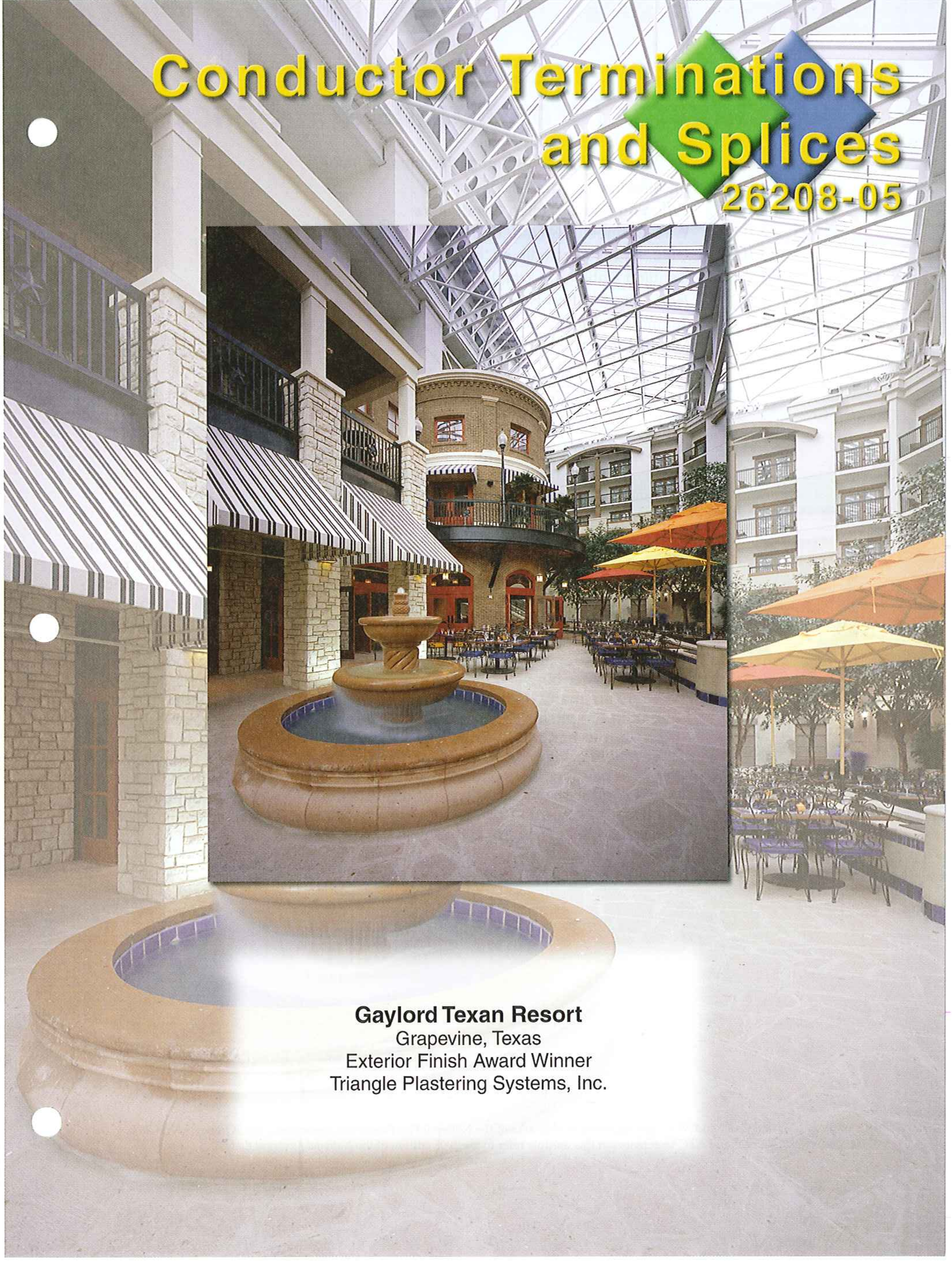
Conductor Terminations and Splices

26208-05



Gaylord Texan Resort
Grapevine, Texas
Exterior Finish Award Winner
Triangle Plastering Systems, Inc.

26208-05
Conductor Terminations and Splices

Topics to be presented in this module include:

Overview

The job is not over once the raceway system and conductors are installed. The final assignment is splicing and terminating the conductors. Certain procedures must be followed when preparing the conductors for splicing or termination. A specific length of conductor insulation must be carefully removed to expose the conductor's end. After this, specific cleaning methods intended to remove any remaining insulation residue or contamination must be employed. A properly prepared conductor end provides the maximum conduction and least resistance between the conductor and termination point or splice.

There are many methods that can be used to prepare the conductor for termination or splicing. The tools available for preparing conductor ends range from simple hand-held knives to specialized cable stripping tools used for large power cables and wires. Regardless of the tool or method used to prepare the wire or cable, the conductor must be left undamaged, with a cleanly exposed conductor end. The type of termination or splice used depends on the application. Common connectors include wire nuts, mechanical connectors, and compression (crimp) connectors.

Objectives

When you have completed this module, you will be able to do the following:

1. Describe how to make a good conductor termination.
2. Prepare cable ends for terminations and splices.
3. Install lugs and connectors onto conductors.
4. Train cable at termination points.
5. Explain the role of the *NEC*® in making cable terminations and splices.
6. Explain why mechanical stress should be avoided at cable termination points.
7. Describe the importance of using proper bolt torque when bolting lugs onto busbars.
8. Describe crimping techniques.
9. Select the proper lug or connector for the job.
10. Describe splicing techniques.
11. Explain how to use hand and power crimping tools.

Trade Terms

AL-CU	Splice
Connection	Strand
Connector	Tap
Insulating tape	Terminal
Lug	Termination
Pressure connector	Wire nut
Reducing connector	

Required Trainee Materials

1. Paper and pencil
2. Appropriate personal protective equipment
3. Copy of the latest edition of the *National Electrical Code*®

Prerequisites

Before you begin this module, it is recommended that you successfully complete *Core Curriculum; Electrical Level One;* and *Electrical Level Two,* Modules 26201-05 through 26207-05. You should also read *NEC Article 312.*

This course map shows all of the modules in *Electrical Level Two.* The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map. The local Training Program Sponsor may adjust the training order.

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1.0.0 ◆ INTRODUCTION

Anyone involved with electrical systems of any type should have a good knowledge of wire **connectors** and splicing, as they are both necessary to make the numerous electrical joints required during the course of any electrical installation. A properly made **splice** and **connection** will often last as long as the insulation on the wire itself, while a poorly made connection will always be a source of trouble; that is, the joints will overheat under load and eventually fail with the potential for starting a fire.

The basic requirements for a good electrical connection include the following:

- It should be mechanically and electrically secure.
- It should be insulated as well as or better than the existing insulation on the conductors.
- These characteristics should last as long as the conductor is in service.

There are many different types of electrical joints, and the selection of the proper type for a given application will depend to a great extent on how and where the splice or connection is used. Electrical joints are normally made with a solderless **pressure connector** or **lug** to save time.

2.0.0 ◆ STRIPPING AND CLEANING CONDUCTORS

Before any connection or splice can be made, the ends of the conductors must be properly stripped and cleaned. Stripping is the removal of insulation from the conductors at the end of the wire or at the location of the splice. Wires should only be stripped using the appropriate stripping tool. This will help to prevent cuts and nicks in the wire, which can reduce the conductor area as well as weaken the conductor.

Poorly stripped wire can result in nicks, scrapes, or burnishes. Any of these can lead to a stress concentration at the damaged cross section. Heat, rapid temperature change, mechanical vibration, and oscillatory motion can aggravate the damage, causing faults in the circuitry or even total failure.

Lost **strands** are a problem in splice or crimp-type **terminals,** while exposed strands might be a safety hazard.

Slight burnishes on conductors, as long as they had no sharp edges, were acceptable at one time. Now, however, most experts believe that under certain conditions, removing as little as 40 microinches of conductor plating from some wires can cause a failure.

Faulty stripping can pierce, scuff, or split the insulation. This can cause changes in dielectric strength and lower the wire's resistance to moisture and abrasion. Insulation particles often get trapped in solder and crimp joints. These form the basis for a defective **termination.** A variety of factors determine how precisely a wire can be stripped, including: wire size, insulation concentricity, adherence, and others.

It is a common mistake to believe that a certain gauge of stranded conductor has the same diameter as a solid conductor. This is a very important consideration in selecting the proper blades for strippers. *Table 1* shows the nominal sizes referenced for the different wire gauges.

To eliminate nicking, cutting, and fraying, wires should only be stripped using the appropriate stripping tool. The specific tool used depends on the size and type of wire being stripped.

2.1.0 Stripping Small Wires

There are many kinds of wire strippers available. *Figure 1* shows two common types of wire strippers for small wires. Note that the one on the left is ergonomically designed with a curved soft foam handle. To use these tools, insert the wire into the proper size knife groove, then squeeze the tool handles. The tool cuts the wire insulation, allowing the wire to be easily removed without crushing its stripped end. The length of the strip is regulated by the amount of wire extending beyond the blades when the wire is inserted in the knife groove.

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Conductor Terminations and Splices

Poor electrical connections are responsible for a large percentage of equipment burnouts and fires. Many of these failures are a direct result of improper terminations, poor workmanship, and the use of improper splicing devices.

Table 1 Dimensions of Common Wire Sizes

Size (AWG/kcmil)	Area (Circular Mils)	Overall Diameter in Inches	
		Solid	Stranded
18	1,620	0.040	0.046
16	2,580	0.051	0.058
14	4,130	0.064	0.073
12	6,530	0.081	0.092
10	10,380	0.102	0.116
8	16,510	0.128	0.146
6	26,240	—	0.184
4	41,740	—	0.232
3	52,620	—	0.260
2	66,360	—	0.292
1	83,690	—	0.332
1/0	105,600	—	0.373
2/0	133,100	—	0.419
3/0	167,800	—	0.470
4/0	211,600	—	0.528
250	—	—	0.575
300	—	—	0.630
350	—	—	0.681
400	—	—	0.728
500	—	—	0.813
600	—	—	0.893
700	—	—	0.964
750	—	—	0.998
800	—	—	1.03
900	—	—	1.09
1,000	—	—	1.15
1,250	—	—	1.29
1,500	—	—	1.41
1,750	—	—	1.52
2,000	—	—	1.63

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Figure 1 ◆ Wire strippers.

2.2.0 Stripping Power Cables and Large Wires

Figure 2 shows a heavy-duty stripper used to strip power cables with outside diameters ranging from ½" to 1¾". It can be used to strip insulation starting from the end of the cable, strip insulation from some point to the end of the cable, or to make a window cut. All stripping tools should be operated according to the manufacturer's instructions. The procedures for using the tool to strip insulation from the end of the cable and to make a window cut are described here.

To strip insulation from the end of the cable (*Figure 3*), proceed as follows:

Step 1 Loosen the locking knob to open the tool to the maximum position. Place the cable in the V-groove and close the tool firmly around the cable. Tighten the locking knob.

Step 2 Turn the cap assembly until the blade reaches the required depth.

CAUTION

Do not allow the blade to contact the conductor because damage to the conductor and/or the blade can result.

Step 3 Rotate the tool around the cable, advancing to the required strip length.

Step 4 Rotate the tool in the reverse direction to produce a square end cut (*Figure 3*).

Step 5 Loosen the locking knob to release the tool and remove it from the cable.

Step 6 Peel off the insulation.

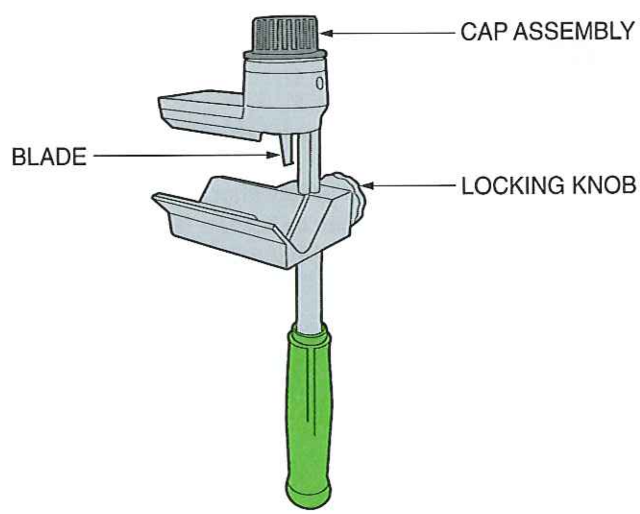

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Figure 2 ◆ Cable stripper.

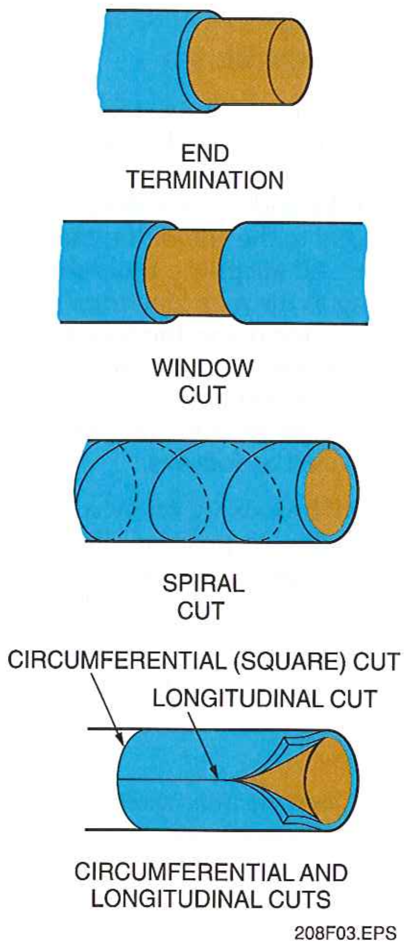

Figure 3 ◆ Types of cable stripping.

To make a window cut (*Figure 3*), proceed as follows:

Step 1 With the tool opened to the maximum position, place the cable in the V-groove and close the tool firmly around the cable. Tighten the locking knob.

Step 2 Turn the cap assembly until the blade reaches the required depth.

Step 3 Rotate the tool to produce the first square cut.

Step 4 Rotate the tool in the reverse direction to cut the required window strip length.

Step 5 Rotate the tool in the original direction to produce the second square cut.

Step 6 Loosen the locking knob assembly to release the tool and remove it from the cable.

Step 7 Peel off the insulation.

Figure 4 shows a round cable slitting and ringing tool that can be used to strip single- or multiple-conductor cables. The tool can be used to cut around the cable (square cut) or slit the length of the cable jacket (longitudinal cut) for easy removal. The tool blade is adjustable to accommodate different jacket thicknesses.

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Cutting Large Power Cable

When cutting large power cables prior to stripping, you can make the job easier by using a ratchet-type or hydraulic-type cable cutter to cut the cable.

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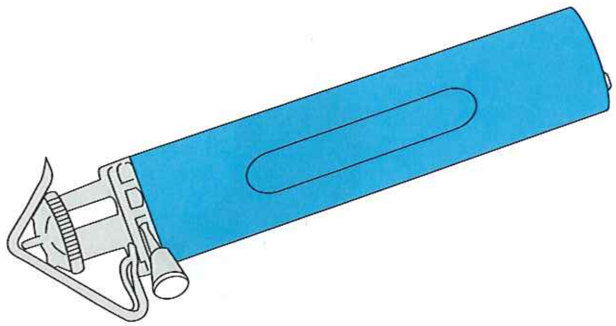

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Figure 4 ◆ Round cable slitting and ringing tool.

3.0.0 ◆ WIRE CONNECTIONS UNDER 600 VOLTS

NEC Section 110.14 governs electrical connections, including terminations and splices. Wire connections are used to connect a wire or cable to such electrically operated devices as fan coil units, duct heaters, oil burners, motors, pumps, and control circuits of all types.

A variety of wire connectors for stranded wire are shown in *Figure 5*. These connectors are available in various sizes to accommodate wire sizes No. 22 AWG and larger. They can be installed with crimping tools having a single indenter or double indenter. The range is normally stamped on the tongue of each terminal.

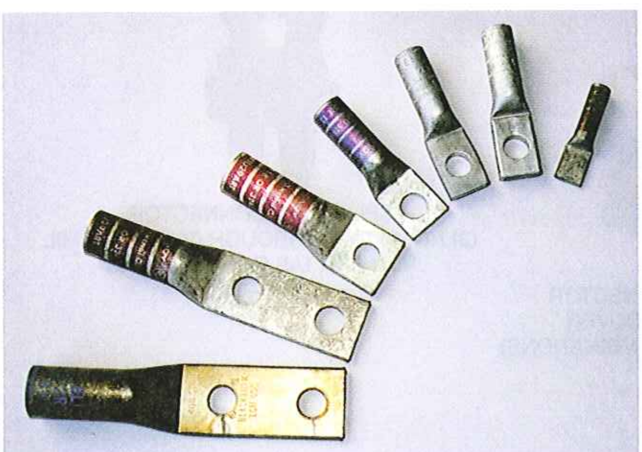

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Figure 5 ◆ Crimp-on wire lugs.

Mechanical compression-type terminators are also available to accommodate wires from No. 8 AWG through 1,000 kcmil. One-hole lugs, two-hole lugs, split-bolt connectors, and other types are shown in *Figure 6*.

Crimp-type connectors made to accommodate wires smaller than No. 8 are normally made to accept at least two wire sizes and are often color coded. For example, one manufacturer's color code used for such connectors is red for No. 18 or No. 20 wire, blue for No. 16 or No. 14 wire, and yellow for No. 12 or No. 10 wire. Crimp-type connectors used for wire sizes No. 8 and larger, commonly called lugs, are made to accept one specific conductor size. Crimp-type **reducing connectors** are used to connect two different size wires. Mechanical compression-type connectors and lugs are made so that they accommodate a range of different wire sizes.

The parallel-tap connector with an insulated cover shown in *Figure 6* is one example of a pre-insulated, molded mechanical compression connector. There are several kinds available. They come in setscrew/pressure plate and insulation-piercing configurations made for use in a variety of feeder **tap** and splice applications. Because they are equipped with an insulating cover, the requirement for taping the joint is eliminated.

3.1.0 Aluminum Connections

Aluminum has certain properties that are different from copper and must be understood if reliable connections are to be made. These properties are: cold flow, coefficient of thermal expansion, susceptibility to galvanic corrosion, and the formation of oxide film on the surface.

Because of the thermal expansion and cold flow of aluminum, standard copper connectors cannot be safely used on aluminum wire. Most

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Stripping Power and Large Cables

When using any bladed-type cable stripper, always be careful to keep your fingers away from the blade. Also, make sure to replace the blade whenever it becomes dull. Remember, a dull blade is more dangerous than a sharp one because you are more likely to apply undue pressure when using a dull blade, causing it to slip.

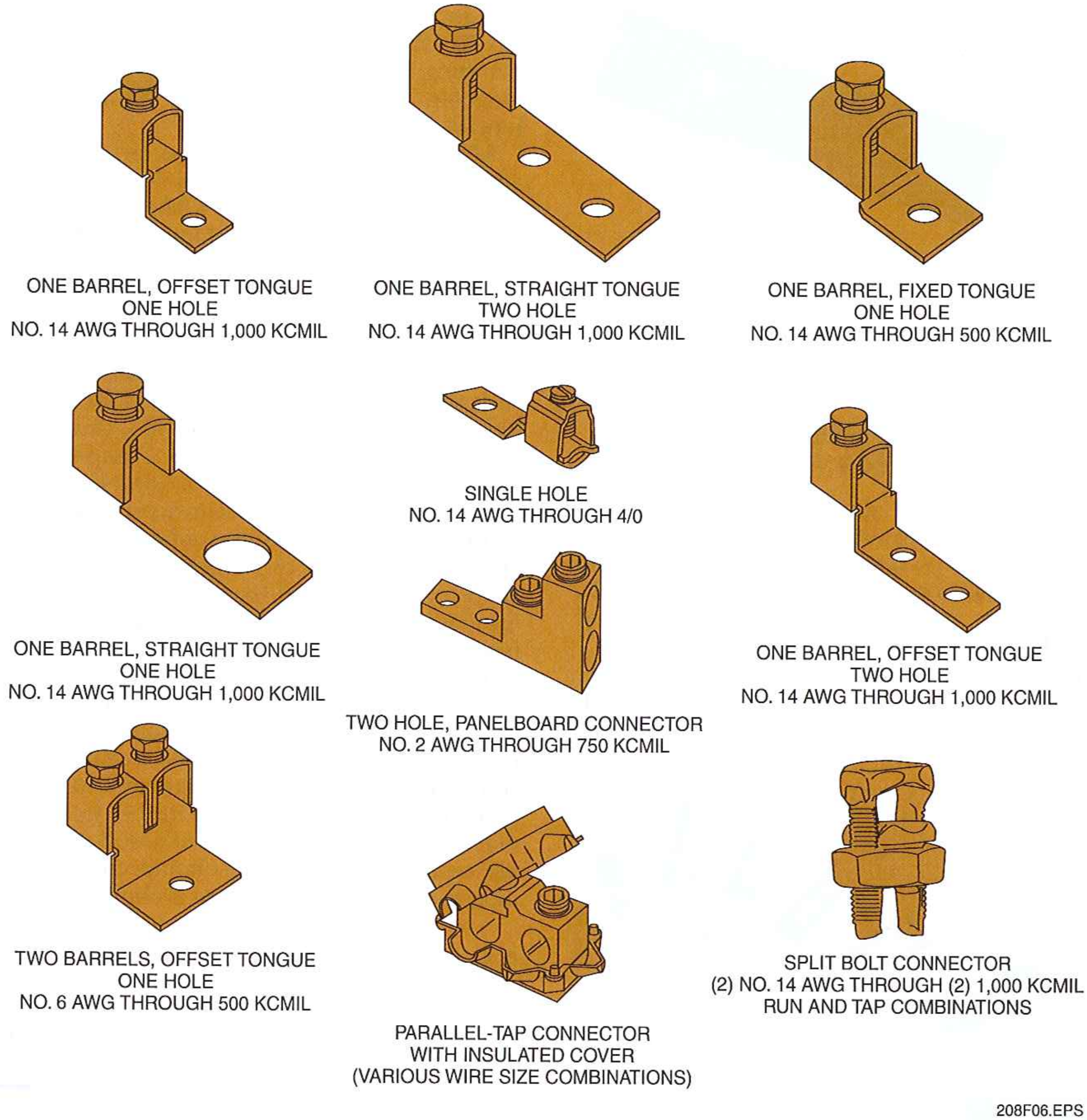

Figure 6 ◆ Various mechanical compression connectors.

THINK ABOUT IT

Mechanical Compression Connectors

What might be a use for a compression connector with a two-hole tongue?

manufacturers design their aluminum connectors with greater contact area to counteract these properties of aluminum. Tongues and barrels of all aluminum connectors are larger or deeper than comparable copper connectors.

The electrolytic action between aluminum and copper can be controlled by plating the aluminum with a neutral metal (usually tin). The plating prevents electrolysis from taking place, and the joint remains tight. As an additional precaution, a joint-sealing compound should be used. Connectors should also be tin-plated and prefilled with an oxide-inhibiting compound.

The insulating aluminum oxide film must be removed or penetrated before a reliable aluminum joint can be made. Aluminum connectors are designed to bite through this film as they are applied to conductors. It is further recommended that the conductor be wire brushed and preferably coated with a joint compound to guarantee a reliable joint.

CAUTION

Never use connectors designed strictly for use on copper conductors on aluminum conductors. Connectors listed for use on both metals will normally be marked AL-CU. All connectors must be applied and installed in the manner for which they are listed and labeled.

NEC Section 110.14 prohibits conductors made of dissimilar metals (copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum) from being intermixed in a terminal or splicing connector unless the device is identified for the purpose and for the conditions under which it may be used. As a general rule:

- Connectors marked with only the wire size should only be used with copper conductors.
- Connectors marked with AL and the wire size should only be used with aluminum wire.
- Connectors marked with **AL-CU** and the wire size may be safely used with either copper or aluminum.

3.2.0 Heat-Shrink Insulators

Heat-shrink insulators for small connectors provide skintight insulation protection and are fast and easy to use. They are designed to slip over wires, taper pins, connectors, terminals, and splices. When heat is applied, the insulation becomes semi-rigid and will provide positive strain relief at the flex point of the conductor. A vapor-proof band will seal and protect the conductor from abrasion, chemicals, dust, gasoline, oil, and moisture. Extreme temperatures, both hot and cold, will not affect the performance of these insulators. The source of heat can be any number of types, but most manufacturers of these insulators

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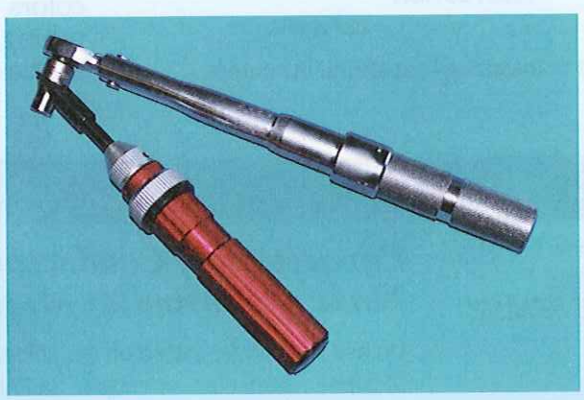
Tightening Compression Connector Screws and Bolts

Mechanical compression connectors must be tightened to a specified torque using a torque screwdriver or torque wrench. Overtightening can cut the wires or break the fitting, while undertightening may lead to loose connections, resulting in overheating and failure.



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also produce a heat gun especially designed for use on heat-shrink insulators. It closely resembles and operates the same as a conventional hair dryer, as shown in *Figure 7*.

In general, a heat-shrink insulator may be thought of as tubing with a memory. After it is initially manufactured, it is heated and expanded to a predetermined diameter and then cooled. Upon application of heat through various methods, the tubing compound "remembers" its original size and shrinks to that smaller diameter. It is available in a range of sizes and is designed to shrink easily over any wire or device when heat is applied. This property enables it to conform to the contours of any object. The following describes some of the types currently available. A typical tubing selector guide appears in *Table 2*.

- *PVC* – This type is a general-purpose, economical tubing that is widely used in the electronics industry. The PVC compound is irradiated by being bombarded with high-velocity electrons. This results in a denser, cross-linked material with superior electrical and mechanical properties. It also ensures that the tubing will resist cracking and splitting.
- *Polyolefin* – Polyolefin tubing has a wide range of uses for wire bundling, harnessing, strain relief, and other applications where cables and components require additional insulation. It is irradiated, flame-retardant, flexible, and comes in a wide variety of colors.
- *Double wall* – This type is available and designed for outstanding protective characteristics. It is a semi-rigid tubing with an inner wall that melts and an outer wall that shrinks to conform to the melted area.
- *Teflon®* – This type is considered by many users to be the best overall heat-shrink tubing—physically, electrically, and chemically. Its high-temperature rating of 250°C resists brittleness and loss of translucency from extended exposure to high heat and will not support combustion.
- *Neoprene* – Components that warrant extra protection from abrasion require a highly durable yet flexible tubing. Irradiated neoprene tubing offers this optimal coverage.
- *Kynar®* – Irradiated Kynar® is a thin-wall, semi-rigid tubing with outstanding resistance to abrasion. This transparent tubing enables easy inspection of components that are covered and retains its properties at its rated temperature.

Most tubing is available in a wide variety of colors and configurations. The manufacturer's tubing selector guide can help in the selection of the best tubing for any given application.

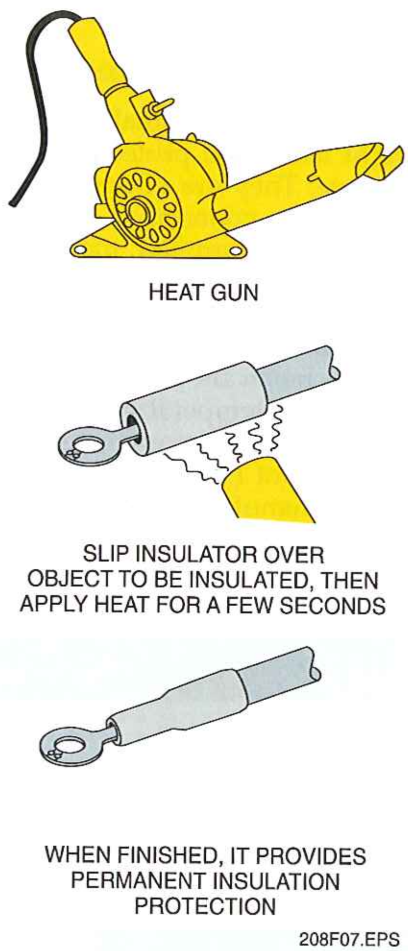

Figure 7 ◆ Method of installing heat-shrink insulators.

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Connection of Conductors Made of Dissimilar Materials

Unless specifically stated on the shipping carton or on the connector itself, wires made of copper, aluminum, or copper-clad aluminum may not be spliced together in the same connector.

Type	Material	Temp. Range (°C)	Shrink Ratio	Max. Long. Shrinkage (%)	Tensile Strength (psi)	Colors	Dielectric Strength (V/mil)
Nonshrinkable	PVC	+105	—	—	2,700	White, red, clear, black	800
Shrinkable	PVC	−35 to +105	2:1	10	2,700	Clear, black	750
Nonshrinkable	Teflon®	−65 to +260	—	—	2,700	Clear	1,400
Shrinkable	Flexible polyolefin	−55 to +135	2:1	5	2,500	Black, white, red, yellow, blue, clear	1,300
Nonshrinkable	Teflon®	−65 to +260	—	—	7,500	Clear	1,400
Shrinkable	Polyolefin double wall	−55 to +110	6:1	5	2,500	Black	1,100
Shrinkable	Kynar®	−55 to +175	2:1	10	8,000	Clear	1,500
Shrinkable	Teflon®	+250	1.2:2	10	6,000	Clear	1,500
Shrinkable	Teflon®	+250	1½:1	10	6,000	Clear	1,500
Shrinkable	Neoprene	+120	2:1	10	1,500	Black	300

Table 2 Tubing Selector Guide

3.3.0 Wire Nuts

Ever since its invention in 1927, the **wire nut,** also known as the *Wirenut*® and the solderless connector (*Figure 8*), has been a favorite wire connector for use on residential and commercial branch circuit applications. Several varieties of wire nuts are available, but the following are the ones used most often:

- Those for use on wiring systems 300V and under
- Those for use on wiring systems 600V and under (1,000V in lighting fixtures and signs)

Most brands are UL listed for aluminum to copper in dry locations only; aluminum to aluminum only; and copper to copper only. The maximum temperature rating is 105°C (221°F).

Wire nuts are frequently used for all types of splices in residential and commercial applications and are considered to be the fastest connectors on the market for this type of work.

To use a wire nut, trim the bare conductors using the appropriate tool, and then screw on the wire nut. The wire nut draws the conductors and insulation into the shirt of the connector, which increases resistance to flashover. The internal spring is designed to tightly thread the conductors into the wire nut and then hold them with a positive grip. Some types of wire nuts have thin wings on each side of the connector to facilitate their installation. See *Figure 9*. Wire nuts are normally made in sizes to accommodate conductors as small as No. 22 AWG up to as large as No. 10 AWG, with practically any combination of those sizes in between.

Specially designed wire nuts are also made specifically for use in wet locations and/or direct burial applications. These wire nuts have a water repellent, non-hardening sealant inside the body that completely seals out moisture to protect the conductors against moisture, fungus, and

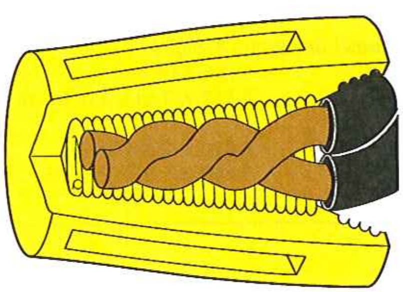

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Figure 8 ◆ Typical wire nut showing interior arrangement.

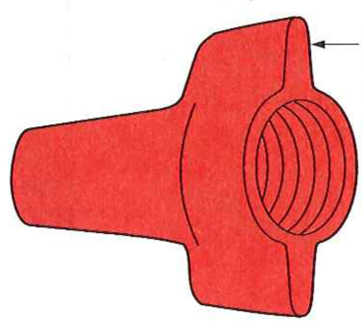

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Figure 9 ◆ Some wire nuts have thin wings on each side to facilitate installation.

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Insulated Spring Connectors

Insulated spring connectors, commonly called wire nuts or Wirenuts®, are solderless connectors made in various color-coded sizes that allow for splicing the hundreds of different solid or stranded wire combinations typically encountered in branch-circuit and fixture splicing applications.

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corrosion. The sealant remains in a gel state and will not melt or run out of the wire nut body throughout the life of the connection. Unlike other types of wire nuts, this type can be used one time only. The wire nut can be backed off, eliminating the need to cut the wires for future or retrofit applications, but once removed, it must be discarded.

The general procedure for splicing wires with wire nuts is as follows:

Step 1 Select the proper size wire nut to accommodate the wires being spliced. Wire nut packages contain charts that list the allowable combinations of wires by size. Refer to the label on the wire nut box or container for this information (*Figure 10*).

Step 2 Strip the insulation from the ends of the wires to be spliced. The length of insulation stripped off is typically about ½"; however, it depends on the wire sizes and the wire nut being used. Follow the manufacturer's directions given on the wire nut package.

Step 3 Stick the ends of the wires into the wire nut and turn clockwise until tight. Note that some manufacturers of wire nuts require that the wires be pre-twisted before screwing on the nut. Also, some manufacturers recommend using a nut driver to tighten the wire nut. Always follow the manufacturer's instructions.

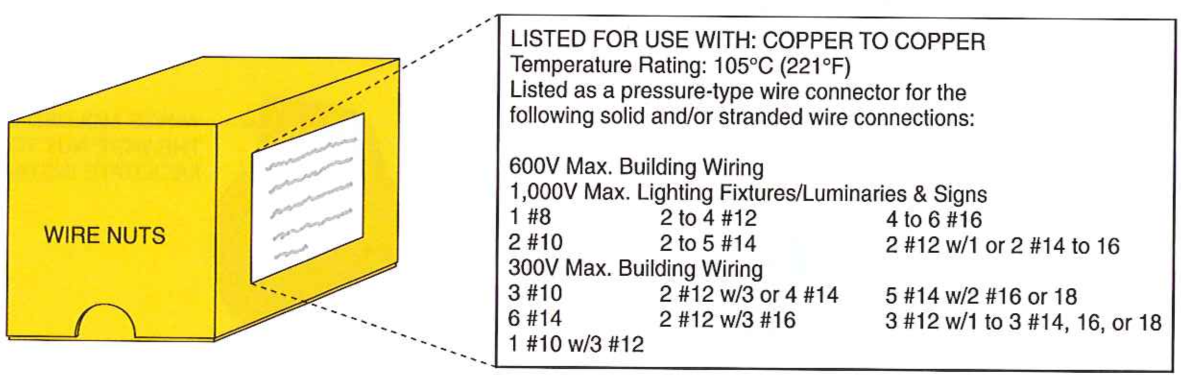

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Figure 10 ◆ Read package label to find allowable wire combinations.

Making Box Connections

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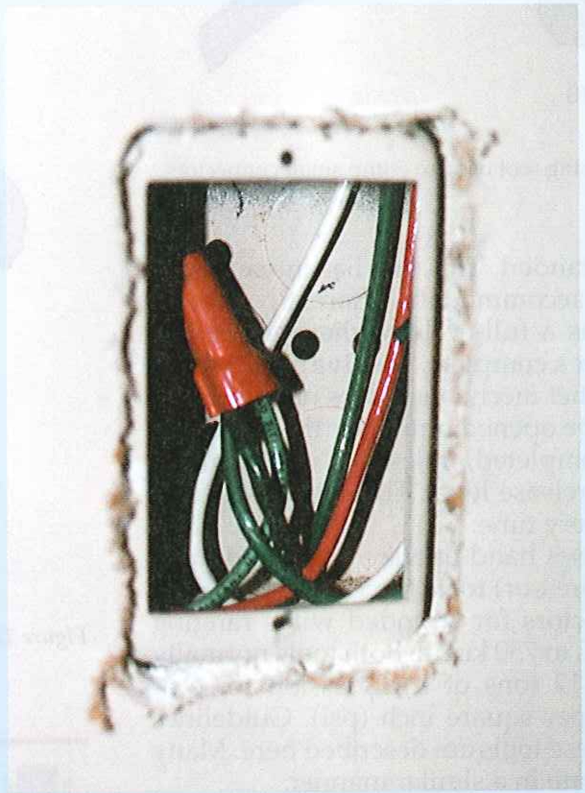
After making the connections within a box, tuck the wires neatly into the back of the box, as shown here. That way, when the painters and plasterers come along to finish the walls, the wires will not be covered in drywall compound or paint.



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4.0.0 ◆ GUIDELINES FOR INSTALLING CONNECTORS

Guidelines for installing the different types of connectors covered in this module are given in the following sections.

4.1.0 Installing Crimp-Type Terminals and Connectors

The task of fastening a compression-type connector to a wire requires the use of the proper connector, crimping tool, and installation procedure.

4.1.1 Crimping Tools

Compression-type connectors and lugs must be attached to wires using the appropriate crimping tool. Since connectors, crimping tools, and crimping tool dies are designed as a unit for specific wire sizes, only the recommended tool and dies should be used. There are a wide variety of crimping tools available, from simple to complex. Most crimping tools are designed for use with either insulated connectors or non-insulated connectors. Quality tools used to crimp larger connectors and wires are typically made with hand-operated ratcheting mechanisms or hydraulic mechanisms that do not release until adequate crimping pressure has been applied. Some crimping tools require the use of related die sets. Some types are dieless. Many manufacturers color code both their connectors and matching crimping tool dies as an aid in selecting the proper die. They also mark their dies with die index numbers to identify the use of the proper connector/die combination.

Figure 11 shows one manufacturer's hand-operated tool. It is designed to crimp connectors to wires ranging in size from No. 8 AWG through

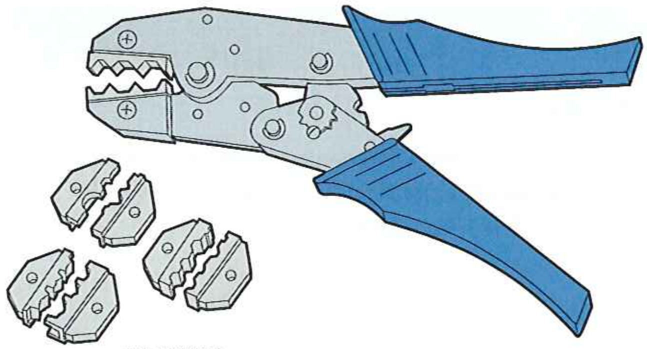


Figure 11 ◆ Crimping tool used to crimp small connectors.

No. 22 AWG stranded. This tool has interchangeable die sets to accommodate different connector sizes. It also has a full-cycle ratchet mechanism that provides for a complete, positive crimp. Once started, the ratchet mechanism does not allow the tool handles to be opened until after the full ratcheting cycle is completed, unless the user actuates the emergency release lever. This ensures a completed crimp every time.

Figure 12 shows hand-operated and hydraulic crimping (compressor) tools typical of those used to crimp connectors for stranded wires ranging from No. 8 AWG to 750 kcmil. Both tools normally develop about 12 tons of compression force at 10,000 pounds per square inch (psi). Guidelines for the use of these tools are described here. Many other tools operate in a similar manner.

To use a hand-operated crimping tool, proceed as follows:

Step 1 Select the proper dies for use with the connector to be crimped. Do not operate the tool without the dies.

Step 2 Push the die release button on the C-head and slide one of the die halves into position until the retainer snaps. Insert the other die half in the piston body by pushing the die release button and sliding the die in until the retainer snaps.

Step 3 Place the tool C-head in position over the connector to be crimped. Pump the handle until compression is complete, as indicated by the dies touching at their flat surfaces nearest the throat of the C-head.

Step 4 Retract the ram and remove the connector after completion of the crimp. This is done by raising the pump handle slightly, rotating it clockwise until it stops, then pushing the handle down in a pumping motion until the pressure release snaps.

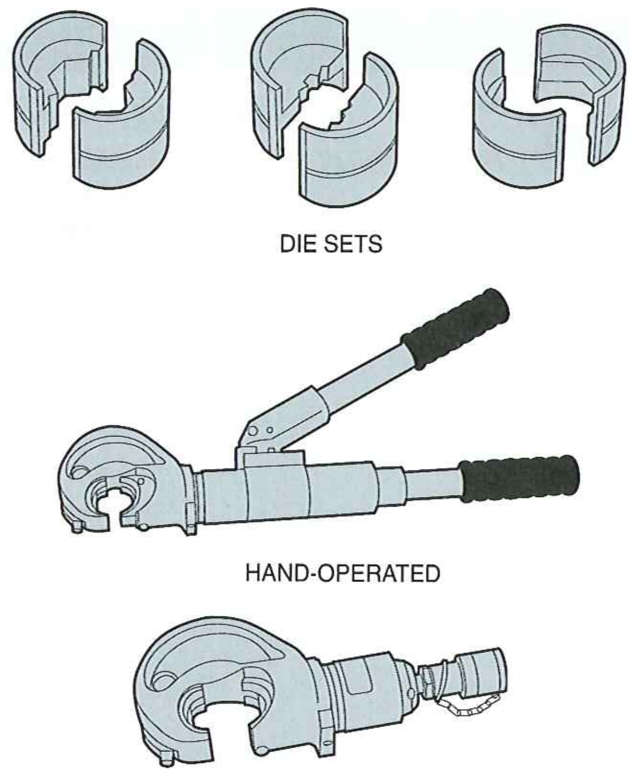


Figure 12 ◆ Crimping (compression) tools used to crimp large connectors.

WARNING!
Always read and follow the manufacturer's instructions when using power tools.

To operate a hydraulic crimping tool, proceed as follows:

Step 1 Using a suitable hydraulic hose, connect the hydraulic pump to the crimping tool.

Step 2 Select the proper dies for use with the connector to be crimped. Do not operate the tool without the dies.

Step 3 Push the die release button on the C-head and slide one of the die halves into position until the retainer pin snaps. In a similar manner, install the other die half in the piston body.

Step 4 Place the tool C-head in position over the connector to be crimped. Operate the remote pump until compression is complete, as indicated by the dies touching on the frame side.

Step 5 Release the pressure at the hydraulic pump to retract the lower die half, then remove the connector from the tool.

4.1.2 General Compression (Crimp) Connector Installation Procedure

Step 1 Select a crimp-type connector of the proper size and of appropriate material for the wire size you are using. Copper connectors should be used with copper wires and aluminum connectors with aluminum wires. Dual-rated connectors may be used with both copper and aluminum wires.

Step 2 Using a suitable wire stripper, remove the insulation from the end of the wire, being careful not to nick the wire. Strip the insulation back far enough so that the bare conductor will go fully into the connector. Make sure not to strip off too much insulation; it should fit close to the connector when the wire is fully inserted into the connector.

Step 3 Clean the stripped portion of the wire. Use a wire brush for large wire sizes. Also clean the related unplated terminal pad and the surface to which the connector will be attached.

Step 4 Obtain the crimping tool and dies made for the type and size of connector to be crimped.

Step 5 Insert the stripped end of the wire completely into the connector. Position the crimping tool in place over the connector, then operate the tool to fully crimp the connector, as directed in the tool manufacturer's instructions. Make sure that the crimping tool jaws are fully closed, indicating that a full compression crimp has been made. Failure to make a secure crimp will create a weak joint.

Step 6 Using a bolt or screw and washers (if required), secure the crimped connector and attached wire to the correct terminal in the equipment. Tighten the terminal bolt and torque to the level specified by the equipment manufacturer. Too little or too much torque can adversely affect the performance of the connection.

Table 3 lists some torque values typical of those used for tightening common sizes of steel and aluminum terminal bolts.

Table 3 Recommended Tightening Torques for Various Bolt Sizes

Steel Hardware		Aluminum Hardware	
Bolt Size	**Recommended Torque (Inch-Pounds)**	**Bolt Size**	**Recommended Torque (Inch-Pounds)**
¼–20	80	½–13	300
5/16–18	180	⅝–11	480
⅜–16	240	¾–10	650
½–13	480	—	—
⅝–11	660	—	—
¾–10	1,900	—	—

4.2.0 Installing Mechanical-Type Terminals and Connectors

The procedure for installing mechanical-type connectors is basically the same as that described above for compression-type connectors, with the following exceptions. Before installing the mechanical connector on the wire, an oxide-inhibiting joint compound should be applied liberally to the conductor to prevent the formation of surface oxides once the connection is made (also apply the compound to any terminal pad). Following this, the connector is installed on the wire, then the connector's bolt/screw is tightened to the torque level specified by the connector manufacturer. Proper torque is important. Too much torque may sever the wires or break the connector; too little torque can cause overheating and failure.

4.3.0 Installing Specialized Cable Connectors

There are a wide variety of cables that require specially designed connectors, commonly called terminators, to secure them to equipment enclosures. Normally, all such specialized connectors are supplied with complete instructions for their installation. This section will introduce you to one type of specialized connector designed for use with metal-clad (Type MC) cable. Its construction and installation are typical of many specialized connectors.

Type MC cable is a factory assembly of one or more insulated circuit conductors with or without optical fiber members. It is enclosed in a metallic sheath of interlocking tape or a smooth or corrugated tube. Throughout the industry, there is increasing use of Type MC cable installed in trays and on racks instead of non-armored cable in conduit. At the appropriate locations, the cables are

INSIDE TRACK

Tightening Torques

Many terminations and types of equipment are marked with tightening torque information. For items of equipment, torque information is often marked on the equipment and/or is given in the manufacturer's installation instructions. When specific torque requirements are given, always follow the manufacturer's recommendations.

In cases where no tightening requirements are given, guidelines for tightening screw and bolt-type mechanical compression connectors can be found in the *National Electrical Code® Handbook* comments pertaining to *NEC Section 110.14.* Other good sources of tightening information are manufacturers' catalogs and product literature.

routed from the trays or racks, then along the structure to the various items of equipment. *NEC Article 330* governs the installation of Type MC cable. There are several types of connectors that can be used with Type MC cable. The specific connector used is determined by the size and type of cable and the application.

For the purpose of an example, the procedure for installing one manufacturer's weatherproof connector (*Figure 13*) designed for use with Type MC cable is given here:

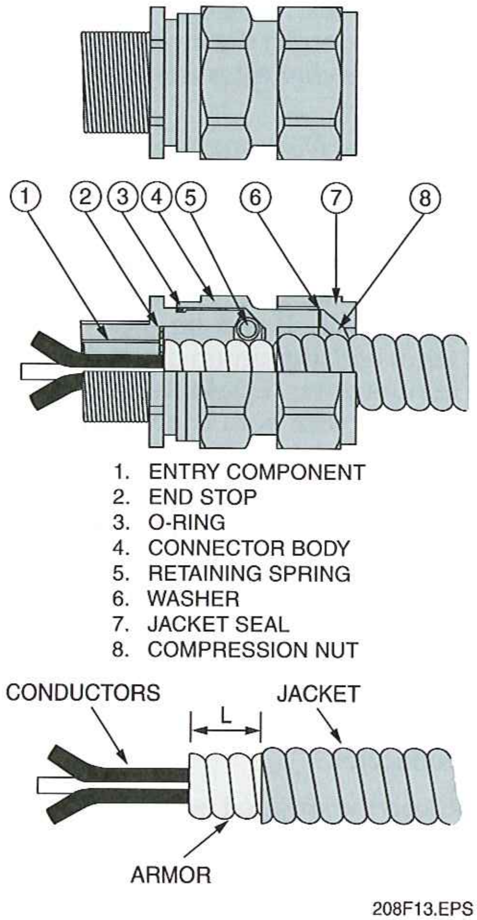


Figure 13 ◆ Weatherproof connector used with Type MC cable.

Step 1 Select the correct connector size. This is normally done by comparing the physical dimensions of the cable to a cross-reference table given in the manufacturer's product literature and/or installation instructions.

Step 2 Strip back the jacket and armor of the cable as needed to meet equipment requirements. Expose the cable armoring further by stripping the cable jacket for a specified distance (L), as shown in *Figure 13*. This distance will be found in the manufacturer's installation instructions.

Step 3 Make sure that the jacket seal and retaining spring are in their uncompressed state. If necessary, loosen the connector body and the compression nut. Note that it is not necessary to separate the connector parts.

Step 4 Screw the connector body into the equipment if it has a threaded entry, or secure it with a locknut if it has an unthreaded entry.

Step 5 Pass the cable through the connector until the armor makes contact with the end stop. If it is not possible for the insulated wires to pass through the end stop, then the end stop should be removed so that the wires can move past it and the armor can make contact with the integral end stop within the entry component.

Step 6 Tighten the connector body to compress the retaining spring and secure the armor. Normally, this is hand-tight plus one and a half full turns.

Step 7 Tighten the outer compression nut to form a seal on the cable jacket. Normally, this is hand-tight plus one full turn.

Step 8 If appropriate, terminate the individual wires contained in the cable using compression or mechanical-type connectors, as described above.

5.0.0 ◆ BENDING CABLE AND TRAINING CONDUCTORS

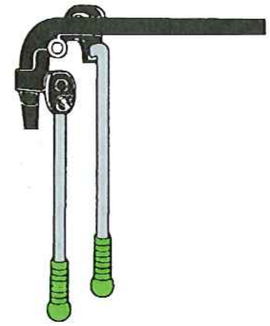
Training is the positioning of cable so that it is not under tension. Bending is the positioning of cable that is under tension. When installing cable or any large conductors, the object is to limit the tension so that the cable's physical and electrical characteristics are maintained for the expected service life. Training conductors, rather than bending them, also reduces the tension on lugs and connectors, extending their service life considerably.

All bends made in cable must comply with the *NEC®*. Minimum bending radii are determined by the cable diameter and, in some instances, by the construction of the cable. For example, bends in Type MC cable must be made so that the cable is not damaged, and the radius of the curve of the inner edge of any bend shall not be less than the following:

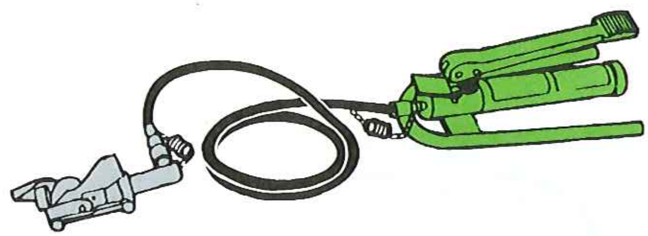
- *Smooth sheath* – Ten times the external diameter of the metallic sheath for cable not more than ¾" in external diameter; twelve times the external diameter of the metallic sheath for cable more than ¾" but not more than 1½" in external diameter; and fifteen times the external diameter of the metallic sheath for cable more than 1½" in external diameter.
- *Interlocked-type armor or corrugated sheath* – Seven times the external diameter of the metal sheath.
- *Shielded conductors* – Twelve times the overall diameter of the individual conductors or seven times the overall diameter of the multiconductor cable, whichever is greater.

The two types of cable bending tools in common use are the ratchet bender and the hydraulic bender (*Figure 14*). The ratchet cable bender in *Figure 14(A)* bends 600V copper or aluminum conductors up to 500 kcmil, while the hydraulic bender in *Figure 14(B)* is designed for cables from 350 kcmil through 1,000 kcmil. In addition, the hydraulic bender is capable of one-shot bends up to 90° and automatically unloading the cable when the bend is finished. Either type simplifies and speeds cable installation.

Conductors at terminals or conductors entering or leaving cabinets or cutout boxes and the like must comply with certain *NEC®* requirements, many of which are covered in *NEC Article 312.* The bending radii for various sizes of conductors that do not enter or leave an enclosure through the wall opposite its terminal are shown in *Table 4*. When using this table, the bending space at terminals must be measured in a straight line from the end of the lug or wire connector (in the direction



(A) RATCHET CABLE BENDER



(B) HYDRAULIC CABLE BENDER

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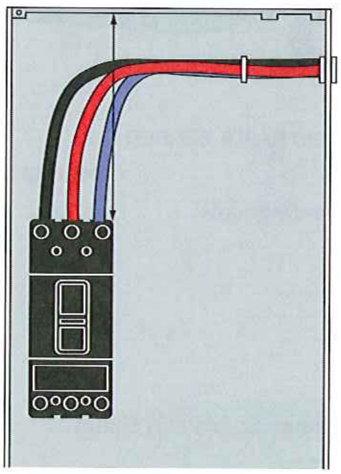
Figure 14 ◆ Types of cable bending tools.

Table 4 Minimum Wire Bending Space and Gutter Width

AWG or Circular-Mil Size of Wire	Wires per Terminal				
	1	2	3	4	5
14–10	Not Specified	—	—	—	—
8–6	1½	—	—	—	—
4–3	2	—	—	—	—
2	2½	—	—	—	—
1	3	—	—	—	—
1/0–2/0	3½	5	7	—	—
3/0–4/0	4	6	8	—	—
250 kcmil	4½	6	8	10	—
300–350 kcmil	5	8	10	12	—
400–500 kcmil	6	8	10	12	14
600–700 kcmil	8	10	12	14	16
750–900 kcmil	8	12	14	16	18
1,000–1,250 kcmil	10	—	—	—	—
1,500–2,000 kcmil	12	—	—	—	—

that the wire leaves the terminal) to the wall, barrier, or obstruction, as shown in *Figure 15*.

An unshielded cable can tolerate a sharper bend than a shielded cable. This is especially true of cables having helical metal tapes, which, when bent too sharply, can separate or buckle and cut into the insulation. The problem is compounded by the fact that most tapes are under jackets that conceal such damage. The shielding bedding tapes or extruded polymers may initially have sufficient conductivity and coverage to pass acceptance testing, but they often fail prematurely at the shield/insulation interface.



When using *NEC Table 312.6(A)*, bending space at terminals must be measured in a straight line from the end of the lug or wire connector (in the direction that the wire leaves the terminals) to the wall, barrier, or obstruction.

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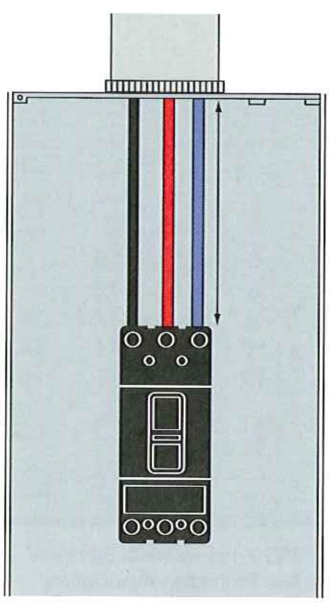
Figure 15 ◆ Bending space at terminals is measured in a straight line.



Bending space at terminals must be measured in a straight line from the end of the lug or wire connector in a direction perpendicular to the enclosure wall. Use the values in *NEC Table 312.6(B)*.

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Figure 16 ◆ Conductors entering an enclosure opposite the conductor terminals.

NOTE

Remember that cable offsets are bends.

When conductors enter or leave an enclosure through the wall opposite its terminals (*Figure 16*), *NEC Table 312.6(B)* applies. See *Table 5*. In using this table, the bending space at terminals must be measured in a straight line from the end of the lug or wire connector in a direction perpendicular to the enclosure wall. For removable and lay-in wire terminals intended for only one wire, the bending space in the table may be reduced by the number of inches shown in parentheses.

Table 5 Minimum Wire Bending Space at Terminals

AWG or Circular-Mil Size of Wire	Wires per Terminal			
	1	2	3	4 or More
14–10	Not Specified	—	—	—
8	1½	—	—	—
6	2	—	—	—
4	3	—	—	—
3	3	—	—	—
2	3½	—	—	—
1	4½	—	—	—
1/0	5½	5½	7	—
2/0	6	6	7½	—
3/0	6½ (½)	6½ (½)	8	—
4/0	7 (1)	7½ (1½)	8½ (½)	—
250	8½ (2)	8½ (2)	9 (1)	10
300	10 (3)	10 (2)	11 (1)	12
350	12 (3)	12 (3)	13 (3)	14 (2)
400	13 (3)	13 (3)	14 (3)	15 (3)
500	14 (3)	14 (3)	15 (3)	16 (3)
600	15 (3)	16 (3)	18 (3)	19 (3)
700	16 (3)	18 (3)	20 (3)	22 (3)
750	17 (3)	19 (3)	22 (3)	24 (3)
800	18	20	22	24
900	19	22	24	24
1,000	20	—	—	—
1,250	22	—	—	—
1,500–2,000	24	—	—	—

6.0.0 ◆ *NEC®* TERMINATION REQUIREMENTS

There are several *NEC®* requirements governing the termination of conductors as well as the installation of enclosures containing conductors. *NEC Sections 110.14 and 312.6* cover most installations and terminations. However, other sections, such as *NEC Sections 300.4(F) and 430.10*, will apply for specific applications.

6.1.0 Incoming Line Connections

In general, all ungrounded conductors in a motor control center (MCC) installation require some form of overcurrent protection to comply with *NEC Section 240.20.* Such overcurrent protection for the incoming lines to the MCC is usually in the form of fuses or a circuit breaker located at the transformer secondary that supplies the MCC. The conductors from the transformer secondary constitute the feeder to the MCC, and the rules of *NEC Section 240.21* apply. These rules allow the disconnect means and overcurrent protection to be located in the MCC, provided that the feeder taps from the transformer are sufficiently short and other requirements are met.

6.1.1 Main Disconnect

A circuit breaker or a circuit interrupter combined with fuses controlling the power to the entire MCC may provide the required overcurrent protection as described above or there may be a supplementary disconnect (isolation) means. *Figure 17* shows a main disconnect with stab load connectors.

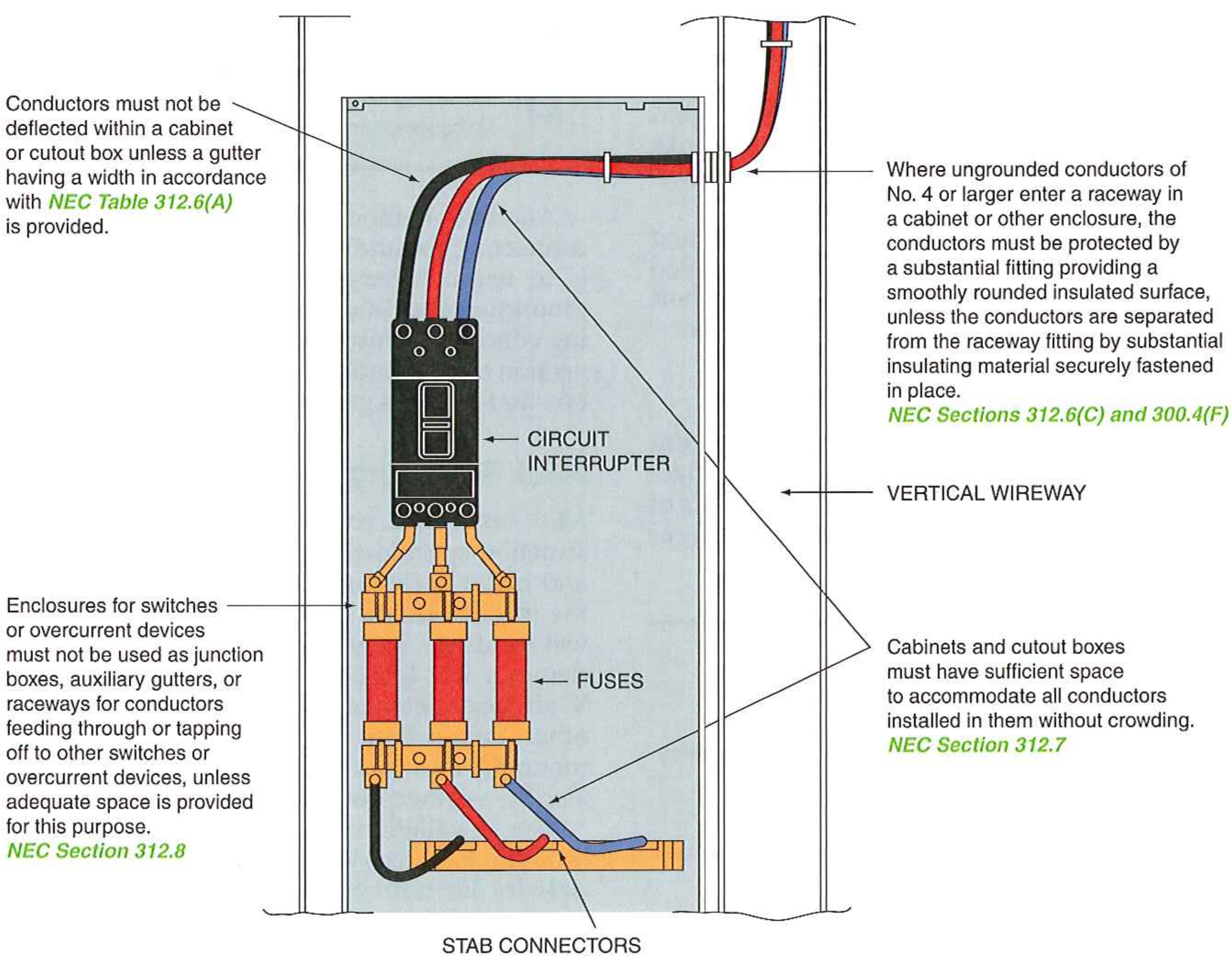


Figure 17 ◆ Main disconnect with stab load connectors.

When the MCC has a main disconnect, the incoming lines (feeders) are brought to the line terminals of the circuit breaker or circuit interrupter. The load side of the circuit breaker or the load side of the fuses associated with the circuit interrupter is usually connected to the MCC busbar distribution system. In cases where the main disconnect is rated at 400A or less, the load connection may be made with stab connections to vertical busbars that connect to the horizontal bus distribution system.

6.1.2 Short Circuit Bracing

All incoming lines to either incoming line lugs or main disconnects must be braced to withstand the mechanical force created by a high fault current. If the cables are not anchored sufficiently or the lugs are not tightened correctly, the connections become the weakest part of a panelboard or motor control center when a fault develops. In most cases, each incoming line compartment is equipped with a two-piece spreader bar located at a certain distance from the conduit entry. This spreader bar should be used along with appropriate lacing material to tie cables together where they can be bundled and to hold them apart where they must be separated. In other words, the incoming line cables should first be positioned and then anchored in place.

Manufacturers of electrical panelboards and motor control centers normally furnish detailed information on recommended methods of short circuit bracing; follow this information exactly.

6.1.3 Making Connections

Before beginning work on incoming line connections, refer to all drawings and specifications dealing with the project at hand. Details of terminations are usually furnished on larger installations.

WARNING!

All incoming line compartments present an obvious hazard when the door is opened or covers are removed with power on. When working in this area, the incoming feeder should be de-energized.

6.1.4 Making Grounding Conductor Connections

NEC Section 250.8 requires that grounding conductors be connected to boxes and enclosures using exothermic welding, listed pressure conductors, clamps, or other listed means. When more than one equipment grounding conductor enters a box, all the conductors must be spliced or joined either within the box or to the box using devices suitable for this purpose. The arrangement of the grounding connections must be made so that the disconnection or removal of a receptacle, fixture, etc., fed from the box will not interfere with or interrupt the grounding continuity.

When connecting grounding conductors in metal outlet boxes or enclosures, *NEC Section 250.148* requires that a connection be made between the grounding conductors and the metal box by means of a grounding screw that shall not be used for any other purpose, or a listed grounding device.

NOTE

Sheet metal screws are not permitted to be used as a means of connecting grounding conductors to boxes or enclosures.

Another method approved by the *NEC®* for connecting grounding conductors to a metal box is to use a listed grounding device such as a grounding clip. In nonmetallic boxes, the grounding conductors must be connected so that a connection can be made to any fitting or device in the box that requires grounding.

6.2.0 Mounting Enclosures

NEC Article 312 covers the installation and construction specifications of cabinets, cutout boxes, and meter socket enclosures. Part A begins with the installation of such equipment in damp and wet locations. In general, enclosures mounted in damp or wet locations must have a minimum of ¼" air space between the enclosure and the wall or other supporting surface. If the enclosure is mounted in a wet location, the enclosure must also be weatherproof. See *Figure 18*.

The installation of enclosures used in hazardous (classified) locations must conform to *NEC Articles 500 through 517* and will be covered later in your training.

The *NEC®* requirements governing the position of enclosures in walls is covered in *NEC Section 312.3;* a summary of these requirements appears in *Figure 19*.

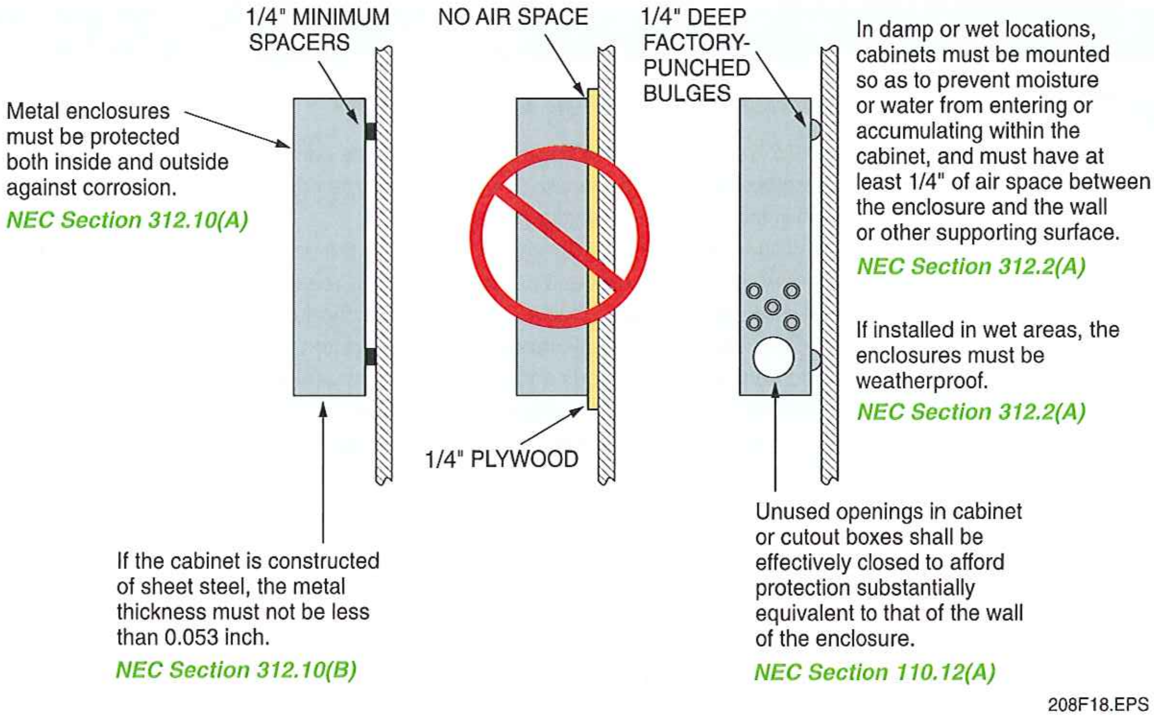


Figure 18 ◆ *NEC®* requirements governing the mounting of enclosures in damp or wet locations.

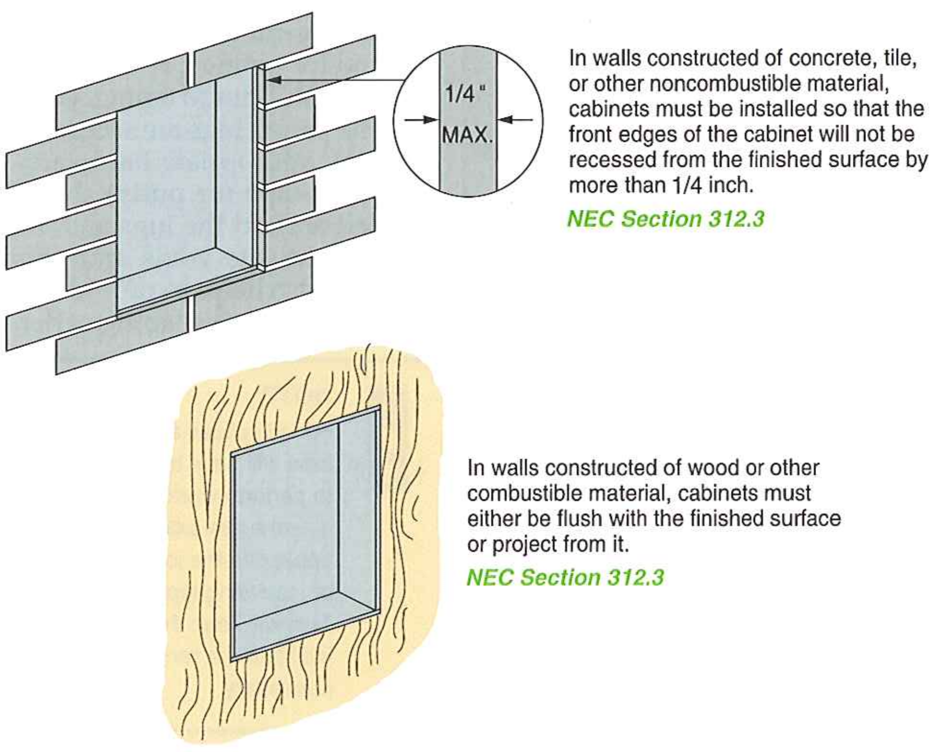


Figure 19 ◆ *NEC®* requirements governing the position of enclosures in walls.

INSIDE TRACK

Exothermic Welded Connections

Per **NEC Section 250.64(C)**, grounding electrode conductors may be spliced at any location by means of irreversible compression-type connectors listed for that purpose or by using the exothermic welding process.

In grounding systems, connections are often the weakest link, especially if they are subjected to high currents and corrosion. For this reason, exothermic welded connections are typically used in commercial and industrial structures to splice and/or connect the grounding electrode conductor system in a building. An exothermic welded connection produces a joint or connection that is better than compression-type connectors because of its welded molecular bond. It normally will not loosen, corrode, or increase in resistance over the lifetime of the installation.

7.0.0 ◆ TAPING ELECTRICAL JOINTS

When it is not practical to protect a spliced joint by some other means, electrical tape may be used to insulate the joint. When tape is used, the joint should be taped carefully to provide the same quality of insulation over the splice as over the rest of the wires.

There is a wide variety of electrical **insulating tapes** made from nonconductive materials for use in specific applications. Some common types of electrical tape include vinyl plastic tape, linerless rubber tape, high-temperature silicone rubber tape, and glass cloth tape. Electrical tapes made of vinyl plastic are widely used as a primary insulation on joints made with thermoplastic-insulated wires. They are used for splices up to 600V and for fixture and wire splices up to 1,000V. Depending on the product, they are made for indoor use, outdoor use, or both. Linerless rubber splicing tape provides for a tight, void-free, moisture-resistant insulation without loss of electrical characteristics. It is typically used as a primary insulation with all solid dielectric cables through 70kV. Other applications include jacketing on high-voltage splices and terminals, moisture-sealing electrical connections, busbar insulations, and end sealing high-voltage cables. High-temperature silicone rubber tapes are used as a protective overwrap for terminating high-voltage cables. Glass cloth electrical tapes provide a heat-stable insulation for hot-spot applications such as furnace and oven controls, motor leads, and switches. They are also used to reinforce insulation where heavy loads cause high heat and breakdown of insulation, such as in motor control exciter feeds, etc. All-metal braid tapes are also available. These are used to continue electrostatic shielding across a splice. When taping a splice, begin by selecting the correct tape for the job. Always follow the tape manufacturer's recommendations.

A general procedure describing one method of taping a splice or joint, such as encountered when connecting motor lugs, is shown in *Figure 20*. A method for taping a split-bolt connector is shown in *Figure 21*. Prior to taping, you should make sure that the joined lugs are securely fastened together with the appropriate hardware. Pieces of a suitable filler tape (or putty) should be wrapped or molded around the lugs and attaching hardware so as to fill the voids and eliminate any sharp edges. It also helps to provide a smooth, even surface that will make taping easier.

NOTE

For all splices and joints where it is likely that the tape will have to be removed at some future date to perform work on the joint, an upside down (that is, adhesive side up) wrap of tape should be applied to the joint before applying the final layers of insulating tape to the joint in the usual manner. This will keep the area free from tape residue and facilitate the removal of the tape later on, if necessary.

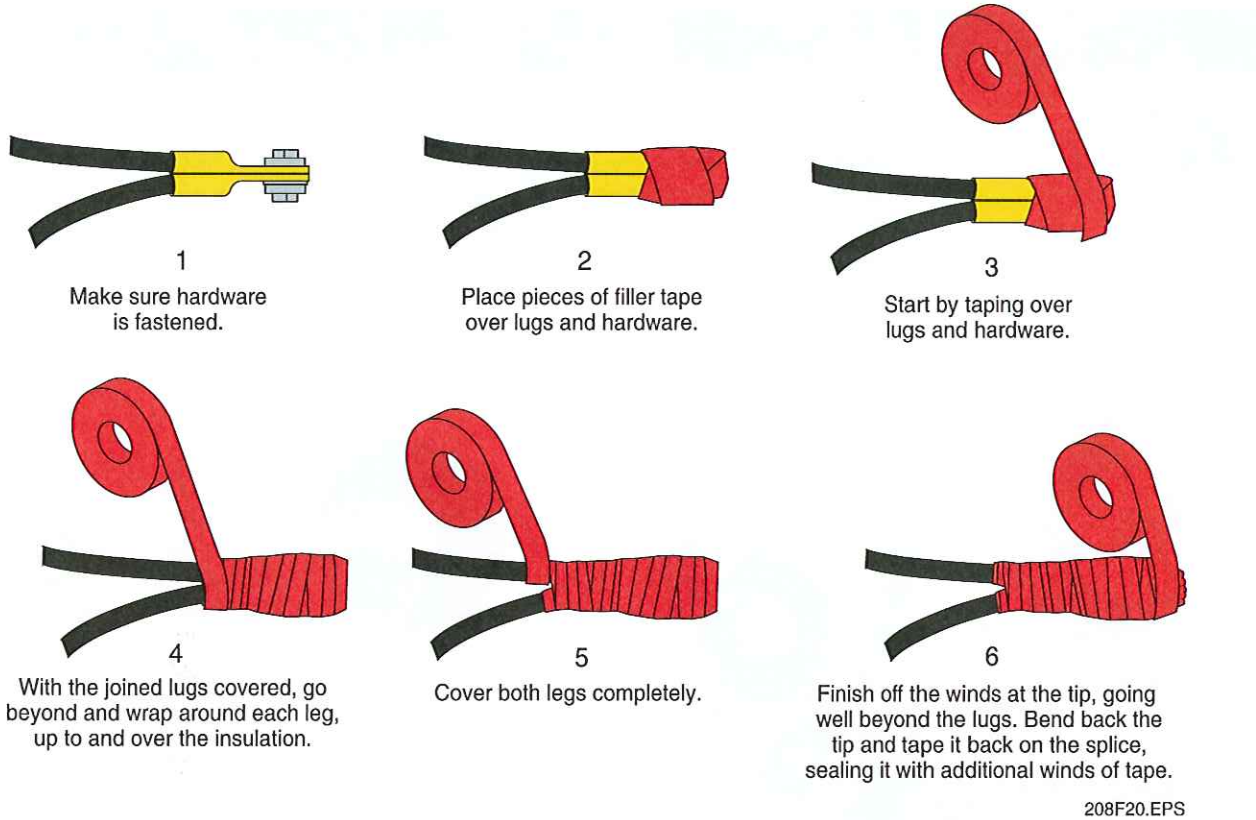
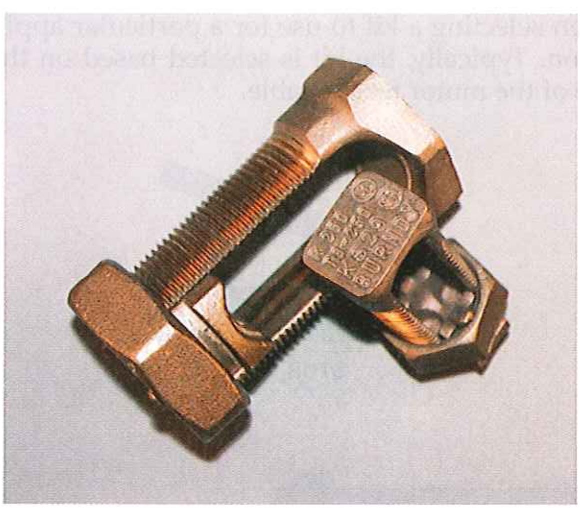


Figure 20 ◆ Typical method for taping motor lug connections.



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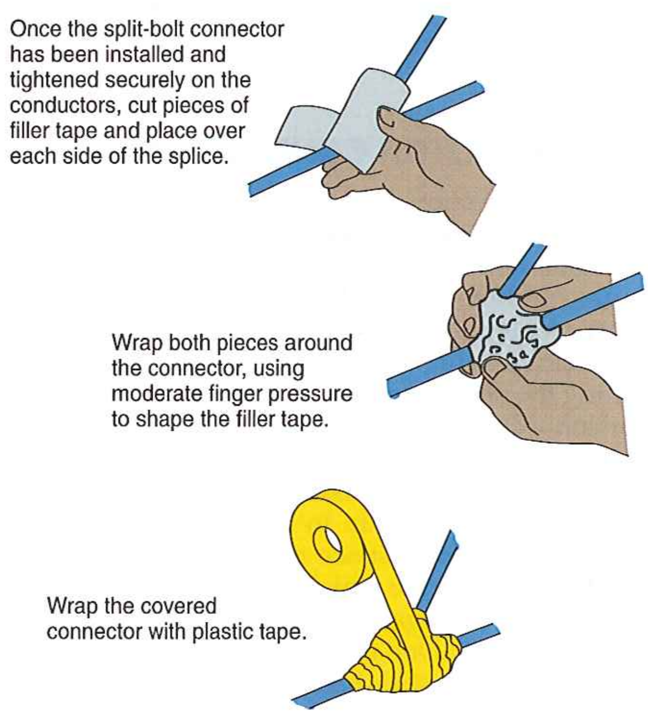
(A) SPLIT-BOLT CONNECTOR



(B) TAPING PROCEDURE 208F21B.EPS

Figure 21 ◆ Typical method of taping a split-bolt connector.

Electrical Tape

Most non-electricians think of electrical tape as only the simple black vinyl variety found in nearly every home toolbox. Electrical tape actually comes in a wide range of colors to be used for labeling various conductors when making terminations. See photo (A). High-voltage electrical tape, as shown in photo (B), can be used to make connections on wires up to 1,000V, depending on the listing of the product being used. Always check the product label to be sure it matches the intended application.

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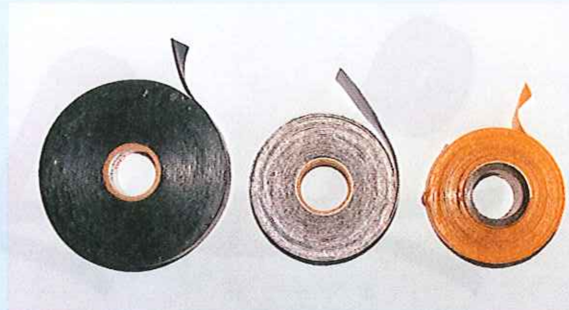
(A)



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(B)

8.0.0 ◆ MOTOR CONNECTION KITS

Motor connection kits are available to insulate bolted splice connections, such as those in motor terminal boxes. These kits eliminate the need for taping and the use of filler tape or putty. To aid in joint reentry during rework, the insulator strips off easily, leaving a clean bolt area and thus eliminating the need to remove old tape and putty. Motor connection kits are available for use with stub (butt splice) connections (*Figure 22*) where there is insufficient room to make in-line connections.

They are also made to insulate in-line splice connections where space permits. These insulating kits incorporate a high-voltage mastic, which seals the splice against moisture, dirt, and other contamination. One type of motor connection kit insulator is heat-shrinkable. It installs easily using heat from a propane torch to shrink the insulator in a manner similar to that of heat-shrink tubing (*Figure 23*). Another type of kit used for insulating stub connections comes in the form of an elastomeric insulating cap that is cold-applied by rolling it over the stub splice (*Figure 23*). Always follow the kit manufacturer's recommendations when selecting a kit to use for a particular application. Typically, the kit is selected based on the size of the motor feeder cable.

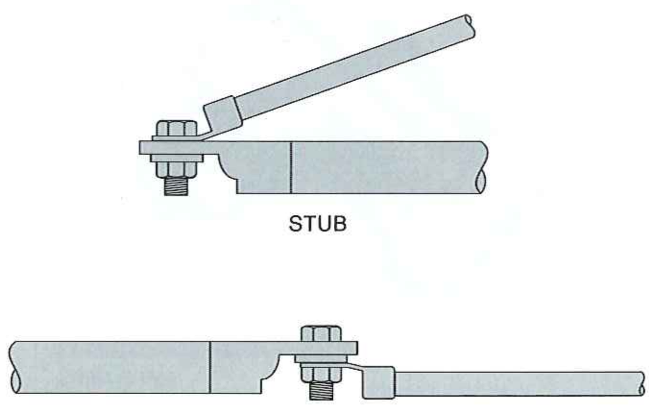

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Figure 22 ◆ Stub and in-line splice connections.

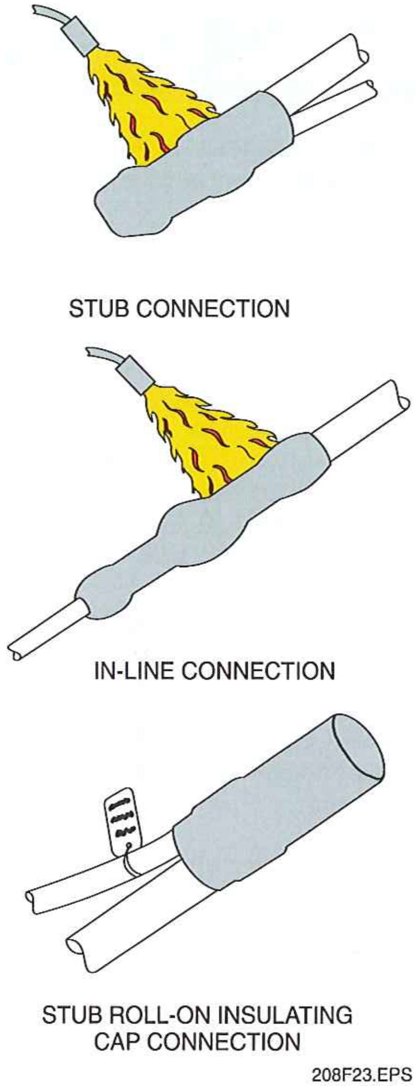

Figure 23 ◆ Motor connection kits installed on splices.

THINK ABOUT IT

Making Connections to Equipment Terminals

Are there any requirements as to how many conductors can be connected to the terminals provided in electric equipment?

Putting It All Together

Examine the wiring connections in your home or workplace. Are they properly made? Can you determine if any connections have the potential for failure?

Review Questions

1. How long should a good conductor splice last?
   a. 60 days
   b. 6 years
   c. As long as current flows
   d. As long as the insulation on the wire itself

2. Which of the following best describes the term stripping as it applies to conductor splicing?
   a. Removal of the insulation from conductors
   b. Removal of the packing material from the carton
   c. Removal of any excess strands of wire from a splice
   d. Removal of the pulling ring from lead sheath conductors

3. Which of the following is *not* a type of stripping?
   a. End termination
   b. Window cut
   c. Spiral cut
   d. Indent cut

4. What is the diameter, in inches, of 2,000 kcmil wire?
   a. 0.893
   b. 0.998
   c. 1.29
   d. 1.63

5. Which of the following best describes the purpose of a reducing connector?
   a. To temporarily connect a circuit
   b. To join two different size conductors
   c. To join conductors of the same size
   d. To make a 90° bend in parallel conductors

6. How long should heat be applied to a heat-shrink insulator in order for it to take the required shape?
   a. A few hours
   b. A few minutes
   c. A few seconds
   d. A few days

7. Which of the following sizes of wire would you normally use wire nuts on?
   a. No. 22 through No. 10 AWG
   b. No. 8 through No. 2 AWG
   c. No. 1 through 1/0 AWG
   d. 4/0 through 250 kcmil

8. Which of the following tools is best for positioning cable?
   a. Split-bolt connectors
   b. A heat gun
   c. A power connector indenter
   d. Wire-bending tools (either ratchet or hydraulic)

9. Which of the following types of electrical tape is best for taping most joints for voltages up to 600V?
   a. High-temperature silicone rubber
   b. Rubber
   c. Glass cloth
   d. Vinyl plastic

10. Crimping tools include all of the following *except* _____.
    a. hand-operated crimping tools
    b. hydraulic compression tools
    c. die sets
    d. pliers

Summary

Solderless connectors (wire nuts) are devices used to join wires without the need for solder. Such connectors are convenient and save much time on the job. Wire nuts are used to splice smaller conductors (No. 10 AWG and smaller) on residential and some commercial installations.

Crimp connectors or terminals are used for larger wire sizes. They are convenient for terminating conductors at terminal boards, control wiring terminals, and the like.

Lugs are provided for the larger wire sizes on panelboards and motor control centers. It is very important to tighten these lugs properly to provide a sound electrical connection as well as to provide short circuit bracing.

There are a variety of insulating tapes available to seal spliced joints. Always match the tape with the application.

Notes

Trade Terms Introduced in This Module

AL-CU: An abbreviation for aluminum and copper, commonly marked on terminals, lugs, and other electrical connectors to indicate that the device is suitable for use with either aluminum conductors or copper conductors.

Connection: That part of a circuit that has negligible impedance and joins components or devices.

Connector: A device used to physically and electrically connect two or more conductors.

Insulating tape: Adhesive tape that has been manufactured from a nonconductive material and is used for covering wire joints and exposed parts.

Lug: A device for terminating a conductor to facilitate the mechanical connection.

Pressure connector: A connector applied using pressure to form a cold weld between the conductor and the connector.

Reducing connector: A connector used to join two different sized conductors.

Splice: The electrical and mechanical connection between two pieces of cable.

Strand: A group of wires, usually stranded or braided.

Tap: A splice connection of a wire to another wire. Also called a tap-off.

Terminal: A device used for connecting cables.

Termination: The connection of a cable.

Wire nut: A form of wire connector that is tightened or loosened by screwing the device clockwise or counterclockwise, respectively. Some wire nuts are provided with two thin, flat wings extending from opposite sides to facilitate tightening the connectors.

Additional Resources

This module is intended to present thorough resources for task training. The following reference works are suggested for further study. These are optional materials for continued education rather than for task training.

American Electrician's Handbook, Latest Edition. New York: Croft and Summers, McGraw-Hill.

National Electrical Code® Handbook, Latest Edition. Quincy, MA: National Fire Protection Association.