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Low-velocity impact to transmission line conductors

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ABSTRACT

This combined experimental and numerical study addresses mechanical effects associated with the energy dissipation from transverse low-velocity impacts on a novel High Temperature Low Sag (HTLS) transmission line conductor, subjected to either free or constrained end conditions and large axial tensile loads. Impact experiments were conducted on one type of Polymer Composite Core Conductor (PCCC) belonging to the family of HTLS designs. The experimental work performed using an original approach was supported by non-linear static and dynamic finite element analysis.

Despite their geometrical simplicity, the numerical models provided useful information regarding the response of the conductor to both static and dynamic conditions. Most importantly it has been determined that the PCCC exhibits good resistance to impact under constrained end conditions with and without initial axial tension. It was also identified that the most damaging condition under impact is when the conductor had free ends and was thus subjected to severe bending. It has been shown in this work that the suggested approach to the impact testing of transmission lines could result in useful predictions of their structural integrity after low-velocity impact either during installation or in service.

1. Introduction

High-Temperature Low-Sag (HTLS) Polymer Core Composite Conductors (PCCC) such as Aluminum Conductor Composite Core (ACCC®) are starting to be used in service replacing older designs based on aluminum and steel alloys. Their response to low-velocity impacts during transportation, installation or in service, however, has not yet been addressed. There are four major overhead high voltage conductor designs currently used as transmission lines all over the world (Fig. 1.1): Aluminum Conductor Steel Reinforced (ACSR), Aluminum Conductor Steel Supported (ACSS), Aluminum Conductor Composite Reinforced (ACCR) and Aluminum Conductor Composite Core (ACCC). Operating temperatures limit the amount of power conventional ACSR and ACSS conductor designs using steel and aluminum can transmit. ACCC and the ACCR utilize composite load-bearing components that are lighter, stronger, and allow increased operating temperatures over ACSR without losing strength to annealing or exceeding maximum sag allowances.

ACCC, shown in Fig. 1.2, is manufactured by CTC Global and has a hybrid Polymer Matrix Composite (PMC) core consisting of carbon fibers with a high temperature epoxy resin surrounded by a galvanic corrosion barrier of glass fibers with the same resin [2]. The conducting strands consist of 1350-O aluminum with a trapezoidal cross-section. Despite the potential benefits, some utilities are reluctant to use these novel HTLS conductors, owing to a combination of unfamiliarity in material behavior of the composite under long term service conditions and a poor knowledge of the reliability of the composite design [3]. Although the majority of installations have been successful, several incidents have occurred where ACCC conductors failed during or shortly after installation, and transverse low-velocity impacts were the suspected causes of those failures.

Extensive research has been conducted on the impact resistance of fiber-reinforced PMC laminates, for example see [5–9], where damage from low-velocity and high-velocity projectiles was investigated given various properties of fibers and matrices. The results, however, are limited to flat laminate plates typically used in aerospace and ballistic protection applications. No research has been found pertaining to any low-velocity impacts to stranded traditional conductors, HTLS conductors, or more specifically to ACCC.

Limited work has been conducted to help characterize the mechanical properties of ACCC under static and dynamic loading conditions [10,11,2,12–14]. Research specific to the bending strength of the PMC rod was conducted by Burks, et al. to determine the minimum static bend radius to initiate damage at the Glass/Carbon interface or at any point within the composite rod [10]. Burks also quantified the residual tensile strength of the hybrid composite rod after excessive static bending [11], a result that can only be applied to static loading conditions. It has also been shown by Burks, that under severe bending exceeding the critical bend radius, the

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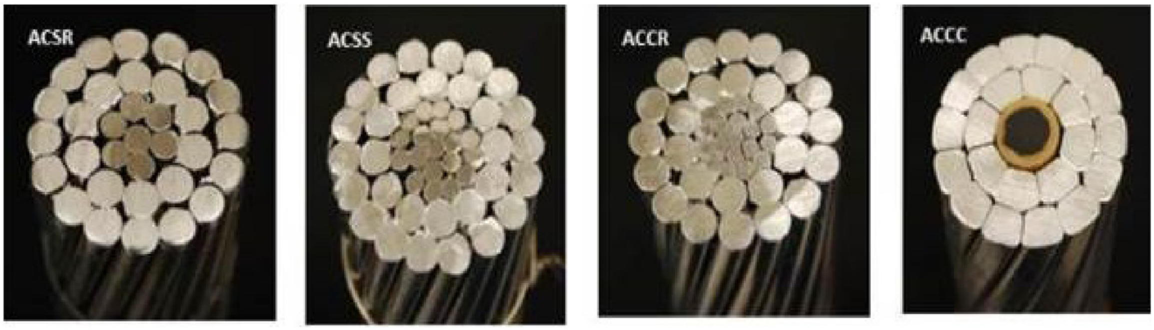

Fig. 1.1. HV overhead conductor designs currently in use [1].

Fig. 1.2. Components of ACCC Conductor [4].

ACCC rod can rapidly collapse and the failure is initiated by the kinking of carbon fibers on the compressive side of the rods [10,11].

The absence of available research on the mechanical response of transmission conductors, including next generation conductors based on PMCs, subjected to low-velocity impact was the driving force behind the research performed in this study. The results obtained allow for a much better understanding of both the damage mechanisms in all types of PCCCs and the conditions that can be most damaging and should be avoided during installation and in service.

2. Experimental methods

2.1. Tested conductors and sample preparation

The Aluminum Conductor Composite Core/Trapezoidal Wire (ACCC/TW) conductor evaluated in this research (Fig. 1.2) was received from the Western Area Power Administration (WAPA). ACCC/TW consists of the hybrid epoxy PMC core surrounded by an inner layer of 8 and an outer layer of 14 helically wound trapezoidal cross-section 1350-O aluminum strands. The overall outer diameter was 28.2 mm. The diameter of the composite rod was 9.3 mm. More properties of the materials of the conductor are presented and discussed in subsequent sections.

2.2. Impact fixture design

A specialized impact test fixture was designed and constructed in this research to perform impact tests on the conductors (Fig. 2.1). The tests used a weighted pendulum and the energy transfer was measured by angular position similar to a Charpy−Izod impact tester. ACCC/TW samples of $l = 1.10$ m in length were held in custom built clamps designed to grip the conductors through the outer aluminum stranding and transfer the loading to the core, as seen in Fig. 2.2.

Tension in the samples was measured by assuming a frictionless first-class lever having a mechanical advantage of $ma = 6.4$. A ratcheting chain puller and a Dillion Mechanical AP Dynamometer were used to increase, hold, and measure the tension on the input side of the tensioning lever arms. The measured input tension was then multiplied by the mechanical advantage to calculate the sample tension. Once the desired tension was reached, the dynamometer and chain-hoist were replaced by a turnbuckle tensioning device to fix the displacement of lever input arms. The calibration of the tensioning method was verified with strain gauges.

Angular position of the pendulum arm was measured using an optical rotary encoder attached to the pendulum axle. The angle encoder had a sensitivity of $\pi/1200$ Rad/pulse, or 2400 pulse/rev. Energies of the rotating pendulum were calculated using the equation of kinetic energy in a rotating system, $KE = 0.5I\omega^2$, where ω is the instantaneous angular velocity of the pendulum and I is the moment of inertia of the pendulum. I was experimentally determined using the equation for the moment of inertia about a fixed pivot, $I_{zz} = Wr(\tau/2\pi)^2$. The period, τ, weight, W, and radius to the center of mass, r, were measured for the entire assembly of the pendulum, four lead bricks, cylinder impactor, and ratchet straps.

The period, τ, of the free swinging pendulum was 2.325 s. The total mass of the assembled pendulum, W, consisting of four lead bricks, cylinder impactor, and ratchet straps was 56.9 kg. The radius to the center of mass, r, was 1.22 m. The resulting mass moment of inertia, I_{zz} for the instrumented pendulum was determined to be 93.2 Nms^2.

In the first part of the mechanical testing, static bending experiments were performed on the conductor subjected to both transverse static bending and axial tension. This was done to verify the accuracy of the numerical modeling under static conditions. Conductor deflections were measured for a static transverse loading of 1.00 kN imparted by a cylindrical steel tool of diameter 41.3 mm and initial axial tensions between 11.47 kN and 43.00 kN.

Subsequently, low velocity impact tests were conducted for boundary conditions of fixed displacement ends at initial tensions of 1.15 kN, 4.59 kN, 11.5 kN, 20.1 kN and 29.2 kN as well as a 3-point impact condition where the conductor was supported across 25.4 mm square support posts separated by 0.46 m. Initial height for release was set at approximately $\frac{\pi}{4} Rad$ above the point of contact. A cylindrical steel impacting tool of diameter 41.3 mm attached to the end of the pendulum struck transverse to the axial direction of the conductor for all tests. Time history of the angular position of the pendulum was recorded for each test and analyzed with MATLAB to calculate angular velocity and kinetic energy stored in the