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An American National Standard

Standard Guide for Cable Splicing Installations[1]

This standard is issued under the fixed designation F 1835; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides direction and recommends cable splicing materials and methods that would satisfy the requirements of extensive cable splicing in modular ship construction and offers sufficient information and data to assist the shipbuilder in evaluating this option of cable splicing for future ship construction.

1.2 This guide deals with cable splicing at a generic level and details a method that will satisfy the vast majority of cable splicing applications.

1.3 This guide covers acceptable methods of cable splicing used in shipboard cable systems and provides information on current applicable technologies and additional information that the shipbuilder may use in decision making for the cost effectiveness of splicing in electrical cable installations.

1.4 This guide is limited to applications of 2000 V or less, but most of the materials and methods discussed are adaptable to higher voltages, such as 5-kV systems. The cables of this guide relate to all marine cables, domestic and foreign, commercial or U.S. Navy.

1.5 The values stated in SI units shall be regarded as standard. The values given in parentheses are inch-pound units and are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the application of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 8 Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft[2]

D 2671 Test Methods for Heat-Shrinkable Tubing for Electrical Use[3]

2.2 *IEEE Standards:*

IEEE 45 Recommended Practice for Electrical Installations on Shipboard[4]

2.3 *UL Standards:*[5]

UL STD 224 Extruded Insulating Tubing

UL STD 486A Wire Connectors and Soldering Lugs for Use with Copper Conductors

2.4 *IEC Standards:*

IEC 228 Conductors of Insulated Cables[6]

2.5 *Federal Regulations:*

Title 46 Code of Federal Regulations (CFR), Shipping[7]

2.6 *Military Specifications:*[7]

MIL-T-16366 Terminals, Electric Lug and Conductor Splices, Crimp-Style

MIL-T-7928 Terminals, Lug, Splices, Conductors, Crimp-Style, Copper

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *adhesive*, *n*—a wide range of materials used extensively for bonding and sealing; coating added to the inner wall of heat-shrinkable tubing to seal the enclosed area against moisture. Adhesive is for pressure retention and load-bearing applications (see also *sealant*).

3.1.2 *barrel*, *n*—the portion of a terminal that is crimped; designed to receive the conductor, it is called the wire barrel.

3.1.3 *butt connector*, *n*—a connector in which two conductors come together, end to end, but do not overlap and with their axes in line.

3.1.4 *butt splice*, *n*—device for joining conductors by butting them end to end.

3.1.5 *circumferential crimp*, *n*—final configuration of a barrel made when crimping dies completely surround the barrel and form symmetrical indentations.

3.1.6 *compression connector*, *n*—connector crimped by an externally applied force; the conductor is also crimped by such force inside the tube-like connector body.

3.1.7 *cold-shrink tubing*, *n*—tubular rubber sleeves that are

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[2] *Annual Book of ASTM Standards*, Vol 02.03.

[3] *Annual Book of ASTM Standards*, Vol 10.02.

[4] Available from the Institute of Electrical and Electronic Engineers, IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08554-1331.

[5] Available from Underwriters Laboratories, Inc., 333 Pfingsten Rd., Northbrook, IL 60062.

[6] Available from the International Electrotechnical Commission, 3 rue de Varembe, Case Postale 131, CH-1211, Geneva 20, Switzerland.

[7] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111–5098, Attn: NPODS.

factory expanded and assembled onto a removable core. No heat is used in installation. Also known as *prestretched tubing* (PST).

3.1.8 *crimp connectors*, *n*—tubular copper connectors made to match various wire sizes and fastened to the conductor ends by means of a crimping tool.

3.1.9 *crimping die*, *n*—portion of the crimping tool that shapes the crimp.

3.1.10 *crimping tool*, *n*—a mechanical device, which is used to fasten electrical connectors to cable conductors by forcefully compressing the connector onto the conductor. This tool may have interchangeable dies or "jaws" to fit various size connectors.

3.1.11 *heat-shrink tubing*, *n*—electrical insulation tubing of a polyolefin material, which shrink in diameter from an expanded size to a predetermined size by the application of heat. It is available in various diameter sizes.

3.1.12 *primary insulation*, *n*—the layer of material that is designed to do the electrical insulating, usually the first layer of material applied over the conductor.

3.1.13 *sealant*, *n*—inner-wall coating optional to shrinkable tubing to prevent ingress of moisture to the enclosed area (see also *adhesive*).

3.1.14 *splice*, *n*—a joint connecting conductors with good mechanical strength and good conductivity.

3.1.15 *tensile*, *n*—amount of axial load required to break or pull wire from the crimped barrel of a terminal or splice.

4. Significance and Use

4.1 Splicing of cables in the shipbuilding industry, both in Navy and commercial undertakings, has been concentrated in repair, conversion, or overhaul programs. However, many commercial industries, including aerospace and nuclear power, have standards defining cable splicing methods and materials that establish the quality of the splice to prevent loss of power or signal, ensure circuit continuity, and avoid potential catastrophic failures. This guide presents cable splicing techniques and hardware for application to commercial and Navy shipbuilding to support the concept of modular ship construction.

4.2 This guide resulted from a study that evaluated the various methods of cable splicing, current technologies, prior studies and recommendations, performance testing, and the expertise of manufacturers and shipbuilders in actual cabling splicing techniques and procedures.

4.3 The use of this guide by a shipbuilder will establish cabling splicing systems that are: simple and safe to install; waterproof, corrosion, and impact resistant; industry accepted with multiple suppliers available; low-cost methods; and suitable for marine, Navy, and IEC cables.

5. General Requirements for Cable Splicing

5.1 Cable splicing requires that cable joints be insulated and sealed with an insulation equal in electrical and mechanical properties to the original cable. Cable splicing shall consist of a conductor connector, replacement of conductor insulation, replacement of the overall cable jacket, and where applicable, reestablishment of shielding in shielded cables and electric continuity in the armor of armored cables.

5.2 *Nonsplice Applications*—The only unacceptable area for a cable splice is established by regulations and concerns the restriction of being unable to splice cables in defined hazardous areas. Hazardous areas are locations in which fire or explosion hazards may exist as a result of flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings.

6. Cable Splicing

6.1 Cable splicing presented in this guide uses a system of compression-crimp, tubular-metal connectors for butt connection of cable conductors and insulating systems of shrinkable tubing to reinsulate the individual conductors and replace the overall cable jacket.

6.2 *Crimp Connectors*—For splice connection of conductors, compression-crimped connectors shall be used for joining an electrical conductor (wire) to another conductor. The joint requires proper compression to achieve good electrical performance while not overcompressing and mechanically damaging the conductor. Compression connections are accomplished by applying a controlled force on a barrel sleeve to the conductor with special tools and precision dies.

6.3 *Conductor Reinsulation*—Thin-wall shrinkable tubing shall be used to reinsulate the conductor and the installed connector. The insulation tubing, when shrunk or recovered, shall be equal in electrical and mechanical properties to the original conductor insulation. Tubing used for conductor reinsulation does not require an interior adhesive sealant coating.

6.4 *Cable Jacket Reinsulation*—Shrinkable tubing shall be used to envelop the overall splice. To satisfy more abusive conditions that cable jackets are exposed to, a flame-retardant, thick-wall tubing construction with factory applied sealant shall be used.

7. Cable Preparation

7.1 Cables to be spliced shall be prepared to the dimensions specified in Fig. 1 and Fig. 2. Fig. 1 provides cable preparation for power cables from single to four conductor sizes. Dimensions for multiple conductor cables (conductor size of No. 14 or less) are shown in Fig. 2.

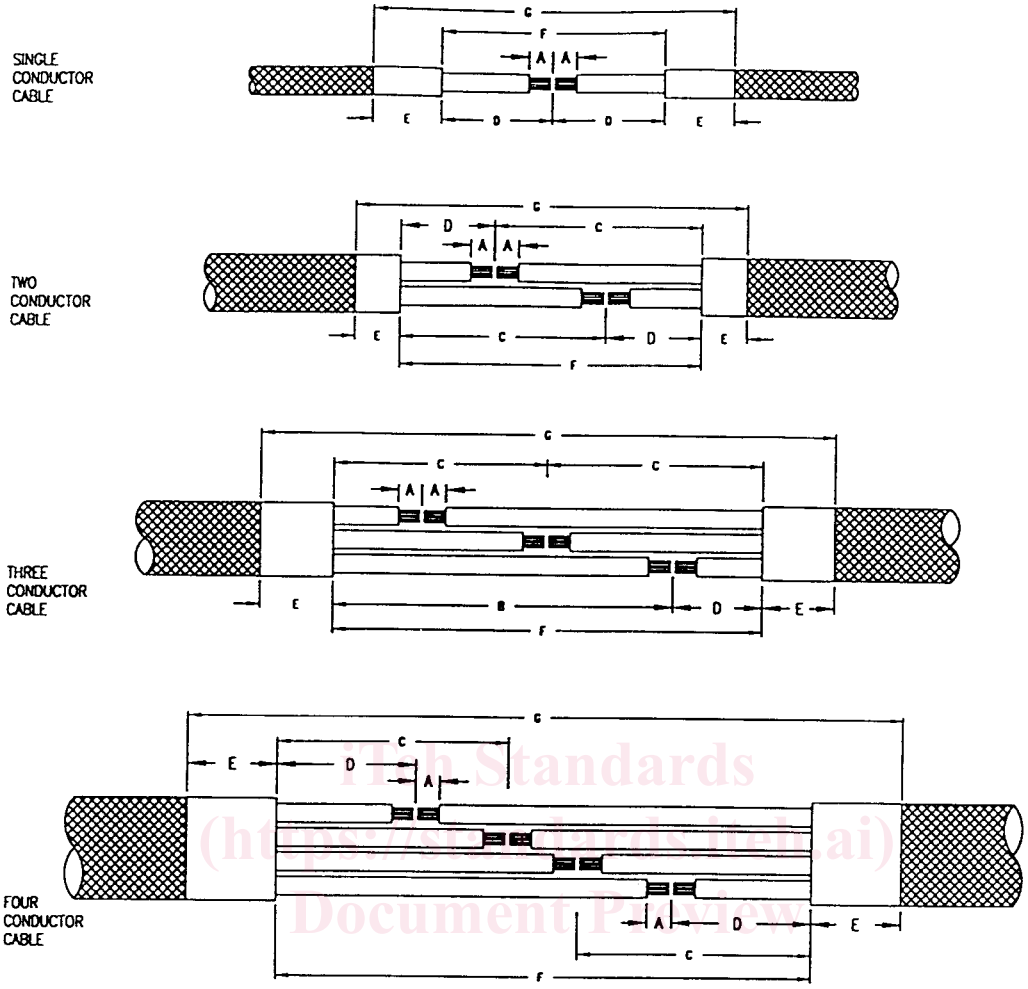
7.2 Care must be exercised when preparing the cable ends so that conductor insulation is not cut when removing the overall cable jacket, shield, or cable armor, where applicable. Similar care is required when removing the individual shield or insulation protecting the conductor to prevent cuts or nicks on the individual conductor strands.

7.2.1 Insulation cutting tools that limit depth of cut should be used to prepare cable ends so that underlying insulation is not cut. Similar care is required when removing the individual conductor insulation to protect the conductor copper strands from nicks and cuts.

7.2.2 Cable preparation shall result in stripping the individual conductors so that the bare copper is long enough to reach the full depth of the butt connector plus 3.2 mm (⅛ in.).

7.3 Match the geometrical arrangement between cables to be spliced using conductor color code identification to eliminate crossovers or mismatch when splicing.

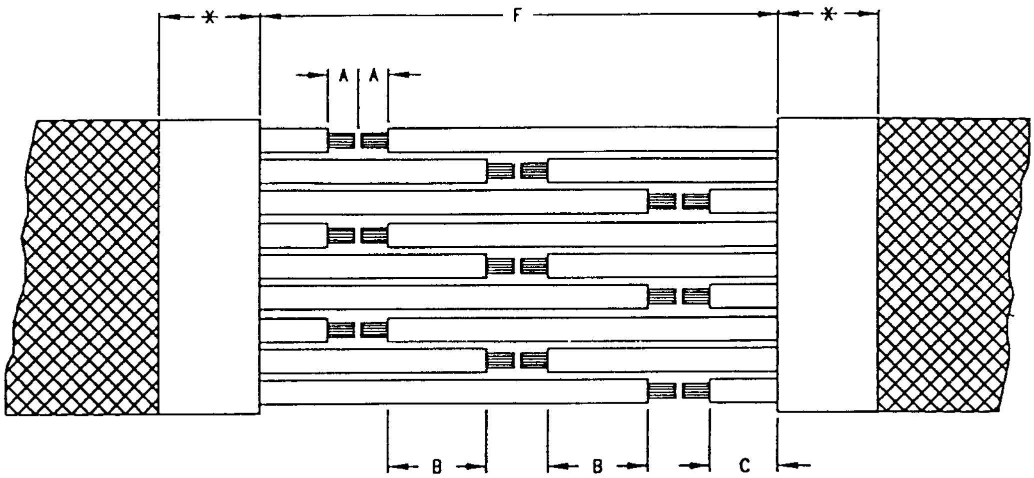
7.4 Cable ends shall be in or near their final position before being spliced.



CONDUCTOR SIZE (AWG or MCM)	A	B	C	D	E	F				G			
						1/C	2/C	3/C	4/C	1/C	2/C	3/C	4/C
16 to 10	-	203 (8)	127 (5)	50 (2)	76 (3)	102 (4)	178 (7)	254 (10)	330 (13)	254 (10)	330 (13)	406.4 (16)	559 (22)
9 to 4	-	279 (11)	178 (7)	76 (3)	76 (3)	152 (6)	254 (10)	356 (14)	406 (16)	305 (12)	406 (16)	508 (20)	660 (26)
3 to 1/0	-	330 (13)	203 (8)	76 (3)	102 (4)	152 (6)	279 (11)	406 (16)	584 (23)	356 (14)	483 (19)	610 (24)	813 (32)
2/0 to 250	-	381 (15)	254 (10)	127 (5)	102 (4)	254 (10)	381 (15)	508 (20)	635 (25)	457 (18)	584 (23)	711 (28)	914 (36)
300 to 500	-	495 (19.5)	330 (13)	165 (6.5)	102 (4)	330 (13)	495 (19.5)	660 (26)	-	533 (21)	699 (27.5)	864 (34)	-
650 to 2000	-	-	-	254 (10)	102 (4)	508 (20)	-	-	-	711 (28)	-	-	-

LEGEND:
- All dimensions are in millimeters (inches are shown in parenthesis).
- Dimension "A" equals half the connector length plus 3 mm (1/8-inch). Bare copper on each conductor equals "A."

FIG. 1 Splice Dimensions for Power Cables



SPLICES DIMENSIONS FOR CONTROL CABLES

NO. OF CONDUCTORS	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-90
DIMENSION F	127 (5)	203 (8)	254 (10)	305 (12)	356 (14)	406 (16)	457 (18)	508 (20)	610 (24)

LEGEND:

- All dimensions are in millimeters (inches).
- 9 Conductor cable shown above.
- "A" equals ½ connector length plus 3 mm (1/8-inch).
- "B" equals 4A (distance from any adjacent butt splice.
- "C" equals 4A (distance from cable sheath from either end).
- "F" equals the length of stripped back cable jacket for wire, unshielded, sizes No. 18 to No. 14.

* For armored cables, it is recommended that the armor be stripped back approximately 75 mm (3-inches) for overlapping of cable jacket replacement with shrink tubing.

FIG. 2 Splice Dimensions for Control-Multiple Conductor Cables

8. Materials and Tools

8.1 *Cable Splicing Materials*—The following sections provide an overview of the various splice materials. In addition, specific recommendations and suggested guidelines are offered that would enhance the cable splicing process.

8.1.1 *Crimp-Type Connectors*—Splice connectors shall be compression-type, butt connectors conforming to the requirements of UL STD 486A and shall be satisfactory to Section 20.11 of IEEE 45.

8.1.1.1 Connector shall be seamless, tin-plated copper.

8.1.1.2 Butt connector shall have positive center wire stops for proper depth of conductor insertion.

8.1.1.3 Connectors shall be marked with wire size for easy identification.

8.1.1.4 Connector shall have inspection holes to allow visual inspection for proper wire insertion.

8.1.1.5 Butt connector for wire sizes No. 10 (AWG) or larger shall be the "long barrel" type to permit multiple crimps on each side of the connector for greater tensile strength. The conductor ends shall be fully inserted to the "stop" at the center of the connector. For smaller conductor sizes (No. 10 AWG or less), a single crimp should be spaced half way between the end of the connector and the center wire stop.

8.1.1.6 Connector shall be color-coded in accordance with Table 1 or Table 2.

8.1.2 *Conductor Reinsulating Material*—To reinsulate the conductor and the installed connector, heat-shrink tubing shall be used. (see Table 3).

8.1.2.1 When recovered or shrink, the tubing used shall be equal to or greater than the thickness of the original conductor insulation.

8.1.2.2 Shrink tubing used for conductor reinsulation shall be heat-shrink tubing. The tubing shall be thin-wall cross-linked polyolefin tubing, flame-retardant (FR-1) construction in accordance with UL STD 224 requirements. Performance requirements shall include:

Shrink ratio	2:1
Operating temperature range	–55 to +135°C
Minimum shrinkage temperature	+121°C
Longitudinal shrinkage	±5 %
Electrical rating	600-V continuous operation
Dielectric strength in accordance with Test Methods D 2671	19.7 kV/mm (500 V/mil) min

8.1.2.3 Shrink tubing to cover the connection of individual conductors does not require an interior coating of adhesive (mastic) sealant.

8.1.3 *Cable Jacket Replacement Materials*—Several methods and a variety of materials are available that will provide the mechanical protection, moisture-sealing properties, and electrical performance characteristics needed in a cable splice. For a splice reliability and ease of installation replacement of cable jacket and to envelop the splice area, however, either the heat-shrink or the cold-shrink (prestretched) type shall be used.

8.1.3.1 The tubing used, when recovered or shrunk, shall be equal to or greater than the thickness of the original conductor insulation (see Table 3).

8.1.3.2 The tubing used for cable jacket replacement shall be thick wall, also referred to as heavy-duty shrink tubing, cross-linked polyolefin tubing.

8.1.3.3 Shrink tubing shall be flame retardant (FR-1) in accordance with UL STD 224 requirements.

8.1.3.4 Tubing used for rejacketing of a splice bundle shall have an interior coating of adhesive (mastic) sealant.

8.1.3.5 Table 3 provides dimensions for thick-wall tubing used for rejacketing of cables.

8.1.3.6 Tubing shall have the following performance requirements:

Shrink ratio	3:1
Operating temperature range	–55 to +135°C
Minimum shrinkage temperature (for heat-shrink tubing)	+121°C
Longitudinal shrinkage	±5 %
Electrical rating	600-V continuous operation
Dielectric strength in accordance with Test Methods D 2671	7.9 kV/mm (200 V/mil) min

8.1.4 *Shield Terminations*—Cables that require continued shielding shall have at least a 13-mm (½-in.) overlap between the replacement shielding material and the permanent shielding and shall be attached with either solder-type connectors or a mechanical connection using inner and outer compression (crimp-type) rings.

8.2 *Splicing Tools*:

8.2.1 *Cable Preparation*—The basic tools required for cable splice preparation include a cable cutter, measuring tape or ruler, and a wire insulation stripper. Following the cable preparation, the types of tools required to complete a cable splice include the crimp tool for compression of the butt connectors and a heat source for reducing heat-shrinkable tubing.

8.2.2 *Crimping Tools*—The crimp compression method for making electrical cable splices as recommended in this guide consists of compressing a butt connector onto the wire very tightly so that good metal-to-metal contact is achieved. A

TABLE 1 Connector Data (English Units)

Conductor Size AWG or MCM Designation	Connector Overall Length (min)	Depth of Each Side of Barrel (min)	Overall Diameter of Barrel (Approximate)	Color Code[A]	Conductor Nominal Diameter, in.	Number of Crimps/ End[B]
22	5/8	1/4	0.150	–	0.025	1
20	5/8	1/4	0.150	–	0.039	1
18	5/8	1/4	0.150	–	0.049	1
16	5/8	1/4	0.150	–	0.061	1
14	5/8	1/4	0.150	–	0.077	1
12	3/4	5/16	0.212	–	0.092	1
10	3/4	5/16	0.212	–	0.108	1
8	1 3/4	13/16	1/4	red	0.146	2
6	2 3/8	1 1/8	5/16	blue	0.184	2
4	2 3/8	1 1/8	5/16	gray	0.226	2
3	2 5/8	1 1/4	3/8	white	0.254	2
2	2 5/8	1 1/4	7/16	brown	0.282	2
1	2 7/8	1 3/8	1/2	green	0.317	4
1/0	2 7/8	1 3/8	1/2	pink	0.363	4
2/0	3 1/8	1 1/2	9/16	black	0.407	4
3/0	3 1/8	1 1/2	5/8	orange	0.457	4
4/0	3 3/8	1 5/8	11/16	purple	0.514	4
250 MCM	3 3/8	1 5/8	3/4	yellow	0.577	4
300 MCM	4 1/8	2	13/16	white	0.628	4
350 MCM	4 1/8	2	7/8	red	0.682	4
500 MCM	4 5/8	2 1/4	1 1/16	brown	0.742	4
600 MCM	5 3/4	2 13/16	1 1/4	green	0.893	4
750 MCM	6	2 15/16	1 3/8	black	0.998	4
1000 MCM	6 1/8	3	1 1/2	white	1.180	4

[A] Recommended colors for connectors; however, variances do exist between manufacturers.

[B] For conductors No. 1 or larger, the type of crimping tool used determines the number of crimps to be made. Number and location of compression points (crimps) shall be in accordance with the manufacturer's recommendations.

TABLE 2 Connector Data (Metric)

Conductor Size AWG or MCM Designation	Connector Overall Length (min)	Depth of Each Side of Barrel (Min)	Overall Diameter of Barrel (Approximate)	Color Code[A]	Conductor Nominal Diameter, mm	Number of Crimps/ End[B]
22	16.0	6.5	4.0	–	0.6	1
20	16.0	6.5	4.0	–	1.0	1
18	16.0	6.5	4.0	–	1.5	1
16	16.0	6.5	4.0	–	2.0	1
14	16.0	6.5	4.0	–	2.0	1
12	19.0	8.0	5.5	–	2.5	1
10	19.0	8.0	5.5	–	3.0	1
8	45.0	21.0	6.5	red	4.0	2
6	60.0	29.0	8.0	blue	5.0	2
4	60.0	29.0	8.0	gray	6.0	2
3	67.0	32.0	9.5	white	6.5	2
2	67.0	32.0	9.5	brown	7.5	2
1	73.0	35.0	13.0	green	8.0	4
1/0	73.0	35.0	13.0	pink	9.0	4
2/0	80.0	39.0	14.5	black	10.0	4
3/0	80.0	39.0	14.5	orange	11.5	4
4/0	86.0	41.0	17.5	purple	13.0	4
250 MCM	86.0	41.0	17.5	yellow	15.0	4
300 MCM	105.0	51.0	22.0	white	16.0	4
350 MCM	105.0	51.0	22.0	red	17.5	4
500 MCM	118.0	57.0	27.0	brown	19.0	4
600 MCM	146.0	72.0	32.0	green	23.0	4
750 MCM	153.0	75.0	35.0	black	25.5	4
1000 MCM	156.0	76.0	38.0	white	30.0	4

[A] Recommended colors for connectors; however, variances do exist between manufacturers.
[B] For conductors No. 1 or larger, the type of crimping tool used determines the number of crimps to be made. Number and location of compression points (crimps) shall be in accordance with manufacturer's recommendations.

crimping tool is necessary so that the process is controlled, the crimp is made easily and correctly and can be reproduced reliably.

8.2.2.1 This guide recommends the use of compression systems that coordinate connectors, crimping tools and dies, and include built-in installation and inspection features that prevent improper field connections.

8.2.2.2 The crimping tool shall be a single-cycle type, requiring full-cycle compression before release. Full-cycle control requires that the crimping tool to be closed to its fullest extent, thereby completing the crimping cycle before the tool can be opened.

8.2.2.3 Mechanical-type (manual) compression tools used for crimping connectors shall be a one-cycle device and require full compression before release.

8.2.2.4 Hydraulic crimping devices shall have an emergency release mechanism to abort the crimp cycle if necessary.

8.2.2.5 Crimp tool shall allow easy visual field check for proper tool adjustment with butting surfaces.

8.2.2.6 Crimping tool and crimp dies shall result in circumferential-shaped configuration.

8.2.3 *Heat Guns*—Heat-shrink tubing installation requires that the source of heat be controllable. Limited electric heat guns and hot air blowers that are portable and provide even controlled heat at nozzle temperatures of 260 to 399°C (500 to 750°F) are recommended devices for installing heat-shrink tubing. Propane torches shall be used with extreme care. Torches shall not be used to shrink thin-wall tubing.

9. Quality Assurance

9.1 *General Guidelines for Quality Assurance*—For extensive cable splicing activities, such as found with modular ship construction techniques, it is recommended that a material control program and a personnel training program that includes certification of personnel for both splicing installation and inspection. Quality control issues are of major significance and factors that can be controlled and monitored by the shipbuilder before, during, and following cable splicing. A cable splicing program as envisioned for modular ship construction should include use of only approved materials and devices, only qualified personnel to make the electrical cable splices, and establish inspection procedures, using only qualified inspectors, to verify proper installation.

9.2 *Material Control*—Since crimping is a mechanical process and, by controlling the material and dimensional properties of the conductor, the butt connector, and the crimp tool, the reliability of the crimped connection may be controlled closely. An in-process quality assurance program based on controlled distribution of materials and tools should be established. For installation tools, the program should include inspections to assure that:

9.2.1 Splicing equipment shall be inspected before the first use each month to verify the performance of insulation removal devices and of crimping tools.

9.2.2 Crimp tool dies shall be checked before the first use each month for correct tolerances.

9.3 *Material Procurement; Recommended Use of Kits*—A material control program should adopt the use of cable splice kits. Splice kits may be procured directly from a number of qualified manufacturers or can be assembled by the shipbuilder from quantity-purchased materials for the various types and sizes of materials necessary. All kits shall be for one-to-one cable splices. For selection of cable-splice kit, the following minimum information should be established:

9.3.1 Number of conductors in the cable,

9.3.2 Size (gage) of each conductor,

9.3.3 Ground wire size, if included,