CHAPTER 5

Conduit Wiring

Conduit wiring provides mechanical protection and electrical safety to persons and property and provides convenient and accessible ducts for the conductor. A well-designed electrical raceway system has adequate capacity for future expansion and is readily adaptable to changing conditions.

Section I. Rigid Conduit

USES AND ADVANTAGES

Black-enamel or galvanized rigid metal conduit is approved for use under most conditions and in most locations. Metal conduit and fittings that are protected from corrosion by enamel may only be used indoors and in areas that are not subject to severe corrosion. Although rigid conduit is generally the most expensive type of wiring installation, its inherent strength permits installation without running boards and provides additional damage protection. Its capacity facilitates carrying more conductors in one run than in any other system, and its rigidity permits installation with fewer supports than the other types of wiring systems. Moreover, the size of conduit used in the system's installation usually provides for the addition of several more conductors in the conduit when additional circuits and outlets are required in the run.

MATERIALS

Though the materials used in rigid conduit wiring have been outlined in detail in Chapter 2, the following discussion will review the advantages of these standard materials as well as their limitations.

Rigid conduit *(Figure 5-1, page 5-2)* has the same size designations as water pipe. Conduit smaller than 1/2 inch can only be used in finished buildings where extensions are to be made under plaster. In these installations, 5/16-inch conduit or tubing is permitted. The size of conduit is determined by the inside diameter. For example, 1/2-inch conduit has an inside diameter of approximately 1/2 inch. Standard conduit sizes used in interior wiring are 1/2, 3/4, 1, 1 1/4, 1 1/2, 2, and 2 1/2 inches. Larger sizes (up to 6 inches) are available for special use in certain commercial and factory installations.

Though conduit is made in dimensions similar to water pipe, it differs from water pipe in a number of ways. It is softer than water pipe and thus can be bent fairly easily. In addition, the inner surface is smooth to prevent damage to wires being pulled through it, and the finish is rust-resistant. Black-enamel conduit is used for dry and indoor installations, and galvanized conduit is used in outside installations to provide moisture protection for the conductors. For wiring installations in corrosive atmospheres, aluminum, copper-alloy, or plastic-jacketed conduit is available.

CONDUCTORS

Rubber-covered, insulated Types R and RH wire are used with conduit in most interior wiring installations; but thermoplastic, insulated Types T and TW are gaining favor because of their superior insulating characteristics. Underground or wet installations require the insertion of lead-covered cables in galvanized conduit for permanent protection.

SUPPORTS

The conduit straps described in Chapter 2 are preferred for use when mounting conduit in interior wiring systems. Rigid conduit should be supported on spacings as shown in *Table B-17, page B-17*.

FITTINGS

The two types of fittings are the standard, ordinary-size outlet box and the small junction or pull boxes called *condulets*. The standard outlet-box fittings are classified as Type F and are normally used in exposed installations to house receptacles or switches where a high quality of installation is desired. Condulets *(Figure 5-1)* provide intermediate points in long conduit runs for the pull-through of wire or provide junctions for several concealed installations where they will not be accessible. They are classified by the manufacturers as follows:

- Service entrance, Type SE.
- Elbow or turn fittings, Type L.
- Through fittings, Type C.
- Through fittings with 90-degree take-off, Type T.

BOXES AND CONNECTORS

Steel or cast-iron outlet boxes are used in rigid-conduit installations. Boxes are normally supplied with knockouts that are removable for inserting conduit. Bushings and locknuts are provided for attaching the conduit to the boxes as shown in *Figure 5-1*. Boxes that are used in wet or hazardous locations must have threaded hubs into which the conduit is screwed.

DEVICES

The devices used to install conduit are all box-mounted units and are covered in Chapter 2.

ACCESSORIES

Threaded Couplings. Threaded couplings are furnished with each length of rigid conduit.

Threadless Couplings. Rigid conduit may be installed using threadless couplings if they are installed tightly.

Elbows. Standard conduit elbows are manufactured for use where 90-degree bends are required.

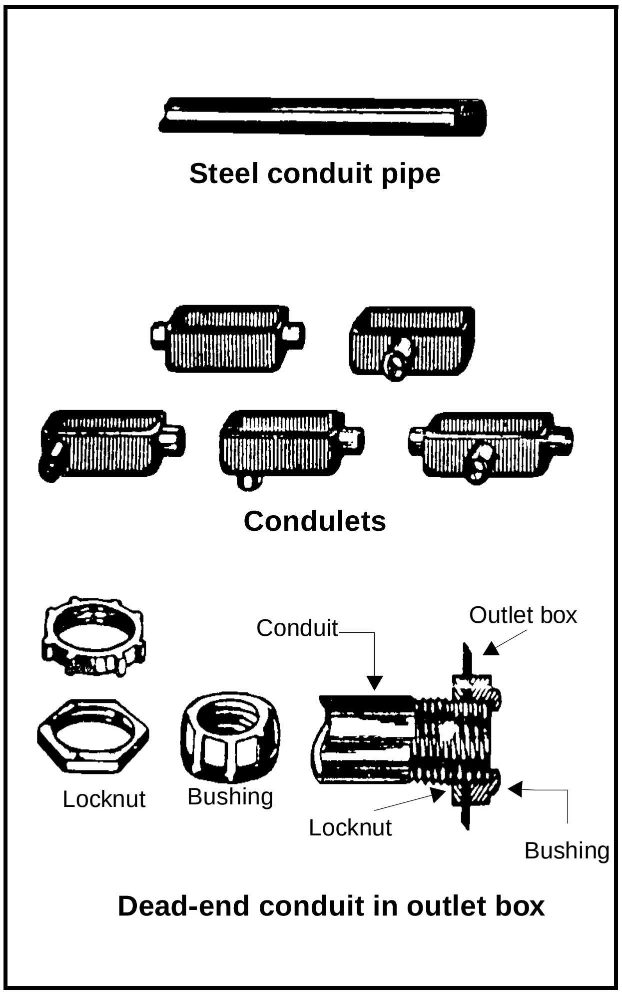

Figure 5-1. Rigid conduit and fittings

Conduit Unions. Conduit unions are installed to permit the opening of a conduit at any point without sawing or breaking the conduit run. By using unions, conduit may be started from two outlets and joined together at any convenient place in the run.

PROCEDURES

MAKING BENDS

Bends in rigid conduit must be made without collapsing the conduit wall or reducing the internal diameter of the conduit at the bend. Electricians make most bends as an integral part of the installation procedure. These are called *field bends*. The radius of the curve on the inner edge of any field bend must be at least six times the internal diameter of the conduit for rubber-, braid-, or thermoplastic-covered conductors and at least 10 times the internal diameter of the conduit for lead-covered conductors. *Table B-18, page B-17,* shows the minimum radii for field bends. A maximum of four quarter bends can be placed in a conduit run between two openings. Moreover, a 10-foot length of conduit should have no more than three quarter bends.

Factory-made bends are available as an option rather than bending conduit on the job. However, these bends are not commonly used because of the increased costs inherent in the additional cutting and threading that is required and the additional couplings that must be used.

Conduit up to and including 3/4 inch is usually bent with a hand conduit bender called a *hickey* as shown in *Figure 5-2, page 5-4*. This hickey can be slipped over the conduit. Conduit-bending forms are also available as built-in units of pipe-vise stands. If these tools are not available, you can make bends using the lever advantage between two fixed posts or building members.

The following procedure *(illustrated in Figure 5-2*) is one method of making a right-angle bend in a length of 1/2-inch conduit. If you are making a 90-degree bend in a length of conduit at a distance of 20 inches from one end, you must—

- Mark off 20 inches from the end of the conduit.
- Place the hickey 2 inches in front of the 20-inch mark and bend the conduit about 25 degrees.
- Move the bender to the 20-inch mark and bring the bend up to 45 degrees.
- Move the bender 1 inch behind the 20-inch mark and bring the conduit up to 70 degrees.
- Move the bender back 2 inches behind the 20-inch mark and bring the bend up to 90 degrees.

You can make conduit bends more accurately if you use chalk to draw the contour of the bend on the floor, and then match the bend in the pipe with the chalk diagram as you form the bend. You will usually use a hydraulic bender to bend conduit in excess of 1 inch.

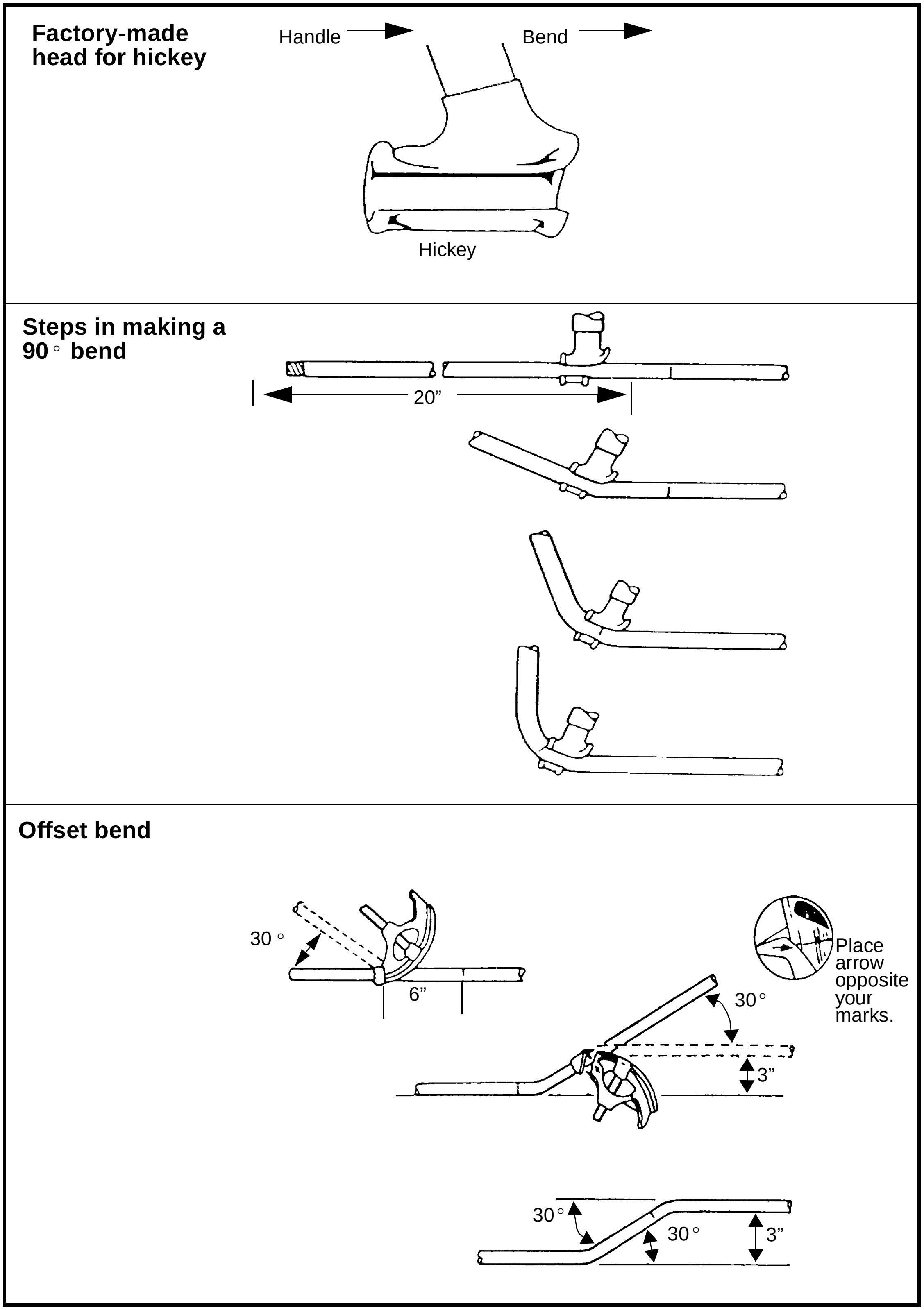

Figure 5-2. Bending rigid conduit

CUTTING CONDUIT

You can use a hacksaw or a standard pipe cutter to cut conduit. When using a hand hacksaw, hold the conduit in a vise and keep the cut at right angles to the length of the pipe. If a large amount of conduit is being cut, a power hacksaw is recommended. Even though you may use pipe cutters, which are standard equipment, a hacksaw is recommended for electrical conduit cutting because considerable time is required to remove the burr left in the inside of a pipe by a pipe cutter. Always use cutting oil when cutting pipe.

REAMING CONDUIT

Regardless of the cutting method used, a sharp edge always remains inside the conduit after cutting. Before installing the conduit, remove this edge with a pipe reamer or a file to avoid conductor damage. This process is called *reaming*.

CUTTING THREADS

Since the outside and inside diameters of rigid conduit are the same as those of gas, water, or steam pipes, the standard thread forms, threading tools, and dies are used. Normally, the smaller sizes of pipe are threaded with dies that cut a thread for every turn of the die. For larger sizes (1 1/2 inches and over), you will generally use a ratchet-type cutter. Motor-driven, pipe-threading machines are also available for large installations and when threading a considerable amount of conduit. As a good practice, you should examine each piece of threaded conduit before installation for—

- Foreign matter inside the pipe. Remove this material to prevent conductor damage.
- Thread condition. Mishandling, extraneous paint, or dirt may require the conduit to be rethreaded before installation. Always use cutting oil when threading conduit.

INSTALLING CONDUIT

Conduit should be run as straight and direct as possible. When you are installing a number of conduits parallel and adjacent to each other in exposed multiple-conduit runs, you should erect them simultaneously instead of installing one line and then another. You can use straps or hangers to support conduit installed on building surfaces.

Wood Surfaces. Use nails or wood screws to secure the straps.

Brick or Concrete Surfaces. Drill holes with a star or carbide drill, install expansion anchors, and secure the straps to the surface with machine screws.

Tile or Other Hollow Material. Secure the straps with toggle bolts.

Metal Surfaces. Drill holes, tap into the metal, and secure the straps with machine screws.

Provide an adequate number of supports according to *Table B-17, page B-17*. Cut the conduit between boxes (called a *conduit run*) to the proper length, thread it, ream it, and then bend it to suit the building contours. Attach the conduit-run ends to the boxes. In a concealed installation, you may notch the building members sufficiently to allow placing the conduit behind the wall surface, but avoid undue weakening of the structure.

CONNECTING BOXES

When the boxes are of threaded-hub construction, screw the conduit ends into the box hubs and connect the conduit runs at midpoint with a coupling. If the boxes are of knockout-type construction, use the following installation steps:

Step 1. Place the boxes loosely in the required position on studs and joists.

Step 2. Screw a bowed locknut, with the teeth of the locknut adjacent to the box, onto the threads at the run ends of the conduit.

Step 3. Insert the conduit ends into the knockout openings.

Step 4. Screw the bushings tightly onto the conduit ends in the boxes. (Bushings have smooth surfaces on their inside diameter to ensure damage-free conductor installation.)

Step 5. Tighten the locknuts against the boxes so that the teeth will dig into the metal sides of the boxes. You can do this by driving a drive punch against one of the locknut lugs and forcing the locknut to move on the threaded conduit against the box.

Step 6. Fasten the box securely to the building after you have made all the box connections.

PULLING WIRE

When installing boxes and conduit runs, pull the conductor wires into the conduit. For short runs with few wires, you can pair conductors and push them through the conduit run from box to box. When the conduit run has several bends and more than two conductors, you must use a fish tape to pull wire. After baring the conductor ends of insulation, connect them to the fish tape. Tape the conductor junction to the fish tape to preclude damaging the conduit interior and existing conductors in the conduit. Taping also compacts and strengthens the joint to ensure easier pulling. (See *Figure 5-3*.)

For efficient and safe operation, wire pulling is generally a two-man procedure. One electrician pulls the conductors through the conduit, while the other feeds the conductors into the conduit. In this operation, take care in feeding and pulling the wires so that they maintain their same relative position in the conduit throughout the run length, thus avoiding insulation injury. For ease of operation, you may rub a wire lubricant, such as powdered soapstone, on the conductors or blow the lubricant into the conduit. In intricate runs, you may perform wire pulling in sections between boxes. This procedure requires a large amount of additional splicing to be made in the boxes and requires that you take more time in wiring. The preferred practice in wire pulling is to pull the conductors from the source through to the last box in the conductor run. Make loops that extend about 8 inches from the box openings for each conductor that is to be tapped or connected to a device in the box. If conductors are not to be tapped, pull them directly through the box to their connection.

USING SPLICES

Wire splices in conduit installations are not under tension; therefore, you can use a simple pigtail splice that is carefully made to obtain a good electrical joint. Do not make

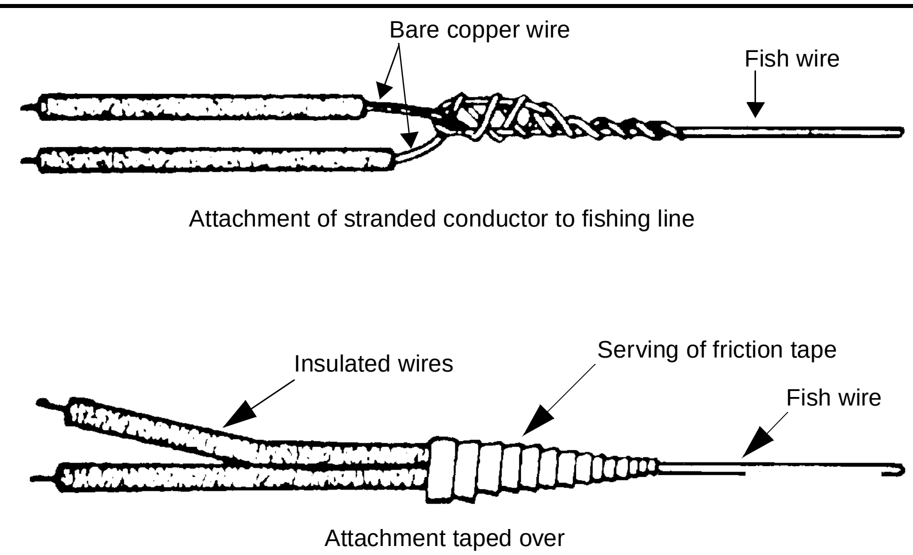

Figure 5-3. Attachment of fish wire

any wire splices that will be concealed in the conduit runs. This requirement is necessary because splices reduce the pulling area in a conduit and could easily be a source of electrical failure.

CIRCUITING

LAYOUT

Follow the directions and procedures in Chapter 3 for layout and circuiting of devices in a conduit installation. The availability of different sizes of conduit, along with their varying conductor capacities, makes the wiring installation for conduit somewhat different from that of the open or cable type. For example, where cable installation requires several runs in a particular location, a conduit installation would use a single conduit with multiple conductors. Consequently, conduit layouts and runs should be planned to use the minimum amount of conduit possible and also to keep the conductor runs to each outlet short enough to maintain a low voltage drop.

CONDUCTOR CONNECTION

No exceptions to the standard color coding of wires, as outlined in the other systems, are permitted in conduit wiring. All load utilization devices (fixtures and receptacles) operating at line-to-neutral voltage in a grounded neutral system must be connected to both a white and a black (or substitute color) wire. The white wire is always the grounded neutral wire. Black wires are the hot leads that are fused and connected to the switch when controlling power to a lamp holder or an outlet. Red, blue, and orange insulated wires can be used as substitutes for black wire when wire combinations are combined in a conduit or a circuit. Never connect the white wire to a black or substitute-color wire. You must not fuse or switch the white wire except in a multipole device that opens all conductors of the circuit simultaneously. A green insulated conductor denotes a wire used to provide an auxiliary equipment ground. As an expedient measure, the ends of the wire insulation may be painted to obtain proper color coding when the colored insulation is not available. They may also be identified by the use of wire code markers.

CONDUIT CAPACITY

Cable wiring, described in Chapter 4, is normally limited to two or three standard combinations of wire sizes. Conduit, however, has the capacity to accommodate several conductors in one run. *Table B-19, page B-18,* lists the maximum number of conductors of a certain gauge that can be inserted in the various sizes of conduit used in interior wiring. For example, the table shows that six No 14 wires would require the installation of a 3/4-inch conduit run. In many installations, it is necessary to use more than one wire size in a conduit run. In such cases, the conductors cannot have a combined or cross-sectional area equal to more than the allowable percent of cross-sectional area of conduit as shown in *Table B-20, page B-18*.

Table B-21, page B-19, lists the percent of conduit cross-sectional area in square inches available for conductor use. For example, if three No 10, Type R, and four No 8, Type R, conductors are to be inserted in a conduit, their combined cross-sectional area obtained from *Table B-22, page B-19,* is 0.4420 square inch (3 x 0.0460 + 4 x 0.0760). The proper size of conduit for this installation is 1 1/4 inches per *Table B-21*. You can find this by first looking for the total area in column 7. You will see that 0.4420 lies between 0.34 square inch (for 1-inch conduit) and 0.60 square inch (for 1 1/4-inch conduit). The 1-inch conduit is too small, so you would use the 1 1/4-inch size.

CIRCUIT WIRING

A fundamental law of electricity generation can be restated for wiring purposes as follows: When a conductor carrying current changes position or the current reverses direction in the conductor, it induces a current in an iron or steel conduit carrying the conductor. Consequently, if this conductor was isolated in an iron or steel conduit, the conduit would be heated by the induced current. This would result in considerable power loss. In an AC system, both wires of a circuit are encased in a single conduit, thereby causing the induced current of each to balance and cancel each other. To eliminate any possibility of induced heating of iron or steel conduit, both wires of a circuit must travel in the same conduit.

ADDITIONS TO EXISTING WIRING

INCREASE OF CIRCUIT AMPERAGE

A standard conduit installation has enough flexibility to accommodate a normal increase in circuit load even if an increase in circuit amperage is required. For example, a 1/2-inch conduit in a standard conduit wiring installation generally carries two No 14 conductors, which have a 15-ampere capacity. From *Table B-19, page B-18*, you can see that the 1/2-inch conduit can also accommodate two No 12 conductors, which have a 20-ampere capacity. Consequently, if you are increasing the load in an existing circuit, you can use two No 12 wires to replace the No 14 wire. When you have replaced all the wires in the circuit, you can safely increase the amperage for the fuse or circuit breaker in the central fuse panel for the circuit from 15 to 20 amperes to accommodate the additional load.

ADDITION OF NEW CIRCUIT

When adding a new load to an existing building with conduit wiring and the circuit analysis indicates the need for a new circuit, you can often use the existing conduit to carry the new circuit most of its distance. Install the new circuit by pulling in an additional wire (red) from the circuit-breaker panel to the existing outlet and then adding the required outlet box beyond this location. The new load is connected to the additional circuit. Use *Table B-19* to determine whether the existing conduit can accommodate an additional wire. The installation of the additional outlet box and conduit should conform to the rules and practices outlined previously. In this type of installation, use a common grounded-neutral wire.

Section II. Thin-Wall Conduit

USES AND ADVANTAGES

Electrical metallic tubing (EMT), commonly called *thin-wall conduit*, is a metallic tubing that can be used for exposed or concealed electrical installations. Its use should be confined to dry interior locations because it has a very thin plating that does not protect it from rusting when exposed to the elements or humid conditions. It is less expensive than rigid conduit and much easier to install. The process of bending requires less effort, and the ends do not have to be threaded. In comparison to the other wiring systems, it ranks behind rigid conduit but ahead of the other types of wiring when considering the quality and durability of the installation. For this reason and because of the decreased cost in materials and labor, it is most generally specified for home-building construction. Install it in the same manner as rigid conduit except use pressure-type couplings and connectors instead of threaded units.

CONDUIT AND FITTINGS

Thin-wall conduit is more easily installed than rigid conduit. This conduit, as its name implies, has a thinner wall than rigid conduit but has the same interior diameter and cross-sectional area. It is available in sizes from 3/8 to 2 inches. Use the 3/8-inch size only for under-plaster extensions. The inside surface is enameled to protect the wire insulation and minimize friction when pulling wire. All couplings and connections to boxes are threadless and are of clamp or compression type. *Figure 5-4* shows thin-wall conduit and the fittings commonly used. Some fittings are similar to sleeves and are secured to the conduit by an impinger tool, which pinches a circular indentation in the fittings to hold them firmly against the conduit. Others have threaded bushings that are tightened to force the tapered sleeve firmly against the tubing.

CONDUCTORS

The same type, capacity, and maximum number of conductors per size of conduit previously given in *Tables B-17 through B-21, pages B-17 through B-19*, for rigid conduit also apply to thin-wall installations.

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Figure 5-4. Thin-wall conduit and fittings

BENDS

Use extreme care when bending metallic tubing to avoid kinking the pipe or reducing its inside area. When using thermoplastic-covered conductors, the radius of the curve of the inner edge of any field bend must be at least six times the internal diameter of the tubing. When using lead-covered conductors, it must be at least 10 times the interior diameter of the tubing. *Table B-18, page B-17,* shows the minimum radii for field bends.

CONSTRUCTION

The thin-wall conduit bender (*Figure 5-5*) has a cast-steel head that is attached to a steel pipe handle that is approximately 4 feet long. It is used in the field to form thin-wall conduit into standard and offset bends. Benders are made for each size of conduit; therefore, use them only on those sizes for which they are designed. Each size bends the conduit to the recommended safe radius. Use the projection on the head of the bender, sometimes called a *foot step*, to steady the bender in operation and reduce the pressure required on the handle. The numbers cast on the bender shaft are inch measurements that you can use to check the depths of offset bends.

OPERATION

When making a 90-degree bend, place the conduit on a level surface and hook the end of the proper-size tube bender under the conduit's stub end. Using a steady and continuous force, firmly hold the conduit and bender (with the bending groove over the conduit), push down on the handle, and step on the footstep to bend the conduit to the desired angle. To make a 45-degree bend in this manner, move the bending tool until the handle is vertical. For accurately bending conduit stubs, place the bender at a predetermined distance from the end of the conduit. This distance is equal to the required stub dimension minus an amount commonly called a *take-up height*. The take-up height is based on a constant allowance determined by the bending radii for various-size conduit. The take-up height is 5 inches for 1/2-inch conduit, 6 inches for 3/4-inch conduit, and 8 inches for 1-inch conduit.

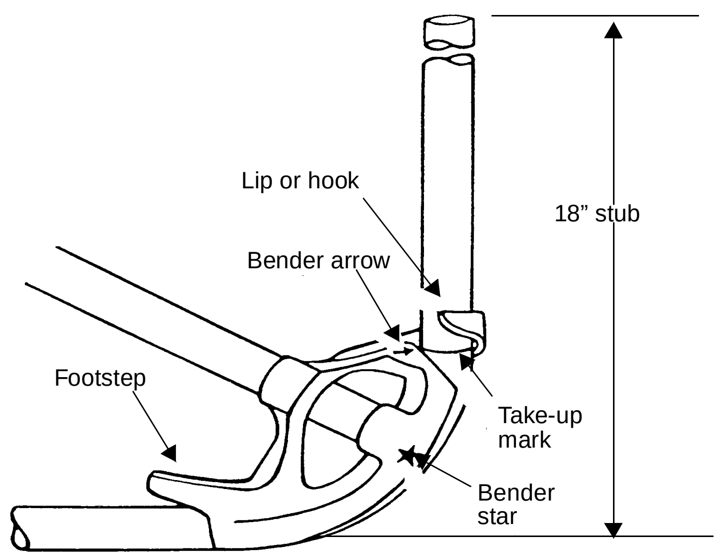

Figure 5-5. Thin-wall conduit bender

INSTALLATION

You may cut thin-wall conduit with a hacksaw or a special thin-wall cutter. As with rigid conduit, you should also ream the sharp edge in thin-wall tubing after cutting to prevent premature wire damage. Exposed thin-wall conduit is supported in a similar manner and with the same type of supports used with rigid conduit. Since there is no positive link between the couplings, box connectors, and thin-wall conduit, ensure that each conduit joint is electrically and mechanically secure. Insert all conduit ends into the fittings until they touch the inner limiting edges. Then, firmly tighten the fittings so that they securely grip the conduit walls.

DANGER

Avoid loosening the conduit from the fittings because it could cause a loose connection, a short circuit, or an electrical fire at the point of wire and conduit contact. A mechan-ically loose conduit joint will not maintain the ground continuity required in all electrical wiring installation. This could also create an operating hazard for Army personnel.

Section III. Flexible Conduit

MATERIALS

Flexible metal conduit, generally called *Greenfield*, resembles armored cable in appearance but is more adaptable than cable because various sizes and numbers of wires can be pulled into it after it is installed. You may use plastic-covered Greenfield when the internal conductors are exposed to oil, gasoline, or other materials that have a deteriorative effect on the wire insulation. This metal conduit has a thermoplastic outer-sheath covering similar to that used on Type T wire, the characteristics and uses of which are detailed in *Table B-2, pages B-2 through B-4*. *Figure 5-6, page 5-12*, shows flexible conduit and the various fittings available.

INSTALLATION

Flexible conduit installation is similar to that for thin-wall conduit except that Greenfield must be supported more frequently. Its prohibitive cost limits its use to connections between rigid wiring systems and movable or vibrating equipment such as motors or fans. It may also be installed where the construction requires a conduit bend that is difficult or impossible to make.

GROUNDING

Because of restrictions, you must ground most flexible conduit systems by running a separate grounding wire along with the circuit conductors.

BENDING AND SUPPORTING

Despite its flexibility, runs of flexible conduit between boxes and fittings must not bend more than the equivalent of four quarter turns. This conduit must be supported with a conduit strap within 12 inches of every box or fitting and at intervals no longer than 4 1/2 feet.

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Figure 5-6. Flexible conduit and fittings

Section IV. Nonmetallic Conduit

USES

Many types of nonmetallic conduit are available, but schedule 40 polyvinyl chloride (PVC) is the one most electricians use. It is a rigid, heavy-walled, flame-retardant, heat- and sunlight-resistant conduit. It may be used in wet or dry locations, in walls, in ceilings, and above or below the ground. Do not try to substitute PVC irrigation pipe for schedule 40 PVC conduit; look for the insignia of an electrical materials testing laboratory. You can use nonmetallic conduit with metal or nonmetallic boxes, but the nonmetallic boxes are not the same as those used with Type NMC cable.

WIRING

Nonmetallic conduit does not constitute a grounded system, so you must run a separate grounding wire with the circuit conductors.

TRIMMING

After cutting PVC, trim the ends inside and out with a pocketknife to remove any rough edges that might damage conductor insulation.

BENDING

Bends in PVC are made by heating the conduit in a special infrared heater until it is soft. Do not try to heat PVC with a torch because you will char the conduit. Design your runs so that no piece of conduit between fittings bends more than the equivalent of four quarter turns.

JOINING

PVC comes in 10-foot lengths, each one with a coupling. Glue the conduit together with gray conduit cement; do not use water-pipe cement. Male and female adapters are available for transitions to other types of conduit and for box connections.