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IEEE Standard for Helically-Applied Fiber Optic Cable Systems (WRAP) for Use on Overhead Utility Lines

IEEE Power and Energy Society

Developed by the
Power System Communications and Cybersecurity Committee

IEEE Std 1594™-2020
(Revision of
IEEE Std 1594-2008)

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IEEE SA Standards Board

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Introduction

This introduction is not part of IEEE Std 1594-2020, IEEE Standard for Helically-Applied Fiber Optic Cable Systems (WRAP) for Use on Overhead Utility Lines.

This introduction is not part of IEEE Std 1594™-2020, IEEE Standard for Helically-Applied Fiber Optic Cable Systems (WRAP Cable) for Use on Overhead Utility Lines.

This standard is the first standard focused on fiber optic cables that are wrapped around either an overhead conductor, the ground wire (sometimes called earth wire), or a messenger wire. This type of system is typically utilized where optical fiber is desired to be installed in the overhead transmission line right-of-way and where other fiber optic options either cannot be utilized or there is some constraint preventing their use.

Contents

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IEEE Standard for Helically-Applied Fiber Optic Cable Systems (WRAP) for Use on Overhead Utility Lines

1. Overview

1.1 Scope

This standard covers an all-dielectric fiber optic (WRAP) cable designed to be helically wrapped around a conductor or other messenger on overhead power facilities. This covers the mechanical, electrical, and optical performance; installation guidelines; acceptance criteria; test requirements; environmental considerations; packaging and shipping guidelines; and accessories.

1.2 Purpose

Other existing standards do not cover all-dielectric fiber optic (WRAP) cable designed to be helically wrapped around a conductor or other messenger on overhead power facilities. This standard simplifies procurement, standardizes testing, assures product quality, and assists usage.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM E29-06b, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.[1]

IEC 60068-1, Environmental Testing—Part 1: General and Guidance.[2]

IEC 60068-2-5, Environmental Testing—Part 2: Tests. Test S: Simulated Solar Radiation at Ground Level and Guidance for Solar Radiation Testing and Weathering.

IEC 60068-2-38, Basic Environmental Testing Procedures—Part 2: Tests—Test Z/AD: Composite Temperature/Humidity Cyclic Test.

[1]ASTM publications are available from the American Society for Testing and Materials (https://www.astm.org/).
[2]IEC publications are available from the International Electrotechnical Commission (https://www.iec.ch) and the American National Standards Institute (https://www.ansi.org/).

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TIA/EIA 455-3B, Procedure to Measure Temperature Cycling Effects on Optical Fiber Units, Optical Cable, and Other Passive Fiber Optic Components.[3]

TIA/EIA 455-25D, Impact Testing of Optical Fiber Cables.

TIA/EIA 455-33B, Optical Fiber Cable Tensile Loading and Bending Test.

TIA/EIA 455-41A, Compressive Loading Resistance of Optical Fiber Cables.

TIA/EIA 455-81B, Compound Flow (Drip) Test for Filled Fiber Optic Cable.

TIA/EIA 455-82B, Fluid Penetration Test for Fluid-Blocked Fiber Optic Cable.

TIA/EIA 455-85A, Fiber Optic Cable Twist Test.

TIA/EIA 455-104B, Fiber Optic Cable Cyclic Flexing Test.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[4]

basic lightning-impulse level (BIL): Test voltage level used to check the protection of an insulator within a high voltage system.

optical time domain reflectometer (OTDR): Test equipment used in conjunction with optical fibers.

switching impulse insulation level (SWIL): Test voltage level used to check the protection of an insulator within a high voltage system.

ultimate test strength (UTS): The ultimate tensile strength of a cable.

ultraviolet (UV): Radiation with wavelengths shorter than visible light.

3.2 Acronyms and abbreviations

BIL	basic lightning-impulse level
OD	outside diameter
OTDR	optical time domain reflectometer
RIV	radio interference voltage
SWIL	switching impulse insulation level
UTS	ultimate tensile strength
UV	ultraviolet

[3]TIA/EIA publications are available from the Telecommunications Industry Association (https://www.tiaonline.org/).
[4]*IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

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4. Description of WRAP cable and component

The WRAP cable shall consist of coated glass optical fibers contained in a protective dielectric fiber optic unit, surrounded by a UV resistant jacket. The cable shall not contain metallic components. The cable shall meet the design requirements under all installation conditions, operating temperatures, and ground wire environmental loadings.

5. Component requirements

5.1 Support systems

Support systems for the cable itself are not required. The ground wire, phase wire, or other messenger in overhead power facilities around which the cable is wrapped provides all the support for the composite system and eliminates the need for the cable to be self-supporting.

5.2 Fiber optic cable core

The fiber optic cable core shall be made of coated glass optical fibers housed to protect them from mechanical, environmental, and electrical stresses. Materials used within the core shall be compatible with one another, shall not degrade under the electrical stresses to which they may be exposed, and shall not evolve hydrogen sufficient to degrade optical performance of fibers within the cable.

5.2.1 Fiber strain allowance

The fiber optic cable core shall be designed so that the fibers remain tensile stress-free under the maximum working elongation of the cable being wrapped on, and taking into consideration strains created during the installation.

5.2.2 Central structural element

If a central structural element is necessary, it shall be of reinforced plastic, epoxiglass, or other dielectric material. If required, this element shall provide the necessary tensile strength to limit axial strain on the fibers and minimize fiber buckling due to cable contraction at low temperatures.

5.2.3 Buffer tube filling compound

Loose buffer tubes shall be filled with a suitable compound compatible with the tubing material, fiber coating, and coloring to protect the optical fibers and prevent moisture ingress.

5.2.4 Cable core filling/flooding compound

The design of the cable shall include a suitable filling/flooding compound or water-swellable material in the interstices to prohibit water migration along the fiber optic cable core. The filling/flooding compound or water-swellable compound shall be compatible with all components with which it may come in contact.

5.2.5 Binder/tape

A binder yarn(s) and/or layer(s) of overlapping non-hydroscopic tape(s) may be used to hold the cable core elements in place during application of the jacket.

5.3 Optical fibers

Single-mode fibers, dispersion-unshifted or dispersion-shifted, and multimode fibers with 50/125 µm or 62.5/125 µm core/clad diameters are considered in this document. The core and the cladding shall consist of

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glass, which is predominantly silica (SiO2). The coating, usually made from one or more acrylate materials or compositions, shall be provided to protect the fiber during manufacture, handling, and use.

5.4 Buffer construction

The individually coated optical fiber(s) may be surrounded by a buffer for protection from physical damage during fabrication, installation, and performance of the WRAP cable. Loose buffer or tight buffer construction are two types of protection that may be used. The fiber coating and buffer shall be strippable for splicing and termination.

5.4.1 Loose buffer

Loose buffer construction shall consist of a tube or channel that surrounds each fiber or fiber group. The inside of the tube or channel shall be filled with a filling compound.

5.4.2 Tight buffer

Tight buffer construction shall consist of a suitable material that comes in contact with the coated fiber.

5.5 Color coding

Color coding is essential for identifying individual optical fibers and groups of optical fibers. The colors shall be in accordance with TIA/EIA 598-D.[5]

5.5.1 Color performance

The original color-coding system shall be discernible and permanent, in accordance with TIA/EIA 598-D, throughout the design life of the cable, when cleaned and prepared per WRAP cable manufacturer's recommendations.

5.6 Jackets

The outer jacket shall be designed to house and protect the inner elements of the cable from damage due to moisture, sunlight, environmental, thermal, mechanical, and electrical stresses, as follows:

a) The jacket material shall be dielectric, non-nutrient to fungus, and may consist of a polyethylene containing carbon black and an antioxidant.

b) The jacket shall be extruded over the underlying element and shall be of uniform diameter.

c) When installed on ground wires, electrical stress requirements and concerns normally do not apply; for some high voltage transmission line designs, the ground wire may exhibit higher than normal surface gradients (i.e., 10 kV/cm). In these cases, a track-resistant jacket shall be considered. For cable that is wrapped around a phase conductor, the jacket shall be track resistant.

6. Test requirements

6.1 Test guidelines

For all test procedures described in Clause 6, the test temperature is 25 °C ± 5 °C unless otherwise stated. All measured and computed values shall be rounded to the number of decimal places given in the corresponding requirement using the procedures of ASTM E29-06b.

[5]Information on references can be found in Clause 2.

Where fiber loss measurements are required, at least ten fibers, or 100% of the fibers if less than ten fibers, of the test cable shall be measured for optical attenuation or attenuation change. Where the fibers are housed in more than one loose tube, the number selected from each tube shall be equal.

6.2 Cable tests

6.2.1 Design tests

A WRAP cable shall successfully pass the design tests discussed in 6.2.1.1, 6.2.1.2, and 6.2.1.3. However, design tests may be waived at the option of the user if a WRAP cable of equivalent design has already been successfully tested.

6.2.1.1 Waterblocking test

A waterblocking test shall be performed. No water shall leak through the open end of the sample.

A waterblocking test for cable shall be made in accordance with the requirements for TIA/EIA 455-82B, except that the test length shall be 1 m.

6.2.1.2 Seepage and filling/flooding compound test

For filled/flooded fiber optic cable, seepage of filling/flooding compound test shall be performed. The filling and flooding compound shall not flow (drip or leak) at 65 °C.

A 0.3 m sample of cable shall be tested in accordance with TIA/EIA 455-81B. The optional preconditioning cycle as described in TIA/EIA 455-81B may be used. The unprepared cable end may be sealed.

6.2.1.3 Aeolian vibration test

An aeolian vibration test shall be carried out. As the combinations of wrapped cables and ground wire/conductor/messenger wire are significant, a representative test can be performed for a family of cable combinations. Any damage that will affect the mechanical performance of the cable or causes a permanent or temporary increase in optical attenuation greater than 1.0 dB/test fiber km (defined as the actual fiber in the vibration test span) at 1550 nm ± 20 nm for single-mode fibers, or 1300 nm ± 20 nm for multimode fibers, shall constitute failure. There shall be no breach of the jacket after the test. The objective of this test is to assess the fatigue performance of the WRAP cable and the ground wire on which it is installed and the optical characteristics of the fibers under typical aeolian vibrations.

6.2.1.3.1 Test setup

The general arrangement to be used for the aeolian vibration tests and the support details are shown in (Annex A). The end abutments are used to load and maintain tension in the conductor or ground wire on which the WRAP cable is installed (in the correct manner so as to simulate its installation on the line). The test section is contained between the two intermediate abutments. End and intermediate abutments need not be separate units if the combined unit affords sufficient space for the setup. The fiber optic cable to be tested shall be cut a sufficient length beyond the intermediate abutments to allow removal of the cable coverings and to allow access to the optical fibers. Suitable dead-end assemblies or end abutments are installed on ground wire or conductor to fit between the intermediate abutments. The test sample shall be terminated at both ends prior to tensioning in a manner such that the optical fibers cannot move relative to the cable. The load during the test shall be monitored using a dynamometer, load cell, calibration beam, or other device. Some means shall be provided to maintain constant tension to allow for temperature fluctuations during the testing. The conductor or ground wire shall be tensioned to 100% of its rated maximum installation tension.

In order to achieve repeatability of test results, the active span shall be 20 m or more in length, with a suitable suspension assembly located approximately two-thirds of the distance between the two dead-end assemblies.

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Longer active and/or back spans may be used. (see Figure A.1) The suspension assembly shall be supported at a height such that the static sag angle of the cable to the horizontal is 1¾ ° ± ¾ ° in the active span.

Means shall be provided for measuring and monitoring the mid-loop (antinode) vibration amplitude at a free loop, not a support loop.

An electronically controlled shaker shall be used to excite the cable in the vertical plane. The shaker armature shall be securely fastened to the cable so that it is perpendicular to the cable in the vertical plane. The shaker shall be located in the span to allow for a minimum of six vibration loops between the suspension assembly and the shaker.

The test length (i.e., between the dead-end assemblies) of the optical fiber shall be a minimum of 100 m. To achieve this length several fibers may be spliced together. At least one fiber shall be tested from each buffer tube or fiber bundle. Measurements shall be made using a light source with a nominal wavelength of 1550 nm ± 20 nm for single-mode fibers and a nominal wavelength of 1300 nm ± 20 nm for multimode fibers.

The source shall be split into two signals. One signal shall be connected to an optical power meter and shall act as a reference. The other signal shall be connected to a free end of the test fiber. The returning signal shall be connected to a second optical power meter. All optical connections and splices shall remain intact through the entire test duration.

An initial optical measurement shall be taken when the span is pre-tensioned to approximately 10% of the maximum installation tension. A second optical measurement shall be taken after final tensioning to the maximum installation tension. The difference between the two signals for the initial measurement provides a reference level. The change in this difference during the test will indicate the change in attenuation of the test fiber. The signals may be output on a strip chart recorder for a continuous hardcopy report.

6.2.1.3.2 Test procedure

The cable shall be subjected to a minimum of 100 million vibration cycles. The frequency of the test span shall be equal to and maintained at the nearest resonant frequency produced by a 16.1 km/h wind [i.e., frequency = 92.92/(diameter of cable in cm)]. The free loop peak to peak anti-node amplitude shall be maintained at a level equal to one-half the diameter of the conductor or ground wire.

In the initial stages, the test span requires continuous attention and recordings shall be taken approximately every 15 min until the test span has stabilized. After the span has stabilized, readings shall be taken a minimum of two times per day, typically at the start and end of the working day.

A final optical measurement shall be taken at least 2 h after the completion of the vibration test. A section of the conductor or ground wire from the location of the hardware support shall be loaded to the maximum rated cable load. The attenuation shall comply with 6.2.1.3.

6.2.1.4 Strain margin test

As there is no specific tensile strength required, the purpose of the test is to determine the strain margin, namely the cable elongation where the fiber begins to be under strain. The strain margin shall be 0.50% unless otherwise agreed between the user and the supplier. Any damage that will affect the mechanical performance of the cable or causes a permanent or temporary increase in optical attenuation greater than 0.1 dB/test fiber km at 1550 nm ± 20 nm for single-mode fibers, or 1300 nm ± 20 nm for multimode fibers, shall constitute failure. There shall be no breach of the jacket after the test. The WRAP cable shall be installed at a tension that is sufficient for it remain under a net tension for all environmental conditions.

The tensile strength of a cable shall be conducted in accordance with TIA/EIA 455-33B.

6.2.1.5 Cable twist

A cable twist test shall be performed. A permanent or temporary increase in optical attenuation greater than 0.10 dB at 1550 nm ± 20 nm for single-mode fibers and 0.40 dB at 1300 nm ± 20 nm for multi-mode fibers shall constitute a failure.

The cable twist test shall be conducted in accordance with TIA/EIA 455-85A. The cable length subjected to the test shall be a maximum of 4 m.

6.2.1.6 Cable cyclic flexing

A cable cyclic flexing test shall be performed. A permanent or temporary increase in optical attenuation greater than 0.10 dB at 1550 nm ± 20 nm for single-mode fibers and 0.20 dB at 1300 nm ± 20 nm for multimode fibers shall constitute a failure.

The cable cyclic flexing test shall be conducted in accordance with TIA/EIA 455-104B. The sheave diameter shall be a maximum of twenty times the cable outside diameter. The cable shall be flexed at 30 ± 1 cycles/min for 25 cycles.

6.2.1.7 Crush and impact tests

6.2.1.7.1 Crush test

A crush test shall be performed. A permanent or temporary increase in optical attenuation greater than 0.20 dB at 1550 nm ± 20 nm for single-mode fibers, and 0.40 dB at 1300 nm ± 20 nm for multimode fibers, shall constitute failure.

The crush test shall be carried out on a sample of cable according to the method provided by TIA/EIA 455-41A. The cable shall withstand a compressive load of 220 N/cm for 10 min. This load requirement is a function of field handling rather than a function of installation forces.

6.2.1.7.2 Impact test

An impact test shall be performed. A permanent increase in optical attenuation value greater than 0.20 dB at 1550 nm ± 20 nm for single-mode fibers, and 0.40 dB at 1300 nm ± 20 nm for multimode fibers, shall constitute failure.

The impact test shall be carried out on a sample of cable according to the method provided by TIA/EIA 455-25D. The test level shall be as per Table 1, Outside plant (TIA/EIA 455-25D).

6.2.1.8 Temperature cycle test

A temperature cycle test shall be performed. The increase in optical attenuation for each individual single-mode fiber shall be less than 0.20 dB/km at 1550 nm ± 20 nm, with 80% of the measured values less than 0.10 dB/km. For multimode fibers, the increase shall be less than 0.50 dB/km at 1300 nm ± 20 nm, with 80% of the measured values less than 0.25 dB/km.

At least 200 m of cable shall be taken from a representative sample of the cable. The cable shall be wound, at nominally the intended installation tension, on a steel reel and placed in an environmental chamber. The reel shall have the following minimum dimensions:

— Barrel diameter: 0.8 m

— Width: 0.7 m

— Flange diameter: 0.84 m

The reel shall be supported in such a manner as to facilitate handling and free movement of air through it when it is in the chamber. Each end extending out of the chamber shall be as short as practical.

At least ten fibers, or 100% of the fibers if less than ten fibers, of the test cable shall be measured for optical attenuation or attenuation change. Where the fibers are housed in more than one loose tube, the number selected from each tube shall be equal. The chosen fibers may be concatenated for ease of measurement with an optical time domain reflectometer (OTDR). The change in attenuation is measured with respect to the baseline attenuation values measured at room temperature before temperature cycling. The cable samples shall be tested in accordance with TIA/EIA 455-3B. Test condition B-1 shall apply. Testing shall be conducted as follows:

a) The sample shall be preconditioned for 24 h at 23 °C ± 5 °C. The baseline attenuation measurements shall be made at the end of this period.
b) Decrease the temperature to the minimum operating temperature of −40 °C ± 2 °C. Maintain this temperature for 24 h. Attenuation measurements shall be made at the end of this period.
c) Raise the temperature to the maximum operating temperature of 85 °C ± 2 °C. Maintain this temperature for 24 h. Attenuation measurements shall be made at the end of this period.
d) Decrease the temperature to the minimum operating temperature of −40 °C ± 2 °C. Maintain the temperature for 24 h. Attenuation measurements shall be made at the end of this period.
e) Raise the temperature to the maximum temperature of 85 °C ± 2 °C. Maintain this temperature for 24 h. Attenuation measurements shall be made at the end of this period.
f) Return the cable to 25 °C ± 5 °C. Maintain this temperature for 24 h. Attenuation measurements shall be made at the end of this period.

6.2.1.9 Cable aging test

The cable aging test shall be performed. The increase in optical attenuation for single-mode fibers shall be less than 0.10 dB/km. The maximum attenuation increase for an individual fiber shall not be greater than 0.25 dB/km at 1550 nm ± 20 nm.

For multimode fibers the change in attenuation shall be less than 1.00 dB/km at 1300 nm ± 20 nm, with 80% of the measured values less than 0.50 dB/km.

There shall be no significant difference between the jacket identification and length marking colors of the aged sample relative to those of an unaged sample of the same cable. The fiber coating colors and unit/bundle identifier colors shall be in accordance with TIA/EIA 598-D.

The cable-aging test shall be conducted as a continuation of the temperature cycling test. At the completion of the temperature cycling test, the test cable shall be exposed to 85 °C ± 2 °C (185 °F ± 3.6 °F) for 168 h. After this period, attenuation measurements shall be made. These measurements shall be compliant with the requirements listed above. A 1 m section of the cable sample used in the temperature cycling and cable aging tests shall be cut out and dissected, and the fibers removed for examination. The fibers shall be inspected for loss of color identification and visible degradation of the coating. Either of these findings will constitute a failure of the test.

6.2.1.10 UV resistance test

The cable and its jacket are expected to perform satisfactorily in the user-specified environment in which it is to be installed. A UV (ultra-violet light) resistance test shall be performed.

The cable jacket shall meet the requirements in the following list:

a) Where carbon black is used as a UV damage inhibitor, the cable shall have a minimum absorption coefficient of 320 milli (absorbance/meter).

b) Where the other cable UV blocking systems are being employed, the cable shall:

  1) Meet the equivalent UV performance of carbon black at 320 milli (absorbance/ meter); or

  2) Meet the performance requirements as stated in IEC 60068-1 testing.

Carbon black UV resistance shall be tested in accordance with individual national performance standards such as average testing per ASTM D-3349 or equivalent user-supplier standard.

IEC 60068-2-5 testing shall be specified per the particular IEC blank specification requirements as agreed to by both the user and supplier with the guidelines listed in the following list:

For Solar Radiation use IEC 60068-2-5 S:

a) Method C for 56 d.

b) Support method fixed at either end with no heat sink available.

c) Temperature not to exceed 80 °C for low- and medium-density polyethylene, 85 °C for high-density or altered polyethylene, or 90 °C for cross-linked polyethylene. Temperature not to fall below 50 °C.

d) Maximum air velocity shall be no more than that to maintain temperature requirements stated in item c) above.

e) Humidity shall be cycled per IEC 60068-2-38 test Z/AD minus the cold cycles, or per humidity cycling that more closely reflects the proposed installation locations.

f) The test box and cable samples shall be preconditioned to full test conditions prior to the start of the 56 d cycle testing period.

6.2.1.11 Fault current test

A fault current test shall be performed. A permanent or temporary increase in optical attenuation (including during the test) greater than 0.20 dB at 1550 nm ± 20 nm for single-mode fibers, and 0.40 dB at 1300 nm ± 20 nm for multimode fibers, shall constitute failure. There shall be no breach of the jacket after the completion of the test and no damage whatsoever to the tubes or jackets protecting the fibers.

The fault current test shall be done at the I^2t value determined by the system engineer for that conductor, or ground wire, on that particular line. The WRAP cable shall withstand the associated temperature rise of the conductor or ground wire.

6.2.1.11.1 Test setup

The end abutments are needed to load and maintain tension in the ground wire on which the WRAP cable is installed (in the correct manner so as to simulate its installation on line). At least 10 m of ground wire shall be installed between the two dead-end clamps. The ground wire shall be tensioned to its normal installation tension. The ground wire shall be connected to a transformer terminal. A return path shall be placed in parallel to the tested ground wire at 1 m distance. Optical fibers from the WRAP cable shall be spliced in series such that the tested fiber length is at least 100 m. The tested fiber length shall include a minimum of one fiber from each tube or bundle of fibers. The measuring devices used for the test shall be capable of the following resolution:

a) Optical fiber attenuation variations, which may occur within 0.1 s

b) Current to an accuracy of ± 0.5 kA

c) Fault duration to a tolerance of 0.01 s

d) Temperature to an accuracy of ± 2.5 °C

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Temperature measurement shall be performed by locating three thermocouples under the first layer of strands of the ground wire; one at the center of the 10 m sample and two on either side, each distanced 0.5 m from the center.

Measurement of the optical parameters shall be performed immediately before the test and 5 min after the fault current.

6.2.1.11.2 Test procedure

The test shall consist of five fault currents with a current value arising from the value I^2t to be used for the test. The duration of each fault current shall be 0.5 s ± 0.15 s. The temperature of the ground wire before the first fault current shall be 20 °C ± 5 °C. Successive fault currents shall be applied after the ground wire has cooled naturally to 40 °C ± 5 °C. It is possible to heat up the conductor with a current to raise the temperature to 40 °C ± 5 °C. This current shall be switched off 15 s before the fault current is applied and can be reapplied 30 s after the fault current has been applied. Measurements shall be compliant to 6.2.1.11.

6.2.1.12 Lightning test

A lightning test shall be performed. A permanent or temporary increase in optical attenuation (including during the test) greater than 0.20 dB at 1550 nm ± 20 nm for single-mode fibers, or 0.40 dB at 1300 nm ± 20 nm for multimode fibers, shall constitute failure. There shall be no breach of the jacket after completion of the test and no damage whatsoever to the tubes or jackets protecting the fibers.

6.2.1.12.1 Test setup

The ground wire shall be secured in the manner approved by the laboratory undertaking the testing. A sample of WRAP cable shall be attached securely to the ground wire in the manner in which it would be installed in the field. The total length of WRAP cable, including those sections not under test, shall be at least 10 m in length. Optical fibers shall be spliced in series such that the total fiber length under test is in excess of 100 m. At least one optical fiber from each bundle or tube shall be included in this length.

The electrode shall be positioned at a distance of 100 mm from the ground wire directly above it. A fuse wire of diameter no greater than 70 µm shall be attached to the electrode and the ground wire. Polyethylene sheeting may be used to limit the point of contact of the arc on the ground wire though the section exposed under the electrode shall be at least 200 m in length centered directly beneath the electrode.

Refer to Annex A on the methodology on establishing incidence of lightning strokes.

The lightning arc test shall be performed on ground wire with WRAP cable samples of sufficient length to provide a test length that is a minimum of 2 m on either side of the test point. The cable shall be terminated at each end with suitable fittings, and a tension of 20% ± 5% of ultimate tensile strength (UTS) shall be applied.

6.2.1.12.2 Test procedure

The current wave shall be delivered through a non-thoriated, tungsten rod. The rod shall have a diameter of 3 mm to 4 mm and a hemispherical tip. The rod shall be mounted with its axis aligned with the radius of the cable, with the tip 4 cm to 6 cm from the cable surface. The rod shall be connected to the cable with a fuse wire.

The surface of the cable in the test field shall be externally heated to 40 °C ± 5 °C. This may be accomplished by using a heat gun to warm the area near the test electrode to several degrees beyond the test requirement, and allowing several minutes for the heat to dissipate and for the cable to cool to within the specified range.

The applied waveform shall include an arc-initiation component and a continuing current component applied as one continuous discharge. The arc initiation component is a current pulse of sufficient rise and magnitude to melt the fuse wire on the rising edge (i.e., before the current peak). The continuing current component is intended to simulate the damaging effects of lightning. The direct current magnitude shall be verified with a short circuit in place of the fuse wire. The duration shall be adjusted to deliver the specified charge. The discharge shall meet the specifications provided in Table 1.

Table 1—Simulated lightning current specifications

Parameter		Electrode polarity	
		Negative	**Positive**
Arc initiation component	Peak	2 kA	to be specified
	Tail	3 ms± 0.5ms	to be specified
Continuing current	DC magnitude	225 A−265 A	to be specified
Total charge		$Q_{negative}$ ±20%	$Q_{positive}$ ±20%

Five samples shall be tested with a negative electrode. If $Q_{positive}$ is more than twice $Q_{negative}$, then an additional five samples shall be tested with a positive electrode potential.

6.2.2 Routine tests

6.2.2.1 Fiber optic cable dimensions

6.2.2.1.1 Jacket thickness

The minimal jacket thickness at any cross-section may not be less than 70% of the nominal thickness.

6.2.2.1.2 Cable outside diameter

The maximum deviation of the cable outside diameter shall be < 0.25 mm.

6.2.2.2 Optical acceptance tests

Optical acceptance tests shall adhere to the following:

a) An optical attenuation test shall be performed on each fiber of each individual reel or double reel and may be made using an OTDR. The WRAP cable manufacturer shall supply test reports.

b) Attenuation loss values exceeding the specified values shall constitute failure.

7. Manufacturing recommendations

7.1 Cable lengths

The WRAP cable manufacturer shall determine the cable lengths and obtain approval prior to release to manufacturing. The WRAP cable shall be tightly and uniformly wound onto reels that can be directly fitted to the installation equipment.

7.2 Production tests

During manufacturing of cables and accessories, the WRAP cable manufacturer shall perform production tests as necessary for the compliance of the finished products with this standard.

7.3 Factory acceptance tests

The contractor shall, before each delivery of goods, perform routine factory acceptance tests to confirm that the goods meet the requirement of this specification.

8. Field acceptance testing

8.1 Fiber continuity

A continuity check of each fiber may be made to determine if any fiber is broken or any attenuation irregularities exist. This check shall only be carried out in the event, for example, that the reel packaging is damaged in transit.

8.2 Attenuation

Total attenuation for the entire installation length shall be measured on every fiber and expressed in dB/km.

8.3 Fiber length

The fiber length may be measured using the OTDR. The effective group index of refraction factor shall be provided by the fiber manufacturer.

9. Installation recommendations

9.1 Installation recommendations for WRAP cables

The installation techniques and equipment used for WRAP cables are specific to the manufacturer of the cable. The manufacturer's recommended installation procedures and equipment shall be used to install the WRAP cable.

9.2 Installation in live line conditions

It is possible to install WRAP cable in certain live line conditions. In such circumstances the WRAP cable manufacturer's recommended installation techniques and equipment for use in these conditions shall be followed.

9.3 Wrap recovery

Removal of damaged WRAP shall be carried out in a controlled manner using either an unwrapping machine or alternative recovery device. The recovery systems shall be rated for use, e.g., live line, 400 kV.

Under live-line conditions, the WRAP cable shall be wound onto a take-up drum as it is removed, thus avoiding the risk of it coming into contact with the live conductors.

9.4 Sag and tension of the ground wire

The sag and tension of the ground wire shall be taken into consideration prior to the installation of WRAP cable. The WRAP cable manufacturer shall be able to provide sag and tension information for specific situations and conditions. In particular, the manufacturer shall be able to provide values for the sag and tension of the ground wire when the installation equipment is on the line.

9.5 Pitch and tension of the WRAP on the ground wire

The WRAP cable shall be installed with a substantially constant pitch and tension, with a value such that the WRAP cable does not become loose on the ground wire for the temperature range −40 °C to +85 °C. If the tension and pitch are inappropriate, loops can develop, which could create performance issues for the cable.

9.6 Handling

Care shall be taken when coiling or bending the WRAP cable. The WRAP cable manufacturer shall be consulted to determine the minimum cable bend diameter. Care shall be taken not to kink the cable.

9.7 Hardware and accessories

Clamps that are used to hold the WRAP cable under tension on the ground wire are specifically designed for the application. Only fittings approved by the WRAP cable manufacturer, and that meet the requirements set out in IEEE Std 1591.3 [B8], shall be used to attach the WRAP cable.

9.8 Wrap splices

The cable shall not be installed with splices mid-span. The splice enclosures shall be fixed close to tower or other conductor support structures. All fiber splices shall be of the fusion type.

10. Cable packaging and shipping guidelines

10.1 Packaging

All reels may be non-returnable, in which case they shall be manufactured from wood. Each reel shall be sufficient in strength to prevent damage to the cable during transit, storage, and installation.

All double reels and single reels shall be boxed separately for protection during shipment.

All double reels and single reels shall be palletized and securely braced together to prevent slippage during transit.

10.2 Cable protection

For all reels of cable a "test tail" shall be provided (typically 2 m in length) to enable OTDR checks to be carried out on site, if required. The "test tail" shall be securely fastened to the outside flange to prevent it from becoming loose during transit.

10.3 Labeling

All labels shall be adhesive and weather resistant.

All cassettes/reel labels shall include, but not be limited to, the following:

- Cable description
- Manufacturing batch number
- Planned cable length requirement
- Actual cable length supplied

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— Tower numbers. Destination from and to for each reel
— Manufacturing and quality control inspection stamp
— Planned cassette/single reel number

All outer packing labels shall include, but not be limited to, the following:

— Cable description
— Manufacturing batch number
— Actual cable length supplied
— Tower numbers. Destination from and to for each reel
— Manufacturing and quality control inspection stamp
— Planned cassette/single reel number
— Customer name
— Factory order number/reference

10.4 Certified test data

If requested, the WRAP cable manufacturer shall furnish at the time of shipment a certified record of quality control measured values for each fiber on each reel. This certification shall be attached to the outside flange of the reel in a weatherproof package.

Annex A

(informative)

Establish incidence of lightning strokes

A ground flash density, N_g, (lightning strokes per square km per year) shall be obtained for the area of installation using automatic lightning location equipment and a sufficient period of observation to yield 400 observations in the selected study area. [NLDN (National Lightning Detection Network), CIGRE (International Council on Large Electrical Systems), LFC (Lightning Flash)]. In areas where automatic equipment has not been deployed, the global measurements of Optical Transient Density[6] shall be used, along with an approximate conversion factor of ten optical transients per ground flash.

The number of strokes to the overhead line shall be estimated using the expression in Equation (A.1):

$$N = N_g \left(\frac{28h_t^{0.6} + b}{10} \right) \tag{A.1}$$

where

N is the flashes/100 km/year
N_g is the ground flash density/km^2/year
h_t is the height of the conductor (or overhead ground wire) at the tower
b is the overhead ground wire separation in meters

When there are two or more overhead shield wires, the total number of flashes, N lightning, shall be assumed to split equally and uniformly along the exposed spans. A small proportion, equal to b divided by the span length in meters, shall be deducted for direct strokes to the tower.

If possible, a proportion of positive and negative flashes shall also be established. Otherwise a fraction of F_{neg} = 95% negative and F_{pos} = 5% positive flashes shall be used.

The exposure interval Y, in years, and the line length L, in km, will be specified by the user.

The probability level for total negative flash charge shall be computed using Equation (A.2):

$$P_{neg} = 100 \text{ km } / \left(Y \times N \times L \times F_{neg} \right) \tag{A.2}$$

The total negative flash charge level shall be computed from Equation (A.3):

$$7\left(P_{neg}^{-1} - 1\right)^{1/1.7} = Q_{negative}\, coulombs \tag{A.3}$$

The probability level for total positive flash charge shall be computed from Equation (A.4):

$$P_{pos} = 100 \text{ km } / \left(Y \times N \times L \times F_{pos} \right) \tag{A.4}$$

[6]The optical transient detector can be found by searching the Internet for "NASA" and "OTD."

The total positive flash charge level shall be computed from Equation (A.5):

$$85\left(P_{pos}^{\ -1}-1\right)^{1/2.0} = Q_{positive}coulombs \qquad \text{(A.5)}$$

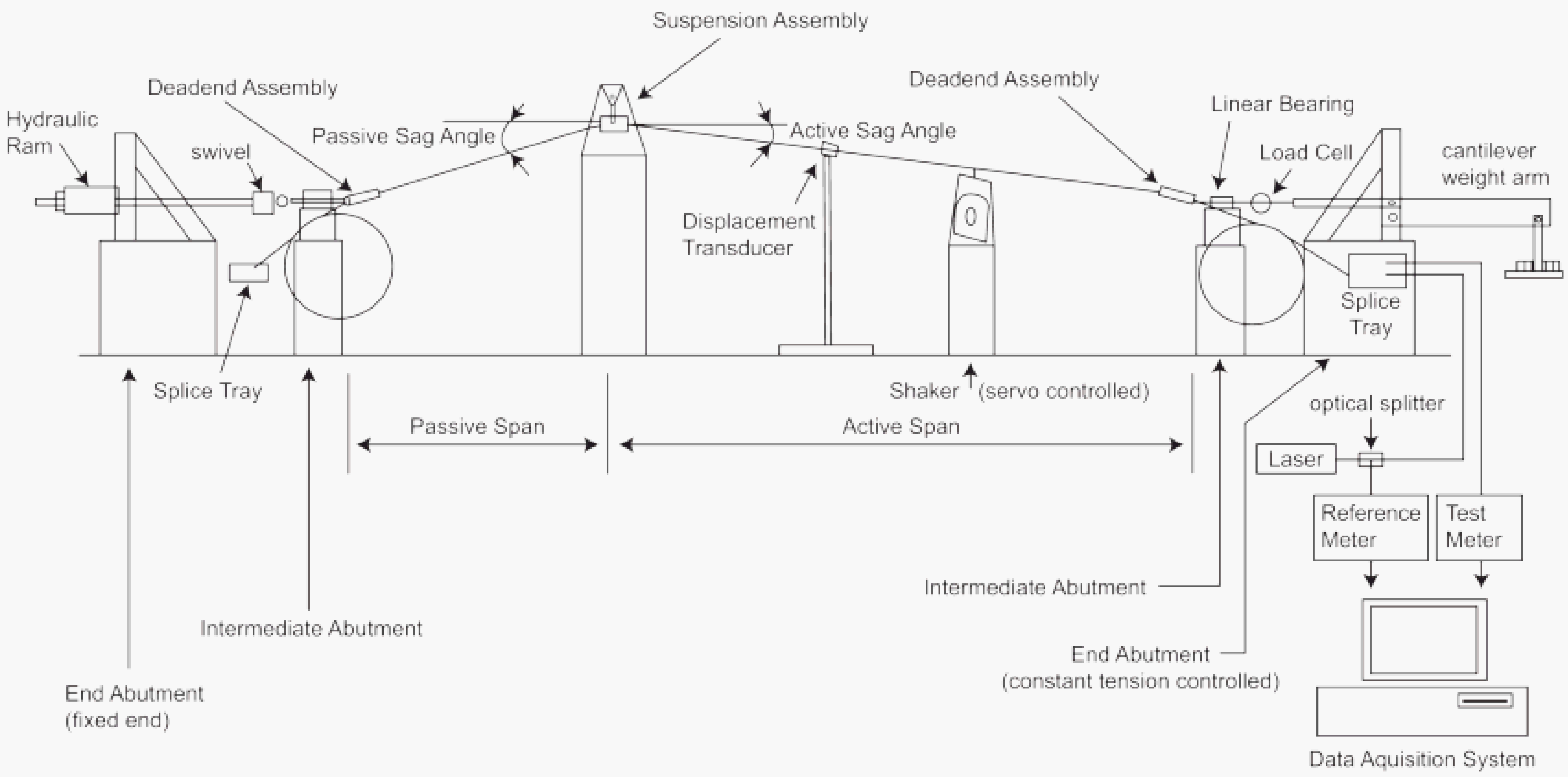

Figure A.1—Aeolian vibration test setup

Annex B

(informative)

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