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Finite element model of the contact between a vibrating conductor and a suspension clamp

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ABSTRACT

Aeolian vibrations may lead to failure of the overhead conductors of electrical transmission lines. Damages are caused by fretting fatigue at the attachment position of pieces of hardware. This phenomenon depends much on contact mechanics. The contact between a wire and a suspension clamp, a critical location, was modelled using the finite element method. Results from strain measurements on vibrating conductors served as input. The numerical results gave estimates of stresses and slip amplitudes. We can use these results to compute crack initiation criteria. The Ruiz and Chen criterion was chosen here and results compared well with experimental data.

1. Introduction

Under the effect of wind, transmission lines can suffer damages that may lead to catastrophic failure [1]. Wind excites conductors following two main ways [2]. When the conductor stands alone in the airflow, vortex-shedding induced vibrations are observed. When we have bundles of conductors, wake-induced vibrations become an additional concern. A third excitation mode exists under colder climates, which is galloping [3]. 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.

The damaging of conductors is observed at the attachment position of the conductor to the pieces of equipment that hold it (suspension clamps, spacers, spacer-dampers, etc.) [4–6]. 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. It has been observed that the contact was continuous between the conductor and the clamp with the keeper bolted [7]. Aeolian vibrations apply an alternate loading, causing slip at specific contact points. Hence, the failure of conductors have to be considered as a fretting fatigue problem [8].

Compared to classical fatigue cases, the initiation of cracks is obviously quicker when there is fretting. Hence, the life of the fretting parts is seriously reduced. The reduction of components life is more and more pronounced as slip amplitude increases. We are talking about fretting fatigue in that case. With the continuous increase of sliding, the increased wear rate tends to wear out cracks before they get the chance to propagate. Then we are talking about fretting wear. The relations between slip, wear and life can be presented in fretting maps [9,10]. Both fretting fatigue and fretting wear were observed on conductors depending on bending amplitude [8,11]. At high bending amplitudes, the outer layer undergoes fretting wear, while fretting fatigue fractures are observed on inner layer wires. At low bending amplitudes, the critical area is the contact between the wires of the outer layer and the suspension clamp. It has been observed in the GREMCA laboratory that the first wire break usually appears at the last point of contact (LPC) between the conductor and the bed of the suspension clamp (see [12] for example). Another critical point might be at the keeper edge (KE).

Based on these facts, it appears that the fretting behaviour of the conductor strongly depends on the amplitude of vibration (which influences the slip and wear inside the contact areas), the clamping system (they each induce their own fretting behaviour) and lubrication of the interface (lubrication reduces oxidation and diminishes the tangential forces) [8]. The importance of contact stresses is thus obvious. In order to analyze them, it is of interest

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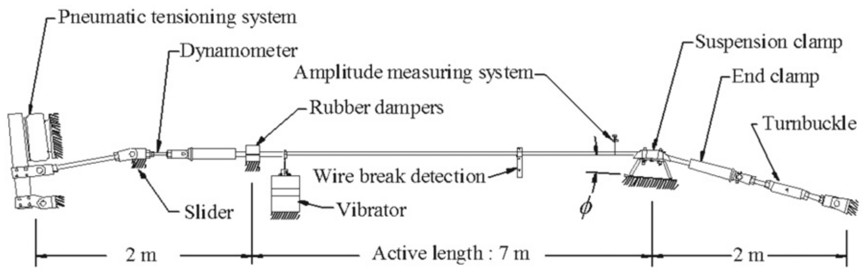

Fig. 1. Resonance fatigue test bench.

Table 1
Characteristics of the conductors.

Conductor	Drake	Bersfort
Total area (mm^2)	468.5	746.9
Conductor diameter (mm)	28.14	35.56
Number of wires on each layer		
Steel	6-1	6-1
Aluminium	16-10	22-16-10
Diameter of aluminium wires (mm)	4.44	4.27
Diameter of steel wires (mm)	3.46	3.32
Linear mass (kg/m)	1.628	2.375
Minimum bending stiffness ($N\,m^2$)	44.4	62.7
Rated tensile strength (kN)	140	180

to know the actual loading on the conductor during a fatigue test. Strain measurements on conductors during fatigue tests revealed that the alternating loading is mainly an alternating traction [13,14]. A finite element model of the contact between a suspension clamp and a wire of a conductor should give useful information on the physics within the contact patch.

2. Suspension clamp/conductor system

Two conductors were tested on a resonance fatigue test bench (Fig. 1) in [13]: the ACSR Drake and the ACSR Bersfort. ACSR stands for Aluminium Conductor Steel Reinforced. The first one has two layers of aluminium wires, while the second has three such layers. The aluminium wires are composed mainly (99.5%) of pure aluminium (1350-H19: Young's modulus $E=69$ GPa, Poisson's ratio $\nu=0.33$, yield stress $S_y=167$ MPa). These wires are wrapped around a seven-steel-wire strand core. Table 1 reports the main characteristics of the conductors. The conductors are supported in a short radius commercial suspension clamp with a sag angle ϕ (7° for the Drake and 6.2° for the Bersfort). The geometric characteristics of ACSR Bersfort's clamp are taken from its technical drawing. In the case of the ACSR Drake, the coordinates of the clamp bed longitudinal profile were measured using a Coordinates Measuring Machine (CMM). The radii at the LPC are labelled *Rx* and *Ry* (Fig. 2). These values are presented in Table 2. The keeper is held by bolts tightened with a 35 lb ft ($\sim$47.5 N m) torque. The traction force imposed onto the conductor during a typical fatigue test corresponds to 25% of its rated tensile strength (RTS). The chosen bending amplitudes Y_b for the ACSR Drake were 0.3, 0.5, 0.7 and 0.9 mm. Bending amplitudes were 0.3, 0.43, 0.5 and 0.7 mm for the ACSR Bersfort. Y_b is measured peak-to-peak at 89 mm from the LPC [15].

3. Finite element analysis

ABAQUS has been used in this study to model the contact between a conductor and a clamp. The size of the clamp being

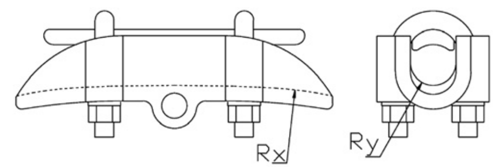

Fig. 2. Radii *Rx* and *Ry* of suspension clamps.

Table 2
Geometrical parameters of models.

Conductor	*Rx* (mm)	*Ry* (mm)	Geometrical model (mm)		
			Clamp (whole)	Clamp (C3D8R)	Wire
ACSR Drake	179	13	$14\times5\times10$	$7\times2.5\times5$	$R2.22\times23$
ACSR Bersfort	330	17	$18\times5\times10$	$9\times2.5\times5$	$R2.135\times27$

much greater than that of the wire, it is considered being infinite. While the wire and the part of the clamp directly involved in contact are meshed with eight-node linear brick elements with reduced integration (C3D8R), the surrounding of the clamp is meshed with eight-node linear infinite elements (CIN3D8) to model its extension to infinity.

In order to simplify the analysis, we consider the contact between a single wire and a commercial suspension clamp. This single wire reproduces the case of a contact between a conductor with a lay angle of 0° and a clamp. This angle gives the opportunity to take advantage of symmetry planes in order to reduce computing time. If we consider the origin being at the first point of contact, the *x* axis parallel to the wire axis, and the *z* axis going inside the clamp (see Fig. 3), the *xz* plane is obviously a symmetry plane. We consider the wire as being squizzed between two similar clamps. Hence, the plane parallel to the *xy* plane and passing through the axis of the wire is also a symmetry plane. Hence, a quarter of wire is modelled, with the part of the clamp with which it interacts. In order to anchor the model along the *x* axis, the *yz* plane is considered being a symmetry plane. Zhou et al. [11] showed that fretting happens only on one side of the contact area. So, this last simplifying hypothesis gives us an equivalent contact pattern. This pattern differs much from Cattaneo's [16] and Mindlin's [17] models (which do not take bulk traction into account) and Nowell and Hills' model [18] for fretting fatigue tests.

A previous experimental study [13] showed that the alternating loading on a wire can be considered as an alternating traction. Hence, only tensions will be applied to the wire in this finite element study. The loading sequence follows that of the experimental study [13]. The wire is pre-stressed in the first case and