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IEEE Guide for Installation Methods for Fiber-Optic Cables in Electric Power Generating Stations and in Industrial Facilities

IEEE Power Engineering Society

Sponsored by the
Insulated Conductors Committee

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Abstract: This guide is intended for cables designed for use in power generating stations and industrial facilities, in both the outside plant environment and indoor applications—the latter with adequate consideration for requirements of the National Electrical Code® (NEC®.)

Keywords: cable construction, electric power generating stations, fiber-optic cables, index of refraction, local area network connections, multimode fibers, numerical aperture, optical cable designs, optical performance, reflectometer, singlemode fibers, telecommunication

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Introduction

This introduction is not part of IEEE Std 1428-2004, IEEE Guide for Installation Methods for Fiber-Optic Cables in Electric Power Generating Stations and in Industrial Facilities.

This guide was prepared by the Task Group D6 of Subcommittee D, Station, Control, and Utilization Cables, of the Insulated Conductors Committee within the Power Engineering Society.

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IEEE Guide for Installation Methods for Fiber-Optic Cables in Electric Power Generating Stations and in Industrial Facilities

1. Overview

1.1 Scope

This guide is intended for cables designed for use in power generating stations and industrial facilities, in both the outside plant environment and indoor applications—the latter with adequate consideration for requirements of the National Electrical Code® (NEC®) (NFPA 70[1]).

It is not the intention of this guide to establish requirements for cables designed for installation in a high-voltage environment, such as optical ground wire and all-dielectric, self supporting. These applications are covered by other IEEE documents (IEEE Std 1138™ and IEEE Std 1222™).

1.2 Purpose

This document is intended to provide guidance for the selection, application, and installation of fiber-optic cable in power generating plants and industrial facilities. The selection and application of fiber-optic cable in these facilities differ in many respects from conventional telecommunications and local area network (LAN) installations. Those issues, which require special consideration, are identified and discussed.

2. Normative references

The following referenced documents are indispensable for the application of this guide. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1222™, IEEE Standard for All-Dielectric Self-Supporting Fiber Optic Cable.[2]

NFPA 70, National Electrical Code® (NEC®).[3]

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[1] For information on references, see Clause 2.

[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

NFPA 262, Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces.[4]

UL 1581, Reference Standard for Electrical Wires, Cables, and Flexible Cords.[5]

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B9][6] should be referenced for terms not defined in this clause.

3.1 all-dielectric: An optical fiber cable construction having no metallic or conductive components.

3.2 blown fiber: A term describing a system that uses the force of moving compressed gas to carry bare or specially coated fibers or fiber bundles into small, flexible tubes. Long installed lengths are possible without the need for splices or lubricants and without the need to apply pulling tension to the fiber. Such systems provide a high degree of flexibility. Installed fibers can be blown out and new fibers blown in. Tube raceways can be reconfigured to facilitate modifications.

3.3 chromatic dispersion: The process by which a pulse traveling in a fiber is distorted (broadened) as it travels along the fiber core.

3.4 critical angle: The maximum angle of travel in the core of an optical fiber, which will result in continued propagation of light through the core. Light that strikes the core at an angle greater than the critical angle will pass into the fiber's cladding structure and be dissipated.

3.5 equilibrium modes distribution (EMD): The modal distribution of light transmission in a fiber that exists after high order modes and cladding modes have been attenuated. EMD is naturally achieved in long cables but can be artificially achieved to improve the accuracy of loss measurements through use of a tight coil of fiber or a mode stripper at the output of the light source.

3.6 innerduct: A smooth or corrugated, tubular raceway system used to protect fiber-optic cables in ducts, conduits, cable trays, air plenums, and panels.

3.7 loose tube cable: A style of optical cable construction for which the fiber is loosely encased in a buffer tube to isolate the fiber from external environmental and installation forces.

3.8 microbending: Sharp curvatures of the fiber resulting in axial displacements on the order of a few micrometers. Such bends can cause significant loss of signal into the cladding and are typically the result of improperly applied coatings, cabling, jacketing, and installation.

3.9 modal dispersion: The process by which a pulse traveling along the core of a multimode fiber is distorted (broadened) as a result of the differing path (mode) lengths.

3.10 mode: A distinct path of light in The number of paths that can exist within a fiber are a function of the size of the core and the wavelength of the light source of interest. Singlemode cables support only one path while multimode fibers may support thousands of paths. The differing path lengths of each mode result in signal distortion known as modal dispersion.

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[3] The NEC is published by the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101, USA (http://www.nfpa.org). Copies are also available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[4] NFPA publications are available from Publication Sales, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101, USA (http://www.nfpa.org/).

[5] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://global.ihs.com/).

[6] The numbers in brackets correspond to those of the bibliography in Annex A.

3.11 numerical aperture (NA): Numerical aperture is a measure of a fiber's light-gathering ability when exposed to a source such as an LED or laser. Fibers having a low NA will require more precise alignment when spliced or connectorized than similar fibers having a high NA. The NA of a fiber is established by the refractive indices of its core and cladding.

3.12 tensile strength members: A component of fiber-optic cable that provides the tensile strength necessary to endure the forces of installation and any residual long-term tensile load (such as a vertical drop).

3.13 tight tube cable: A style of optical cable construction where the fiber is tightly encased in a buffer tube.

3.14 tube cable: A hollow tube or assembly of tubes (with or without an overall jacket) that serves as the raceway for air blown fiber.

4. Optical fiber specifications

4.1 Optical cable designs

4.1.1 Fiber type

4.1.1.1 Singlemode

An optical waveguide in which light travels in one mode. The most common core/cladding size is 8/125 µm. Singlemode fibers typically have a higher bandwidth-distance product than multimode fibers and thus can transmit more data over longer distances. Given their small core diameter, singlemode fibers require a higher degree of precision in the splicing and connectorizing process.

Because of their smaller core size, NA, and the need to minimize chromatic dispersion to support long circuits or high data rates, singlemode fibers typically require the use of laser light sources.

4.1.1.2 Multimode

An optical waveguide in which light travels in multiple modes. Typical glass core/cladding optical fiber sizes are 50/125 µm, 62.5/125 µm, 100/140 µm, and 200/230 µm. Typical core/cladding sizes for plastic fiber have been 485/500 µm, 735/750 µm, and 980/1000 µm though the same level of standardization has not been established. Due to the larger core diameters of multimode fibers, splicing and connectorizing requirements are not as restrictive as for singlemode fibers.

Early installations at generating stations and industrial facilities (typically low data rate applications) utilized the larger glass core sizes with a step index design because of their relative ease of connectorization and their good performance when tightly bent (due to their high NA). Increased bandwidth demands and improved termination methodologies have led to widespread use of smaller core, standard graded index fibers.

Historically, inexpensive light emitting diodes (LEDs) have been the most popular light sources for use with multimode fibers. However, with the emergence of high-speed protocols such as gigabit Ethernet, laser sources are increasingly required.

4.1.1.3 Index of refraction profiles

Singlemode and multimode fibers are both available with a step or graded index profile.

Step index fibers are those for which the glass in the fiber core is of the same index of refraction (IOR) across its entire diameter. Graded index fibers are those for which the IOR has been altered as a function of radial position. Many different profiles can be achieved during the manufacturing process.

The most common variety of singlemode fiber has a step index profile. Historically, industrial facilities and power generating stations have made minimal use of singlemode fibers except for circuits that connect to a wide area network (WAN) or telecommunications carrier.

With increasing bandwidth demands, the applications requiring singlemode fiber can be expected to rapidly grow. Singlemode fibers are also produced with a variety of different IOR profiles to meet the increased data rate or distance requirements.

Multimode fibers may have either step or graded IOR profiles. Step index multimode fibers have been a commonly used design in industrial facilities, where bandwidth requirements were frequently limited and the low cost and ease of connectorization of these large cores were important. All-silica-glass, step index, multimode fibers are still commonly used in radiation environments due to their resistance to degradation. Plastic optical fibers are presently fabricated using only step index designs.

Graded index profile glass fibers, the standard design for LAN cabling, have also become the preferred design for multimode fiber in both industrial facilities and power generating stations. This is due in part to its higher bandwidth-distance product, its wide availability, and low cost. The emergence of gigabit Ethernet has resulted in the development of laser optimized index profiles to minimize modal dispersion. Finally, graded index, radiation hardened fibers are also available. This design limits core degradation in moderate radiation environments without the performance limitations of step index cores.

4.1.1.4 Core/cladding materials

Industrial facilities and power generating stations generally utilize fibers (similar to those used in telecommunication and LAN applications) that have silica glass cores that have been doped to achieve the desired IOR or alter the IOR profile. Less common are all silica glass cores (i.e., where no dopants have been added).

Unlike LAN and telecommunication applications, industrial facility and power generating station cables are frequently exposed to high temperatures, harsh environments, or radiation. In these applications, consideration should be given to the use of a polyimide or fluoropolymer cladding.

Transmission in glass based cores has historically occurred via several “windows” (wavelengths at which the core could be said to be relatively transparent). Standard wavelengths for transmission via glass are 850 nm, 1310 nm, and 1550 nm.

Large-diameter plastic cores [typically polymethyl methacrylate (PMMA)] are also available. Plastic fibers presently have a much higher loss rate than typical glass core fibers and are optimized for a minimum attenuation in the 650 nm window. Special light sources are required for operation at this wavelength.

4.1.2 Cable construction (duct, tray, and direct burial installations)

4.1.2.1 General

Industrial facilities and power generating stations will generally employ the same range of constructions found in telecommunication and LAN service with the exception of light duty (“interconnect” or zipcord) cables. Such light duty cables are generally not suitable for industrial or generation service environments.

Given that industrial and generation station fiber-optic cables must frequently be installed in long conduit runs or in trays with many other cables, such constructions will typically consist of one or more fibers forming a subunit. Multiple subunits are cabled together with strength member(s) and/or anti-buckling elements and covered with an outer jacket. Cables intended for direct burial service may also be covered with a metallic armor to increase protection from rodent attack and mechanical damage, though the presence of the metallic element requires special treatment at building entry points.

4.1.2.2 Number of fibers

The guidelines for selecting the number of fibers are similar to those used in LAN and telecommunication service. Standard constructions consist of 1, 2, 4, 6, 12, 18, and 24 fibers. Units of 6 fibers or 12 fibers are commonly used.

Single-fiber cables may be used where simplex communication is adequate (i.e., telemetry or video links where there is no need to transmit back to the transducer or to a camera). Two fibers are required for duplex operation where the telemetry results in a need to send a command for device adjustment or to remotely control a camera. Duplex communication is also the norm for most voice and data communications.

In selecting the fiber count to be used in a given application, consideration should be given to the desirability of spare fibers to satisfy future growth (more signals), technology advances (higher bandwidth signals), or maintenance (broken fibers).

4.1.2.3 Fiber protection

There are two basic methods of encapsulating the fiber to protect it during the cabling operation and during its service life. Selection of a particular design has implications for durability and installation as described below:

a) *Loose tube:* The loose tube design isolates the fiber from mechanical and environmental stresses. The mechanical stresses seen by the cable jacket during installation (twisting, crushing, etc.) are decoupled from the fiber by the loose tube design. The environmental stresses are the result of each component of the cable having a unique coefficient of thermal expansion and contraction. The loose tube isolates the fiber from the other components and allows this design to be rated for use over a wider temperature range than a similar tight tube design. Interstices of loose tube cables are frequently water-blocked with either water swellable tapes or yarn, or filled with a gel to prevent water migration along the length of the fiber. Loose tube designs dominate the telecommunication market and are generally the preferred design for outdoor applications at industrial facilities and power generation stations.

b) *Tight tube:* This design features a buffer tube in intimate contact with the fiber, which permits a tighter bend radius. However, tight tube cables are more susceptible to permanent attenuation due to external physical stresses, temperature, and moisture than their loose tube counterparts. The tight tube is typically the preferred design for indoor applications at industrial facilities and power generation stations.

4.1.2.4 Electrical characteristics

Two basic families of cable designs exist with respect to their inclusion of conductive elements. Selection of the design family has implications for installation, safety, and durability as described below:

a) *All-dielectric:* All-dielectric (no conductive materials) designs are immune to electromagnetic fields and switching surges from adjacent copper cables. The inadvertent contact of any portion of the fiber-optic cable with an energized conductor or component will not result in an electrical shock hazard to personnel or equipment during installation, operation, or maintenance of the fiber-optic cable. Also, outdoor cables of this construction that terminate in a building will not conduct lightning into the building.

Cables of this construction that are direct buried or installed in typical non-metallic innerduct cannot be located using typical electromagnetic detection devices. Non-metallic innerducts are available that include an embedded tracer wire.

b) *Conductive:* The second major family of fiber-optic cables is that which contains electrically conductive components. Typically, these components include steel strength members to facilitate pulling or long-term support, metallic sheaths that provide rodent or mechanical protection, and metallic tapes or conductors to facilitate location when direct buried or installed in non-conductive innerducts. While making the cable immune to such physical damage, the presence of these conductive elements does increase personnel and equipment hazards as outlined above.

4.1.2.5 Fillers

Filler material may be included to obtain a circular cross-section. The filler materials should be nonhygroscopic.

4.1.2.6 Binder tapes

Subunits, fillers, and strength members may be held together during assembly through the use of binder tapes or cords. The binder materials should be nonhygroscopic.

4.1.2.7 Tensile strength members

The strength member may be a collection of aramid or fiberglass yarns, a small fiberglass or plastic rod or tube, a combination of both, or a steel cable. The fiberglass or plastic rod or tube can serve a dual purpose as both a strength member and an anti-buckling element. The latter feature helps to prevent kinking of the cable that can lead to fiber breakage.

4.1.2.8 Jacketing

An overall jacket should be provided to protect the fibers from the stresses of installation and environmental exposure (water, heat, and sunlight). Jacketing materials generally determine a cable's overall level of fire resistance. Jackets for indoor cables are frequently colored to readily identify the cables as containing singlemode (yellow) or multimode (orange) fibers. Outdoor cables, which typically have no fire rating, are most commonly jacketed with polyethylene (to minimize moisture ingress and provide UV stabilization) and colored black.

4.1.3 Cable construction (air blown fiber installations)

Instead of utilizing innerduct to protect the fiber-optic cable and facilitate installation, air blown fiber utilizes tube cables. The tube cables have a semi-conducting coating on the inside to dissipate static electricity buildup that will occur during air blown installation. This static electricity would cause the fibers to adhere to the tube wall and prevent installation. The fibers are specially coated to allow air to propel the fiber through the tube. Tube cables are available in a variety of flame ratings.

4.2 Design considerations

4.2.1 Environment

4.2.1.1 Ambient temperatures

Fiber-optic cables must be rated to withstand the range of temperatures to which they will be exposed during storage, installation, and operation. Since fiber-optic cables do not experience self-heating like copper cables, the ratings are based solely on the ambient temperatures to which they are exposed.

The glasses in the core and cladding alone are not directly affected by changes in temperature over the range of interest. However, when coated and cabled, the coefficients of thermal expansion of the various layers make the fiber-optic cable a complex system. The differential expansion when exposed to either high or low temperature extremes can create microbending of the fiber and cause attenuation of the light.

4.2.1.2 Moisture

For plant cable, special care must be taken to ensure that the fiber is not exposed to water, unless the cable is specifically designed for submergence. Moisture can cause the fiber to darken and attenuate light. The formation of ice on a fiber can result in microbending or cause the fiber to fracture.

4.2.1.3 Radiation

Fiber-optic cables that may be exposed to radiation need to be selected with consideration for the following effects:

a) *Fiber damage:* When irradiated, the energy imparted to the glass can result in the formation of defect sites that attenuate the transmission of light. The nature of the effect is chiefly determined by the dopant used in the glass. Pure silica core fibers and radiation-hardened doped core fibers experience the least degradation under such exposure.

b) *Fluorescence:* When irradiated, the core material can fluoresce creating an internally generated noise signal that can rival signal data strength under marginal conditions. System designers should ensure that adequate signal strength margin exists so that the desired signals are not obscured.

c) *Damage to associated cable structural components:* Irradiation of fiber-optic cable may lead to degradation of components other than the core/cladding assembly, which can lead to reduced performance or reduced life. For instance, degradation of the fiber coating can lead to its flaking and peeling and attendant microbending. Degradation of buffer tubes or outer jackets may lead to increased exposure of the fiber to moisture or chemical attack.

4.2.1.4 Fire

Fiber-optic cables (and tubes for air blown fibers) typically fall into one of four classifications according to their fire endurance capabilities as follows:

a) *Plenum:* Cables that are suitable for installation in ducts, plenums, and other enclosures that transport environmental air. Plenum-rated (NFPA 262) cables are constructed of fire-resistant, low smoke producing materials.

b) *Riser:* Cables that are suitable for use in a vertical run in a shaft or from floor to floor and constructed of materials that have fire-resistant characteristics capable of preventing the spread of a fire from floor to floor (UL 1666).

c) *General purpose:* Cables that are suitable for use in all areas (except plenum and riser) requiring fire-resistant materials (UL 1581).

d) *Not rated:* Cables not classified according to one of the above ratings. At present, most loose tube cables are not rated.

4.2.2 Fiber characteristics

Generally, the physical and optical characteristics of fibers used in industrial facilities and power generating stations are the same as those used in LAN and telecommunication applications. Numerous manufacturing specifications are available to the users that detail these criteria, their tolerances, and their applications. The following is not intended to replace those specifications but to characterize those fibers typically used in industrial and generation facilities and alert the user to those parameters that must be considered in development of purchase specifications.

4.2.2.1 Dimensions

The dimensional precision with which a fiber is manufactured has a significant impact on the performance of spliced or connectorized cable systems. Critical dimensions are as described below:

a) *Core/cladding diameters:* A typical fiber consists of the glass core, a glass cladding, and an acrylate coating. The diameters of the core and cladding determine many of the critical characteristics of a fiber-optic cable. For instance, the core diameter determines the number of different paths (modes) for the transmission of light, the critical angle (and hence the fiber's NA), and the difficulty of splicing and connectorizing. Typically, the core diameter of multimode cables must be within ±3 μm of the nominal value and the cladding diameter must be within ±2 μm of the nominal value.

b) *Core noncircularity:* The core of an ideal fiber has a truly circular cross-section. The core of an actual fiber may have a core with a cross-section that deviates somewhat from the ideal. Noncircularity for both singlemode and multimode fibers is typically limited to 6.0% in order to minimize the losses that would result from splicing or connectorizing matched fibers.

c) *Cladding noncircularity:* The cladding of an ideal fiber also has a truly circular cross-section. As with the core, the cladding of an actual fiber may deviate somewhat from the ideal. Noncircularity of the cladding for both singlemode and multimode fibers is typically limited to 2.0% in order to minimize the losses that would result from splicing or connectorizing imperfectly matched fibers. This is especially important when mechanical methods (such as a V-groove) are utilized to align the fibers.

d) Core/cladding offset: The core of an ideal fiber will be exactly centered within the cladding. The core/cladding of an actual fiber may deviate somewhat from the ideal. An offset of less than 3 μm is typically permitted for multimode fibers and of less than 1 μm for singlemode fibers in order to minimize the losses that would result from splicing or connectorizing imperfectly matched fibers. This is especially important when mechanical methods (such as a V-groove) are utilized to align the fibers.

4.2.2.2 Numerical aperture

Numerical aperture (NA) is a measure of fiber's light-gathering ability. Light rays that are incident upon the core at an angle that is less than or equal to the acceptance angle will enter the core and be propagated along the fiber. Light that is incident upon the core at angles above the acceptance angle will enter the core but be quickly refracted into the cladding and lost. For an acceptance angle ϕ, numerical aperture is defined as shown in Equation (1):

$$\mathrm{NA}=\sin(\phi) \tag{1}$$

The cone of acceptance established by the NA is equal to twice the acceptance angle ϕ.

The NA of a fiber is important because it describes how well a fiber will accept and propagate light. Thus, a fiber having a low NA will require more critical alignment of fibers when spliced or connectorized than a similar fiber having a high NA. Likewise, fibers having a low NA will experience greater loss when tightly bent.

The NA of a fiber is established by the refractive indices of its core and cladding, n1 and n2, respectively, in Equation (2):

$$NA = (n1\text{-}n2)^{1/2} \tag{2}$$

NAs typically range from 0.1 (for singlemode fibers) to 0.5 (for plastic fibers).. Since the larger NA permits light to enter over a much wider angle, those fibers will also support more modes (paths) for the light rays to travel. This multipath propagation leads to dispersion of the signal and ultimately limits the distance that signals can be transmitted.

NA is not typically specified for singlemode fibers since by definition there is only one mode (meaning no light is refracted or reflected, just transmitted).

Sources and detectors also have NA ratings. It is important that both the fiber and source/detector ratings be considered when designing a system. In general, the NA of a fiber should be greater than or equal to that of the source to ensure that as much of the light is coupled into the fiber as possible. Detector NAs should be greater than fiber NAs to ensure that the maximum signal is captured.

4.2.3 Optical performance

4.2.3.1 Attenuation

When light is transmitted through a fiber, the signal is scattered or absorbed due to impurities in the glass. Attenuation is generally expressed in decibels per kilometer at a particular wavelength. The loss per unit length is also known as the quality factor of the fiber. Attenuation may be affected by the cabling or installation processes.

4.2.3.2 Bandwidth

Bandwidth is the information carrying capacity of a fiber-optic cable and is expressed as the highest frequency that can be transmitted over the fiber without exceeding the permissible bit error rate (BER). Though commonly referred to as simply bandwidth, the capacity of the transmission medium changes as a function of distance of the link and the wavelength of the transmission window utilized. This bandwidth-distance product is normally expressed in units of MHz × km. For example, a fiber with a published bandwidth of 200 Mhz × km will support transmission of a 200 Mhz signal over 1 km with an acceptable BER, but will only support 100 Mhz over 2 km.

Bandwidth is an inherent property of the fiber and is not affected by the cabling or installation processes.

4.2.4 Connectors and splices

4.2.4.1 Connectors

System loss calculations should assume that circuit attenuation will increase by 1.0 dB per connector pair.

4.2.4.2 Splices

System loss calculations should assume that circuit attenuation will increase by 0.3 dB per splice. System loss calculations should also assume a 0.6 dB fiber repair attenuation (two splices at 0.3 dB per splice).

4.2.4.3 Mismatch loss

Under normal circumstances, fiber size and NA should be consistent throughout a given circuit. It will sometimes be necessary to splice into an existing circuit with a different size (typically smaller core) fiber. Additional losses (beyond ordinary connector loss) occur when transmitting from a large core to a small core or from a high NA core to a low NA core. Such losses should be accounted for in system power budget calculations using the formulas found in Equation (3) and Equation (4). Total mismatch loss is simply the sum of these two components. Typical results of an analysis for diameter mismatch only are shown in Table 1. Transmitting in the opposite direction (small core to large core and low NA to high NA) will not result in additional losses.

$$\text{Mismatch Loss (OD)} = 10 * \log\left(\frac{ODr}{ODt}\right)^2 \tag{3}$$

$$\text{Mismatch Loss (NA)} = 10 * \log\left(\frac{NAr}{NAt}\right)^2 \tag{4}$$

where

ODr is the core diameter of the receiving fiber

ODt is the core diameter of the transmitting fiber

NAr is the core numerical aperture of the receiving fiber

NAt is the core numerical aperture of the transmitting fiber

Table 1—Diameter mismatch loss, dB

Transmitting	**Receiving core size, *ODr*, μm**			
Core size, *ODt*, μm	**50**	**62.5**	**100**	**200**
50	N/A	N/A	N/A	N/A
62.5	4.70	N/A	N/A	N/A
100	6.85	2.14	N/A	N/A
200	17.38	12.68	10.54	N/A

5. Installation and handling

5.1 Storage

There are no storage requirements for fiber-optic cables that are unique to industrial facilities and power generating stations. The following practices should be considered in any storage program:

- Storage should be on a firm, dry surface.
- Cables should be stored on wood or metal reels.
- Consideration should be given to the use of wood lagging on the face of reels for protection against impact damage.
- Both ends of the cables should be sealed with heat- or cold-shrink end caps (not tape).
- If stored outdoors, cables should be provided with light-colored, opaque, sunlight protection.
- Reels should be blocked to prevent movement.

5.2 Cable pulling—design considerations

5.2.1 General

The general approach to pulling fiber-optic cable (other than air blown fiber) is very similar to that used with conventional copper and aluminum conductor cables. Special consideration must be given as a result of the susceptibility of optical cables to crushing, excessive pull tension, bend radius, and repair techniques.

5.2.2 Pull tension

The maximum allowable pull tension is typically governed by the construction of the cable. Cables may be supplied with a central strength member, with distributed strength members or with the strength member function provided by an armored jacket. Regardless of the specific cable construction, the pull force should be applied in a uniform and steady manner. Under no circumstances should cables be “jerked”.

Outdoor cables typically have an allowable pull tension of 2670 N (600 lbf).

Indoor cables typically have an allowable pull tension of 1335 N (300 lbf). However, since indoor cable designs may vary greatly, specific values should be obtained from the manufacturer.

5.2.3 Sidewall bearing pressure

The cable manufacturer also supplies the maximum allowable sidewall bearing pressure.

5.2.4 Jam ratio

Cable jamming can occur when three identical cables are pulled simultaneously, and the diameter of a single cable is approximately 1/3 the interior diameter of the conduit. If jamming occurs, the cables will become wedged in the conduit at a bend. When jamming occurs, the pull tensions of the cable will increase and the cable may be damaged. The jam ratio is defined in Equation (5):

$$\text{Jam ratio} = 1.05 \times (\text{ID conduit} / \text{OD cable}) \tag{5}$$

As the jam ratio approaches 3, the probability of jamming increases.

If calculations indicate that jamming may be a concern, several actions, or a combination of actions, can be taken to lessen the likelihood of cable damage, as follows:

- Ensure cables are properly lubricated.
- Change the size of the conduit and cables.
- Tie the cables together at various points along the cable run.

5.2.5 Bend radius

Fiber-optic cables may be damaged by too tight a bend either during the pulling operation or subsequent to its completion when the cable is “trained” into its final configuration. Violation of the cable’s minimum bending radius can result in increased attenuation or lead to fracture of the glass. Bend radius limitations may vary according to specific construction, so manufacturer’s instructions should be consulted. In the absence of such guidance, the minimum bend radius when under tension should not be less than 20 times the overall diameter of the cable. Cables or cable components that are under no tension should be bent no tighter than 10 times their overall diameter.

5.2.6 Installation considerations

Fiber-optic cables are susceptible to damage due to the effects of crushing and twisting. This can occur if the fiber-optic cable is installed in the same raceway as copper conductor cables. Therefore, if fiber-optic cables share a common conduit with copper cables for raceway lengths greater than 3.7 m (12 ft), the fiber should be installed in dedicated inner duct. Use of fiber cables that are constructed with integral metal jackets is also acceptable. The installation of fiber-optic cables, which utilize metallic components in their construction, will require the same grounding as other cables that contain a metallic shield or sheath.

5.2.6.1 Inner duct

Inner duct is plastic tubing, available in smooth, ribbed, and corrugated constructions. Inner duct for outdoor applications is typically manufactured from polyethylene or polyvinylchloride (PVC). Inner duct for use indoors is typically manufactured from a flame-retardant PVC or polyvinylidenefluoride (PVDF). Some indoor constructions may be suitable for riser or plenum application. Inner duct cable fill should not exceed 50%. There are also special fittings for joining sections and there are split sections for covering air drops and exposed segments in manholes, etc.

5.2.6.2 Direct burial

Direct burial installations will generally utilize armored cable to increase crush and bending resistance. This additional protection is necessary in the absence of a distinct raceway. The armor will also provide protection against rodent damage. If an all-dielectric design is utilized, consideration should be given to burying a metallic conductor with the fiber-optic cable. This will facilitate locating the cable if troubleshooting is required at a future date. When using armored cable, the cable should be grounded at all splice points and at building entrances. The burial depth should be below the local freeze line and sufficient to protect the cable from exposure due to erosion or evacuation.

5.2.6.3 Fire stops

Only qualified fire stops should be utilized. The cable should also be tested after the fire stop has completed its initial curing process. This is necessary to ensure that the fiber has not been damaged. If inner duct will pass directly through the fire stop, the fire stop material must be qualified or evaluated for its compatibility with the inner duct configuration. This determination should ensure that the integrity of the fire stop has not been compromised by the introduction of the inner duct.

5.2.6.4 Splice locations

Consideration should be given to placing some excess cable at pull points or splice boxes along the cable route. The amount of cable left will depend on location and the type of equipment required to perform the splice. In ductbanks, the manholes may not provide an environment suitable for making an acceptable splice (dry, clean, fresh air, adequate space, etc.). In this case enough coiled cable (typically 10 m) should be left to reach inside a splice vehicle or tent. If the splice location is indoors, lesser amounts may be acceptable to facilitate future work. The minimum training bend radius should not be violated when the cables are coiled.

5.2.7 Repair margin

In addition to the cable slack coiled in the splice boxes, a coil of approximately 1 m should be formed at each termination panel in order to facilitate future repairs. The minimum training bend radius should not be violated.

5.3 Installation

5.3.1 Pre-installation inspection

Prior to installation of the fiber-optic cable, the cable should be inspected to ensure that the following conditions do not exist:

- A damaged or broken reel
- Damaged or broken lagging over the cable or, if the lagging has been removed, evidence of impact to the cable itself
- Missing end caps
- Protruding nails or screws on the inner face of the reel flange

If these conditions are found to exist, the cable should not be installed until it has been evaluated. That evaluation should include an assessment of the cable’s physical condition (cuts, tears, indentations of the jacket, etc.) and an optical evaluation of fiber integrity using an optical time-domain reflectometer (OTDR).

5.3.2 Pulling

5.3.2.1 General

Fiber-optic cables should be installed following all of the requirements used for metal conductor cables and the additional guidance provided in this document.

Cables should be reeled off the spool and not spun off over the flanges to avoid the introduction of twisting. When unreeling, tension should be applied only to the strength member, to avoid stretching the jacket and the microbending of the fibers that may occur during jacket shrinkback.

Special care must be exercised to ensure that the fibers are not damaged by excessive tension, kinks, tight bend radii (including around sheaves and capstans), excessive sidewall bearing pressure, surging, or twisting. The pulling force should be applied in a steady and constant manner. When pulling into unoccupied metallic raceways, speeds of 15 m/min to 30 m/min may be acceptable. When pulling into non-metallic raceways, speeds should be limited to approximately 1 m/s when using rope and 3 m/s when using low coefficient of friction pull tapes. This reduced rate will ensure that the non-metallic raceway is not cut or grooved during the process.

5.3.2.2 Installing innerduct

When installing innerduct in existing conduits or ductbanks, care must be taken to ensure that the inner duct is not stretched or distorted. Innerduct manufacturers publish maximum allowable pull tensions that should not be exceeded. Excessive pull tension will typically cause smoothwall and ribbed innerducts to “neck-down”, whereas corrugated innerducts may tend to increase in diameter when stretched. Should any evidence of “necking” or stretching be observed, the innerduct should be replaced. Twisting of the innerduct during installation should be avoided since the cables will tend to follow the path formed by the tube and pull tensions will dramatically increase. Upon completion of the innerduct installation, caps or plugs should be installed to prevent the entrance of moisture or other contaminants that could impact cable installation.

5.3.2.3 Underground ductbanks

Explosive or toxic gases may be present in manholes in ductbank systems. Before entering such enclosed spaces, the air should be checked by qualified personnel to ensure safety. Adequate ventilation must be established to ensure that sufficient oxygen is present. If the duct system or manhole contains petroleum-based liquids, the cables may require special protection. The cable manufacturer should be consulted.

5.3.2.4 Selection of pull ropes

Various styles of pull ropes have been used to successfully install fiber-optic cable. These include both round and rectangular cross-sections. Wire rope, polypropylene, and aramid fibers are all commonly used materials. Pull rope selection will generally be determined by the anticipated installation conditions. Short, low-tension pulls will permit the use of almost any rope style. Long, high-tension pulls require careful attention to rope selection. When high tension exists, the pull rope should be of a large enough diameter such that it does not cut the duct. It should be of low elasticity to minimize surging since the fibers may be damaged during such transients.

5.3.2.5 Attachment to the cable

Pulling grips should be used to attach to fiber-optic cables. Grips should be selected and installed per the grip manufacturer's recommendations. In general, grip sizing is based on cable diameter. Typically, the pulling grip is installed over the cable jacket and a section of jacket is removed exposing the buffer tubes and strength member(s). Where the fiber-optic cable under consideration contains discrete or distributed strength members, attachment should be made to the strength members and not to the cable jacket. The cable jacket should be removed, buffer tubes cut off, and where distributed strength members have been used, they should be formed into a single bundle and attached to the pull rope.

5.3.2.6 Swivels

The use of swivels is required between the pull rope and grip to prevent the pull rope from imparting a twisting action to the cables during the pull. Such twisting action can readily damage the fibers. The swivel should have a cone shape to facilitate easy passage through the duct and should have ball bearings to prevent binding at high tensions.

5.3.2.7 Pullbys

In general, the practice of pulling new cables past existing cables in ducts or conduits is discouraged due to the danger to the resident cable. Where fiber-optic cables are involved, this risk is increased. Pulling fiber-optic cables past existing cables should be analyzed with consideration for damage that may result to the existing cables. Where a pullby is necessitated by other factors, special attention must be paid to obtaining a clear path for the pull rope, the selection of the pull rope, and lubrication of the pull rope, resident cables, and new cables.

5.3.2.8 Preconnectorized cables

If preconnectorized cables must be pulled through raceway, care must be taken to ensure that the connector is not damaged during installation. If the cable is to be installed in raceway or innerduct with existing cables, care must also be taken to ensure that existing cables are not damaged.

5.3.2.9 Lubrication

Due to the sensitivity of fiber-optic cables to damage from excessive tension, crushing, and twisting, they should be thoroughly lubricated prior to installation in innerduct, conduit, or duct banks. The lubricant should be compatible with the cable's jacket and duct or innerduct. Liquid detergents should not be used on fiber-optic cables jacketed with polyethylene or polyethylene innerduct since most detergents will cause stress cracking in that polymer. Other considerations include its ability to be re-wetted (to facilitate future cable removal), drying time, cleanup and residues. It should be noted that high-viscosity lubricants typically used for power cable pulls may actually result in increased tensions if used on light-weight fiber-optic cables. Thus, the lubricant should be material that is specifically designed for that purpose. The lubricant should be used in accordance with the manufacturer's instructions. For long or difficult pulls, lubricant should be distributed throughout the conduit or duct during pull line placement using swabs or bags of lubricant. Lubricants may be applied to the cable as it enters the raceway by hand or by using special applicators.

5.3.2.10 Direct burial placement

The two most common methods of direct burial cable placement are "plow-in" and trenching. Two types of cable plows are available—vibratory and static. Warning tapes should be installed above the cables approximately 30 cm (1 ft) below grade. Such tapes are typically bright orange, a minimum of 8 cm (3 in) wide and printed with a legend such as "Warning—Optical Cable." Tapes can be hand placed over the cables in open trenches or automatically placed in the furrow by most plows. After optical cables are placed in the trench, a sand or sandy loam backfill should be placed over the cable to within 60 cm (2 ft) of grade level (rocky soil should never be used as the backfill). Native soil can then be used to fill the trench to grade level.

5.3.3 Post-installation

5.3.3.1 Training cables

The minimum training bend radii of the overall cable and the minimum training bend radius of the individual buffer tubes once the breakout kit has been applied should be obtained from the manufacturer and followed.

5.3.3.2 Supporting cables in groups or vertical runs

Tie wraps that are installed on fiber-optic cables for the purposes of grouping or supporting should be loosely applied (i.e., should not be applied tight enough to apply pressure on the fiber itself). Excess pressure from tie wraps can cause high-localized attenuation. Jacketed fiber-optic cables should be free to slide under the tie wraps with a slight pull by hand.

5.3.3.3 Post-pull cutoff

Following the pull of a new cable that does not have connectors installed, approximately 2 m of the lead end of the cable should be cut off.

5.3.3.4 Inspection

Following installation of the cable, all pull points must be inspected to ensure that no residual tension or pressure points exist. Ties used to group or secure the cables should be snug but should not indent the jacket. Excessive pressure at such points can lead to microbending of the fiber (with resultant increased losses) and its eventual breakage.

5.3.3.5 Protection of cables

Fiber-optic cables are susceptible to increased attenuation if water gets into the buffer tubes that protect the fibers. Therefore, except when pulling and terminating, fiber-optic cables should be protected with end caps. If fibers with connectors installed are temporarily in an environment that could be exposed to water (i.e., outdoors) and not in a suitable termination or splice enclosure, end caps should be installed. All manholes, handholes, and other outdoor raceways should be maintained free of water at all times, unless the cable is designed for installation in wet areas.

5.4 Blown fiber

5.4.1 General

"Blown fiber" or "air blown fiber" describes an installation technique that allows low-stress, high-speed installation of fiber in bulk or on an "as needed" basis. The blown fiber process uses the force of moving air to carry the fiber into small, pre-installed tubes. Such systems utilize raceway components that provide a high degree of network flexibility.

5.4.2 Tube installation

These tubes come in bundles that look like small cables. Tube size and tube type can change along the route to accommodate differing installation needs or different flame ratings. The tubes are installed in segments that can be configured to provide direct point-to-point fiber runs.

5.4.3 Fiber installation

Special fittings or "heads" blow the fiber into the tubes. The installable length is a function of tube size, number of fibers, complexity of the route (number of bends), and efficiency of the blowing equipment. When fiber is blown vertically, 360 ° loops may be required to provide the necessary restraining force when the air is removed to keep the fiber from "falling". Once installed, the fiber is connected or spliced using conventional techniques.

6. Connectors and splices

6.1 General

Numerous styles of connectors have been developed for use in terminating the fiber to its end equipment. While each style has its advantages and disadvantages, it is generally recommended that one style be utilized throughout a project to facilitate testing, maintenance, and stocking.

Almost all connectors have a ferrule. It is the function of the ferrule to mechanically hold the end face of one fiber in line with the end face of another fiber or device in order to pass light from one to the other. The difference in the various connectors is the shape and size of the connector body and the method of assembly.

Some connectors require adhesives to assemble and some do not. Of those that require adhesive, there are epoxies, ultraviolet curing adhesive, and anaerobic adhesives. There are also connectors that use mechanical means to hold the fiber in the connector. Among those are some that already have a fiber inserted in the connector and require no polishing before use.

In choosing a connector style, consideration should be given to the following parameters:

- Optical power loss
- Repeatability (losses can vary each time a connector pair is mated as a function of the angular misalignment and fiber dimensional characteristics; keyed connectors or connector pairs minimize this misalignment)
- Ease of use
- Ease of installation (some designs require special tools and curing ovens, while others do not)
- Cost (materials and installation labor)
- Maximum connector density (bayonet or threaded connectors do not permit as high a density as "push-and-click" style connectors)

6.2 Connectors

6.2.1 Types

The major connector differences are construction materials (e.g., ceramic, stainless steel, plastic), and the method of affixing the fiber to the connector (e.g., hot melt adhesive epoxy, crimping). Each connector has its own advantages and disadvantages, therefore engineering judgment should be applied to identify the best type of connector for the intended service. The selection should consider environmental conditions, durability, compatibility with existing equipment, installation time, and criticality of the signal. The connectors should be installed in accordance with the applicable vendor's termination procedure, using the tooling and supplies recommended therein. Most often this involves the use of a termination kit and a multistep process that involves cleaving the fiber, inserting and bonding the fiber in the connector, and then polishing the end fiber at the connector end.

6.2.2 Assembly

Presently there are several types of connectors available that utilize the adhesive already in the connector. It is necessary to heat the connector in a small oven causing the adhesive to soften. The stripped and cleaned fiber is then inserted into the connector and the connector is allowed to cool.

6.2.3 Protection

All terminations should be made inside an appropriate housing that provides protection as well as a location to coil the extra footage (required to facilitate future repairs) while maintaining the required bend radius. Stress relief should be provided for all fiber-optic cables in their terminating enclosure at a point prior to removal of the overall jacket. The stress relief may be provided by tie wraps or grips that are specifically manufactured for fiber-optic cables. However, the stress relieving mechanism should not indent the cable jacket to the extent that pressure would be applied to the fiber.

6.2.4 Maintenance

A clean dust cap should be placed on the connector every time it is removed from a piece of equipment, and shall be cleaned before reinstalling it on a piece of equipment. The receptacle on the equipment should be covered with a dust cap as well, if another connector is not placed on it right away. Isopropyl alcohol or alcohol swabs (not rubbing alcohol) and canned air should be used to clean connectors.

6.2.5 Couplers

Couplers, sometimes referred to as barrels, are designed to mate two connectors face to face. They are found in interconnect units, cross-connect units, and patch panels. Couplers are available with ceramic, metal, and plastic sleeves. In general, ceramic and metallic couplers will withstand more cycling while maintaining low insertion losses and be more stable over a wide temperature range.

6.3 Splices

6.3.1 General

The two basic methods of splicing are fusion splicing and mechanical splicing. In the fusing technique, a special machine is used in which the two fiber ends are placed between electrodes that cause the tips of the fibers to melt and then fuse. In the mechanical method the fibers are clamped together, and often, a transparent epoxy is used to glue the ends together. Some mechanical splices are reusable.

Fusion splicing equipment costs more than mechanical splicing equipment, requires sophisticated equipment, and requires more time and expertise to perform but generally it gives a stronger splice and lower losses. Typical losses in fusion and mechanical splices are 0.02 dB and 0.2 dB, respectively. With proper fiber preparation, fusion splicing will produce very consistent results, while mechanical splicing is much more dependent upon the skill of the technician.

Since the cable's jacket must be removed in order to perform either fusion or mechanical splicing, some form of supplemental mechanical protection is required. A splice case is used for this.

An important factor in the selection of a splicing method is the location where the splicing will be made. Key considerations are relative cleanliness, wind environment, etc. Also consider that in confined spaces, explosive gases can build up and the arc from a fusion splicer could lead to an explosion.

6.3.2 Fusion splicing

A portable electric arc fusion splicer consists of fiber-holding and alignment devices, a viewing microscope or video monitor, arc positioning and intensity controls, a built-in arc power supply, and a fiber-cleaving tool. In fusion splicing, the tips of the two fibers are heated in an electric arc. Most machine electrodes will fire twice. The first is a prefusion arc that cleans the fiber. The second fuses the fibers.

6.3.3 Mechanical splicing

Mechanical splicing is the most common method of joining fibers when doing restoration work. Installing a quick mechanical splice in the field can get the system running at an acceptable level. Work to repair the fault for the long term can then be planned and done in a more controlled manner.

When doing a mechanical splice, the ends of the fiber are prepared in the same way as with a fusion splice. Once the ends are prepared, the following steps are performed: Insert the ends of the fibers into the mechanical splice; align them manually using a power meter and then secure the fibers in the splice (this might require two technicians).

6.3.4 Splice protection

Both mechanical and fusion splices should be installed in a protective enclosure in such a manner as to ensure that they are free from strain, mechanical damage, and moisture. Numerous vendors provide splice trays that meet the above criteria. Many enclosures provide for storage and protection of additional fiber (at an acceptable bend radius) to ensure that adequate length exists for future splicing. Designs should provide adequate space to house such enclosures. Where the splice is below grade or subject to moisture, the enclosure should be one of several available specifically for outdoor use. Most of these are designed with O-ring seals, a method of handling the gel encapsulant used in many outdoor cables, and a method of storing an additional footage to facilitate re-splicing. The splice case should be mounted to a suitable structure, closed, and sealed per the manufacturer's instructions.

7. Field tests

7.1 General

The types of tests, test methods, and test equipment that are available to the industrial facility and generating station engineer are identical to those available to the telecommunications and LAN engineer. However, the nature of the facility may impact the scope of the test program and the level of documentation.

Field testing of fiber-optic cables may be conducted to satisfy a number of considerations. The user should first identify the objective(s) of the test program and then utilize the following paragraphs as guidance in the selection of test instrumentation and settings for those tests. In determining the scope of the field test program, the user should consider the complexity of the installation and the significance of the circuits to the operation of the facility. Where installation and connectorization work is contracted out, such tests may serve as demonstration of acceptable performance of those tasks. Field test programs may be undertaken for any combination of the following reasons:

- Demonstration that shipping damage has not occurred
- Demonstration that pulling damage has not occurred prior to connectorization or splicing
- Determination of connector or splice loss
- Confirmation of the absence of kinks
- Confirmation of the absence of pinch points
- Confirmation of circuit length
- Evaluation of power loss
- Verification of continuity
- Determination of location of damage
- Documentation of baseline condition

NOTE—It is not unusual for the fiber's loss factor (dB/km) to be lower once the cable is installed than it was at the factory or as received on the reel. This apparent improvement results from the cable having been straightened when removed from the reel and the consequent reduction in microbending losses.[7]

When conducting the tests described in this clause, users should give consideration to all safety provisions outlined in Clause 8.

7.2 Test equipment

Numerous types of test equipment have been developed to perform the above tests (see Table 2). No one type of equipment is appropriate for every type of task. Regardless of the device utilized, it is important that the dynamic range of the test instrument be well suited for use with the circuit under test. Dynamic range is a measure of the power difference in decibels between the power output of the device source and the receiver threshold. An estimate of the required dynamic range can be made by summing the anticipated power loss (in decibels) of the fiber, connectors, and splices (including launch fibers and test connectors or splices).

Table 2—Test objectives and equipment

Parameter	Instrument
Optical power (source output or receiver input)	Optical power meter (OPM)
Attenuation (fibers, cables, and connectors)	OPM and source, OTDR
Point attenuation	OTDR
Length	OTDR
Fault location	OTDR, visual fault locator (VFL)
Continuity	OPM, OTDR, fiber identifiers
Fiber identification	Fiber identifiers, OPM

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[7] Notes in text, tables, and figures of a standard are given for information only, and do not contain requirements needed to implement the standard.

7.3 Optical time-domain reflectometer testing

Optical time-domain reflectometers (OTDRs) are the most sophisticated of the common field test instruments for evaluating fiber, connectors, and splices and can therefore yield both the most information regarding the tested components and the greatest problems in interpretation. OTDRs consist of light sources for one or more wavelengths. Pulses are launched into the cable under test or a special launch fiber. Light is reflected back to the OTDR by impurities in the glass, connectors, splices, or breaks in the fiber. The magnitude of the returned light is then displayed as a function of length.

As a minimum, the fiber should be tested at the wavelength at which it will operate. Dual window fiber should be tested at both wavelengths, even if operation is planned for only one window. Point discontinuities can best be discriminated at the longer wavelength.

Tests should be conducted with the lowest power that gives a good return signal from the far end of the circuit under test. A good return from the far end is characterized by a clear reflective spike from the cleaved fiber face or connector that is well above the noise floor of the device.

Tests should be conducted at the shortest pulsewidth that gives an adequate return signal from the far end of the circuit. The short pulsewidth will minimize saturation of the OTDR electronics after any reflective event and will also provide the best resolution for physically locating anomalies.

OTDRs are best suited to testing long circuits. Immediately adjacent to the OTDR, the fiber core is typically “over-filled”. That is, light will be traveling in many more modes (or paths) than the core will sustain for long distances. These modes are typically paths having an angle of incidence just above the critical angle for the core/cladding structure. Nominally speaking, such light is refracted into the cladding and does not continue along the core. In reality, it does continue for some short distance before finally being bent away from the core. Eventually, only light paths with an angle of incidence below the critical angle will be propagated.

7.4 Power meter testing

Optical power meters (OPMs) directly measure the amount of light exiting a fiber. OPMs and power sources are sometimes marketed together as optical loss test sets. OPM testing provides the most direct and accurate means of measuring circuit attenuation but provides no information regarding how the loss is distributed.

As a minimum, the fiber should be tested at the wavelength at which it will operate. Dual window fiber should be tested at both wavelengths, even if operation is planned for only one window.

7.5 Visual fault locator testing

Visual fault locators (VFLs) are typically among the least expensive of field test devices. VFLs typically have powerful laser sources operating in the visible spectrum. Such sources can locate breaks, kinks and tight bends, and bad splices on many types of cables and jumpers. Orange and yellow jackets commonly used on multimode and singlemode cables (respectively) will typically pass visible light. Black and gray jackets are generally opaque to visible light and cannot be successfully tested with this method. Lower power LED VFLs are also available, but are limited to use on short runs with the most translucent of coverings.

7.6 Fiber identifier

Fiber identifiers are devices frequently used by termination, splicing, or restoration crews that clamp around a bare fiber. By bending the fiber slightly, some light leakage occurs that can be detected by the device.

Most fiber identifiers have two modes. The first permits the identification of "traffic" to confirm that the fiber of interest is in service. The second mode, in conjunction with a special source, permits identification of a test signal that can readily be distinguished from ordinary data transmission.

7.7 Documentation of test results

The level of documentation to be generated and the results of installation/acceptance testing will vary according to the complexity of the installation and its criticality.

As a minimum, OTDR traces should be marked with the following:

- Identification of the cable and specific fiber under test
- IOR of the core and cladding of the fiber under test
- Date of the test
- Wavelength or "window" being tested
- Launch conditions
- Identification of the test device used to take the traces
- Pulsewidth

8. Safety

WARNING

Serious injury may result if the following parameters are not followed exactly.

8.1 Cable installation

Installation of fiber-optic cable is very similar to the installation of copper cable in industrial facilities and power generating stations. Common safety practices applied to the installation of copper cables are likewise appropriate for fiber with few additional cautions. Those special concerns include the following:

- Even though fiber-optic cables frequently contain no electrically conductive members, caution must be applied when working near energized copper cables.
- When fiber-optic cables contain metallic strength members or other metallic components, they should be treated the same as copper cables when working around energized circuits. Additional care must be exercised with such constructions since they are capable of conducting lightning induced surges.
- Caution should be exercised when working with the cleaners and adhesives used in terminating fiber-optic cables, since many are flammable.
- Fusion splicers utilize an electric arc to join two fibers, so care must be taken to ensure that the work area is free of combustible gases.

8.2 Laser safety

Industrial facility and generating station personnel share the same risks as LAN and telecommunication personnel when working with lasers and therefore must follow similar safety practices. Light sources utilized in fiber-optic systems fall into one of two categories: low-power LEDs and higher power lasers. Both types of light sources generally operate in the infrared portion of the electromagnetic spectrum and are therefore invisible. Light sources have been classified according to output power and permissible exposure time.

Laser sources are increasingly used because of the high bandwidth or long circuit length that such devices permit. Recent advances in technology have also resulted in the development of multiplexed systems that permit multiple laser sources to transmit along the same fiber core simultaneously. The high-power, small core diameter of laser-based systems may produce energy densities that can cause visual impairment or even blindness. Therefore, when working with fiber-optic circuits, installers should *never* look directly into a fiber or connector unless *positive* confirmation has been made that the circuit is not energized. Special safety glasses are available that filter infrared light. When disconnecting circuits at end equipment, the circuits should be assumed to be energized and dust caps should immediately be installed. These will preclude the possibility of eye damage and protect the circuit from attenuation due to dust.

Two applications that warrant special note are visible fault locators and offsite circuits. The former employs a relatively high-power visible spectrum laser to enable light leaking from a cracked or broken fiber to penetrate the buffer tube and cable jacket. Likewise, high-power lasers are frequently encountered as sources in offsite telecommunication or WAN circuits. Extra caution should be used when working both applications.

8.3 Termination

Care should always be taken when cutting, cleaving, splicing, or terminating fiber-optic cables, since these activities will expose workers to small scraps of bare fibers. Such scraps are small, almost invisible, and sharp. When such glass slivers get into the body, they are very difficult to locate and very painful. Such scraps are of particular danger to the eye. Good housekeeping practices are very important when working with bare fiber. Scraps should be collected (i.e., not allowed to drop on the floor or workbench) and disposed of immediately. Safety glasses shall be worn at all times when working with bare fibers. Eating and drinking should be prohibited in the work area to prevent ingestion of fiber.

Special caution should be exercised when using ultraviolet (UV) curing systems. The lamps used to generate the UV light can cause both eye and skin damage. Manufacturer’s instructions for the safe use of such equipment should be followed. Users should ensure that all protective shields are in place before energizing the curing lamps.

Annex A

(informative)

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