EPRI

2024 TECHNICAL UPDATE

Advanced Conductor Specification Guide

GET SET

Grid-Enhancing Technologies for a Smart Energy Transition

Advanced Conductor Specification Guide

3002030304

Technical Update, May 2024

EPRI Project Manager
G. Sibilant

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

EPRI PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Together…Shaping the Future of Energy®

ACKNOWLEDGMENTS

EPRI prepared this report.

Principal Investigator
G. Sibilant

This report describes research sponsored by EPRI. This report is being made available freely to the public as part of EPRI's GET SET (Grid Enhancing Technologies for a Smart Energy Transition) initiative.

This publication is a corporate document that should be cited in the literature in the following manner: *Advanced Conductor Specification Guide.* EPRI, Palo Alto, CA: 2024. 3002030304.

ABSTRACT

This report aims to provide utilities with information on developing a specification for procuring advanced conductors and connectors. The specification can be used to ensure that the conductors purchased are within standard specifications and help de-risk the use of the conductors by detailing the technical specifications (including the EPRI-developed test that the carbon core conductors need to be subjected to) that the conductors need to satisfy. The information in this report enables utilities to confidently specify and procure advanced conductors, which assists in de-risking the use of this technology.

Keywords

Advanced Conductors
Conductor specification
Connector specification
Specification guide

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 EXECUTIVE SUMMARY

Advanced Conductors use new and existing materials to increase the thermal capacity of power lines. They are part of a family of technologies called Grid-Enhancing Technologies (or GETs). These hardware and/or software technologies can increase the capacity, efficiency, reliability, and safety of existing transmission lines. GETs can reduce congestion costs, improve integration of renewables, and increase capacity. GETs can be used alongside new transmission lines to facilitate the clean energy transition.

This report aims to provide utilities with information on developing a specification for procuring advanced conductors and connectors. The specification can be used to ensure that the conductors purchased are within standard specifications and help de-risk the use of the conductors by detailing the technical specifications (including the EPRI-developed test that the carbon core conductors need to be subjected to) that the conductors need to satisfy. The information in this report enables utilities to confidently specify and procure advanced conductors, which assists in de-risking the use of this technology.

This report results from two decades of testing conducted at EPRI's laboratories, various utility-based field trials, and numerous technical sessions held with utilities and technology vendors. EPRI developed a conductor and connector testing protocol that utilizes a 90-ft long test bed that can accommodate up to 24 conductors in six independent tests. This protocol was unique at the time since the conductors could be tested and evaluated for electrical and mechanical stresses.

To date, EPRI has tested the following conductors:

1. Aluminum Conductor Composite Core (ACCC):
   - Regular core
   - Ultra-low sag core
2. Aluminum Conductor Composite Reinforced (ACCR)
3. Aluminum Conductor Steel Supported (ACSS):
   - High strength
   - Extra-high strength
   - Ultra-high strength

GET SET
Grid-Enhancing Technologies for a Smart Energy Transition

What is GET SET?

Energy companies are seeking all options for increasing delivery capacity to support energy transition objectives and large demand increases from AI and manufacturing growth. EPRI's GET SET (Grid-Enhancing Technologies for a Smart Energy Transition) initiative aims to support the deployment of a subset of technologies to respond to the rapid load growth, changing generation mix, and extreme weather that energy companies are facing today. These solutions can potentially maximize the capacity of existing assets now, while working to build new capacity in the long term.

The GET SET initiative is committed to assimilating and disseminating existing GETs knowledge to support utilities in assessing and deploying GETs now, as well as leveraging those deployments and additonal research to answer remaining questions and provide the tools that utilities need to evaluate and deploy more broadly.

4. C7:
   - Aluminum Conductor Composite Supported (ACCS) – Thermoset and Thermoplastic
   - Aluminum Conductor Composite Reinforced (ACCR) – Thermoplastic
5. Gap-Type Conductor
6. High-Voltage Composite Reinforced Conductor (HVCRC)
7. TS Conductor

This report will assist utilities:

- Develop specifications for procuring Advanced Conductors and connectors
- Get a better understanding of the specification tests required
- De-risk specifying and procuring advanced conductors

2 INTRODUCTION

Background

This guide is designed to assist utilities in specifying advanced conductors for overhead transmission line applications. Advanced conductors are products developed to meet the need to increase the transmission capacity of existing corridors; advanced conductors have subsequently also been used for high-capacity new overhead lines. The characteristics of Advanced Conductors are higher current carrying capacity (by allowing the conductor to operate at high temperatures) and generally lower sags for the same conductor temperature when compared to the conventional aluminum-conductor, steel-reinforced (ACSR) conductors. Although all advanced conductors possess the same general characteristics, many differ substantially. Some of these conductors use materials such as ACSR conductors and, thus, closely resemble conventional conductors. For other Advanced Conductors, recently developed non-conventional composite materials are used for the conductor core.

EPRI started a pilot project in 2004 to investigate conductor performance with a field trial on five different Advanced Conductors. Since then, EPRI has tested many of the advanced conductors currently available, developed test protocols and specification guidelines, and collected utility use cases of advanced conductor applications. Details of this work are shown below.

EPRI Advanced Conductor Resources

Conductor Specification

EPRI has developed an advanced conductor specification guide that utilities can use in developing their specification when purchasing advanced conductors. This specification includes information regarding the specific carbon-core conductor tests that must be performed. A sample specification has been compiled as an example and is presented in this report.

Accelerated Aging Tests

In the early 2000s, EPRI developed an accelerated thermal-mechanical aging test. The test setup was unique at the time as it simultaneously evaluated the effect of both electrical and mechanical stress on the conductor. A photograph of the test setup is shown below. EPRI has the capability to test up to 24 different conductors in six unique tests.

Figure 1. EPRI Charlotte, Conductor Test Bay

The test simulates 40 years of in-service life during an 18–24-month period. The tests help to provide information on the performance and longevity of advanced conductors and the connectors used. This information can help to de-risk the use of Advanced Conductors. EPRI has completed thermal-mechanical aging tests on nine different advanced conductor-connector systems. Of the nine systems tested, five passed the thermal and mechanical requirements. A tenth conductor is currently being installed in the EPRI laboratory for testing.

Table 1. Conductors tested

<table>
<tr><th colspan="4">Conductors Previously Tested</th></tr>
<tr><td>Aluminum Conductor Composite Core (ACCC) manufactured by CTC Global</td><td>Aluminum Conductor Composite Reinforced (ACCR) manufactured by 3M</td><td>Gap-Type Conductor manufactured by J-Power</td><td>Aluminum Conductor Steel Supported (ACSS) manufactured by Southwire</td></tr>
<tr><td>Aluminum Conductor Steel Supported (ACSS), a utility-specific design</td><td>Lo-Sag Carbon Core Conductor manufactured by Nexans</td><td>High-Voltage Carbon Reinforced Conductor (HVCRC) manufactured by Mercury Cable</td><td>C^7 Conductor (Celanese Core) manufactured by Southwire
Aluminum Zirconium Outer Strands
Fully Annealed Outer Strands</td></tr>
<tr><th colspan="4">Conductors Currently Being Tested</th></tr>
<tr><td colspan="4">Aluminum Conductor Steel Supported (ACSS) manufactured by Southwire
High Strength
Ultra-High Strength
Four different connector manufacturers</td></tr>
<tr><th colspan="4">Conductors Planned to Be Tested</th></tr>
<tr><td colspan="4">TS Carbon Core Conductor manufactured by TS Conductor</td></tr>
</table>

Advanced Conductor Use Cases

More than twenty (20) advanced conductor use cases from utilities worldwide have been collected by EPRI, providing a source of reference and insight into the rationale that justified the selection of a particular advanced conductor (*Advanced Conductor Experience: Utility Applications*, 3002030317). The case studies highlighted that the selection of advanced conductors varied due to technical, economical, time-restraint, or other merits.

Ongoing Research and Development (R&D)

For Advanced Conductors, open questions exist for special cases and to address managing the asset for decades in the future. EPRI has ongoing research into the following:

1. **Icing Performance**: investigating the icing performance of carbon core conductors will include a fully monitored, extended field demonstration in an icing-prone region of the United States for more than 12 months.
2. **Vibration Performance**: advanced conductors—including ACSS and carbon core technologies—will be subjected to both small-scale and full-scale experimentation. Monitoring data from the field demonstration in (1) will support this.
3. **Inspection and Assessment**: evaluating inspection technologies, as well as determining assessment criteria to manage the end-of-life of aged populations of advanced conductors, including life extension.
4. **Application Guide**: EPRI has developed an application guide that provides the most up-to-date information on the various conductors available, the latest research, results, and future trends. This guide is updated annually.
5. **Installation Best Practices**: collecting, evaluating, and compiling installation practices recommended by each manufacturer, compiling feedback from utility installations, and developing best-practice guidelines for advanced conductor installation.
6. **Maintenance**: Work is underway to determine the effect of traditional tools on the performance of advanced conductors and to evaluate the effect of high temperatures on the performance of traditional maintenance work tools.

3 ADVANCED CONDUCTOR SPECIFICATION GUIDE

This section provides guidance for developing specifications for purchasing advanced conductors. The purchasing specifications may contain some or all the following sections. Each section consists of a heading for the addressed topic, a description of the section's content, its purpose, and sample statements. Sample statements are itemized in bullet form for the user's reference. In general, the conductor specification document consists of the following sections:

Scope

General

Applicable Codes and Standards

Detailed Requirements

Inspection and Testing

Packing and Marking

Conductor Storage and Handling

Utilities may choose to modify, omit, or add to the contents as the circumstances require. The intent of this section is to provide guidance to the utility for building an appropriate specification for purchasing its advanced conductors. A draft specification based on the content of this section is shown in Appendix C: Example of a Conductor Specification.

Scope Sample Specification

The Scope shall contain a brief description of the content of the specification (for example, a "purchase specification") and identification of the conductor type (for example, ACSS and ACCC).

Sample:

- This specification defines the minimum requirements for a concentric-lay-stranded aluminum conductor with a "type" core and "conductor–type" for an overhead transmission conductor application.
- The intent of this specification is to define the minimum requirements to which the Manufacturer must conform to meet the utility's requirements for purchase.

General Sample Specification

This section may contain several generic requirements that preface the details of the document. Details to be addressed may include:

- If there is any ambiguity or contradiction between the Standards identified below and this specification, the specification will take precedence. The Manufacturer shall bring any discrepancy to the Buyer's attention.
- Conductor size and stranding shall be in accordance with the itemized purchase request.
- The Buyer may request installation support and supervision from the Manufacturer. A separate line item addressing the cost and description of this work shall be provided with the bid response.
- Plants specified by the Manufacturer in their bid response, including proof of their ISO 9001 certification, shall supply all cores and conductors.

Applicable Codes and Standards Sample Specification

This section shall list the various standards, codes, and specifications that address the type of conductor being purchased. The inference is that the latest version is to be adhered to; however, the Buyer may request a specific edition if a particular aspect is required. The list shall include the standard/specification number and title, plus any specific edition reference, if not the most recent version.

Detail samples:

- The electrical and mechanical characteristics, geometry, and features of the conductor supplied under this specification shall meet the requirements specified herein and shall conform to the latest revisions of applicable ASTM, NEMA, and IEC Standards.

Electrical and mechanical characteristics may include the following:

(**Note**: Do not use the entire list; only use those specific to the type of conductor and its construction.)

- **ASTM B230** – Standard specification for aluminum H1350-H18 wire for electrical purposes
- **ASTM B609** – Aluminum 1350 round wire, annealed and intermediate tempers, for electrical purposes
- **ASTM D792** – Standard test methods for density and specific gravity (relative density) of plastics by displacement
- **ASTM B802** – Standard specification for zinc-5% aluminum-mischmetal alloy coated steel core wire for aluminum conductors, steel reinforced
- **ASTM B803** – Standard specification for high strength zinc-5% aluminum-mischmetal alloy coated steel core wire for use in overhead electrical conductors

- **ASTM B958** – Standard specification for extra-high strength and ultra-high strength class a zinc-5% aluminum-mischmetal alloy coated steel core wire for use in overhead electrical conductors
- **ASTM B987** – Standard specification for carbon fiber composite core (CFCC/TS) for use in overhead electrical conductors
- **ASTM D3916** – Standard test method for tensile properties of pultruded glass-fiber-reinforced plastic rod
- **ASTM D5117** – Standard test method for dye penetration of solid fiberglass reinforced pultruded stock
- **ASTM D7028** – Standard test method for glass transition temperature (DMA Tg) of polymer matrix composites by dynamic mechanical analysis (DMA)

Conductor construction standards may include the following:

(**Note**: Do not use the entire list; only use those specific to the type of conductor and its construction.)

- **ASTM E29** – Standard practice for using significant digits in test data to determine conformance with specifications
- **ASTM E228** – Standard test method for linear thermal expansion of solid materials with a push-rod dilatometer
- **ASTM B856** – Standard specification for concentric-lay-stranded aluminum conductors, coated steel supported (ACSS)
- **ASTM B857** – Standard specification for shaped wire compact concentric-lay-stranded aluminum conductors, coated steel supported (ACSS/TW)
- **ASTM B500** – Metallic coated or aluminum-clad stranded steel core wire for use in overhead conductors
- **EN 50540** – Conductors for overhead lines – aluminum conductors steel supported (ACSS); non-steel sections are applicable
- **IEC 61395** – Overhead electrical conductors – creep test procedures for stranded conductors
- **IEC 62219** – Overhead electrical conductors – formed wire concentric lay stranded conductors
- **IEEE Standard 738** – Standard for calculating the current temperature of bare overhead conductors
- **NEMA WC-26** – Binational wire and cable packaging standard

Typical test standards include the following:

- **ASTM E8** – Standard test methods for tension testing of metallic materials
- **ASTM E21** – Standard test methods for elevated temperature tension tests of metallic materials
- **ASTM A370** – Standard test methods and definitions for mechanical testing of steel products
- **ASTM B803** – Standard specification for high-strength zinc-5% aluminum-mischmetal alloy-coated steel core wire for use in overhead electrical conductors
- **ASTM B958** – Standard specification for extra-high-strength zinc-5% aluminum-mischmetal alloy-coated steel core wire for use in overhead electrical conductors
- **ASTM B976-21** – Standard specification for fiber-reinforced aluminum matrix composite (AMC) core wire for aluminum conductors aluminum matrix composite reinforced (ACAMCR) (formerly known as ACCR)
- **ASTM B978/B978M-23** – Standard specification for concentric-lay-stranded aluminum conductors, aluminum matrix composite reinforced (ACAMCR) (formerly ACCR)
- **ASTM B987** – Standard specification for the carbon fiber thermoset polymer matrix composite core (CFC) for use in overhead connectors
- **ASTM B557** – Standard test methods for tension testing wrought and cast aluminum- and magnesium-alloy products
- **ASTM D3552** – Standard test methods for tensile properties of fiber-reinforced metal matrix composites
- **ASTM D3039** – Standard test methods for tensile properties of polymer matrix composites
- **ASTM D696** – Standard test method for coefficient of linear thermal expansion of plastics between -30°C and 30°C with a vitreous silica dilatometer
- **ASTM E228** – Standard test method for linear thermal expansion of solid materials with a push-rod dilatometer
- **ASTM E831** – Standard test method for linear thermal expansion of solid materials by thermomechanical analysis
- **ASTM E466** – Standard practice for conducting force-controlled constant amplitude axial fatigue tests of metallic materials
- **ASTM E606** – Standard practice for strain-controlled fatigue testing
- **ASTM D3479** – Standard test method for tension-tension fatigue of polymer matrix composite materials
- **ASTM E139** – Standard test methods for conducting creep, creep-rupture, and stress-rupture tests of metallic materials
- **ASTM B117** – Standard practice for operating salt spray (fog) apparatus
- **ASTM D4329** – Standard practice for fluorescent ultraviolet (UV) lamp apparatus exposure of plastics

- **ASTM D5894** – Standard practice for cyclic salt fog/UV exposure of painted metal (alternating exposures in a fog/dry cabinet and a UV/condensation cabinet)
- **ASTM D5229** – Standard test method for moisture absorption properties and equilibrium conditioning of polymer matrix composite materials
- **ASTM E1556** – Standard specification for epoxy resin system for composite skin, honeycomb sandwich panel repair
- **ASTM D2303** – Standard test methods for liquid-contaminant, inclined-plane tracking, and erosion of insulating materials
- **ASTM B193** – Standard test method for resistivity of electrical conductor materials
- **ASTM B941** – Standard specification for heat-resistant aluminum-zirconium alloy wire for electrical purposes
- **ASTM D7264** – Standard test method for flexural properties of polymer matrix composite materials
- **ASTM E1640** – Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis
- **ASTM D4475** – Standard test method for apparent horizontal shear strength of pultruded reinforced plastic rods by the short-beam method
- **IEC 62004-2007** – Thermal-resistant aluminum alloy wire for overhead line conductor
- **IEC 62217** – Polymeric high-voltage insulators for indoor and outdoor use – general definitions, test methods, and acceptance criteria
- **IEC 61395** – Overhead electrical conductors – creep test procedures for stranded conductors
- **IEC 60468** – Method of measurement of resistivity of metallic materials
- **IS0 16151** – Corrosion of metals and alloys – accelerated cyclic tests with exposure to acidified salt spray, “dry” and “wet” conditions
- **ISO 14125** – Fiber-reinforced plastic composites – determination of flexural properties
- **ISO 11359-1** – Plastics – thermomechanical analysis (TMA) – Part 1: General principles
- **ISO 11359-2** – Plastics – thermomechanical analysis (TMA) – Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature
- **ISO 11358** – Plastics – thermogravimetry (TG) of polymers – Part 1: General principles

Detailed Requirements Sample Specification

This section shall provide any specific requirements or details of the conductor that the buyer wishes to identify beyond the appropriate specifications and standards listed above or as an exception to a specific standard.

Sample requirements may include the following (by choice of the user, as applicable for the conductor type).

Aluminum strands shall be specified:

- The aluminum strands shall be in accordance with ASTM *(standard number and title)*.
- The aluminum strands shall be fully annealed before or after stranding (if applicable).
- Aluminum strands shall conform to ASTM B230 or B609, except the electrical resistivity shall not exceed 16.462-ohms-circular-mil/ft at 20°C for transmission conductors. (Some buyers require 63% aluminum conductivity, and may include a requirement.)

Core material shall be specified:

- The coated steel core wires shall conform to ASTM *(standard number and title)*.
- The steel wires of the core shall be so formed that when the cable is cut and the aluminum wires are stripped away from the core—as required for splicing—the steel wires can be readily regrouped and easily held in place by one hand to allow a splicing sleeve to be slipped over the cut end of the core. This construction permits the core to be made of either preformed or unformed wires but prohibits the use of any deformed wire in the core.
- The core and conductor wires shall be resistant to corrosion or other bi-metal corrosive effects, which may reduce the conductor's strength.

Construction shall be specified:

- The conductor shall be capable of continuous operation up to *nnn°C* and a Maximum Operating Temperature (MOT) of *nnn°C* (or some variation of this text).
- The wires of each layer shall be near each other, and each layer shall be in contact with the layer underneath. The intent is to be a tight stranding and winding on the reels to eliminate bird caging and slack strand construction.
- The lay of the outer layer shall be right-handed, and subsequent under layers reversed from the layer above, including the transition from aluminum strands to core.
- Stranded conductors shall be capable of withstanding the normal handling necessary for manufacture and erection (such as reeling, unreeling, and pulling through stringing sheaves under sufficient tension to keep the conductor off the ground) without being deformed from a circular form in such a way as to increase the power loss due to corona formation.
- The surface of the final conductor shall be free from all imperfections visible to the naked eye. The conductor surface shall be smooth (free from scratches, rust, and cracks) and free from defects, which might be harmful for practical use.
- To reduce the propensity for the surface of the conductor to collect dust or other surface contaminants, the Manufacturer shall minimize the amount of stranding lubricant used in the manufacture of the conductor.
- Trapezoidal-shaped conductors shall be rejected for the following issues:
  - Excessive canting (twisting) of the trapezoidal strands that would be considered detrimental to the serviceability of the conductor.
  - Minor spacing between the strands is necessary; however, gaps between outer strands of more than half the strand diameter shall be considered a defect.

  - Splaying (defined as the spreading of the peripheral strands of the conductor that potentially weakens the conductor) that exceeds the following limits:
    - Any raised strands that cannot be pressed back into their position with the normal force of one finger.
    - Crossovers: Any strand that has popped out of position and is lying over another strand.
  - Excessive scuffing, which is characterized as multiple scrapes on the surface and along the length of the conductor with associated burrs of aluminum protruding from the strand.
- Each conductor wrap shall be tightly placed next to the preceding wrap and level-wound onto reels to produce level layers.

Inspection and Testing Sample Specification

As the buyer, you want access to the manufacturing facilities and their subcomponents during the fabrication of your core and conductor. The buyer can waive these requirements or use a representative to perform the effort; however, the rights to do so should be established in the specification.

These tests need to be performed on your purchase quantity, that is, lot testing—as opposed to qualification testing. Qualification testing is performed during your assessment of a new conductor type or vendor (or whenever it meets your needs) and will provide the performance, reliability, and service life required. This testing is covered in Appendix A.

The following clauses are samples of typical inclusions in this topical area:

Inspections

- No material or equipment shall be shipped from its point of manufacture before it has been inspected unless the manufacturer has been authorized to make the inspection elsewhere.
- The acceptance of any material or equipment shall in no way relieve the contractor of any of his responsibility for meeting all the requirements of the specification and shall not prevent subsequent rejection if such material or equipment is later found to be defective.
- The Buyer's representative shall always have access to all places of manufacture where materials or equipment are being made or prepared for use under this contract, and they shall have full facilities for unrestricted inspection of such materials or equipment.

Core Receiving Inspection

- Receiving inspection tests to be carried out on the composite core materials upon receipt at the stranding facility are listed in Table 2. These tests are designed to ensure that the correct materials have been shipped and that no damage occurred during shipment.

Table 2. Receiving inspection tests for the conductor composite core

Test Description	Applicable Testing Standard
Document Review	Manufacturer Managed
Surface Condition	ASTM B987 Section 20.1
Density	ASTM B987 Section 11.1
Diameter	ASTM B987 Section 12.2 and 12.3

Testing

The Type Tests are designed to verify the full set of characteristics of the conductor and core. These tests are required to be performed on new conductor designs or when new construction methods or materials are used to fabricate previously qualified conductor designs. Test requirements listed for Type Tests represent properties at the time of manufacturing.

Acceptance Tests, Routine Tests, Sample Tests, or Factory Acceptance Tests are defined as equivalent nomenclatures for tests that are carried out on each production run of material to guarantee continued compliance with the requirements of this specification. Test requirements listed for Acceptance Tests represent properties at the time of manufacturing.

Sample testing details include:

- Retests – In the event of an equipment failure or error in the testing procedure, setup, or similar issue, the test shall be deemed a non-test, and a new sample shall be prepared and tested. In the event of a failure with an unassignable cause, the test may be retested by selecting three (3) additional samples from the same area of the reel (drum) and testing these samples for the discrepant test or property. If the three retests successfully meet the test requirements, the original test shall be discarded, and the lowest value for the three retests shall be recorded as the test result.
- Buyers—at their discretion—may waive any or all the provisions for inspection and tests, either in the invitation for bids or at the time of award of contract.
- The Manufacturer shall complete certified reports of the tests on samples of conductors and of individual strand wires, in accordance with ASTM requirements. Electronic copies of the reports shall, at a minimum, provide the information shown in Appendix A, as well as the pass/fail wrap test and the adherence-of-coating test. These reports must state the number of reels and net weight of conductor covered by the report. The report must also indicate which tests were made before stranding and which tests were made after stranding.

- The test specified in this section shall be performed in accordance with all applicable standards. The results of all tests and supporting data shall be included in the final test report. Each reel/coil shipped shall be traceable to certified test data on file.
- A final test report covering the physical properties listed in Table 3 shall be kept on file for a minimum period of five years and shall be submitted to the Buyer upon request. The Manufacturer may use the core Manufacturer's Certified Test Report information for the test results for physical properties and weight coating on steel core strands.
- Joints and welds in the finished individual aluminum wires composing the conductor shall meet the requirements of ASTM B-232, except there shall be no joints in the outer layer of aluminum strands other than those occasioned by strand breakage during the stranding operation. Joints in the outer aluminum layer shall be limited to a total of three in a length of conductor. The weld area shall be cleaned and smoothed carefully to be (as nearly as possible) the same diameter and the same finish as the aluminum strand. There shall be no joints or welds in the zinc-coated steel core wire.

Table 3. Report of physical properties

Aluminum Wire	Core
Diameter (in.)	Diameter (in.)
% Conductivity	Stress at 1% Elongation (lb/in^2)
Ultimate Strength* (lb, lb/in^2)	Ultimate Strength (lb, lb/in^2)
% Elongation*	% Elongation
	Weight of Coating (oz/ft^2)

*The tensile and elongation measurements of the aluminum are indicators that the material was fully annealed within ASTM limits.

Applicable to Aluminum Strands

Aluminum wire shall be tested, as required in ASTM B 230.

Applicable to Steel Core Strand

- Steel wire shall be tested as required in ASTM B 498.
- Tests shall be made on individual wires before stranding, except the weight-of-coating test shall be performed on samples of the core wire taken from the completed core.
- Samples to be given the weight-of-coating test shall be taken from not less than 20% of the reels of stranded core wire, with a minimum of one sample for every ten reels of conductor. All wires from each stranded sample shall be tested. If a sample taken from any reel (either on the original sampling or any subsequent sampling) fails to meet the weight of Class A coating values specified in ASTM B 498, that reel should be rejected. In addition, if a sample fails, the Buyer's inspector will take a sample to be given the test from each reel offered in the lot being tested. If more than 20% of the total number of samples taken from any lot fail this test, the entire lot shall be rejected. Certified test reports from the steel wire Manufacturer shall be accepted in lieu of the testing specified.

Stress-Strain Tests

- Buyer will require that stress-strain tests be completed and submitted electronically for the initial purchase of any conductor design.
- If requested by the Buyer, repeated stress-strain tests on the conductor and the core shall be made in the presence of the Buyer's inspector.
- One reel will be required if ordering ten reels or less. One sample of conductor and one sample of core from each of two different reels will be required for orders between 11 and 20 reels. One sample of conductor and one sample of core from each of three different reels will be required for an order of 21 or more reels unless otherwise specified. The test samples shall each be approximately 50-feet long to provide 500 inches between measure points of unstressed conductor.
- Tests on the conductor shall be made. Sufficient tension, not to exceed 8% of the rated strength of the cable being tested, or 1000 pounds, whichever is the smaller, shall be applied gradually to the sample to eliminate sag and ensure comparative straightness before the scales fastened to the cable at each end of the gage length are set. The tension applied to each sample shall be increased by small increments for the following loading conditions in the sequence shown in Table 4, and simultaneous readings of tension and elongation up to 80% of rated breaking strength (RBS) shall be recorded.

Table 4. Sequence of sample load conditions

Load initially to 8% of RBS or 1000 pounds, whichever is smaller.	Set gages at zero.
Load to 30% of RBS.	Hold 30 minutes.
Reduce to initial loading. Load to 50% of rated strength.	Hold 60 minutes.
Reduce to initial loading. Load to 70% of RBS.	Hold 60 minutes.
Reduce to initial loading. Load until sample is broken.	Record the breaking load.

- The breaking strength of the conductor (obtained from the above test) shall be not less than the rated strength if failure occurs in the free length at least 6 inches (15.2 cm) beyond the end of either gripping device, or shall be not less than the 95% value shown in the following tabulation if failure occurs inside or within 6 inches (15.2 cm) of the end of either gripping device.
- Tests on the steel core shall be made; these consist of three successive applications of load applied in a manner like that for the conductor. Pull core to the same amount of elongation as the conductor at 30%, 50%, and 70% of RBS. Determine actual breaking strength and record data in the same manner as for the conductor.

- In electronic format, the Manufacturer shall furnish certified reports of stress-strain tests—in both tabulated and graphic forms—on the conductor and core. These reports shall include the following data:
  - Temperature at which tests are conducted
  - Identity of reel from which test samples are taken
  - Initial and final modulus of elasticity for the composite conductor and the steel core

Applicable to Composite Core

- **Tensile test.** Tensile tests on the composite core shall be conducted in accordance with the Test Methods and Definitions section of **ASTM D 3916**.
- Calculation of CFCC/TS tensile properties shall be based on the total cross-sectional area of the composite core, including the galvanic protection layer.
- **Glass transition temperature test (Tg).** The glass transition temperature (Tg) shall be determined using a DMA instrument in accordance with **ASTM D 7028,** except for the measurement of Tg. Tg shall be defined as the peak in the loss modulus curve.
- **Density.** Density may be calculated from the mass divided by the volume or determined in accordance with **ASTM D792**.
- **Bending test ASTM B987.** Bending tests shall be performed on two sections of core taken randomly from the manufacturing lot. Testing consists of wrapping the CFCC/TS 180° around a cylindrical mandrel. The composite core sample shall be loaded to 7.5% of its rated tensile strength (RTS), or if measuring the force on the mandrel, the mandrel shall have a force of 15% of the RTS of the composite core being tested. The force shall be applied for a period of 60 seconds. Test details are as follows:
  - The diameter of the cylindrical mandrel shall be equal to 50 times the diameter of the composite core being tested.
  - The section of the composite core that is in direct contact with the mandrel shall be marked so that after the bending test, this section can be easily identified to perform post-testing analysis.
  - After completion of the bending test, the specimen shall be checked visually for damage. If the specimens exhibit no visible damage, the test specimens shall be subjected to the additional testing described in Sections 15.0 (g) and 15.0 (h).
- **Dye penetrant testing after bending test.** One test section taken from either of the two bending tests described in section 15.0 (f) shall be subjected to the dye penetrant test. Specimens for dye penetrant testing shall be taken from the part of the bending test specimen that was in direct contact with the mandrel. Dye penetrant specimens shall be taken as close as possible to the center of this region.

  To detect the presence of any cracks that may have formed inside the composite core during the bending test, a minimum of five specimens shall be taken from the test section and tested per **ASTM D 5117**.

Specimens shall be placed vertically in a dye penetrant bath with the bottom surface submerged in the dye penetrant for a period of 30 minutes.

During the test period, the presence of small (<0.5-mm diameter), separated, wicking dots on the top surface is acceptable. If the dots merge and the top surface of the CFCC/TS becomes covered in dye penetrant to a level of 50% of the surface area or greater, then the sample has sustained damage and has failed the test.

- **Tensile test after bending test ASTM D 3916**. One specimen taken from either of the two bending tests described in Section 15.0 (f) shall be subjected to a tensile test. The specimen for the tensile test shall be selected from the part of the sample that was in direct contact with the mandrel (where the highest stresses would occur) and subjected to the tensile testing.

  The specimen shall be bonded to suitable fixtures for tensile testing following the Manufacturer's suggested method. The CFCC/TS specimen shall be tensile tested according to Section 15.0 (c) and shall retain its minimum rated tensile strength.
- **EPRI qualification test**. Appendix A provides a detailed test methodology and acceptance criteria for composite core conductor qualifications. It is recommended that this test protocol be included in purchase specifications. The accelerated aging test of the thermo-mechanical testing protocol provides a good characterization of the conductor's reliability and serviceability over a projected service life. The pre-aging and post-aging tests provide a measurable diagnostic state of the conductor against proven acceptance criteria.

Packing and Marking Sample Specification

Packaging and marking are important to the deliverable product to ensure that the conductor is easily identifiable, is in its best condition, and is quickly and efficiently installed.

This section of the specification is largely dependent on the Buyer's needs relative to reel sizes and lengths of the conductor on the reel, the making of matching sets of reels for pull-lengths, and multiple conductor bundles. All this information should be established in this section of the specification. Sample details include the following:

- The conductor shall be packed, sealed, and shipped in accordance with recognized standard practice.
- The reel lengths on substantial reels shall be as specified in the Schedule of Prices, in accordance with NEMA WC-26, except that—unless specified otherwise in the Schedule of Prices—reel lengths may vary minus zero (0) to plus n%, and 5% of the order by weight may be shipped in random lengths upon approval by the Buyer. None of these lengths shall be less than 50% of the reel length specified or the reel length agreed upon after the award of contract. Reel lengths can also be specified for a particular order to meet the unique needs of the project; the reel lengths may be specified as a non-standard length for all reels ordered or specific reel lengths for each individual reel on the order. There shall be only one length of conductor on a reel.

- Unless otherwise specified, all reels shall be shipped in matched sets of six (6) (quantity is Buyer-specific) with no variation in lengths. However, a variation of plus or minus 50 ft (15 m) of length specified is permissible between sets *if* reels in matched sets are furnished with no variation in length. Sets must be clearly labeled with weatherproof paint for ready field identification.
- For metal reels, the inside of the flanges and drum of the reel shall be covered to prevent the metal reel surfaces from meeting the aluminum conductor.
- All reels shall have a minimum of a Level 2 reel covering per NEMA WC-26. The specific reel covering to be provided will be identified in the contract document. Product damage during shipping is typically the responsibility of the vendor (or as specified in the shipping terms agreement). The ends of the conductor shall be securely attached to the reel flange.
- Shipping coils and reels shall be marked (as a minimum)with the following information: Buyer Catalogue ID (Buyers should substitute their terminology here) and description, the quantity contained therein, gross weight, the contract number and purchase order, the date of manufacture, and the Manufacturer's name. An arrow indicating the direction in which the cable is wound shall be painted on the reel or coil at the end of the cable.
- Reel heads shall have metal hub bushings with a hole to fit a 5- to 5.25-in. (12.7- to 13.3-cm) arbor shaft for reel support equipment (size is Buyer-dependent).
- Generally, the conductor drum shall be designed to suitably protect the conductors against damage, which could occur in ordinary handling and shipping. The drums shall be constructed to enable the conductors to be unwound smoothly and in lengths if they can be conveniently handled and erected.
- Particular attention must be given to preventing exposure of the conductor to harsh environments while in storage. The conductor drums shall be free from rust or rot and treated with an anti-rust treatment or fumigated and properly galvanized or painted. All drums shall be securely battened around the perimeter to give maximum protection to the conductor; they should be clearly marked with the correct direction of rolling indicated with an arrow in a manner that is not easily removable.
- To prevent the conductors from meeting the bottom and sides of the drums, the inner sides of all drums are required to be covered with approved materials. The first layer of the conductors shall be secured to the hub in a manner that avoids damage to the subsequent layers.
- Each drum shall be clearly marked with the following details:
  - Manufacturer's name
  - Drum number
  - Date of manufacture
  - Conductor type and size
  - Conductor length
  - Gross weight

- The drum label shall be clearly and permanently displayed on the drums' flanges in characters at least 75-mm high. Where dissimilar lengths of one conductor type are specified within the contract requirements, the lengths on each drum shall be clearly marked at the time of winding using a metal or plastic tag, or paint marking on the drum flange adjacent to the drum number.

Conductor Storage and Handling Sample Specification

It is also recommended that some guidance shall be provided that will improve any future storage or handling of the conductor while on reels. Sample details may include the following:

- Conductors shall be stored in a safe, orderly fashion, free from any undesirable environmental conditions to enable identification. Where possible, conductors should be stored in a covered area or under a tarpaulin capable of enduring the planned storage time. Store the conductor in a manner that avoids flooding, standing water, deep mud, or where ground salts may cause corrosion.
- Unlagged drums should be stored in such a way as to prevent other drum flanges or protuberances from damaging the conductor. Only fully lagged and lined drums shall be stored outdoors. Lagging materials shall be handled carefully to prevent damage to the packing or the conductor.
- The completed drums of the conductor shall only be lifted using specialized forklift trucks, cradles, or slings employing a suitable mandrel through the drum spindle hole. The use of forklift trucks lifting by the flange rim is not acceptable.

4 CONNECTOR SPECIFICATION

Purpose and Scope

This specification outlines the technical requirements for the manufacture, testing, supply, and delivery of compression connectors for use with advanced conductors on overhead transmission lines. These connectors include terminal lugs, dead ends, and splices.

General

- If there is any ambiguity or contradiction between the standards identified below and this specification, the specification will take precedence. Any discrepancy shall be brought to the Buyer's attention by the Manufacturer.
- Conductor size and stranding shall be in accordance with the itemized purchase request.
- Installation support and supervision may be requested from the Manufacturer by the Buyer. A separate line item addressing the cost and description of this work shall be provided with the bid response.
- All connectors shall be supplied by plants specified by the Manufacturer in their bid response, including proof of their ISO 9001 certification.

Applicable References

- The electrical and mechanical characteristics, geometry, and features of the connectors supplied under this specification shall meet the requirements specified herein and shall conform to the latest revisions of applicable ASTM, NEMA, and IEC Standards.
- **ANSI C119.7** connectors for use between aluminum-to-aluminum conductors designed for normal operation above 93°C. (This document is currently under development by ANSI C119. Until released, ANSI C119.4 and ANSI C119.0 should be applied with additional considerations for temperatures above 93°C.)
- **ANSI C119.0** electric connectors – Testing methods and equipment common to the ANSI C119 family of standards.
- **IEEE 1283** Guide for determining the effects of high-temperature operation on conductors, connectors, and accessories.
- **IEC 61284** Overhead Lines – Requirements And Tests For Fittings.

Detailed Requirements

It should be noted that connectors are not governed by any of the traditional ASTM Standards associated with different types of conductors that specify the material properties of the different components of the conductor. Instead, the industry has allowed connector

manufacturers to select the materials they apply in the various components of the connector. Therefore, the vendor shall be required to provide documentation of the ASTM standards for the materials and specific alloys used in their connector assemblies.

The documentation requirement applies to every component in the connector assembly.

Inspection and Tests

Shop Inspection

- No material or equipment shall be shipped from its point of manufacture before it has been inspected unless the Buyer authorizes the inspection to be made elsewhere.
- The acceptance of any material or equipment shall in no way relieve the contractor of any responsibility for meeting all the requirements of the specification and shall not prevent subsequent rejection if such material or equipment is later found to be defective.
- The Buyer's representative shall always have access to all places of manufacture where materials or equipment are being made or prepared for use under this contract, and they shall have full facilities for unrestricted inspection of such materials or equipment.

Tests

Proof that the connectors conform to the testing requirements of ANSI C119.0 and C119.7 must be provided by the Manufacturer through a submittal of certified test reports.

Any changes in design, including geometry, dimensions, materials, finishing, or installation procedure, require that new qualification testing be performed on the connectors prior to approval for purchase.

It is at the Buyer's discretion to waive any or all the provisions for inspection and tests, either in the invitation for bids or at the time of the award of contract.

Samples to be given the weight-of-coating test shall be taken from not less than 20% of the ordered quantity of components. Also, if a sample fails, the Buyer's inspector will take a sample to be given the test from every hundred units offered in the lot being tested. If more than 20% of the total number of samples taken from any lot fail this test, the entire lot shall be rejected. Certified test reports from the component Manufacturer shall be accepted in lieu of the testing specified.

Certified reports of the tests on samples in accordance with ASTM requirements shall be completed by the Manufacturer. Electronic copies of the reports shall, at a minimum, provide the information shown in Table 5.

Table 5. Example of certified report (Attachment 1 – Technical Details)

Item Number	Stock Code	
Description	Units	Details
Manufacturer's Name and Address		
Place of Manufacture		
Manufacturer's Product Number		
Manufacturer's Drawing Number		
Product Material: Alloy Type and ASTM Standard		
Will batch test certificates be supplied?	Yes/No	
Type Test Report/Certificate Number		
Dimensions:		
Body Length	Inches	
Body Width or Diameter	Inches	
Recommended Die Type		
Recommended Die Number		
Recommended Hydraulics Size	Tool or Press Reference	
Terminal Lug Size	Inches	
Bolt Size/Qty. (required)		

Signature of Vendor:

_____

Title:

_____

Marking and Packaging

Marking

Each connector shall be stamped with the following information:

- Conductor type and range of sizes the connector is for
- Appropriate die number
- Designations for area to be compressed (if applicable)

Packaging

- Each component of the connector assembly shall be clearly marked to identify its overall connector catalog reference as well as any subassembly identification numbering.
- The connectors shall be packaged, sealed, marked, and shipped in accordance with standard practice.

  Note: Some Buyers may require all components of a connector assembly to be packaged in a unit such as a plastic bag to keep them together, in which case the following text may be included.
- All components of each assembly shall be packaged together in a polyethylene bag to keep them together and identify what is required to complete a connector assembly.
- Each package, both for an individual connector assembly and multi-unit assembly packaging, shall contain only components of one approved connector system, that is, the same product number for a single container.
- Each package shall contain the connector assembly catalog number and conductor size referenced on the package. Installation instructions shall also be included in every package.
- Shipping containers shall be marked, as a minimum, with the following information: Buyer CAT ID and description, the quantity contained therein, gross weight, the contract number and the purchase order, the date of manufacture, and the Manufacturer's name.
- Prefilled connectors with inhibitor compound installed by the Manufacturer shall have a plastic cap sealing the end of the tube.

Storage and Handling

Connectors shall be stored in a safe, orderly fashion—free from any undesirable environmental conditions—to readily enable identification. Where possible, connectors should be stored in a covered area or under a tarpaulin capable of enduring the planned storage time. Store the connectors in a manner that avoids flooding, standing water, deep mud, or where ground salts may cause corrosion.

A QUALIFICATION TEST

A critical aspect of vetting a new composite-core design, manufacturer, or vendor is assuring that the conductor core will have the proper characteristics to meet the mechanical and electrical performance, serviceability, and reliability criteria. Since conductors are exposed to many environmental, mechanical, and electrical conditions during a long service life, any performance characterization test must be able to simultaneously stress and age the conductor and have measurable parameters that can be assessed for its durability and survivability.

To assist engineers in evaluating different Advanced Conductors to select a proper conductor for their use, a test with a shorter duration than the long-term performance test is required. In 2008, EPRI developed a qualification test for carbon-fiber core Advanced Conductors, as described in this Appendix. The test was validated by applying it to carbon-fiber core conductors available in the market. The conductors were tested at the conductor-rated temperature. In some cases, a temperature beyond the rated level was applied for evaluation purposes. The evaluation results indicated that the qualification test provides a good assessment of the quality of the carbon fiber conductors.

The qualification test consists of two testing components: a thermal-mechanical aging test to subject the conductor to simulated conditions that the conductor will encounter in its service, and diagnostic tests to evaluate the degradation of the tested conductor.

The protocol for the qualification test covers the following five steps:

1. Measure the conductor core's starting characteristics.
2. Conduct a thermal-mechanical aging test.
3. Determine the mechanical strength of the aged conductor.
4. Measure the conductor core's final characteristics.
5. Compare the measured mechanical strength with the manufacturer's rated value, and compare the initial with final characteristics.

The changes in chemical and mechanical core characteristics from aging are evaluated according to pre-determined acceptance criteria to verify whether the conductor passes the qualification test.

Conductor Core Characterization

The conductor core is characterized before and after the thermal-mechanical aging using two diagnostic tests. Before aging the conductor, it is necessary to measure the initial characteristics of its composite core. After aging, the characteristics of the composite core are again measured by the same two diagnostic tests to determine the deterioration that has occurred in the conductor core materials.

Typically, the diagnostic tests for conductor components include tensile tests that determine the change in physical characteristics. In the case of carbon fiber core, however, the main tensile strength components are the glass fibers. They are encased in a resin compound. The aging aspect of the core and degradation characteristics are not amenable to standard tensile tests, although they should still be part of the diagnostic tests. Composite cores are best characterized by measuring the glass transition temperature (T_g), which provides an assessment of chemical aging and bending tests, which characterize the core's mechanical properties.

Glass Transition Temperature Measurement

This test determines the temperature at which the properties of the composite core materials of the conductor change. It provides an indication of the maximum allowable operating temperature of the conductor. The test uses DMA to determine the glass transition temperature (Tg) of the composite materials. The test follows, as closely as possible, the procedure described in ASTM D7028-07 and IEC 1006 standards. Figure 2 shows an example of a DMA scan. The T_g is taken to be the temperature of the maximum loss modulus (E"). The initial and final T_g are to be measured using the same test method.

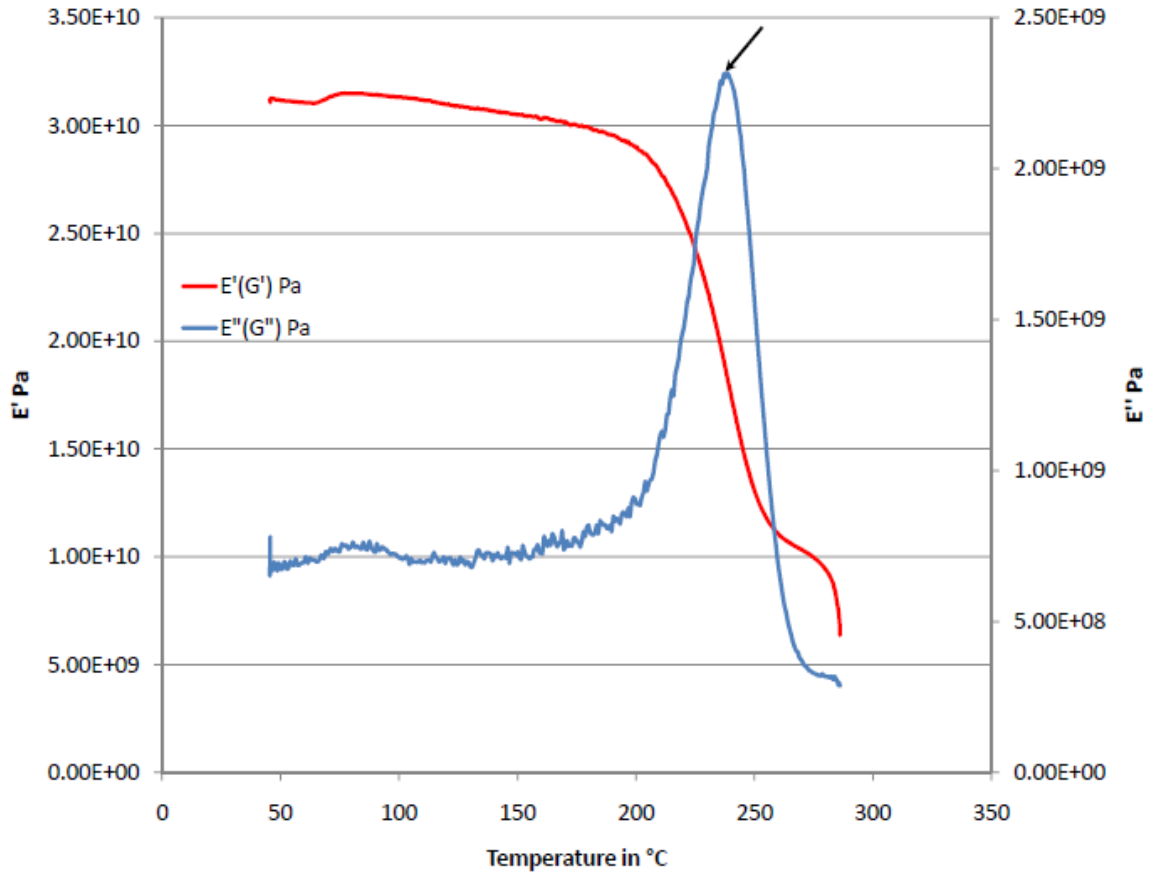

Figure 2. DMA scan (the arrow indicates the maximum loss modulus, E")

Mechanical Bending Test

This test determines the mechanical characteristics of the conductor. The cores are characterized by a three-point bending test. The initial and final mechanical characteristics are to be assessed using the same protocol. The test follows, as closely as possible, the procedure described in NF EN ISO 14125. Figure 3 shows diagrammatically the physical representation of a three-point bending test.

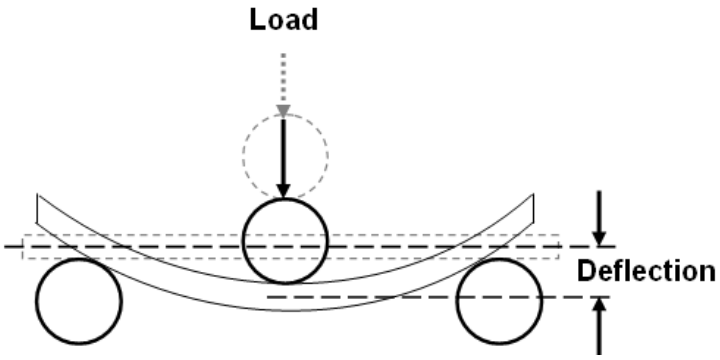

Figure 3. Physical representation of a three-point bending test

The following equations (Equations A-1 and A-2) from the classic theories of strength of materials can be used to represent the three-point bending test:

$$\sigma = \frac{8\,F\,L}{\pi\,D^3} \qquad \text{Eq. A-1}$$

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{4\,\Delta F\,L^3}{3\pi\,D^4\Delta s} \qquad \text{Eq. A-2}$$

Where:

σ (in MPa) is the maximum stress at rupture.

E is the flexural modulus (in GPa).

And:

F is the load in N.

L is the distance between fulcra.

D is the diameter of the core in mm.

$\Delta\sigma$ is the stress increment in MPa corresponding to an increment in deformation, $\Delta\varepsilon$, or of deflection, Δs, (in mm) in the elastic domain.

Note that these equations are valid for linear elastic domain and homogeneous materials and are used here for simplicity.

Thermal-Mechanical Aging Test

The aging test is derived from ANSI 119.4 and IEC 61284. These standards define a thermal cycling protocol to qualify fittings of conventional conductors. The thermal cycling protocol was adjusted with suitable mechanical loads, temperature, and test parameters in developing a thermal-mechanical aging test for carbon fiber composite core advanced conductors.

In operation, the conductor will have to withstand two kinds of stress. The first stress is thermal cycling due to the electrical current change in the conductor. There are two operating temperature limits, one for continuous operation and another for short periods for emergencies. The second stress is mechanical cycling due to changes in temperature and climatic load (from wind and/or ice). Generally, the maximum allowable conductor load in operation is about 70% RTS.

Therefore, the aging test considers these two constraints when selecting suitable test parameters. The maximum operating temperature specified by the manufacturer must be considered as well. For carbon fiber composite materials, a loss of mechanical characteristics will occur and might damage the carbon core if the conductor operates above this maximum allowable temperature. Therefore, the temperature for the aging test will stay within this limit.

Test Conditions

The conductor length shall be 400 times the overall conductor diameter and shall be longer than 10 m. End fittings from the conductor manufacturer are preferred. If epoxy dead ends are chosen, specific care shall be taken to avoid hot spots under the connectors that supply electric current.

The ambient temperature shall be maintained between 15 and 30°C. The assembly shall be supported in such a way that air shall circulate freely around the assembly to provide cooling by natural convection. If forced cooling is applied, care shall be taken to ensure that the temperature along the conductor is uniform.

Measurements

- Conductor and ambient temperatures shall be measured by thermocouples or by other suitable means with an accuracy of 2°C or better. Several thermocouples shall be installed along the conductor to detect the hottest part of the conductor. The conductor temperature shall be regulated by the hottest thermocouple.
- Joint temperature shall be measured for exploratory analysis.
- Conductor mechanical load and electrical current shall be measured.

Test Protocol

- Apply a mechanical tension of 20% RTS to the conductor sample.
- Mark the conductor at the edge of the connectors to detect any slipping during the test.
- Carry out 100 cycles from ambient temperature +/- 2°C to the test temperature +/- 2°C. The conductor temperature shall not exceed the test temperature by 2°C during the current-on period. Further clarifications are provided below.
  - Conductor temperature: The test temperature is to be defined by the manufacturer. The maximum temperature must be maintained for at least 10 minutes. The heating current shall not exceed the steady state current needed to maintain the test temperature by more than 50%.
  - Mechanical load: Before the test, a preliminary calculation shall be performed to determine the minimum mechanical load reached by the conductor on an actual span in the field at high temperatures. During the test, the mechanical load shall be maintained between this value and 20% RTS.
  - A fan can be used to accelerate cooling during the current-off period.
  - Mechanical tension and temperatures shall be recorded at the end of current-on and current-off periods.
- At the end of 100 cycles, apply a mechanical tension of 70% RTS at ambient temperature to the conductor. Maintain the tension for 24 hours, then release it to 20% RTS. The mechanical load shall be applied progressively to the test conductor.
- Check that no dead-end slipping occurs.
- Repeat the thermal-mechanical cycling five times to reach 500 thermal cycles and 5 mechanical cycles in total.
- At the end of the aging test, samples of the test conductor shall be cut for final characterization. A new dead end shall be prepared. According to IEC 61824, a breaking load test shall be performed on the conductor. The conductor strength must be higher than 95% RTS.

Conductor Final Characteristics

The final characterization tests on the composite core are the T_g test with DMA and the bending mechanical test. A detailed description of these tests is provided previously in this section under “Conductor Core Characterization.”

Acceptance Criteria

The acceptance criteria were based on past tests performed on carbon fiber core materials and experience from the aerospace industry on composite material strength deterioration. The acceptance criteria are as follows:

- No conductor failure shall occur during the thermal-mechanical aging test.
- Conductor strength after thermal-mechanical aging test must be above 95% RTS.
- Composite core T_g final > T_g initial–15°C.
- Composite core flexural modulus of elasticity E final > E initial–20%.

The thermal-mechanical aging test, along with the diagnostic tests and the acceptance criteria described in this section, will enable a power company to compare and qualify carbon fiber core composite advanced conductors for their applications.

B SAMPLE CONDUCTOR FORMS

Guaranteed Data

Information called for in the following tabulation shall be furnished with a copy of the bid as guaranteed data for each conductor listed by the schedule of prices.

Conductor cross-section area, in^2					
Conductor diameter, inches:					
Weight of conductor, lb/ft:					
Ultimate tension of conductor, lb:					
Final modulus of elasticity, psi/100					
Outer strands					
Core/core strands					
Polynomial coefficients	0	1	2	3	4
Stress-strain					
Creep					
Thermal coefficient of expansion per 100 degrees F					
Outer strands					
Core					
Conductivity of aluminum strands, percent of IACS, minimum					
Resistance at two (2) different temperatures, ohm/mile		Resistance		Temperature	
Heat capacity, watts-sec/ft-deg F					
Outer strands					
Core					

Certified Test Report Form

CONDUCTOR TYPE: (circle one) ACSS ACCC ACCR Other (specify): _____

Conductor Size: _____ kcmil Stranding: _____ / _____

Reel No.	Sample No.	Diameter – inches	Conductivity – %IACS	Tensile Strength – ksi	Elongation in 10 inches %

Reel No.	Sample No.	Diameter – inches	Stress at 1% Elong. – ksi	Tensile Strength – ksi	Elongation in 10 inches %	Coating Test 2 – oz/ft2

Tested by: _____

Certified: _____

WIRE COMPANY DRAWING TEST REPORT

ORDER# _____

STOCK NUMBER _____

DATE	INSP	SAMPLE#	DIAMETER	IACS %	KSI	ELONG.	BREAK	Wrap[1]

[1] Pass/Fail

Specification Required:

DIAMETER - in		KSI	IACS%	E%
MIN		MIN	MIN.	MIN
MAX				

SPEC. APPLYING	ASTM B500,B609 B857	WIRE COMPANY CONCENTRIC-LAY-STRANDED TEST REPORT	LAY SPEC. TOL. AL MIN. MAX. 15.50 20.15 / 12.22 19.65 / 8.94 15.20
CONDUCTOR SIZE	1926.9 MCM		STEEL 7.93 12.46
CLASS OF STRANDING	AA		AL DIA. SPEC. TOL. MIN. 1.535 MAX. 1.566
NO. OF WIRES	42/19		NOM 1.22
TEMPER	HARD		NOM .894
COATING	BARE	CUMBERLAND ACSS/TW	STEEL 0.557 0.577

REEL NO.		1324	1325	1465	1468	1510	
DATE		12/08/20	12/09/20	12/9/2020	12/9/2020	12/12/2020	
FOOTAGE		8,800	8,800	8,800	8800	8,800	
SAMPLE NO.		204675	204730	204737	204818	204998	
NO. OF WIRES	ALUM.	42	42	42	42	42	
	STEEL	19	19	19	19	19	
							MAX 2531
LBS/1000		2458.71	2442.69	2455.60	2446.32	2471.71	MIN 2412
DIRECTION OF LAY		R.H.	R.H.	R.H.	R.H.	R.H.	
DIAMETER		1.5520	1.5540	1.5650	1.5600	1.5600	OUTER
LENGTH OF LAY		17.10	17.00	17.00	16.20	16.80	LAYER
DIAMETER		1.2200	1.2200	1.2200	1.2200	1.2200	MIDDLE
LENGTH OF LAY		15.50	15.80	15.60	15.80	15.60	LAYER
DIAMETER		0.9000	0.9000	0.9000	0.9000	0.9000	INNER
LENGTH OF LAY		12.80	12.90	12.30	12.30	14.90	LAYER
							MAX .1153
							MIN .1113
DIAMETER		0.5610	0.5640	0.5580	0.5600	0.5600	OUTER
LENGTH OF LAY		8.20	8.90	8.50	8.40	9.00	LAYER
							STEEL
STEEL NO.		650906	650979	132953	132952	132968	
MACHINE NO.		63	63	63	63	63	Caballe
							65
ORDER NO.							

TEST BY _____

CALCULATED BY _____

ANNEALED WIRE TEST RECORD (ACSS)

ORDER#		<Conductor Description> Name & Stranding				**LOT 1**
REEL#	132462					
DATE		**Operator Name** James Russel				
FOOTAGE	8,800					
1st Layer	**WIRE SIZE**	**LBS. BREAK**	**ELONG**	**WEIGHT**	**KSI**	**COND%**
1	0.2164	360	28.00%	49.08	10.00	64.00%
2	0.2144	363	34.00%	48.91	10.40	64.00%
2nd Layer	WIRE SIZE	LBS. BREAK	ELONG	WEIGHT	KSI	COND%
1	0.2142	376	28.00%	49.30	10.70	63.00%
2	0.1255	375	22.00%	48.72	10.60	63.00%
3rd Layer	**WIRE SIZE**	**LBS. BREAK**	**ELONG**	**WEIGHT**	**KSI**	**COND%**
1	0.2146	365	31.00%	48.52	10.70	63.00%
2	0.2148	370	28.00%	47.57	10.00	63.00%
STEEL CORE	**Wire SIZE**	**LBS. BREAK**	**WRAP**	**WEIGHT**	**KSI**	**COND%**
19 X .1133	0.1148	2,617	PASS	39.14	254.00	10.32%

Round Wire Equivalent No Requirement		**KSI/TENSILE MAX** 14.0 **MIN** 8.5		**ELONGATION ELONGATION**	**MIN 20%**	**COND. MIN 63%**
	DIAMETER MAX 0.1153 **MIN** 0.1113		**GALFAN**	**KSI MIN** 230	**COND. MIN** 8.0	

C EXAMPLE OF A CONDUCTOR SPECIFICATION

Standard Purchase Specification for Advanced Conductor

[Can be developed for any Advanced conductor regardless of conductive strand or core materials]

A. SCOPE (see Purpose and Scope description)

This specification covers the un-insulated [Spell out conductor type and description, for example] Aluminum Conductor Steel Supported (ACSS) for use as an electrical conductor.

B. GENERAL (see General description)

If there is any ambiguity or contradiction between the Standards identified below and this specification, the specification will take precedence. The Manufacturer shall bring any discrepancy to the Buyer's attention.

Conductor size and stranding shall be in accordance with the itemized purchase request.

The Buyer may request installation support and supervision from the Manufacturer. A separate line item addressing the cost and description of this work shall be provided with the bid response.

Plants specified by the Manufacturer in their bid response, including proof of their ISO 9001 certification, shall supply all core and conductors.

C. APPLICABLE SPECIFICATIONS (see Applicable Codes, Standards, and Sample Specification)

The electrical and mechanical characteristics, geometry, and features of the conductor supplied under this specification shall meet the requirements specified herein and shall conform to the latest revisions of applicable ASTM, NEMA, and IEC Standards:

[Note: select a subset of specifications applicable to conductor type]

ASTM B609 – Aluminum 1350 round wire, annealed and intermediate tempers, for electrical purposes

ASTM B958 – Standard specification for extra high strength and ultra-high strength Class A Zinc-5% aluminum-mischmetal alloy coated steel core wire for use in overhead electrical conductors

ASTM E29 – Standard practice for using significant digits in test data to determine conformance with specifications

ASTM E228 – Standard test method for linear thermal expansion of solid materials with a push-rod dilatometer

ASTM B856 – Standard specification for concentric-lay-stranded aluminum conductors, coated steel supported (ACSS)

ASTM B857 – Standard specification for shaped wire compact concentric-lay-stranded aluminum conductors, coated steel supported (ACSS/TW)

ASTM B500 – Metallic coated or aluminum-clad stranded steel core wire for use in overhead conductors

EN 50540 – Conductors for overhead lines – Aluminum conductors steel supported (ACSS); non-steel sections are applicable

IEC 61395 – Overhead electrical conductors – Creep test procedures for stranded conductors

IEC 62219 – Overhead Electrical Conductors – Formed wire concentric lay stranded conductors

IEEE Standard 738 – Standard for calculating the current temperature of bare overhead conductors

NEMA WC-26 – Binational wire and cable packaging standard

D. DETAILED REQUIREMENTS (see Detailed Requirements description)

[Note: use a subset of clauses applicable to the advanced conductor type being purchased.]

The conductor shall be of the size and stranding specified in the Schedule of Prices.

Conductor materials, construction, characteristics, and tests shall be in accordance with ASTM B 856, except as otherwise specified herein.

Steel core wire shall be in accordance with ASTM B 498, Class A coating.

Aluminum wire shall be in accordance with ASTM B 609.

Stranded steel core wire shall be in accordance with ASTM B500.

The wires of each layer shall be in close proximity to each other, and each layer shall be in actual contact with the layer underneath.

The lay of the surface wires or segments of the conductor shall be right hand. The direction of the lay of the aluminum and steel wires shall be reversed in successive layers.

Stranded conductors shall be capable of withstanding the normal handling necessary for manufacture and erection (such as reeling, unreeling, and pulling through stringing sheaves under sufficient tension to keep the conductor off the ground) without being deformed from a circular form in such a way as to increase the power loss due to corona formation.

The steel wires of the core shall be so formed that when the cable is cut and the aluminum wires are stripped away from the core, as required for splicing, the steel wires can be readily regrouped and easily held in place by one hand to allow a splicing sleeve to be slipped over the cut end of the core. This structure permits the core to be made of either preformed or unformed wires but prohibits the use of any deformed wire in the core.

E. INSPECTION AND TESTS (see Inspection and Tests description)

[Note: use a subset of clauses applicable to the advanced conductor type being purchased.]

1. Shop Inspection

    a. No material or equipment shall be shipped from its point of manufacture before it has been inspected unless the Buyer authorizes inspection to be made elsewhere.

    b. The acceptance of any material or equipment shall in no way relieve the contractor of any of his responsibility for meeting all of the requirements of the specification and shall not prevent subsequent rejection if such material or equipment is later found to be defective.

    c. Buyer's representative shall, at all times, have access to all places of manufacture where materials or equipment are being made or prepared for use under this contract, and they shall have full facilities for unrestricted inspection of such materials or equipment.

2. Tests

    a. Buyer, at their discretion, may waive any or all of the provisions for inspection and tests, either in the invitation for bids or at the time of award of contract.

    b. Aluminum wire shall be tested as required in ASTM B 609. Steel wire shall be tested as required in ASTM B 498.

    c. Tests shall be made on individual wires before stranding, except the weight-of-coating test shall be performed on samples of the core wire taken from the completed core.

d. Samples to be given the weight-of-coating test shall be taken from not less than 20 percent of the reels of stranded core wire with a minimum of one sample for every ten reels of composite cable. All wires from each stranded sample shall be tested. If a sample taken from any reel (either on the original sampling or any subsequent sampling) fails to meet the weight of Class A coating values specified in ASTM B 498, that reel should be rejected. In addition, if a sample fails, the Buyer inspector will take a sample to be given the test from each reel offered in the lot being tested. If more than 20 percent of the total number of samples taken from any lot fail this test, the entire lot shall be rejected. Certified test reports from the steel wire Manufacturer shall be accepted in lieu of the testing specified.

e. Certified reports of the tests on samples of conductors and of individual strand wires, in accordance with ASTM requirements, shall be completed by the Manufacturer. Electronic copies of the reports shall, at a minimum, provide the information shown in Appendix # as well as the pass/fail wrap test and adherence-of-coating test. These reports must state the number of reels and net weight of ACSS covered by the report. The report must also indicate which tests were made before stranding and which tests were made after stranding.

3. Stress-Strain Tests

   a. Buyer will require stress-strain tests to be completed and submitted electronically for the initial purchase of any conductor design.

   b. If requested by the Buyer, repeated stress-strain tests on the composite cable and the steel core shall be performed in the presence of the Buyer's inspector.

   c. One reel will be required if ordering 10 reels or less. One sample of composite cable and one sample of steel core from each of two different reels will be required for orders between 11–20 reels. One sample of composite cable and one sample of steel core from each of three different reels will be required on an order for 21 or more reels, unless otherwise specified. The test samples shall each be approximately 50 ft long to provide 500 in. between measure points of unstressed conductor.

   d. Tests on the composite cable shall be performed as follows: Sufficient tension, not to exceed 8 percent of the rated strength of the cable being tested or 1000 pounds, whichever is the smaller, shall be applied gradually to the sample in order to eliminate sag and ensure comparative straightness before the scales fastened to the cable at each end of the gage length are set. The tension applied to each sample shall be increased by small increments for the following loading conditions in the sequence shown, and simultaneous readings of tension and elongation up to 80 percent of rated strength shall be recorded:

Load initially to 8 percent of rated strength or set gages at zero.	
1000 pounds, whichever is smaller.	
Load to 30 percent of rated strength.	Hold 30 minutes.
Reduce to initial loading.	
Load to 50 percent of rated strength.	Hold 60 minutes.
Reduce to initial loading.	
Load to 70 percent of rated strength.	Hold 60 minutes.
Reduce to initial loading	
Load until sample is broken.	Record-breaking load.

e. The breaking strength of the conductor, obtained from the above test, shall be not less than the rated strength if failure occurs in the free length at least six inches beyond the end of either gripping device, or shall be not less than the 95 percent value shown in the following tabulation if failure occurs inside or within six inches of the end of either gripping device.

f. Tests on the steel core shall be made as follows: This test shall consist of three successive applications of load applied in a manner similar to that for the composite cable. Pull core to the same amount of elongation as the composite cable at 30, 50, and 70 percent of rated strength (see tabulation E.3.d.). Determine actual breaking strength and record data in the same manner as for the composite cable.

g. Certified reports of stress-strain tests—in both tabulated and graphic form—shall be furnished on the composite cable and steel core by the contractor in electronic format. These reports shall include the following data:

- Temperature at which tests are conducted
- Identity of reel from which test samples are taken
- Initial and final modulus of elasticity for the composite conductor and the steel core

h. Composite core conductors shall have the thermos-mechanical aging tests outlined in Chapter 4 Composite Core Qualification Test performed to validate the performance and serviceability of the composite core material and its application in an overhead conductor.

F. PACKING AND MARKING (see Marking and Packing description)

1. The conductor shall be packed, sealed, and shipped in accordance with recognized standard practice.
2. The reel lengths on substantial reels shall be as specified in the Schedule of Prices, in accordance with NEMA WC-26, except that—unless specified otherwise in the Schedule of Prices—reel lengths may vary minus zero (0) to plus percent, and

5 percent of the order by weight may be shipped in random lengths upon approval by the Buyer. None of these lengths shall be less than 50 percent of the reel length specified or the reel length agreed upon after the award of contract. Reel lengths can also be specified for a particular order to meet the unique needs of the project; the reel lengths may be specified as a non-standard length for all reels ordered or specific reel lengths for each individual reel on the order. There shall be only one length of conductor on a reel. For metal reels, the inside of the flanges and drum of the reel shall be covered to prevent the metal reel surfaces from coming in contact with the aluminum conductor.

3. All reels shall have a minimum of a Level 2 reel covering per NEMA WC-26. The specific reel covering to be provided will be identified in the contract document. Product damage during shipping is typically the responsibility of the vendor. The ends of the conductor shall be securely attached to the reel flange.
4. Shipping coils and reels shall be marked, as a minimum, with the following information: Buyer CAT ID and description, the quantity contained therein, gross weight, the contract number and the Purchase Order, the date of manufacture, and the manufacturer's name. An arrow indicating the direction in which the cable is wound shall be painted on the reel or coil at the end of the cable.
5. Reel heads shall have metal hub bushings with a hole to fit a 5- to 5.25-inch arbor shaft for reel support equipment.

G. CONDUCTOR STORAGE AND HANDLING (see Storage and Handling description)

1. Conductors shall be stored in a safe, orderly fashion, free from any undesirable environmental conditions to enable identification. Where possible, conductors should be stored in a covered area or under a tarpaulin capable of enduring the planned storage time. Store the conductor in a manner that avoids flooding, standing water, deep mud, or where ground salts may cause corrosion.
2. Unlagged drums should be stored in such a way as to prevent other drum flanges or protuberances from damaging the conductor. Only fully lagged and lined drums shall be stored outdoors. Lagging materials shall be handled carefully to prevent damage to the packing or the conductor.
3. Completed drums of the conductor shall only be lifted using specialized forklift trucks, cradles, or slings employing a suitable mandrel through the drum spindle hole. The use of forklift trucks lifting by the flange rim is not acceptable.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

Program:

Overhead Transmission

3002030304

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com