multiple of Cable Diameter

Type of Cable	Bending Radius
0–5kV	6*
Over 5 kV	8*
Control Cable (7 Conductors and Over)	20*

*For fiat twin cables the minor diameter shall be used to determine the bending radii.

Table 4—Recommended Minimum Temperature for Handling and Installing Cables

Type of Insulation or Jacket	Minimum Temperatures for Installation
PVC	−10 °C
Neoprene	−20 °C
CSPE	−2O °C
CPE	−3O °C
XLPE	−40 °C
Polyethylene	−40 °C
EPR	−40 °C

6.2 Cables without Metallic Shielding or Armor

The minimum bending radii for both single and multiple conductor cable without lead sheath and without metallic shielding or armor except portable cables are shown in Table 1.

6.3 Power Cables with Metallic Armor

The minimum bending radii of all interlocked armored, fiat-tape armored, wire armored and corrugated sheathed cables, both single and multiple conductor, are shown in Table 2.

6.4 Shielded Cables

The minimum bending radius for all cables with metallic shield is 12 times the overall diameter of the cable.

6.5 Portable Cables

The minimum bending radii for single- and multiple-conductor portable cables during installation and handling are shown in Table 3.

7. Minimum Installation Temperature

When installing cables under cold ambient conditions, various insulations and jacket materials become brittle and cables may be damaged if worked at too low a temperature. Table 4 is a recommended minimum temperature for handling and installing cables. It should be noted that these are typical values for standard compound materials; minimum temperatures will vary with special compound designs and requirements as specifications dictate.

7.1 After Installation

After the cables are installed they may be subjected to additional lowering of temperature without harm. The danger of damage comes from unreeling, bending, pulling, or accidental hits that could shatter the insulation or jacket.

7.2 Storage Prior to Installation

The cable to be installed at low temperatures or that has been stored at temperatures below the minimum installation temperature should be heated up to the minimum installation temperature before installation.

This should be done by having the cable in heated storage for at least 24 hours prior to installation.

8. Direct Burial

8.1 General

This section discusses installation practices that should be considered when installing direct burial cable. The purpose of this section is not to be totally exhaustive, but to provide sound installation suggestions and recommendations.

8.2 Trenching

The width of trench should be large enough to accommodate the cables to be installed with sufficient separation between cables. Minimum depth of trench should be as defined in the latest edition of the National Electrical Code [5]. Minimum depths are as follows:

600 V and below	24 in
Over 600 V-22 kV	30 in
Over 22 kV-40 kV	36 in
Over 40 kV	42 in

The minimum cover requirements (depths) listed above may be reduced by 6 in for installations where a 2-in thick concrete pad or equivalent in physical protection is placed in the trench above the cables.

The above distances are measured between the top surface of direct buried cable and finished grade. It is recommended that direct buried cables be installed below the frost line.

One method of preparing the trench for cable installation is to pour 3 to 6 in of sand in the bottom of the trench to act as a cushion for the cable. If sand is not available, rock-free screened fill may be used.

Another method is to pour a 3-in concrete seal slab in the bottom of the trench, and then cover it with 3 in of sand. Cable spacers could also be installed with this method at reasonable distances.

8.3 Installation

After trenching, the cables may be installed by one of the following methods:

1) The cable reel may be suspended directly over the trench, or alongside, and the cable laid in place as it is payed off the reel.
2) The cable reel may be set up at one end of the trench and the cable pulled into place.
3) It may be feasible to use a combination of A and B.

Cables should be installed with slack to allow for earth movement due to freezing, drying, or settling.

It is recommended that direct buried cables be installed in a single layer at the same elevation without crossovers.

It is acceptable and economically feasible to install power cables and communication cables in a common trench with defined separation. As a general rule, a 1-ft minimum separation is suggested for working distance. Additional separation may be required due to electromagnetic influence interference for power and communication cables.

8.4 Backfill

An additional layer of sand, approximately 6 in, should be poured and compacted after the cables are installed and before backfilling. Treated wood planks or a concrete slab (approximately 3 in) may be installed on top of this if additional protection is warranted. The trench should then be backfilled with the remaining excavated material to grade.

Backfill containing large rocks, sharp objects, corrosive material, scrap wood, or trees should not be used. If treated wood planks are used above the cable for mechanical protection, they should not be in direct contact with the cables and should not be treated excessively with preservatives that could be harmful to the cables.

8.5 Protection

Where cables run under railroads, or paved or non-paved roads, cables should be run through rigid conduit or pipe sleeves. Cable ampacity derating should be considered as temperatures will be higher here than where directly buried.

Marking strips and warning signs should be installed to readily identify the direct buried cable trench.

9. Pulling Lubrication

It is recommended that adequate lubrication with suitable lubricant be used in pulling cables to reduce friction. The commonly used lubricants are given in Table 5.

Table 5—Pulling Lubricants

	Cable Covering					
Lubricant	**Neoprene**	**PVC**	**XLP & PE**	**Hypalon**	**CPE**	**Lead**
Soap flakes and water	+	+	+	+	+	
Soapstone and water	+					
Bentonite—dry or water	+	+	+	+	+	+
Talc	+	+		+		
Graphite*	+	+		+		
Linseed oil soap	+	+				
Grease						+
Commercially available lubricants	x	x	x	x	x	x
none = OK to use; x = check with lubricant manufacturer.						

*Graphite or other electrically conducting lubricants should not be used on non-shielded cables rated 3 kV and above

9.1 Commercial Lubricants

Various commercial lubricants designed specifically for pulling cables are available. These are designed to be compatible with different types of jacketing material. The choice of a specific commercial lubricant should be coordinated with the lubricant manufacturer to ensure compatibility with the cable jacket material.

10. Splicing

These general guidelines are offered for splicing cables. However, because of the variety of materials covered, they are not intended as a detailed set of instructions. Rather, they are to be used as a basis for developing detailed instructions covering a specific cable construction. This section will cover the basic requirements for splicing insulated copper or aluminum conductors up to 69 kV; shielded and non-shielded; single and three conductor; thermoset or thermoplastic insulated; lead, thermoset, or thermoplastic covered or jacketed.

The objective is to make a joint in a power cable that is electrically equivalent, to the cable. To achieve this objective, the following conditions are necessary:

1) Tools are to be in first-class condition—clean, dry, and sharp.
2) Strict adherence to instructions, dimensions, cleanliness, and freedom from contamination are to be followed.
3) The materials used in the fabrication of the joint must be compatible with the cable materials and of first quality.

10.1 Removal of Cable Jacket

1) Remove the non-metallic jacket by ring cutting and slitting. In this case, it will be necessary to cut further than halfway through the jacket. Extreme care must be exercised in sheath and jacket removal not to damage the underlying insulation.
2) The length of the jacket to be removed on a single-conductor cable is determined by the creepage distance that is required for the cable's operating voltage. For multi-conductor cables an additional distance is required to allow the spreading of the conductors during splicing.
3) In a shielded, single-conductor cable, remove the shielding to within I in of the non-metallic jacket. In a multi-conductor cable, remove the binder tape and fillers back to the non-metallic jacket. In some cases, with multi-conductor cable, it may be desirable to lay back but not remove the fillers in order to reuse them in the completion of the joint.

10.2 Placing Connectors

1) Connectors are available in several types, among which are weld, solder, compression, and indent. All types are suitable for copper conductor with thermosetting insulation. Thermoplastic insulated cable should use the compression or indent types only. Aluminum conductors should use compression or indent types with an oxide inhibitor compound.
2) Remove the cable insulation from each cable end for a distance equal to 1/2 the connector length plus 1/4 in. Apply cotton tape over remaining exposed cable insulation to protect it from damage.
3) In the case of the solder-type connector, clean the strands and apply stearine flux. Fit the connector into place, make sure the conductor ends butt against each other, and squeeze the connector tightly against conductor. Apply stearine flux in connector slot. Solder the connector to the conductors by ladling hot solder over the connector into the slot until a proper joint is produced. Avoid using a torch flame. While the connector is still hot and the solder soft, smooth off all burrs with cotton tape. Polish after cooling with an abrasive cloth to a smooth surface. Leave no solder points or burrs. The manufacturers of weld-, compression-, and indent-type connectors provide detailed instructions for applying their products. It is mandatory that these instructions be followed during application of this type of connector.

10.3 Preparation of Joint for Insulation

In order to provide a smooth, stepless surface for taping, it is necessary to “pencil” the factory applied insulation. The pencil length is determined by the cable voltage but usually is approximately six times the thickness of the factory insulation wall. The pencil surface should be as smooth as possible without gouges or cuts. Because this surface texture is so critical, it is imperative that the tools used to make the pencil be in the best condition. Penciling tools—either hand or powered—are available and drastically reduce the possibility of insulation damage as well as decreasing the time required to produce a pencil.

CAUTION — The use of a penciling tool requires free access to the cable end. Therefore, the connector cannot be applied until after the insulation is penciled.

If the penciling is performed with a knife, it will generally require buffing with an abrasive cloth. Abrasive cloth containing metal particles must not be used. The exposed insulation surface should now be cleaned using a clean, dry, lint-free cloth. The use of a solvent is not recommended except with approval of the cable manufacturer.

10.4 Insulating the Joint

1) If the cables being joined have a semiconducting screen over the conductor, it is desirable to replace it with semiconducting tape over the exposed conductor and connector. The semiconducting tape should provide an absolutely smooth surface for the application of the insulating tapes. There must be no abrupt dimension change. At this time it is prudent to make absolutely sure that the exposed factory insulation surfaces are perfectly clean.
2) Use high-grade insulating tape as recommended by the cable manufacturer for insulation. Apply the tape by following the tape manufacturer's instructions. Fill up any slight irregularities between the pencils with even, firm wrapping of the insulating tape. Continue evenly up to the level of the factory insulation.
3) The insulating of the joint is then completed by taping to a diameter equal to the connector OD plus four times the insulation wall.

10.5 Shielding of the Insulated Joint

1) On shielded cable joints, a layer of semiconducting tape should be applied across the joint to establish a continuous electrostatic shield. The applied semiconducting tape should overlay the semiconducting insulation screen on each of the two joined cables by approximately 1 in.
2) If the joined cables have a concentric neutral, the wires are bound down on each side of the joint and the free ends twisted together and connected by either a solder-or compression-type connector. If the cables were supplied with a metallic tape or wire shield, a copper mesh braid is wrapped over the joint, providing a continuous path for the metallic shields of the jointed cables. The copper braid should overlap the cable shield for approximately 1 in and be soldered to it at each end of the joint. Flexible ground wire(s) should be connected to the cable shield at one end of the joint.

10.6 Protective Covering

The covering of a joint should be of a material similar to the cable jacket. The covering tape should be applied in a half-lapped manner to a thickness equal to or slightly greater than the cable jacket. It should extend completely across the joint, covering all exposed metallic surfaces—except concentric neutrals—and overlay the cable jacket for approximately 1-1/2 in on each end.

10.7 Lead-Sheath Covering

Special consideration must be given to lead-sheathed cables, in removal of the lead sheath and making of the lead joint.

10.7.1 Removal of the Sheath

Remove the lead sheath by ring-cutting the sheath approximately half-way through at a point 1-1/2 in less than half the sleeve length measured from conductor end. Cut the lead lengthwise from the ring to cable end. Grasp the sheath with pliers and tear off. This operation will leave the end of the remaining lead slightly belied which is desirable for splicing.

10.7.2 Making the Lead Joint

The lead sleeve is slid back over the joint, centered, and the ends of the sleeve beaten down snugly against the cable sheath. Scrape all, wiping surfaces clean, and apply stearine flux to the wiping surfaces and paper pasters to limit the wipe area.

Make the wipes by pouring molten lead onto the wipe area. As the solder becomes plastic on cooling, the solder is worked by wiping with a cloth pad. This process is continued until a leakfree, tight joint is effected at each end of the lead sleeve.

Cut and bend back “V” notches (one in each end of the top of the lead sleeve). Pour insulating compound, heated to the recommended temperature, into the lower of the two holes, allowing the sleeve cavity to vent through the upper notch. The pouring operation should be done as quickly as possible and in a single pour. Bend the “V” notches back down into position and solder them tightly closed.

10.8 Non-Hand Type Joints

There are other joint technologies commercially available that are qualified to ANSI/IEEE Std 404-1986 , IEEE Standard for Cable Joints for Use with Extruded Dielectric Cable Rated 5000 V Through 46 000 V and Cable Joints for Use with Laminated Dielectric Cable Rated 2500 Through 500 000 V [1]. Qualification to this standard is indicative of excellent electrical and mechanical properties. Two common technologies are heat-shrink and pre-molded rubber joints.

10.8.1 Heat-Shrink Joints

Heat-shrink joints are pre-engineered complete joints for non-shielded and shielded, single and three-conductor, armored extruded dielectric cable, single and three conductor paper-insulated lead-covered cable, and single and multi-conductor transition joints between paper and extruded dielectric cable. Kits are typically supplied without conductor connectors. Non-tapered secondary compression connectors or sweated connectors can be used. For paper cable or transition joints, connectors must be sweated or have a center oil-stop. Installation time is significantly shorter than hand taping, and complete installations are supplied. Heat-shrink joints fit all common extruded dielectric cable types and permit size transitions, and address all necessary joint functions.

10.8.2 Pre-Molded Joints

Pre-molded joints are typically used for single-conductor inline jointing of identical cable types and cable size. These joints can be used on jacketed power cables when supplied with sealing adaptors. Kits are supplied with a conductor connector and complete instructions. Grounding/sealing adaptors must be specified. Joints may be suitable for use in multi-conductor cable; however, the user must supply overall metallic shielding and overall rejacketing.

10.9 Terminations

Cable terminations are required when connecting insulated power cables to uninsulated conductors such as a busbar or uninsulated overhead lines. For non-shielded cable, environmental sealing of the connector to the jacket is advantageous to keep out water, and an outer insulating non-tracking covering will minimize the possibility of a failure due to surface discharge.

Shielded power cable terminations should contain a method of stress control (stress cone or electrical stress grading material), an outer non-tracking surface (porcelain or heat-shrink), and some means of providing an environmental seal to prevent moisture ingress.

Terminations should be suitable for both single- and three-conductor cable, with or without armor, with or without ground wires. Terminations should be rated for either outdoor (direct weather exposure) or indoor (weather protected) applications and should be designed for the specific application it is to be used in. Cable preparation techniques are identical to that use for joints.

11. Electrical Connections

11.1 General

Electrical connections are made where conductors must be joined to another conductor or terminated. This process usually involves electrical connector, which, if properly used, will ensure a better connection. Connectors are engineered and manufactured under ideal conditions and in a controlled environment; therefore, they become the essential key to a good electrical connection.

Most connectors are devices that are applied to cable ends. It is always advisable to consult a cable or connector manufacturer when selecting the best connector for a particular application.

11.2 Connector Types Available

Connectors may be divided into two general classifications that are determined by their method of attachment. These two general classifications are: 1) thermal, and 2) pressure.

11.2.1 Thermal Connectors

The thermal connector depends on heat to effect its attachment to the conductor. These types consist mainly of soldered, silver-soldered, brazed, welded, and thermite-welded.

11.2.2 Pressure Connectors

A pressure connector is one that utilizes pressure to effect its attachment. There are three general types of pressure connectors. These types are referred to as: 1) mechanical, 2) compression, and 3) internally fired.

11.2.2.1 Mechanical Connectors

Mechanical connectors are those in which the pressure to attach the connector to the conductor is applied by integral screw, cone, or other mechanical parts. A mechanical connector thus applies force and distributes it properly through the use of bolts or screws and properly designed sections. The bolt diameter and number of bolts are selected to produce the clamping and contact pressure required for the most efficient and economical design. The sections are made heavy enough to carry rated current and withstand the mechanical conditions.

11.2.2.2 Compression Connectors

Compression connectors are those in which the pressure to attach the connector to the conductor is applied externally by a compression tool, changing the size and shape of the connector. The compression connector is basically a tube with the inside diameter slightly larger than the outside diameter of the conductor. The wall thickness of the tube must be adequate to carry rated current, withstand the installation stresses, and withstand the mechanical stresses resulting from thermal expansion of the conductor. The connection is made by compressing the conductor and tube into another shape by means of a specially designed compression tool and die. The final shape may be indented, cup, hexagon, circular, or oval. They all have in common the reduction in cross-sectional area by an amount sufficient to ensure intimate and lasting contact between the connector and the conductor. A hydraulic compression tool is preferred for connections or cables sized #4/0 or larger. A properly compressed joint deforms the conductor strands sufficiently to produce good electrical conductivity and mechanical strength, but not so much that the crimping action over-compresses the strands and weakens the joint. The optimum depth of compression or indent is determined by “work curves” that plot the depth of indent of the inducting die against pull-out force and conductivity of the joint. Consult the connector manufacturer for the correct tool and die to be used for each size and type of connector. Different size dies are often required for connectors on the same size cable. This is usually due to difference in metallurgy and connector wall thickness.

11.2.2.3 Internally Fired Connectors

Internally fired connectors are self-contained, propellant-actuated, chuck connectors for joining conductors such as stranded aluminum, aluminum/alloy, and aluminum/steel composite. The pressure from the explosion provides the means of attachment. The housing of this connector contains a high-strength power chamber that is loaded with a fast-burning propellant charge. Igniting the charge creates instantaneous high pressure in the chamber. This pressure drives cylindrical sets of wedge-shaped, serrated, aluminum jaws (into which the conductor ends have been inserted) at high velocity into the tapered ends of the housing. The jaws clamp and lock the conductor ends in position, providing the required holding strength and establishing a low-resistance current path across the housing.

11.3 Contact Resistance

Either type of compression connector brings two surfaces together to establish a connection. Microscopic peaks touch each other and, as force is applied, the relatively few peaks flatten out into large plateaus and a lower contact resistance is obtained. The relationship between contact resistance and contact force is shown in Fig 2. The most significant thing about this relationship is that once sufficient force has been applied to establish a safe value of resistance, considerable relaxation can occur before the resistance starts to rise again. Therefore, a well-designed clamp or compression connector has a built-in safety factor from the start.

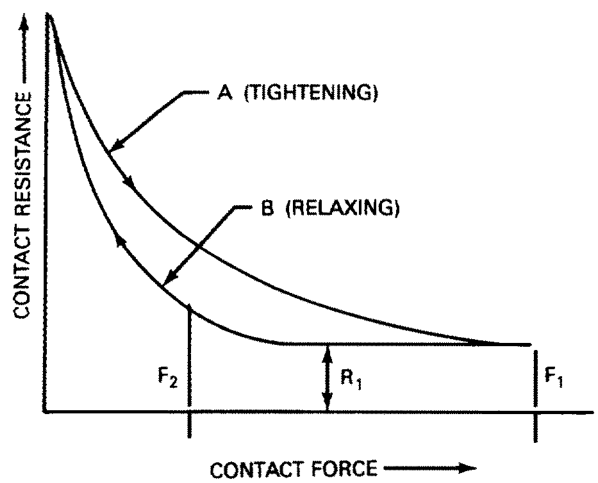

Figure 2—Contact Resistance Curves

11.4 Clamp Connectors

Connectors that mechanically clamp the cable or mechanically clamp two flat surfaces together depend on the thrust developed by the bolts to deliver the force necessary for a sound, stable connection. The bolts must have adequate strength so they can be properly torqued, and they must be reliable and not fail in service.

11.5 Torque Values

The tightening torque values given in Table 6 may be used where manufacturers' specific values are unavailable. These are typical recommended tightening torques for high strength silicon bronze, stainless steel, and aluminum alloy hardware.

11.6 Belleville Washers

A Belleville washer is a dished washer made of spring steel. High-loading and low-deflection spring washers are useful in maintaining constant contact pressure on flat contact electrical connections. They are ideal for use on aluminum, aluminum-to-copper, or other connections where continuous clamping pressure is required. Compact design permits use on NEMA hole spacing as well as on other standard connector hole spacing. For most applications Belleville washers, series #17-7PH, made of #17-7 stainless steel, are ideal.

Table 6—Tightening Torques

Bolt Diameter	Nominal Torque Values			
	Silicon Bronze, Galvanized, or Stainless Steel		Aluminum Alloy (Lubricated)	
	ft-lb	in-lb	ft-lb	in-lb
5/16–18	15	180	—	—
3/8–16	20	240	12	144
1/2–13	40	480	25	300
5/8–11	55	660	40	480
3/4–10	80	960	70	840

11.7 Cable Connections to Bus Bar

When making a flat, bolted connection between a NEMA connector and a bus bar, it is important that the correct bolt, nut, and washer combination be used. Where metals with different coefficients of expansion are used, a follow-up device such as a Belleville washer should be used. This applies both to conductor and hardware materials. Where coefficients of expansion are compatible, high strength, silicon bronze hardware, including a high-strength silicon bronze spring lockwasher and flat washers, can be used.

11.8 Thermal Expansion

The coefficient of thermal expansion of aluminum is greater than that of copper. This is an important consideration in the application of connectors on both aluminum and copper conductors. The use of a connector such as copper on an aluminum cable will result in high stress in the aluminum conductor during heat cycles. This stress can cause plastic deformation and significant creep of the aluminum. Stresses are often magnified because the connector usually operates at a lower temperature than the aluminum cable. The metal lost by creep does not return; therefore, a loosening of the connection will result during the cooling cycle. Aluminum connectors applied to copper cables will produce, an opposite effect. When the connection heats up, there will be a slight loosening effect (with little or no change of contact resistant—see Fig 2) and, consequently, no creep. When the connection cools off, there will be a retightening of the connection due to the higher coefficient of expansion of aluminum. Underwriters Laboratory-approved aluminum compression connectors are suitable for use with both aluminum and copper cables. Copper compression connectors are suitable only for copper cables and under no circumstances are to be used on aluminum cables.

11.9 Joint Compounds for Aluminum Connections

A joint compound consists of zinc granules suspended in a petroleum-based carrier. The zinc granules of carefully controlled size penetrate the aluminum oxide film when compression is applied and form current-carrying bridges between contact surfaces. The continued presence of the compound in the joint seals out air and moisture, prevents oxidation, and ensures continued high conductivity. The following steps should be followed when applying a joint compound.

a) Scratch brush the surface of the dry aluminum conductor with a wire brush until it is bright and clean.
b) Apply joint compound to the conductor and the connector. (If the connector is factory-prefilled with joint compound this step is not required.)
c) Apply joint compound to the fiat surfaces of NEMA pad connections that involve aluminum in one or both surfaces. Bolt threads should be lubricated with the joint compound and then torqued to the required value.
d) All excess joint compound left on the connection after compression has been applied should be removed with a clean, dry cloth.

11.10 Connectors for Aluminum

Underwriters Laboratories (UL) have tested and listed connectors approved for use on aluminum cable. Such connectors have successfully withstood UL performance tests. Both mechanical and compression UL-approved connectors are available. The most satisfactory connectors are those specifically designed for aluminum. They pay particular attention to such things as creep, corrosion, oxide film, and coefficient of expansion.

11.11 Connection Procedures

11.11.1 Aluminum/Aluminum Connection

A typical aluminum/aluminum connection is shown in Fig 3.

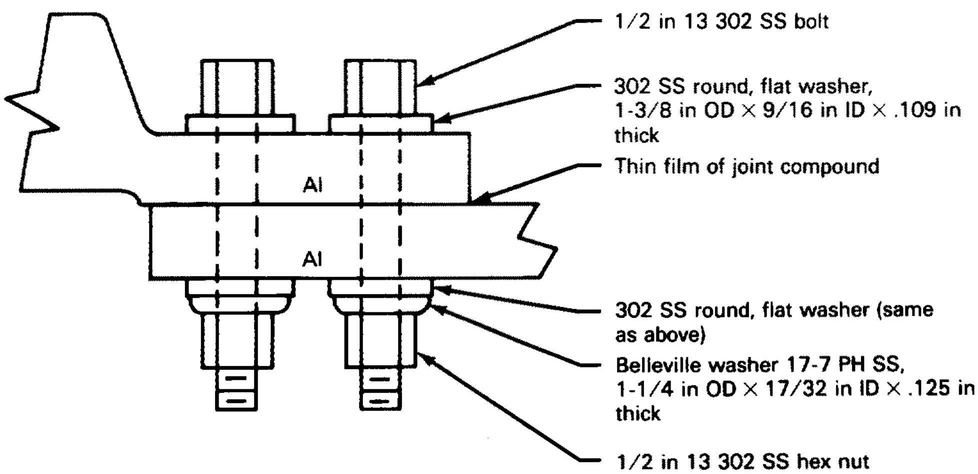

Figure 3—Typical Aluminum/Aluminum Connection

There are two keys to a good aluminum/aluminum connection. The first is to prevent the formation of aluminum oxide, which occurs rapidly in air and is a very poor conductor of electricity. Joint compound will keep air away from aluminum, preventing oxide formation. The compound also has fine zinc granules suspended in a petroleum base that cut through any oxide film that has formed, providing current bridges between the two conductors. The second key to a good connection is to allow for the different expansion rates of aluminum, copper, and steel. A proper Belleville washer will keep constant pressure on the bolted connection and keep it tight throughout heating and cooling cycles.

A) Plated Conductors
   1) Clean lightly with a suitable cleaning solvent. Do not remove plating. Do not use a file or wire brush.
   2) Apply a light film of suitable joint compound.
   3) Lubricate bolt threads with joint compound and tighten to recommended torque. Be sure the correct flat washers and Belleville washers have been installed properly as shown in Fig 3
   4) Remove excess joint compound with a dry, clean cloth.
   5) Insulate the connection for the required operating voltage level or, if the connection is to remain bare, coat with a suitable corrosion-preventing grease.

B) Non-Plated Conductors
   1) Coat contact surfaces liberally with a suitable joint compound.
   2) Wire brush conductor to remove aluminum oxide film. Leave a continuous film of joint compound on the conductors, adding more if required.
   3) Lubricate bolt threads with joint compound and tighten to recommended torque. Be sure the correct flat washers and Belleville washers have been installed properly as shown in Fig 3.
   4) Remove excess joint compound with a dry, clean cloth.
   5) Insulate the connection for the required operating voltage level or, if the connection is to remain bare, coat with a suitable corrosion-preventing grease.

11.11.2 Copper/Aluminum Connection

A typical copper/aluminum connection is shown in Fig 4

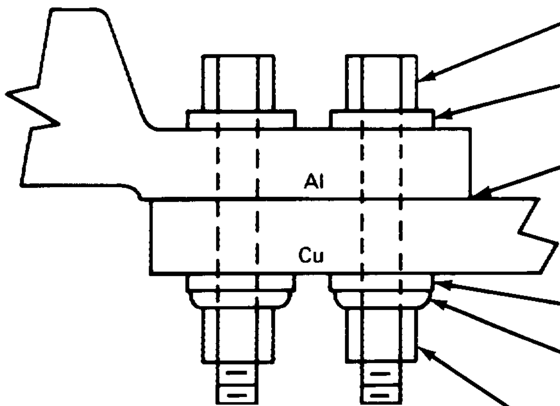

Figure 4—Typical Copper/Aluminum Connection

There are two keys to good copper/ aluminum connection. These are the same as given for a good aluminum/aluminum connection in 11.11.2.

A) Plated Conductors
   1) Clean lightly with a suitable cleaning solvent. Do not remove plating. Do not use a file or wire brush.
   2) Apply a light film of suitable joint compound.
   3) Lubricate bolt threads with joint compound anti tighten to recommended torque. Be sure the correct flat washers and Belleville washers have been installed properly as shown in Fig 4.
   4) Remove excess joint compound with a dry, clean cloth.
   5) Insulate the connection for the required operating voltage level or, if the connection is to remain bare, coat with a suitable corrosion-preventing grease.
B) Non-Plated Conductors
   1) Coat the aluminum surface liberally with a suitable joint compound.
   2) Wire brush aluminum surface to remove aluminum oxide film. Leave a continuous film of joint compound on the aluminum surface, adding more if required.
   3) Remove the oxide film from the copper surface by dressing with a flat file of emery cloth. Wipe clean with a solvent and apply a light film of joint compound.
   4) Lubricate bolt threads with joint compound and tighten to recommended torque. Be sure the correct flat washers and Belleville washers have been installed properly as shown in Fig 4.
   5) Remove excess joint compound with a dry, clean cloth.
   6) Insulate the connection for the required operating voltage level. If the connection is to remain bare, coat with a suitable corrosion-preventing grease.

11.11.3 Copper/Copper Connection

A typical copper/copper connection is shown in Fig 5.

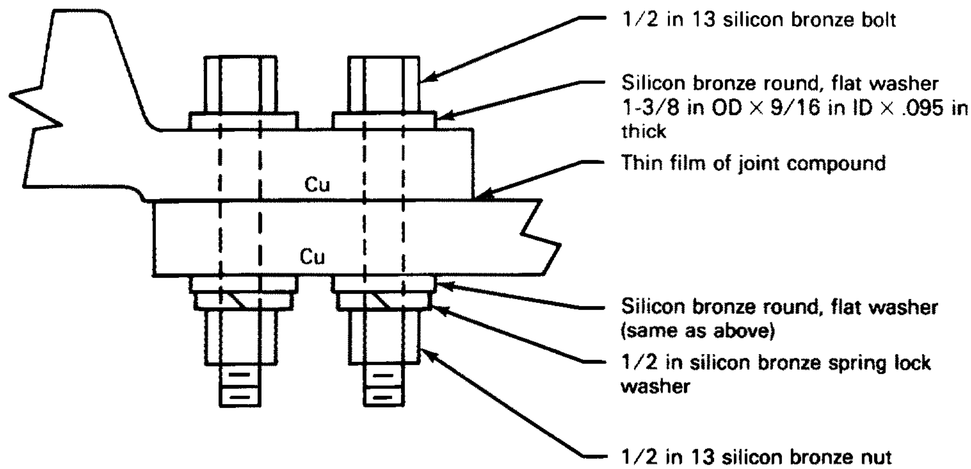

Figure 5—Typical Copper/Copper Connection

The following items should be accomplished to ensure a good and lasting connection.

1) If the conductors are plated, clean lightly with a suitable cleaning solvent. Do not remove or damage plating by filing or wire brushing.
2) If the conductors are bare, remove oxide film and dress with a fiat file or emery cloth and wipe clean with a solvent.
3) Apply a light film of suitable joint compound.
4) Using large, fiat washers to protect the bus and spring, lock washers as shown in Fig 5, tighten to the recommended torque.
5) Remove any excess joint compound with a dry, clean cloth.
6) Coat the connection with a suitable corrosion-preventing grease or, if the bus is insulated, tape the connection for the required voltage.

11.11.4 Copper or Aluminum Compression Connection

A typical compression connection for copper or aluminum cable is shown in Fig 6.

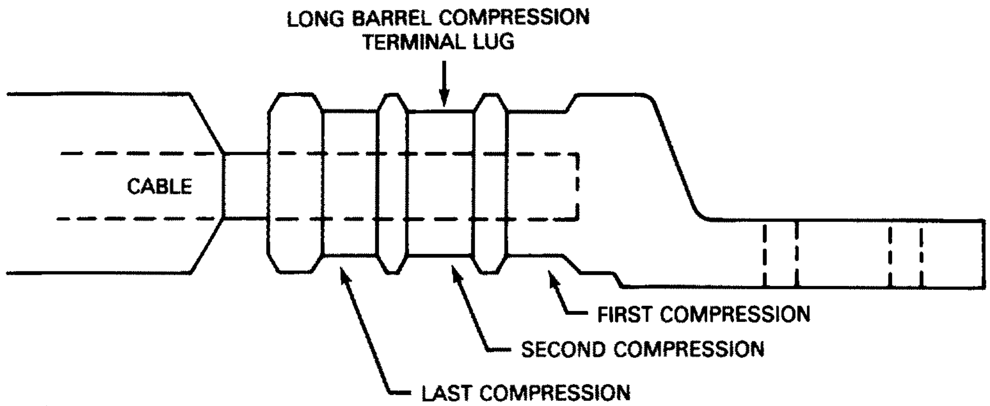

Figure 6—Typical Copper or Aluminum Compression Connection

There are two keys to a good compression connection. The first is to use the correct connector for the connection. The second is to use the correct compression tool and the correct die for the connector being used. The following procedures are for aluminum and copper cable.

A) Aluminum Cable
   1) Use a compression connector approved for aluminum connections. Long barrel connectors give better results on cables larger than #4/0, as this type of connector allows more crimping space.
   2) Do not nick or cut the conductor strands when removing the insulation. Coat the wire with a suitable joint compound. Wire brush to remove oxide film.
   3) Do not wire brush or remove the factory-applied compound from inside the connector.
   4) Insert the conductor all the way into the compression connector and crimp using the correct tool and die for the wire size and connector being used. Make the first crimp near the end of the inserted cable and work back toward the end of the connector.
   5) Remove excess joint compound with a dry, clean cloth.
   6) Insulate according to cable construction and voltage level.

B) Copper Cable
   1) Use a compression connector approved for copper or one approved for copper or aluminum.
   2) Do not nick or cut the conductor strands when removing the insulation. Using a wire brush or emery cloth, brighten the copper conductor, removing the scale and oxide film.
   3) Insert the conductor all the way into the compression connector. Do not remove any factory-applied compound from inside the connector. Crimp the connector using the correct tool and die for the wire size and connector being used. Make the first crimp near the end of the inserted cable and work back toward the end of the connector.
   4) Remove excess joint compound with a dry, clean cloth.
   5) Insulate according to cable construction and voltage level.

12. High Voltage Proof-Testing

12.1 Installation Proof-Testing

The practice of testing cables after installation to be certain that no damage has occurred during installation and that the cables are satisfactory for operation has been increasing. This is particularly important where contractors have installed the cable, as an acceptance test ensures that the cable systems are satisfactory when turned over to the user.

The type of circuit and voltage, as well as the importance of the circuit, determines the method to be used for testing and the frequency of the testing. For low voltage control cables it is general practice to use an insulation resistance tester for checking the reliability of the circuit. This consists essentially of measuring the insulation resistance of the circuit to determine whether or not it is high enough for satisfactory operation. For higher voltage cables, the insulation resistance tester is not usually satisfactory and the use of high voltage testing equipment is becoming more common. Even at the lower voltages, high voltage dc tests are finding increasing favor. The use of high voltage dc has many advantages over other types of testing.

12.2 Advantages of High Voltage DC Testing

High voltage direct current picks out faults or incipient faults without damaging good insulation. Direct current voltage has no harmful or cumulative effects on the insulation, and as long as the voltage is not high enough to break down good insulation it has no deteriorating effects. This permits the use of high test voltages with direct current. With alternating current, the safe test voltage is limited, as there are secondary effects—such as corona discharges—that can damage good insulation.

Much more information can be obtained from examination of faults that are broken down with direct current, as the small arc current does not burn up any appreciable quantity of cable. Thus, in general, it is possible to determine the cause of the failure when it is broken down or located with direct current as compared to a service failure.

The equipment needed for high voltage dc testing is much smaller than with alternating current, since the charging current of the cable need not be provided by this equipment, as is the case with alternating current. Long lengths of cable can be tested with relatively small dc equipment. The only influence the length of the circuit has is in the case where the rate of charging the cable may occasionally be limited if a low-capacity rectifier tube is used.

Table 7—High Voltage Installation Test

	Conductor Size	Test Voltage, kV	
Rated Circuit Voltage Phase to Phase (V)	AWG or MCM	100% Insulation Level	133% Insulation Level
2001–5000	8–1000	25	35
5001–8000	6–1000	35	45
8001–15000	2–1000	55	65
15001–25000	1–1000	80	95
25001–28000	1–1000	85	100
28001–35000	1/0–1000	100	125

12.3 Installation Proof-Test Voltages

Power cables may be proof-tested with high voltage direct current at the voltages given in Table 7 after installation and before being energized.

Tests should be run for a period of 15 minutes for shielded cables and 5 minutes for non-shielded cables. Generally, the voltage is applied and leakage current is recorded after 15, 30, 45, 60 sec and at one-minute intervals thereafter.

12.4 How to Interpret Tests

Considerable experience is needed to properly interpret dc test results. One of the most important things to watch in connection with these tests is the shape of the leakage current curves during the test. In general, the leakage current will start at a relatively high value and drop off rather rapidly, becoming constant at some low value. The fact that the current becomes constant and levels off is more important than the actual magnitude of this leakage current. If the current has not dropped down or if after dropping down it starts to rise again, a strong indication of trouble on the circuit is evident. It is usually the best practice to continue the test beyond the usual time period or for as long as the current continues to rise, until failure occurs—in order that the weak spot may be eliminated.

More data on installation proof testing is available from IEEE Std 400-1980, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field [3].