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# Effect of chromium nitride coatings and cryogenic treatments on wear and fretting fatigue resistance of aluminum

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ABSTRACT

As commonly known, the endurance of overhead conductors is limited by fretting fatigue. The most severe fretting fatigue damage occurrence is the suspension clamp, as a superposition of many different loads occurs in the conductor/clamp assembly. Therefore, this paper focuses on two modification methods, which aim to reduce the fretting fatigue loading in such assemblies. The investigated modification methods are a deep cryogenic treatment and a surface coating. To study the effect of both methods on the duration of overhead conductors, comparative fretting fatigue tests with real conductor/clamp contacts were carried out. A reduced amount of wire breaks was found for both modification methods. Especially the first wire break occurred significantly delayed using deep cryogenic treated and coated suspension clamps (20% for the deep cryogenic treated and 60% for the tests with coated clamps). The post mortem analysis showed severe damage marks in the suspension clamps. The use of the surface coating led to a reduced amount of damage in the suspension clamps.



## 1. Introduction

The lifetime of overhead transmission lines is limited by fretting fatigue [1,2]. This is a damage mechanism that take place at surfaces which are exposed to (i) an oscillating relative motion and (ii) a contact force that pushes the two surfaces together [3]. These conditions occur where different types of devices are fixed to the transmission line. Typical examples are suspension clamps, which attach the conductor on the line supports, spacers, which maintain a given distance between the sub-conductors of lines with bundles, and spacer dampers, which reduce the movement of the conductor caused by aeolian vibration. One of the most critical devices in terms of fatigue damage occurrence is the suspension clamp, as a superposition of many different loads occur in the conductor/clamp assembly. First, the conductors are loaded with a clamping force to guarantee a stable fixation [4]. Second, high static bending stresses arise due to the dead weight and the strong curvature of the conductors at the suspension clamps [5,6]. To keep the safety distance between the conductor and the ground and allow long distances between the insulators and the line supports, a tensile load is applied to conductor. The applied load is determined according to the rated tensile strength (RTS) of the conductor, the acting loads (normally wind and ice loads) and the factor of safety [7]. Aeolian vibrations are another load factor. They lead to a cyclic movement of the conductor, which generates not only alternating bending stresses [8], but also relative movements among the conductor wires and between the conductor and the clamp [9]. The physical background of these movements (stick-slip regime) and the calculation of the related wire stresses have been explained in [10] and [11].

Because of this, current research found abrasive wear debris close to the failed conductor strings in the conductor and in the suspension clamps has been observed [2,7]. The wear debris consist of aluminum oxide ($Al_2O_3$) and silicon dioxide ($SiO_2$) [12,13]. The generation of wear debris occurs after an initial damage of the conductor or the suspension clamp. Since both components (conductor and clamp) consist of aluminum alloy, which in case of the suspension clamp also contains silicon, the origin of the wear debris cannot be explicitly traced back to only one of the components. However, since fretting fatigue marks occur in the conductor and in the clamps, the generation of wear debris is not limited to one of the contact parts.

Based on this context, the lifetime of overhead transmission lines can be possibly improved by reducing the coefficient of friction

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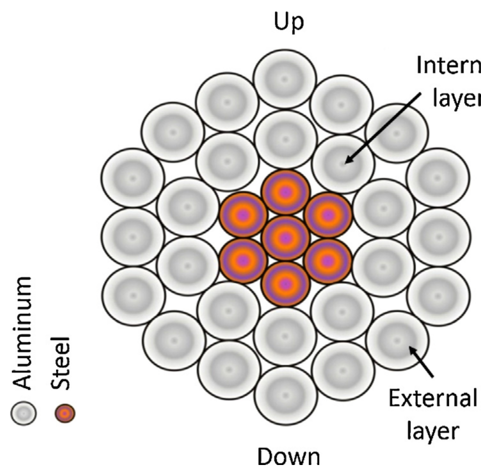


**Fig. 1.** Schematic view of the ACSR Ibis conductor [11].

**Fig. 2.** Fretting fatigue test rig for overhead conductors [11].

in the conductor/clamp interface and improving the wear resistance of the contact surfaces. To do so, two different methods were selected and tested in this work.

The first selected method aims to improve the contact conditions between the conductor and the clamp with a surface coating. The high wear resistance, the well-known deposition technique at low temperatures (physical vapor deposition, PVD) and the capacity to reduce the friction coefficient led to the selection of a chromium nitride coating (CrN) [14]. The use of such coatings aim to enhance the aluminum–aluminum contact between the suspension clamps and the conductor, which exhibit a low wear resistance and high friction coefficient.

The second method that was evaluated is the deep cryogenic treatment (DCT). It aims to improve the hardness and the wear resistance of the suspension clamps. Such effects were found using DCT on steels [15,16]. DCTs are so far not in common use for aluminum alloys, but recent scientific research reports about enhanced hardness and improved mechanical properties [17,18].

These methods could only be applied to the suspension clamps and not to the conductors. To investigate the evidence of these approaches to improve the lifetime of overhead conductors, fretting fatigue tests with a real conductor/clamp contact (CC-contact) were carried out.

## 2. Materials and methods

### 2.1. Materials

The fretting fatigue tests were all carried out using an aluminum conductor steel reinforced, (ACSR) type IBIS. The built up of the conductor is shown in Fig. 1.

The conductor consists of 26 single aluminum wires made of aluminum (AA 1350-H19) (16 wires in the external and 10 in the internal layer). The core of the conductor contains seven steel wires. The International Council of Large Electric Systems (CIGRÉ) recommends stopping laboratory tests after a failure of 10% of conductor wires, or at least after a break of three conductor wires [19]. Due to the number of wires of the conductor, the tests were interrupted after the break of three wires. In order to limit the maximum test duration to a reasonable time, the tests were interrupted independently of the number of wire breaks after 3.5 million cycles (running out conditions). The suspension clamps used consist of an aluminum alloy SAE 305. The chemical composition of this material is given in Table 1.

### 2.2. Modification methods

Since overhead conductors are large assemblies, which cannot be treated in conventional coating ovens or cooling chambers, the modifications methods were only applied to the suspension clamps and not to the conductor.

The chromium nitride coating was deposited on the suspension clamps as a contract work by an external company. Physical vapor deposition was used to install the CrN layer on the surface. Besides a thoroughly cleaning of the clamps with alcohol, no further treatment was applied to the clamps before the coating process. CrN was selected due to its excellent wear resistance, the excessive use in research and industrial applications and its low deposition temperatures [20,21]. Due to the low melting temperature of the used aluminum alloy, low deposition temperatures are important. According to the manufacturer, the temperature at the surface of the clamps is not exceeding 100 °C.

The deep cryogenic treatment was applied by a company, which arose as a startup within the University of Brasília (Kryos Cryogenic Engineering). The equipment used for the treatment is shown in Fig. 2. The deep cryogenic process starts at room temperature and goes down to the target level of −190 °C within a period of 12 h. The temperature of −190 °C is kept constant for further 12 h. After this dwell time, the temperature is increased to room temperature within 12 h. Before the liquid nitrogen was injected in the chamber, it is evaporated to enable a controlled cooling and to prevent a severe gradient of temperature between the surface and the core of the specimens [22].

### 2.3. Fretting fatigue tests

To investigate the effect of the surface coating and the DCT on the fretting fatigue life of overhead conductors, comparative fretting fatigue tests were carried out. Nine tests were conducted in three data series. The first test series was performed with suspension clamps tested As Received (AR-C) The second test series was performed with suspension clamps that have been DCT. Therefore, the test series was abbreviated with DCT-clamps (DCT-C). The third test series was conducted with suspension clamps that were coated

**Table 1**
Elements contained in the aluminum alloy in %.

| Material | Si | Mn | Cr | Fe | Zn | Mg | Ti | Al | Cu |
|---|---|---|---|---|---|---|---|---|---|
| SAE 305 | 12 | 0.35 | – | 0.5 | 0.35 | 0.1 | – | 86.0 | 0.25 |