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Research upon Contact Area between Wires in the Structure of Overhead High Voltage Transmission Line

Daniel Achiriloaiei, Cristian-Sorin Neş, Ion Dumitru

Universitatea “Politehnica” din Timişoara, Bd. Mihai Viteazu nr.1, Timişoara
e-mail: daniel.achiriloaiei@yahoo.com

Abstract

Electricity transmission from source to consumers is achieved through overhead power lines. Under the influence of weather conditions, additional stress is generated and may lead to accelerated deterioration and premature breakage. The analysis of stress and strain at wire level has a decisive role in identifying areas with peak loads and in network lifetime evaluation. The mechanical properties of the conductor may change with the emergence and development of contact imprints. In order to understand how an imprint develops and how it influences the properties of the conductor, imprint and tensile tests were done on wires taken from a steel-aluminum conductor. Theoretical and experimental researches have shown that the shape and size of imprints occurring at the contact points between wires have a significant influence on the tensile strength of the conductors. Additionally, local deformations can lead to the initiation and propagation of fretting fatigue cracks.

Key words: *conductor, wire, contact, tensile test, imprint, fretting.*

Introduction

The importance of the high-voltage power lines, as well as the costs of repair or replacement imposed a regulated lifetime for conductors between 50 and 80 years. Although regular inspection of the conductors is recommended, hidden defects (especially those generate by the contact between the conductor and terminals) can cause premature breakage of the conductor with significant economic and social consequences.

Failure is determined by the intensity and frequency of climatic and weather conditions such as air temperature, wind speed, ice and snow coating. Stress induced by surging and wind-induced vibrations represents a major problem in assessing the durability of electrical conductors, given the conclusions of experimental studies on the devastating effect of combined contact and tensile fatigue on aluminum [3, 8]. Wind generates several types of vibrations. When the conductor stands alone in the airflow, vortex-shedding induced vibrations are observed. If the conductors are grouped in bundles, wake-induced vibrations become an additional concern. A third excitation mode, galloping, occurs in colder climates. The accumulation of ice on conductors modifies their aerodynamic profile to the point of making them aerodynamically and aeroelastically unstable. Very high amplitude vibrations have been observed in such cases [2]. As a result of these vibrations, damage development appears especially at the attachment zones of the conductor and the pieces of equipment that hold it (suspension clamps, spacers, spacer-dampers, etc.). The mechanisms of failure for cables made of different materials are very complex and differ fundamentally for static stress and variable stress. Usually, the initiation points for the cracks that produce the failure of the cable are the imprints generated by wire-on-wire contact.

General Considerations on Imprints Development

Maintenance and refurbishment of conductors installed for 25-40 years is time-consuming and costly [1]. With the increasing of service life, first signs of damage appear on the wires' surface, thus providing information about physical state/morphology and residual lifetime of the conductor.

In exploitation, conductors are exposed to external loads and to minimize the possible damages induced by wind, vibration dampers are clamped regularly on the transmission lines. The conductors are subjected to maximum curvature near the clamps, as well as compressive forces exerted by the clamping devices [4]. The tensioning of the conductor and the tightening of the keeper of the suspension clamp induce contact stresses between the conductor and the bed of the clamp and between the wires of the conductor. Contact stresses in a clamping region can be divided into two categories: static (a sum of constant axial load, bending stress, local clamping pressure and keeper pressure) and cyclic (any variation in tension excites a torsional vibration mode, transmitting a torque to the support). Surging vibrations are produced by the interaction of horizontal and vertical forces generated by wind. Generally, these oscillations are vertical and have a frequency of about 1 Hz [4, 5]. Wind vibrations are the consequence of the turbulence caused by the wind blowing over the conductor. Much more dangerous than the galloping/surging vibrations, these oscillations have a high frequency (between 3 and 200 Hz) [6], usually between 10 and 40 Hz [4]. The amplitude of this vibration at lower frequencies barely reaches the diameter of the conductor. Beside the contact fatigue phenomenon, these vibrations cause alternating bending that affects especially the conductor section near the clamps [5].

The elastic contact between two cylindrical bodies cannot be analyzed by applying the theory of Hertz only, as both the shape and size of the bodies need to be taken into account as well as their relative position [7]. Thus, the contact width is a function of the pressing force between the two bodies, the radius of the cylinder and the modulus of elasticity. The convex profile of the wires generates additional complications, as plastic deformations are much bigger than elastic deformations, thus making specific intensity to be proportional to the depth of penetration.

Experimental Research

Equipment used

The experimental study was conducted in the laboratory of Materials Testing at the Department of Strength of Materials from Politehnica University of Timisoara. The tests were performed using a 5 kN Zwick/Roell tensile testing machine, equipped with data acquisition and processing system (Fig. 1). For gripping the wires, a clamping device was developed. This was designed and manufactured as to be adjusted to the bits of the testing machine (Fig. 2). The imprints left on the surface of the wires were analyzed using an optical microscope produced by Krüss-Optronic Germany.

Test procedure and materials

Aluminum wires were taken from an ACSR (Aluminum-Clad Steel Reinforced) conductor used in high voltage overhead networks.

The main characteristics of the conductor are presented in Table 1.

Fig. 1. The 5 KN Zwick/Roell testing machine

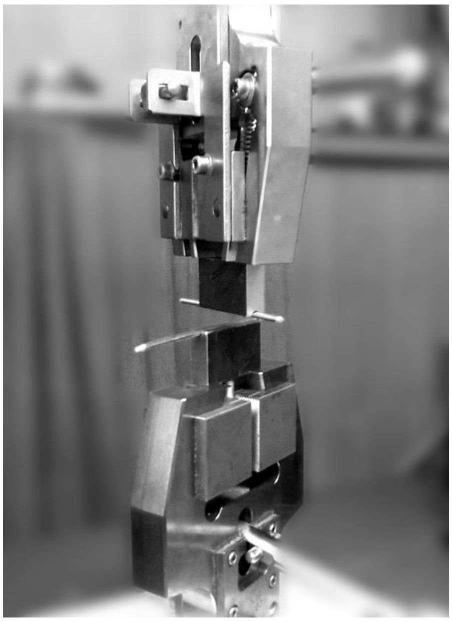


Fig. 2. The fixing device

Table 1 Cable specifications

<table>
<tr><td rowspan="3">Type</td><td colspan="3">Section area</td><td colspan="2">Number of wire</td><td colspan="2">Wire diameter</td><td rowspan="2">Cond. diameter</td><td rowspan="2">Mass</td></tr>
<tr><td>Al</td><td>Steel</td><td>Total</td><td rowspan="2">Al</td><td rowspan="2">Steel</td><td>Al</td><td>Steel</td></tr>
<tr><td>mm²</td><td>mm²</td><td>mm²</td><td>mm</td><td>mm</td><td>mm</td><td>kg/km</td></tr>
<tr><td>450/75</td><td>445.3</td><td>75.55</td><td>520.9</td><td>63</td><td>19</td><td>2.95</td><td>2.25</td><td>29.25</td><td>1823.4</td></tr>
<tr><td colspan="4">Number of layers</td><td colspan="6">Electric Resistance</td></tr>
<tr><td colspan="2">Al</td><td colspan="2">Steel</td><td colspan="6">[kΩ/km]</td></tr>
<tr><td colspan="2">3</td><td colspan="2">2</td><td colspan="6">2.28</td></tr>
</table>

In order to minimize unwanted influences on tests, the conductor samples were cut to a length L_0 = 200mm and were taken from a region which showed no optic defects. They were carefully disassembled starting with the outer Al strands (27 wires), the middle Al strands (21 wires), the inner Al strands (15 wires) and the steel core strands (19 wires) (fig. 3).

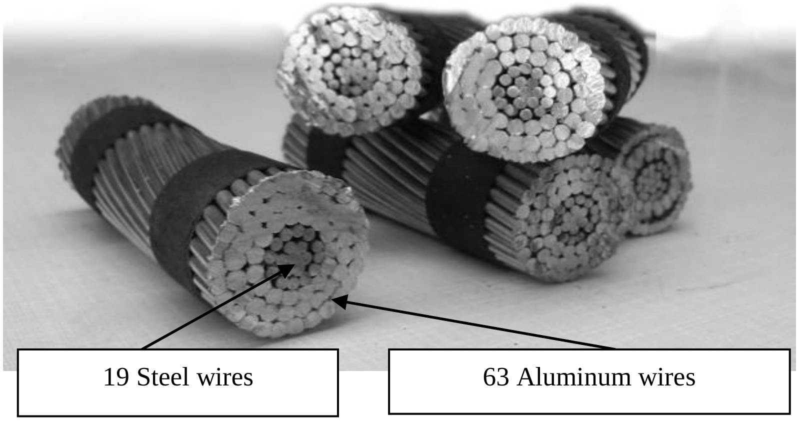


Fig.3 Cross-section view of cable

The tensile tests were performed according to ISO 8493, referring to wires with round, square or hexagonal cross-section, with a nominal size up to 10 mm. The temperature must be at 23 ± 2 [°C] and the relative humidity around 50 ± 5 [%]. A set of aluminum wires of the strand was prepared for imprinting. The shape of the grip and support for the wires determines concentrated and localized deformation in the contact zone between wires when applying force. The diameter of the channel (d_c) is bigger than the diameter of the wire (d_0). One of the fixing devices can be rotated around the direction of the applied force (fig. 4).

The indentations' size will be measured using an optical microscope (fig. 5). The wires will be then subjected to tensile tests.

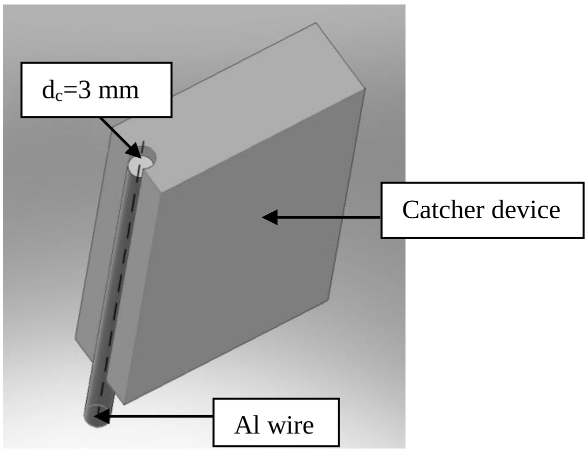


Fig.4 Wire mounting on the catcher device

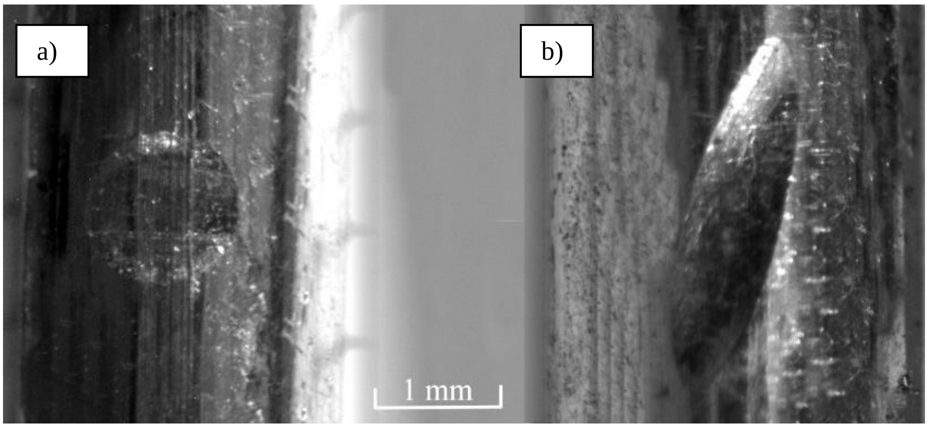


Fig.5 Imprint aspect: a) at 90°; b) at 30°

Damage analysis

As local deformations appear in the contact area between clamps and conductors, their shape and size influence the mechanical features of the conductor.

For the 90 degrees angle, the indent's projection on the surface of the wire is almost circular and gradually becomes elliptic as the angle between the wires begins to decrease (fig. 5).

Results

Analysis of wires before indenting

In order to establish a benchmark, tensile testing of the wires taken from the conductor had to be performed. The tests revealed the mechanical properties that the wire has at its time of operation. Separate testing was done on wires taken from each of the three layers. Figure 6 presents the characteristic curves of the wires for each layer. The average breaking forces for each layer were: 1465 N for the outer strands, 1440 N for the middle strands and 1450 N for the inner strands.

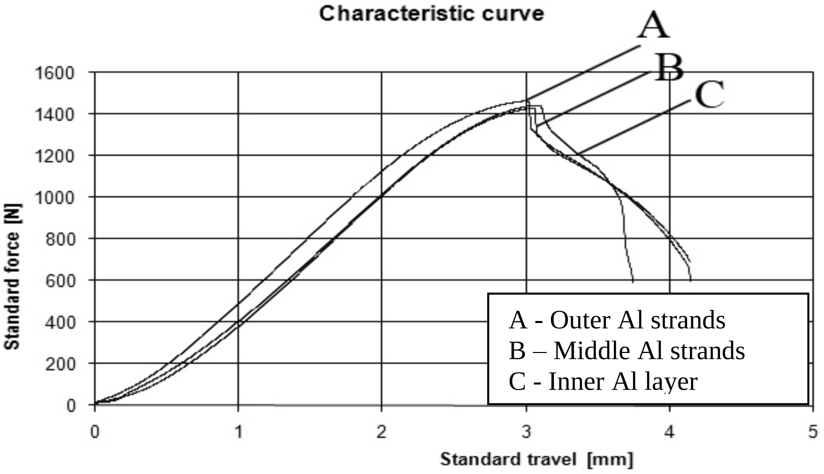


Fig. 6. Characteristic curves for wires

Analysis of indentations

The wires were indented keeping a constant angle of 90° and varying the force between 100 and 500 N. The distance between two diametrically opposite points on the longitudinal direction of the wire is longer than the distance between diametrically opposite points on the sectional direction. The shape of the indent thus created, although very close to a circle, is an ellipse, the semi-axes of which are nearly identical in length. The difference between the surfaces of two consecutive force steps decreases as the loads increase. For low forces, the increase of the wires contact surface leads to increased resistance to wire indentation. Figure 7 presents the variation of the indent size with the increasing force.

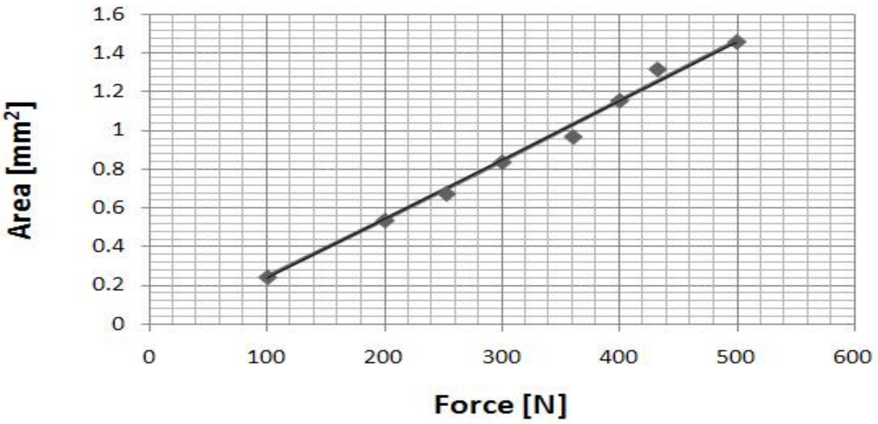


Fig. 7. Variation of the indent size with the increasing force Tests at 90 degrees

Analysis of indented wires

The indented wires were tensile tested. The results showed that the indent size and shape influence the tensile strength of the wire, as local deformations trigger the nucleation and development of cracks. Figure 8 summarizes the characteristic curves for tensile testing of wires at varying indentation surfaces: a = 0.241 mm^2; b = 0.535 mm^2; c = 0.836 mm^2; d = 1.153 mm^2; e = 1.459 mm^2; f = 2.453mm^2.

For small values of the indent area, the breaking forces are close to those of the non-printed wires. As the indent area increases, there is a decrease of the value of the breaking force. Furthermore, the differences between the indented wires and those with no indent are more visible (fig. 9).

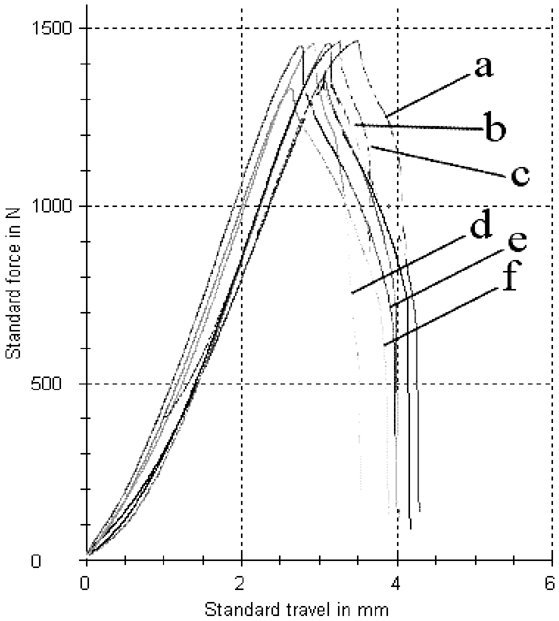


Fig. 8. Characteristic curve for indented wires

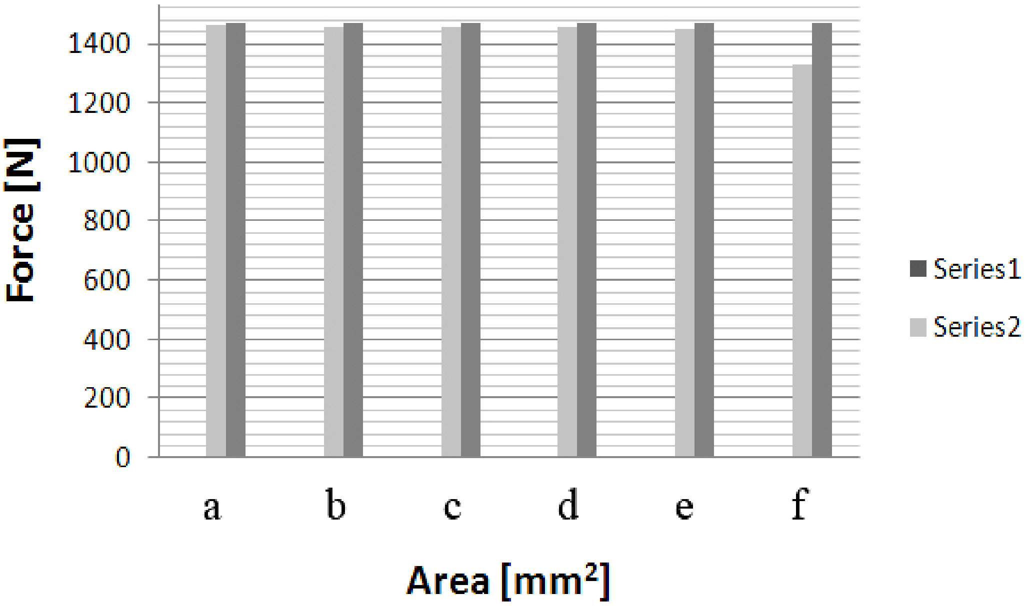
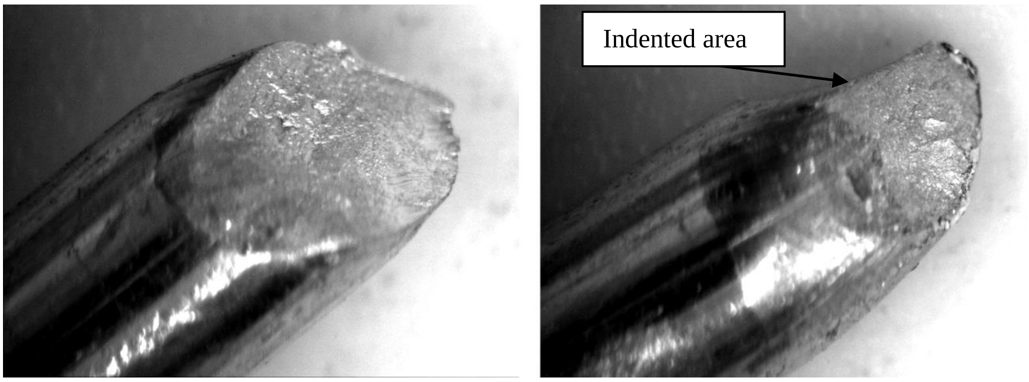


Fig. 9. Comparison between virgin (Series 1) and indented (Series 2) wires

The shape and size of the area where indented wire breakage occurs differs from that of the virgin wires. The surface is visibly smaller and the shape is more elongated (fig. 10). The cracks are initiated in the center of the indent area, where the plastic deformations are maximal.



a) Virgin wire b) Indented wire

Fig. 10. The fracture area for virgin and indented wires

Conclusions

Theoretical and experimental researches have shown that the shape and size of the indents occurring at the wire contact area significantly influence the mechanical characteristics of high voltage conductors. Due to the way the wires are assembled together, in-service loading generates deformations that are maximum and concentrated in the wires contact areas. Additionally, on the conductor clamping areas, one can identify indentations at the wire-clamp and wire-wire contact surfaces.

Elastic and plastic deformations that occur in the contact areas create micro-cracks that develop into cracks when the wire is subjected to tension either by its own weight or external loads.

The size of local deformations that appear on the wires contact surfaces influences the operating life of the conductor by favoring the initiation and propagation of fretting fatigue cracks. Indents with an area of up to 0.2 mm^2 have insignificant influence on the ultimate strength of the wires (the UTS decreases only by 0.04%). As the size of the indentations increases, the tensile strength is more heavily reduced (dropping with 10% for indents with a 2.5 mm^2 area).

Acknowledgement

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Cercetări asupra zonei de contact dintre firele din componenţa conductoarelor de înaltă tensiune

Rezumat

Transportul energiei electrice de la sursă catre consumatori se realizează prin intermediul liniilor aeriene de înaltă tensiune. Sub acţiunea factorilor meteorologici, la nivelul conductoarelor apar solicitări suplimentare care duc la deteriorarea accelerată şi ruperea prematură. Analiza stării de tensiune şi deformaţie a firelor din componenţa conductoarelor are rol decisiv în vederea identificarii zonelor cu solicitari maxime, monitorizării retelei şi evaluării duratei de viaţă.

Modificarea proprietaţilor mecanice ale conductorului se face odată cu apariţia si evoluţia amprentelor de contact. Pentru a înţelege modul cum evoluează o amprentă şi a efectelor pe care aceasta le are, s-au realizat teste de amprentare şi tracţiune pe fire prelevate dintr-un conductor bimetalic oţel-aluminiu. Cercetarile teoretice si experimentale au evidenţiat că forma şi dimensiunile amprentelor care apar la contactul firelor au o influenţă deosebită asupra rezistenţei la rupere a conductoarelor şi că deformatiile locale determină anumite particularităţi ale iniţierii şi propagării fisurilor la oboseală cu fretting.