IOP Conf. Series: Materials Science and Engineering **416** (2018) 012071 doi:10.1088/1757-899X/416/1/012071

Stress and Strain Determination Occurring in Contact Area of the 450/75 ACSR Conductor

D Achiriloaiei[1,*], S V Galatanu[1] and I Vetres[1]

[1] Politehnica University of Timisoara, 1 Mihai Viteazu Blvd., 300222, Timisoara, Romania

[*]Corresponding author: daniel.achiriloaiei@yahoo.com

Abstract. The ACSR conductors are the metallic ropes stretched freely between poles and fixed onto them by supporting elements, which ensure the circulation of electrical energy. The special importance of this electrical conductors, coupled with the very high costs for repairs and replacements have imposed that the lifetime of power lines conductors to be between 50 and 80 years. Energy interruptions due to broken conductors have catastrophic impact from an economic, social and national security point of view. The present paper aims to determine stress and strain which are developing into contact area of the wires in the high voltage conductors. The study was performed using new conductors and 42 years aged conductors. Therefore an analytical calculation was performed in order to understand how the contact types are developed in conductor. The local stress and strain were determined experimental and a series of polynomial equations have been proposed. 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 stress and strain of the conductors. An assessment of contact stresses under plastic deformations cannot be made without taking into consideration the characteristics of the imprints.

1. Introduction

To determine the life of conductor in the literature numerous attempts have been made, but considering the small number of vibration and their effects records applied, they are not relevant enough to the conductor. Response produced by the galloping vibrations, as well as wind vibrations is a major issue in assessing the durability of electrical conductors, under the circumstances that experimental studies have highlighted the devastating role of combined action of contact and fatigue on the durability of aluminium [1].

Even if regular conductor inspection is recommended, hidden defects (especially those generated at the wires contact or between the conductor and the clamps) may cause premature breaking of them. Layout of the high voltage lines significantly influence the occurrence and development of vibrations. Thus, it has been demonstrated that on a section although some common features are encountered, there are several particular situations, depending on the position in the section [2, 3]. Breaking of the component elements of the conductor (the wires) is a first step in deficient operation and a first step to final break. It has been noticed that the breaking of conductors is one of the serious electrical shock loads which a line section may have, through power interruptions and high voltage imbalances which can lead to cascade breaks of the conductors. Under normal operating conditions, the conductors are almost constantly subject to low amplitude wind vibrations. At the same time, they have to sustain their own weight, and in the fastening areas mechanical stresses arise due to increased local pressures around the clamps and within the many devices they come into contact with.

The problem of normal contact in case of plastic deformations is particularly difficult because they are far superior to the elastic ones. In addition, the convex profile of the wire causes additional complications as shown by Achiriloaiei et al. [4] which is a first step towards understanding the phenomena that appear at the contact between wires. Determination of the plastic deformed area is impossible in this case, consequently, the contact pressure can only be approximated. For such applications the use of numerical methods is recommended and experimental validation of the results.

Critical contact areas of high voltage lines with multilayer conductors remain in the fasteners regardless of aerodynamics, and are manifested by degradation of the conductors. To simulate the contact types between wires and to identifying the effects created have been kept the same angles of imprinting that were used in the study of Achiriloaiei et al. [4]. The wires were subjected to an imprint test using three different angles 30°, 60°, 90°. Many of the points where contact stresses develop are located in the area of the clamps, between different layers or between the last layer and the body of the clamping clamps, as can be seen in Figure 1. In Figure 1 is marked with arrows the areas where stress has maximum values and the directions of application of the contact pressures.

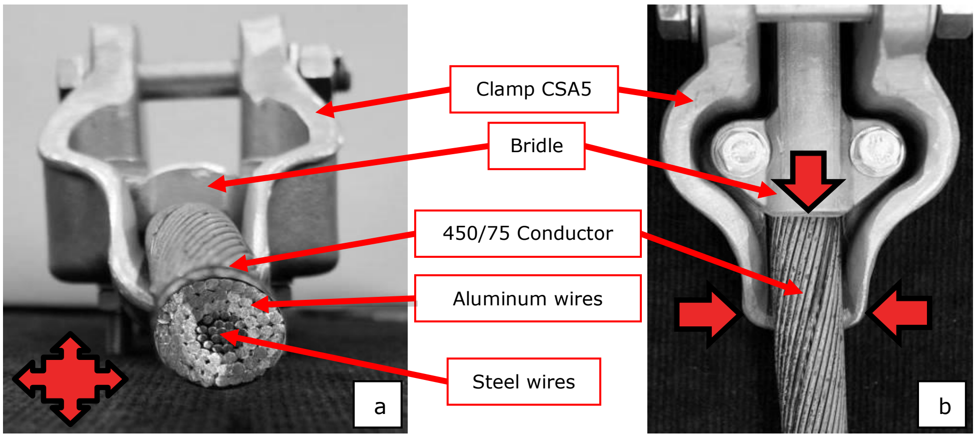


Figure 1. Fixing the conductor to the clamp; a) the section of the conductor - directions and meanings of movement; b) conductor-clamp contact area

Conductor behaviour for multiaxial load creates, beyond the complex contact stress, also gradients of a physical magnitude of stresses at the edge of the contact surface, where cracks can be created and propagations thereof. It must also be taken into account that local contact stress, under the action of friction, is distributed differently depending on the geometry of the contact, pressures, materials in contact and tribology of the contact surface (science and technology of interaction between two contact surfaces in relative motion). The contacts surface, in the case of conductor wires, is in the form of non-conforming couplings or Hertzien and is changing with the type of contact variation and material behaviour.

2. Analytical method

In the case of wires the calculations that are made are similar to those of the cylindrical bodies. Aluminium wires used in electric conductors are considered as cylinders wrapped helically whose radius depends on their position within the layer they belong to. When a normal contact force acts on the bodies local deformations occur and the geometrical configuration of the contact ellipse may change. For a Hertzian contact, the contact pressure is given by the below expression, considering that p_0 is mean pressure on the contact surface:

$$p = p_0\sqrt{1-\left(\frac{x}{dy}\right)^2-\left(\frac{y}{dx}\right)^2} \tag{1}$$

Figure 2 shows the layout of two wires in contact, a specific case of interlayer contact.

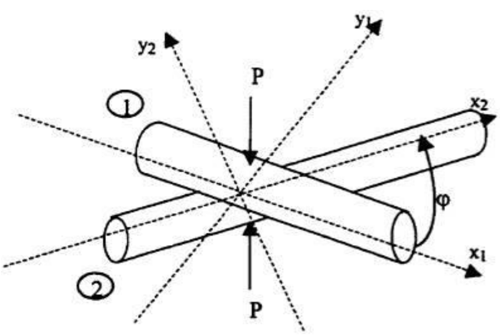


Figure 2. The contact between two wires with the same diameter

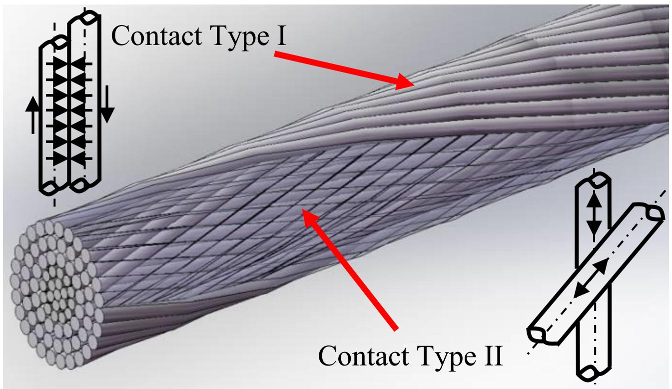


Figure 3. Contact types: Contact Type I – linear contact; Contact Type II – point-to-point contact

Under these conditions, the equations can be written:

$$R_1 = \frac{\rho_1}{\sin^2\alpha_1}; \qquad R_2 = -\frac{\rho_2}{\sin^2\alpha_2} \tag{2}$$

Where $\varphi = |\alpha_1 - \alpha_2|$ and ρ_1, ρ_2 are the rays of curvature of the two wires in contact, and α_1 and α_2 represent their directions in relation to the axial direction of the conductor.

Ouaki et al. [6] in his work considers two geometric profiles whose contact surfaces can be approximated by two polynomial functions δ (x, y). Under conditions of a common axis system (x, y) for the two bodies of the conductor wires having the same radius $R_1 = R_2 = r$, their proximity becomes:

$$\delta(x, y) = Ax^2 - By^2 \tag{3}$$

The coefficient A and B depends on the curves of the two bodies and their orientation towards each other.

$$A = \frac{1}{2r}(1-\cos\varphi); \qquad B = \frac{1}{2r}(1+\cos\varphi) \tag{4}$$

In the literature it is considered dx - higher axis of the ellipse and dy - the smallest axis of the ellipse, and it is indicated that eccentricity of the contact ellipse, e_c, it does not depend on applied force and can be approximated in the form of:

$$e_c = \frac{dy}{dx} \approx \left(\frac{B}{A}\right)^{-\frac{2}{3}} \tag{5}$$

It can be seen that when φ = π/2, dx = dy, the contact area is reduced to a circle, and when φ = π, the ellipse becomes a rectangle of width 2dy and length $e_c = \infty$ as shown in Figure 3.

Due to the linear-elastic character shown at the moderate tensile loading and the helical layout of the wires, in contact areas is being exercised continuous load such as bonding condition (reaction).

Under these forces, the conductor is in balance and it creates a certain state of loading in the form of the two types of contacts. These contacts have shape and dimensions of crystalline interstices changes at the structural level, developing continuous efforts in the mass of wires that lead to the formation of new crystals. Thus, in the mass of the conductors there is a series of efforts, stresses and strains, which influence the lifetime of them and is summed up for tasks that occur in operation

3. Laboratory investigations and test results

3.1. *Material, equipment and methods*

Aluminum Conductor Steel Reinforcement (ACSR) conductor used for laboratory determinations is 450/75. The new wires were taken from a conductor produced by IPROEB Bistrita according to Stas 35/1999. The aged wires are of the same type and were taken from the active conductors on the LEA network, Porţile de Fier-Arad from the Timişoara-Arad section and which have been in service for 42 years. The materials used in the tests are aluminium wire with a purity of 99.5% and a diameter of d = 2.95 mm, which are found in the three layers of windings.

Tensile tests and imprints have been conducted in the Strength of Materials Laboratory from Politehnica University Timisoara. The tests were performed using a tensile-compression testing machine, model Zwick/Roell of 5 kN at the 20°C and the relative humidity around 50 ± 5 %. The microscopic examination on the surface of the wires was performed with the optical microscope. The microscopic analysis was considered in the imprinted area of the wires in order to obtain 3D deformations. Taking into account the imprint angle φ which influences the appearance and size of the imprints, the dependence between the force of pressing and the development of imprints on the surfaces of the new wires has been established.

The indentation of wires was done by a contact loading, using a fixing device which renders the real contact between the conductor wires, figure 4.

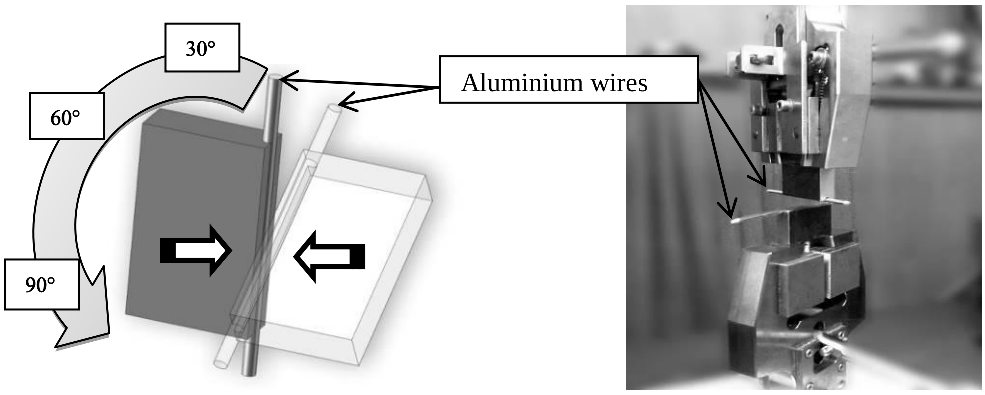
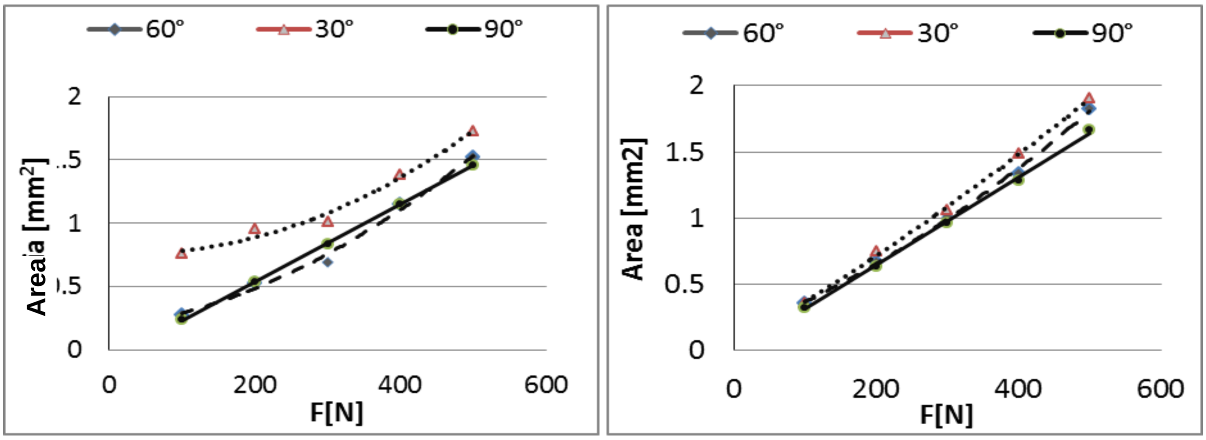


Figure 4. Wires arrangement during the indentation test

The values of the imprints φ have been set to be consistent with those most commonly encountered in reality, with values of 30°, 60°, 90°. At the same time, the normal pressure values were divided into 6 loading steps of 0,54N/mm^2, 1,08N/mm^2, 1,62N/mm^2, 2,16N/mm^2, 2,7N/mm^2 and 5,4N/mm^2.

3.2. *Tensile and imprint tests*

The tests revealed the mechanical behavior of the Al wires from a new and old conductor. The imprints size have been measured and the wires was subjected to tensile tests. Tensile tests were done on wires taken from each three types of imprints. Using the measurements made on the plastic deformed areas, the imprints variation diagrams were drawn according to the force of the press. With the help of the imprint variation diagrams, a series of polynomial equations have been developed to calculate the area of the deformed surface by the contact pressure, depending on the force of the pressing force. These equations can also be used in the case of existing imprints when it is desired to determine the pressing forces. There are two sets of equations for new and aged wires.



a) b)

Figure 5. Comparative variation of the inprinted surface by force of pressure, for variable φ: a) new wires; b) aged wire

$$A_{n30} = \left(4 \cdot 10^{-6}\right)F^2 - 0{,}0003 \cdot F + 0{,}7691 \quad (6)$$

$$A_{n60} = \left(4 \cdot 10^{-6}\right)F^2 - 0{,}0008 \cdot F + 0{,}1712 \quad (7)$$

$$A_{n90} = 0{,}0031 \cdot F + 0{,}0714 \quad (8)$$

$$A_{\hat{\imath}30} = 10^{-6} \cdot F^2 + 0{,}0031 \cdot F + 0{,}0467 \quad (9)$$

$$A_{\hat{\imath}60} = \left(2 \cdot 10^{-6}\right)F^2 + 0{,}0022 \cdot F + 0{,}1253 \quad (10)$$

$$A_{\hat{\imath}90} = 0{,}0033 \cdot F - 0{,}0198 \quad (11)$$

Where: A_{n30} – Area of imprint for new wire and φ=30°, 60°, 90°
$A_{\hat{\imath}30}$ – Area of imprint for aged wire and φ=30°, 60°, 90°

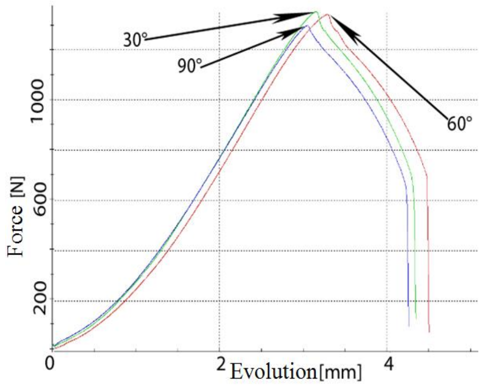


Figure 6. Characteristic diagram of imprinted wires

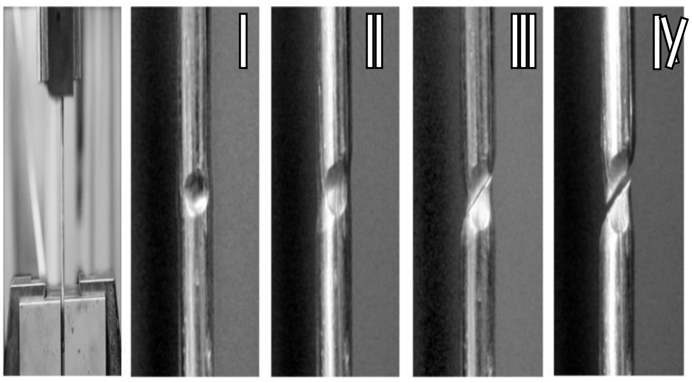


Figure 7. Evolution of traction of the imprinted wire

The traction characteristic pattern was plotted for the imprinted Al wires using 1kN constant force at different imprint angles. In case of imprints with different angles, the size of the imprint varies greatly and influences the tensile breaking strength. Local deformations are deeper for 90° imprint

IOP Conf. Series: Materials Science and Engineering **416** (2018) 012071 doi:10.1088/1757-899X/416/1/012071

angles and tensile strength is lower than for 30 ° and 60 ° imprint angles. Another very important aspect is related to the section where the breakage occurs and the shape it has.

3.3. Stresses and strains estimation

The purpose of static analyses performed on aluminium wires is to determine deformations that occur in the contact area, resulting in the appearance of imprints. The data from the laboratory measurements of new wires were introduced into the SigmaPlot graphics program, with which the graphs of the plastic deformations were plotted. In the case of tensions, it was chosen to present tensions calculated according to the von Mises criterion. They present the three-dimensional variations of the imprints, with the emphasis on the dependence between the imprint surface and the depth of penetration. Was followed, the distribution of the equivalent stresses, σ_{ech} von Mises at the element level and the distribution of the equivalent plastic deformation.

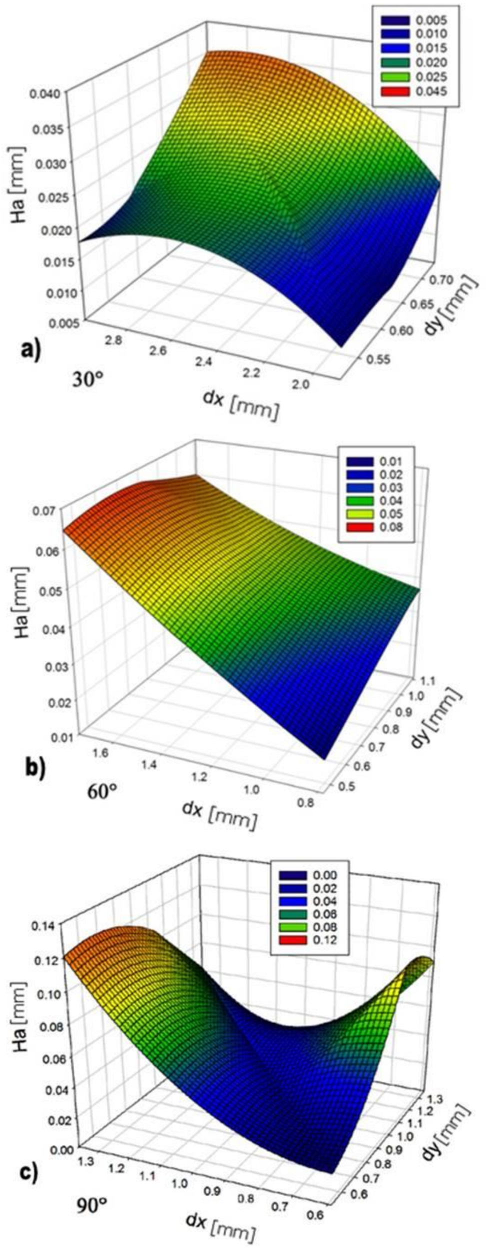


Figure 8. Three-dimensional variation of inprints for the inprint angles φ

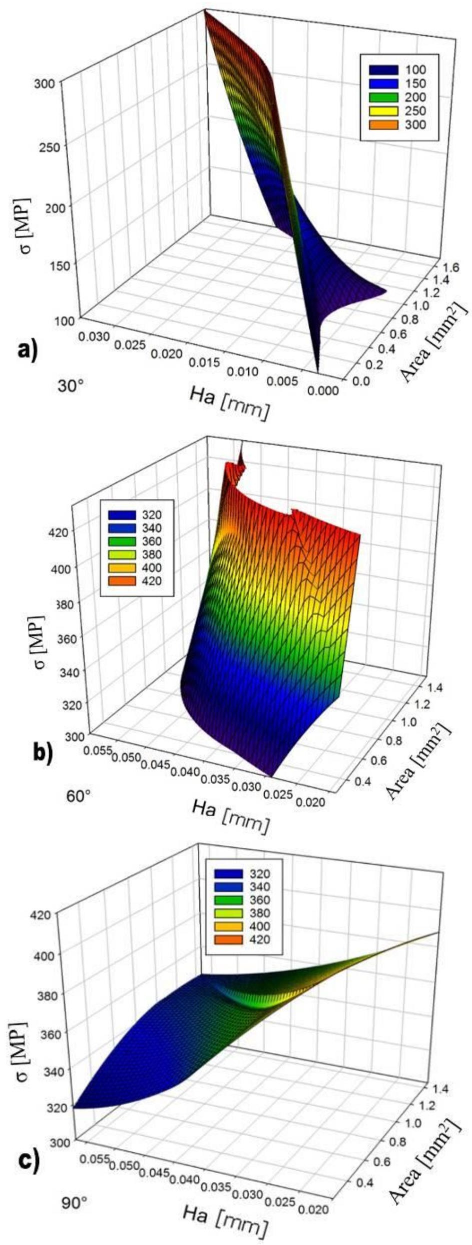


Figure 9. Variance of von Mises stresses for the three inprint angles

IOP Conf. Series: Materials Science and Engineering **416** (2018) 012071 doi:10.1088/1757-899X/416/1/012071

4. Conclusions

Solutions provided by elastic analyses have proven to be inadequate for this type of contacts. The contact area is too large compared to the size of the contact in the bodies to make the analyses on half of the plane. Comparison of tensions with the 2D solution for cylinder contact showed the importance of free wire surface and pressure applied to imprints. The elasto-plastic results are similar to those for cylinder contact but with particularities of pre-existing plastic deformations.

The existence of imprints, of any kind, causes the traction fracture to develop from the imprint section, as in Figure 7. This is not confirmed for small imprint forces due to structural inhomogeneity. In contrast to the breakage of unapplied samples, where the fissure development plane is normal to the axis, in the case of imprints the fissure develops in a plane inclined at 45° to sample axis. This fissure passes through the imprint area, joining the marginal micro-portions, and cuts in the thinned area.

As the size of the imprints increases, the tensile strength is more heavily reduced (dropping with 10% for imprints with a 2.5 mm^2 area). Using linear variations of normal pressure, there was a non-linear variation in the equivalent stress and a change in the ratio between the surface area and the depth of the imprints.

5. References

[1] Martins L.H.L., Rossino L.S., Filho W.W.B., Araujo J.A., Detailed design of fretting fatigue apparatus and tests on 7050–T7451 Al alloy, Tribology - Materials Surfaces and Interfaces, Vol. 2, 2008, pp. 39–49

[2] Kim H.S., Mall S., Investigation into three-dimensional effects of finite contact width on fretting fatigue, Finite Element in Analysis and Design, Vol. 41, 2005, pp. 1140–1159

[3] Suzanne Guerard, Power Line Conductors, a Contribution to the Analysis of their Dynamic Behaviour, Ph.D thesis, 2011

[4] Achiriloaiei D., Neş C.S., Dumitru I., Influenţa contactului dintre fire şi a deformaţiilor locale asupra conductoarelor de înaltă tensiune, Revista Universităţii Petrol–Gaze din Ploieşti, 2015

[5] Achiriloaiei D., Neş C.S., Dumitru I., Cernescu A., On the influence of the contact force and the angle between the wires on ACSR conductors' mechanical properties and durability, Key Engineering Materials, Vol. 665, pp.33-36, 2016

[6] Ouaki B., Analyse expérimentale et théorique de l'endommagement par fatigue à pettits débattements des fils de conducteurs électriques au voisinage d'une pince de suspension, Ph-D These, 1998

[7] Ramey G.E., Townsend J.S., Effect of clamp on fatigue of ACSR conductors, Journal of Energy Division, ASCE (EYl) 1981, Vol. 107, pp.103–119

[8] Zhu Hui-ling, Zhu Xin-yin, Wang Yu-lin, Numerical analysis of sliding friction coefficient and the normal pressure between the cable wire, International journal on smart sensing and intelligent systems vol. 7, no. 4, 2014

[9] EPRI Transmission Line Reference Book: wind induced conductor motion, Electric Power Research Institute, Palo Alto, California, United States, 2006.