

## Understanding Crossarm Testing

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**Abstract** – A variety of crossarm technologies exist for use in electric utility systems. The NESC [8] requires crossarms meet a specified mechanical load. Many utility procurement specifications require other types of tests including electrical and environmental tests. This paper condenses information presented in [6] and will help electric utility engineers better understand how popular mechanical, electrical and environmental tests are performed and how to interpret the results. The paper includes a discussion of the methods and interpretation of test results for various mechanical and electrical tests for the assembled arm, as well as corrosion and accelerated weathering tests.

**Index Terms**—crossarm, basic insulation level, critical flashover voltage, corrosion, environmental, fiberglass, insulation, mechanical load, National Electric Safety Code, ultraviolet radiation.

### I. INTRODUCTION

A crossarm is an assembly of components, installed near the top of an electric utility pole, whose primary purpose is to support the mechanical load of the conductors, insulators, and related hardware. This assembly typically includes a beam, gain and attachment hardware. Popular beam materials include steel, solid wood, laminated wood, hollow or foam filled fiber reinforced extrusions, and solid fiber reinforced extrusions. The gain, when used, is a bracket or spacer located at the interface between the crossarm and the pole. Attachment hardware is typically galvanized steel, installed through holes in the beam or gain to attach conductors, insulators, or other components to the arm, as well as attach the arm to the pole.

NEETRAC is often asked how to properly test crossarms and how to interpret the test results. This paper provides a summary of mechanical, electrical, and environmental testing for assessing crossarm performance characteristics.

This paper does not include specific crossarm performance requirements nor does it compare the performance characteristics of different crossarm technologies. It also does not endorse any specific crossarm technology. Instead, it outlines general test procedures appropriate for evaluating crossarms and makes recommendations for electric utilities to consider when evaluating test results. The mechanical section of the paper focuses on various loading scenarios. The

electrical section reviews a variety of tests used to evaluate crossarm dielectric characteristics and discusses the most appropriate conditions under which these tests should be conducted. The environmental section reviews physical and environmental conditioning tests such as salt fog, UV, chemical exposure and abrasion.

### II. MECHANICAL TESTING

Mechanical loading of crossarms is specified by the structural requirements of the governing code, such as the National Electric Safety Code [8]. It is important to test a crossarm with the hardware and loading scenarios anticipated in the field. The crossarm assembly acts as a system and there are frequently interactions between various components. Any part of the crossarm assembly can fail a test including the beam, washers, bolts, eyes, and gain. A bearing washer may work well with one beam or eye design, but fail when used with another beam or eye design. Therefore, it is extremely important to test the complete assembly to account for interaction effects.

Balanced 3-point bend tests are popular tests that manufacturers typically use for their “catalog rating.” Fig. 1 shows typical 3-point bend loading diagram.

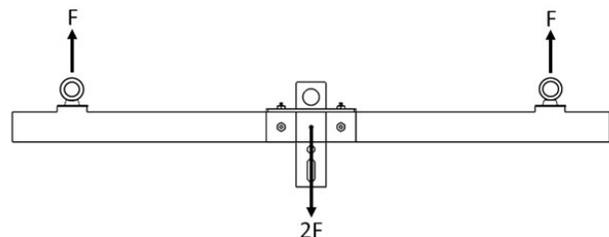


Fig. 1. 3-point bend diagram

Utility specific loading requirements should be used to develop a test plan that includes loading scenarios other than a simple 3-point bend test. Many utilities require imbalanced loading test scenarios that simulate a crossarm’s reaction to a broken conductor, as well as temporary loads that may be applied during line construction. Other utility construction

standards specify imbalanced loading in three-phase construction where one side of the crossarm carries two phases. Imbalanced loads create a moment about the gain or pole attachment point that does not exist in balanced loading. Fig. 2 shows how loads applied at different attachment points would result in moments about the pole and pole gain. Most utilities require tests in at least three directions at an attachment point. In some cases, utilities also require cyclic loading.

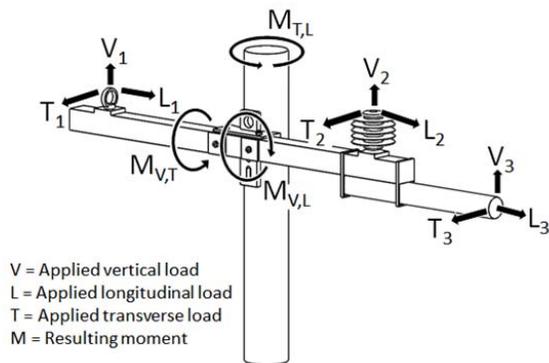


Fig. 2. Hardware load test directions

Fig. 3 provides an example of a real world imbalanced loading scenario. This test was performed to determine the effect of a single broken conductor attached to an insulator.

Applying failure load tests to full size crossarms in a manner that reflects real-world load scenarios allows the user to understand and evaluate different performance characteristics of the arm assembly including flexural and crush failures of the beam, hardware failures and hardware pullout failure.

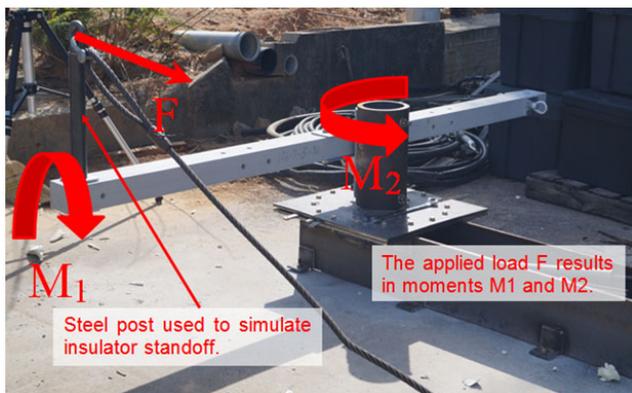


Fig. 3. Imbalanced load scenario

Another scenario to test is a beam's resistance to crushing during installation (torqueing) of the hardware. This typically

involves using a calibrated torque wrench to apply some multiple of the typical installation torque. Fig. 4 shows a crush failure of a beam.



Fig. 4. Crush failure of a beam

For fiberglass crossarms, some utilities and manufacturers require a pre and post UV 3-point bend test comparison of individual sections or plaques removed from manufactured crossarms. Testing plaques can provide useful information for manufacturers and laboratories conducting research on isolated performance characteristics of crossarm components. However, utility engineers should be cautious about extrapolating such test results to the actual performance of a full crossarm. As previously indicated, the design of the beam and interaction of various crossarm assembly components have a significant effect on overall performance.

Finally, users are encouraged to request copies of the manufacturer's test reports to gain a full understanding of the test setups and number of samples used to develop the data.

### III. ELECTRICAL TESTING

Traditionally, distribution crossarms do not have electrical ratings. As stated earlier, the primary function of a crossarm is to support the mechanical load of the conductors, insulators, and related hardware. In addition, the physical arrangement of the crossarm components is determined by the voltage rating of the line, the line design, and the required additional equipment such as fused disconnects, surge arresters, transformers, reclosers, etc. The placement of these components, as well as the grounding design, dictates the electric field patterns and potential leakage current paths across the crossarm.

If the dielectric performance of a distribution utility crossarm is to be evaluated, a full-size, as installed crossarm setup should be used and the phase-to-phase distances, as well as the grounding design, must be documented. Non-wood alternative crossarm materials such as fiber-reinforced polymer (FRP) crossarms have introduced the concept of testing the electrical properties of the crossarm material itself. At the writing of this paper, there are no North American standards that dictate a pass/fail electrical rating for any type of distribution crossarm. Some manufacturers of FRP

crossarms do have published values for electrical properties, but these vary from manufacturer to manufacturer.

The following sections discuss the different types of tests and ratings for consideration when evaluating the electrical properties of different crossarm products. If manufacturers provide electrical property characteristics in their product descriptions, users are encouraged to request copies of the test reports to gain a full understanding of the test setups and number of samples used to develop the data.

#### A. Materials Testing

Crossarm materials can be tested to evaluate their relative dielectric strengths, but these tests are typically performed on small samples and provide an assessment of the material itself, not the full apparatus. One example is ASTM D149-09 [9], which defines three test procedures to determine the dielectric strength of solid insulation materials at commercial power frequencies. This standard specifically states, “*the results obtained by this test method can seldom be used directly to determine the dielectric behavior of a material in an actual application.*” The test results are provided as a dielectric strength typically in V/unit length and are best used for process control, acceptance, or research testing.

#### B. Power-frequency Testing

Power-frequency or ac testing uses an alternating voltage with a frequency between 45 to 65 Hz. Per IEEE 4-2013 [10], the voltage waveshape should be a sinusoid with a ratio of peak-to-rms values equal to  $\sqrt{2}$  within  $\pm 5\%$ . This testing is used to evaluate the apparatus under simulated, in-service field conditions. Two different types of tests are typically used – withstand and disruptive discharge (i.e. flashover). These tests can be performed under dry or wet conditions. IEEE 4-2013 Clause 6.4 describes the typical procedures used for both withstand voltage and disruptive discharge voltage tests. It is left to the apparatus standard to specify either the voltage levels and test duration for the withstand test or the number of voltage applications and pass/fail requirements for the disruptive discharge test.

As there are no established apparatus standards that address electrical ratings for crossarms, both the manufacturer and the user need to define their requirements. Users are cautioned that differences in withstand or disruptive discharge voltages between technologies or within technologies may not be indicative of better or worse performance. It may be worthwhile for users to benchmark their existing crossarm technologies from current stock and field-aged stock. Test plans can be developed for users to determine the present state-of-the-art values for wet and dry withstand voltage ratings and wet and dry disruptive discharge voltage ratings for their specific technologies and crossarm assemblies.

#### C. Impulse Testing

Impulse or lightning impulse testing uses a voltage with a waveshape characterized by its front time, peak voltage and time to half-value. A standard lightning impulse as defined by IEEE 4 [10] is “*a full lightning impulse having a front time of 1.2  $\mu$ s and time to half-value (i.e. tail time) of 50  $\mu$ s, and is described as a 1.2/50 impulse.*” IEEE 4 [10] defines a chopped lightning impulse as “*a lightning impulse during which a disruptive discharge causes a rapid collapse of the voltage to practically zero value. The collapse can occur on the front, at the peak, or on the tail.*” Both types of impulses are needed to define utility impulse ratings for components.

BIL and CFO are the terms commonly used to discuss impulse ratings of utility components. Basic impulse withstand level or basic insulation level (BIL) is accepted by most utilities to be the crest value of a standard lightning impulse for which the insulation exhibits 90% probability of withstand or a 10% probability of failure [4] (where failure is a disruptive discharge). The CFO voltage (critical flashover voltage) has a fixed probability of 50% and is defined as the crest value of a standard lightning impulse for which the insulation exhibits 50% probability of withstand or failure [4]. For a more in depth discussion of the differences between CFO and BIL levels, work by P.B. Jacob et al. [1] and S. Grzybowski et al. [7] provide a more detailed discussion of the statistical differences between the two commonly used rating values.

Research into the CFO levels of crossarms has been conducted on both wood and FRP (fiber-reinforced polymer) crossarms. As stated earlier, these values are a function of the test setup, sample length, and sample material. CFO values for both wood and FRP crossarms are discussed in [1] and [7] with new crossarm material having a dry positive CFO rating of 700 kV for FRP and 600 kV for wood respectively assuming a 4' crossarm length. In each citation, only one type of wood and one type of FRP crossarm were tested and only in new condition. These CFO levels were reduced by approximately 20% under wet conditions. CFO levels most likely will also decrease due to environmental aging of the crossarm materials, but similar studies on aged samples were not available.

## IV. ENVIRONMENTAL TESTING

Several environmental factors affect how long a crossarm will support the required mechanical load. A number of tests can evaluate the change in performance resulting from exposure to conditions that might affect both electrical and mechanical performance.

Corrosion of the gain and attachment hardware is typically evaluated for all types of crossarms, but UV exposure tests are typically only performed on FRP crossarms. In addition to corrosion and UV testing, there are other tests utilities might consider based on local conditions including: abrasion, bird

feces, freeze thaw cycling, and chemical contamination. As with mechanical and electrical testing, to the extent practical, crossarm assemblies should be tested as they would be configured in the field.

#### A. Corrosion

Corrosion causes a reduction in a metal component's cross-sectional area, typically through interaction with oxygen. Coatings are typically used to protect metal components by creating a barrier that prevents oxygen from chemically reacting with the metal part. Zinc is a popular coating for hardware, including threaded fasteners, eyes, and pins. The zinc reacts with the oxygen forming a zinc oxide layer that protects the steel. Zinc reacts more slowly than steel, but eventually the zinc layer will be lost to corrosion, exposing the steel parts. Corrosion can be accelerated in the presence of ionized solutions, such as solutions containing salt (sodium chloride), and salt fog testing is a common way to evaluate coating performance.

ASTM A153 (*Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*) [11] is a manufacturing specification utilities often use to stipulate the coating on their crossarm hardware. ASTM A153 specifies zinc quality and thickness. The first step in evaluating a coating is to check the composition of the zinc and measure the thickness of the coating. A magnetic thickness gauge is a non-destructive way to measure the thickness, while mass-loss is a destructive method. ASTM A153 contains details on these and other methods for measuring thickness loss.

Salt fog testing to ASTM B117 (*Standard Practice for Operating Salt Spray (Fog) Apparatus*) [12] is typically used to evaluate coating performance, though ASTM G85 (*Standard Practice for Modified Salt Spray (Fog) Testing*) [13] is an alternative. ASTM B117 provides a continuous salt spray, while ASTM G85 cycles between spraying salt solution with drying periods. ASTM G85 is more acidic with a pH of 3, while ASTM B117 is neutral with a pH of 7. ASTM G85 is considered more real-world as it uses both wet and dry cycles in the test program, especially for acid rain/industrial environments. In addition, ASTM G85 has various annexes that allow the selection of different environments.

ASTM B117 or ASTM G85 can compare the relative performance of various coatings to the selected salt fog test protocol, but they should not be used to predict the life of a coating. Neither ASTM B117 nor ASTM G85 provide for a procedure to correlate aged samples with control samples and field aged samples. The comparison of coating performance is visual and based on an estimate of the severity and amount of rust present. ASTM D610 (*Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces*) [14] provides a useful resource that can be adapted for grading the performance of zinc coated parts.

Thermal diffusion galvanizing (TDG) is a relatively new

galvanizing technology. ASTM A1059 (*Standard Specification for Zinc Alloy Thermo-Diffusion Coatings (TDC) on Steel Fasteners, Hardware, and Other Products*) [15] provides a loose framework and process controls for thermal diffusion galvanizing. However, tests performed at NEETRAC found that there was significant variation in the effectiveness of the thermal diffusion galvanizing processes used by different manufacturers. Therefore, utilities should require testing that evaluates a specific suppliers' coating performance on production hardware.

#### B. Accelerated Weathering (UV Testing)

Treated wood structures are generally believed not to deteriorate significantly as a result of exposure to ultraviolet light. Therefore, accelerated weathering or UV testing is typically performed only on FRP crossarms comprised of a fiber reinforcement in a resin matrix. When FRP crossarms first penetrated the electric utility market, manufacturers did not address UV resistance of the fiberglass material. Today, FRP crossarm manufacturers typically add UV inhibitors to their resin. Different manufacturers have different formulations and it might be useful to conduct comparative testing. Without control samples and multiple experiments, it is not possible to use accelerated weathering testing to predict the life of a crossarm.

Regardless of the accelerated weathering test protocol chosen, the results only allow comparison of the relative performance of samples tested to the spectral light distribution, temperature, and humidity of the conducted test. The amount of radiation incident on the sample is sometimes wrongly assumed an accelerating factor when predicting the life of a product. For example, if a product receives the equivalent of five years of radiation in six months, this is sometimes wrongly assumed to correlate to five years of UV exposure outdoors. However, equivalent radiation dosage does not lead to equivalent degradation.

ASTM G151-10 [16] states that for accelerated testing: "*Even though it is very tempting, calculation of an acceleration factor (ASTM italics) relating x hours of a laboratory accelerated test to y months or years of exterior exposure is not recommended.*" Other UV testing standards also make similar qualifications regarding acceleration factors [17], [18].

Q-Lab Bulletin LU-8030 [5] explains the reasoning for this warning, stating:

*"Replicate specimens receiving the same accumulated radiation dosage often show vastly different degradation. This is because timing in Joules does not take into account the substantial variations in weathering stress caused by the following other factors:*

- 1. Differences in Spectral Irradiance*
- 2. Differences in Exposure Temperature*
- 3. Differences in Moisture Exposure"*

Spectral irradiance varies with geographic location, time of season, and local weather. Materials will react differently depending on the strength of different wavelengths in the spectrum. Therefore, tests conducted at different times under different weather conditions and at different geographic locations yield different results [5].

Exposure temperature also affects degradation. Fisher et al. [2] conducted a test where multiple specimens received exactly the same radiant dosage, but were at different temperatures because of their location in a support rack: *“It is not surprising that the temperature differences observed on outdoor exposure racks translate to analogous material failure rates. [5]”* Q-Lab bulletin LU-8030 concluded that a *“Joule in the center of the rack was twice as damaging as Joule at the edge [5].”* One rule of thumb is that a 10 °C temperature increase doubles the reaction rate [3].

Additionally, the temperature increase of accelerated testing can overstress a material in a way that would not occur in the field so that *“other degradation processes which would not occur at the normal application temperature may also be activated and lead to results which would not apply in practice [3].”* For example, a Christmas tree light bulb puts out about 1 Watt of power, which is 1 Joule of energy per second. While an individual could hold a Christmas light with little effect for 60 seconds, the same individual would be burned by holding a 60-Watt light bulb for 1 second, even though they are equivalent amounts of energy (60 Joules in both cases).

Moisture is also a significant factor in degradation. LU-8030 states *“in some materials the presence or absence of moisture resulted in radically different types of degradation in replicate exposures with identical radiant exposure [5].”*

Another debate is natural sunlight exposure versus artificial light (fluorescent, xenon arc, etc.). While natural sunlight would appear to be superior to artificial light, engineers should consider that tests using natural sunlight, especially when concentrated using mirrors, is not as repeatable as an artificial light indoor test where spectral irradiance, temperature, and humidity can be better controlled. The higher variability between repeated outdoor tests is why ASTM G90 [18] states,

*“[ASTM G90] should not be used to establish a “pass/fail” approval of materials after a specific period of exposure unless performance comparisons are made relative to a control material exposed simultaneously, or the variability in the test is defined so that statistically significant pass/fail judgements can be made. It is strongly recommended that at least one control test specimen be exposed with each test.”*

Ideally, accelerated weathering tests should be conducted on full size crossarms. Practically, few laboratories have UV

chambers large enough to conduct such testing so plaques are often created from sections of crossarms and placed in test equipment.

Accelerated weathering of thermal diffusion galvanized hardware should also be considered. Some thermal diffusion galvanized treatments use a polymeric coating after galvanizing to seal the surface of the part, which may degrade under UV exposure.

Finally, utilities should consider that accelerated weathering testing in and of itself might not provide a suitable indication of crossarm performance. The question to be answered is, “How does UV degradation affect the mechanical strength of the crossarm?” While one manufacturer’s arm might “look worse” than another manufacturer’s arm after accelerated weathering, visual observation cannot be used to conclude that there is a strength reduction.

### C. Other Environmental Conditions

There are several other environmental conditions that utilities might want to evaluate including heating and cooling, bird feces and other chemical contaminants, and windblown particulates.

Crossarm assemblies are made of many different components and different arm technologies may have significantly different thermal expansion coefficients. Over large temperature ranges, the coefficient mismatch can lead to failed hardware, arm buckling, and crazing of the surface finish.

Bird feces and other chemical contaminants such as agricultural fertilizer and pesticides, as well as chemicals from industrial processes can cause corrosion and affect the life of the crossarm.

Finally, abrasion from windblown particulates could be significant in desert regions. Crossarms transported on a line workers truck are also subject to abrasion. Fig. 5 shows hardware samples tested on a shaker table operated at 55 Hz, which mimics shipping abrasion.



Fig. 5. Abrasion test on galvanized samples

## V. SUMMARY

Mechanical, electrical, and environmental tests are often performed on crossarms, particularly on newer FRP designs, to evaluate their performance. Results from these tests can be useful, but they must be considered carefully.

In the field, a crossarm can be installed in many different configurations, which can lead to various mechanical loading scenarios. Crossarms can experience different types of mechanical failures including failure of the beam, gain, hardware pullout, and hardware failure. All of the components that make up the crossarm assembly interact with each other, so it is important to perform mechanical tests on complete assemblies, as they would be installed in the field.

The same is true when assessing electrical performance, though electrical tests on wood crossarm alternatives, such as FRP crossarms are sometimes performed on crossarm material samples. At the writing of this paper, there are no North American standards that dictate a pass/fail electrical rating for any type of distribution crossarm. Similar to mechanical testing, the exact configuration of the test samples, as well as the voltage application method, must be considered when comparing technologies or comparing designs within technologies. BIL or CFO ratings (lightning impulse) cannot be extrapolated to power-frequency voltage withstand or disruptive discharge (flashover) voltage ratings as the voltage sources have fundamentally different electric field patterns and behavior. The clearance distances between phases and the placement of other apparatus on the crossarm will affect the electrical ratings of the installation. This may result in the choice of crossarm material having little to no effect on the electrical rating of the complete system.

Environmental testing, particularly UV tests on FRP crossarms, is often required by electric utilities. However, changes in temperature, humidity, and spectral irradiance can have a large effect on the outcome of UV tests. Therefore, it is important to perform multiple replicates of tests with high repeatability using conditions that most closely represent the local crossarm installation conditions. UV comparative testing performance depends on the test conditions. Different test conditions can lead to very different comparative test results. Additionally, UV tests should not be used to predict crossarm life in the field without adequate replicates and control samples. Finally, other environmental factors such as chemical exposure and abrasion should be included in performance test programs when warranted.

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