Observation of the phase before DC arc fault apparition in wet conditions

Mohamed Boukhlifa (1), Romaric Landfried (1), Thierry Leblanc (1), Thomas Klonowski (2), Philippe Testé (1)
1: GeePs | Group of electrical engineering – Paris. CNRS, CentraleSupélec, Université Paris-Saclay, Sorbonne Université, 3 & 11 rue Joliot-Curie, Plateau de Moulon 91192 Gif-sur-Yvette CEDEX, France
mohamed.boukhlifa@centralesupelec.fr
romaric.landfried@centralesupelec.fr
thierry.leblanc@centralesupelec.fr
philippe.teste@centralesupelec.fr
2: Safran Helicopter Engines, Avenue Joseph Szydlowski, 64511 Bordes - France
thomas.klonowski@safrangroup.com

Abstract

In this paper, we present a study on the phase before arc faults that can appear in cable harnesses in DC regime. We are particularly interested in the precursor phenomena of the appearance of arc faults in the case of a fault created by wet process. For this purpose, an experimental device was implemented (has being adapted from the standard) *based on the standards usually used for the study of the arc tracking in AC regime. We then studied the chronology of the different events that follow one another and lead to the electric arc (and then to a fire outbreak). A progressive degradation of the cables was highlighted well before the appearance of the arc, linked to a phenomenon that we named "crackle". Some photographs are presented to follow the different phases of the degradation.*

Introduction

As the proportion of electrical energy in on-board networks increases, the issue of reliability and security will also become increasingly important. The electrical on-board network is of course understood to mean everything that constitutes the links, namely both the cable itself and the adjoining connection system (one not without the other). Particularly in the field of aeronautics, failure or damage to wiring can not only cause malfunctions or even destruction of equipment (or even the aircraft itself) ... The risk associated with this type of failure can be reduced if we are able to diagnose the "state of health" of the network, to predict its short-term evolution and if appropriate measures to avoid its aggravation (prevent the aggravation of an "incipient" defect) are taken in time. Consequently, it is necessary to have knowledge concerning the different types of faults as well as their possible evolutions. It's also needy to have techniques and methods to ensure the diagnosis of the constituent elements of the network and the monitoring of their state of aging and degradation. In addition, these degradations can be localized on a short portion of the cable or at the level of the connectors, but they can also have a significant spatial extension. Very many types of fault can thus appear [1] [2]: hot spots linked for example to over currents, partial discharges, wear or carbonization of the insulation, faulty connection due to vibrations, poor screwing, insulation fault between conductors...
This work is the first of a long-term study on arc fault detection. This first step concerns the study of the precursor phenomena of arc faults in the DC regime in the usual case of an arc initiated by wet process.
In the first part of this article, the experimental setup and the test protocol adopted are described. In the second part, the different events likely to appear and progressively leading to the initiation of the arc are described and presented chronologically.

Description of the experimental bench used

The long-term objective of the study presented in this work is related to the detection and propagation of an arc fault within a wire harness made up of 7 cables. We were inspired by the standard valid in AC current to propose a geometric configuration and a methodology that we applied to DC regime. A system according to the standards of requirements AC was implemented. We opted for wet fault priming using a salt water drip.

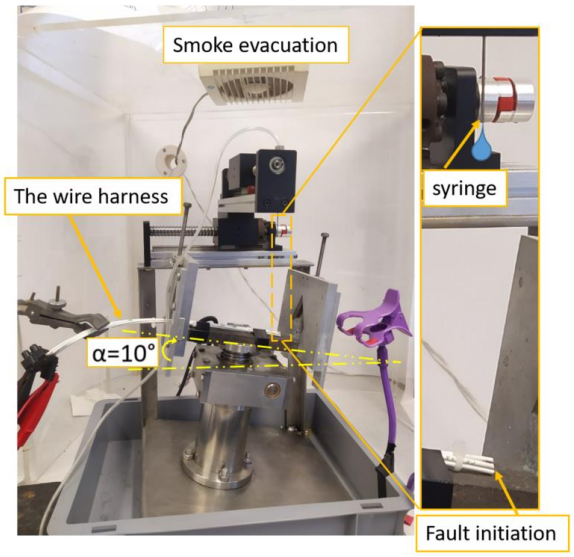


Fig. 1: photograph of the mechanical experimental device for the study of wet "arc tracking".

The experimental bench is presented in fig. 1. It's a wet arc tracking test bench, based on the initiation of a fault to wiring harness by a contaminating fluid (in our case salt water with controlled salinity, namely 30g / L) and corresponds to the recommendations of the AC standard (FprEN 3475-605). The polarity of the sample adjusted for direct current tests is described in figures 2. b and 2. c.

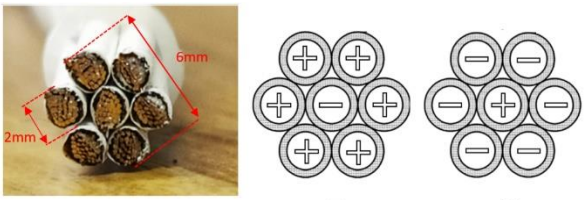


Fig. 2: a: photograph of harness with seven aeronautical cables, b: negative polarity, c: positive polarity

The reference cable used in the tests is: ASNE0261 CF 14, Polyimide tape – white, ASNE (Airbus) High Temperature Wire & Cable. Voltage Rating: 600 V. Temperature Ratings: -55°C to +200°C, used in the European aerospace industry [4].

The fault is in series with the power supply and is connected with the second part of the circuit.

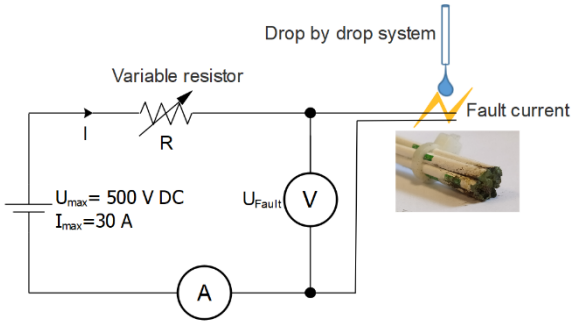


Fig. 3: electrical diagram of the experimental device used for the study of wet arc tracking with a purely resistive load.

Results: Chronological evolution of a fault until the appearance of an arc

This results part will be dedicated to the description study of the evolution of a fault until the appearance of an arc. The first tests having brought to light a whole set of precursor phenomena of the appearance of the arc particularly a so-called "crackle" phase fig. 4, 5, 6 and 7. This precursor phase of the arc, which can span from a few milliseconds to several minutes, is more "discreet" in terms of electrical signals than the arc phase itself, but can cause significant damage.
The detailed study of the evolution of this phase was made highlighting the appearance of a sort of "foam" on the fault followed by the appearance and the multiplication of luminous points, associated with current flow between the harness cables. During this phase, the degradation of the anode can be all the more important as the duration of the phase will be long. The crackle phase is followed by an electric arc phase and rarely followed by open circuit. We will now describe briefly the different "steps" of the crackle phase.

The "Crackle" phase

As previously said we are observed a precursor phase of the arc that we called "crackle" phase. It is characterized by various properties:

- "crackling" noise (hence its name) in an audible frequency range (20 Hz-20 kHz), the voltage of the fault equals to supply voltage.
- Appearance of a sort of foam due to the fault current that is presented in the fig. 4.
- Appearance of luminous points on the surface of the insulation of the central cable (either anode or cathode) fig. 5 and 6.
- Appearance of luminous points on the surface of the anode core which is presented in fig. 7.

This luminous phenomenon does not present any characteristic of a partial discharge or of an electric arc. The experimental conditions are as follows: negative polarity, U_{supply} =50 VDC, I_{max} = 20 A. I_{max} is the fault current case where the electrical fault is a short-circuit. The duration of the crackle phase is highly dependent on the supply voltage conditions. Generally, the higher the voltage, the shorter the crackle phase.

So we can divide the crackle phase on three steps:

- **First step:** start of the current flow in connection with the drop of salt water without luminous phenomenon (fig. 4), it is characterized by slow evaporation of the contaminating liquid and the appearance of a sort of "foam" on the fault. The average value of power dissipated in the fault around to 1 W.

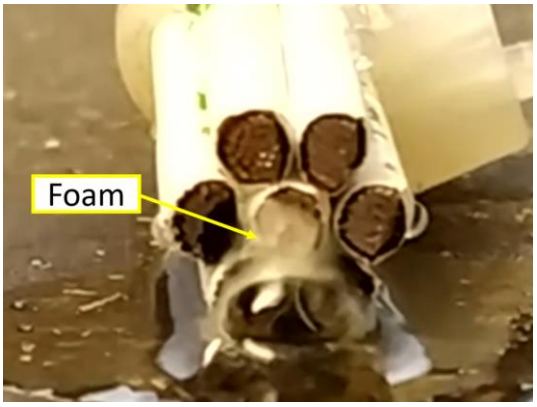


Fig. 4: first step of crackle: appearance of a current in the defect

- **Second step:** appearance of luminous points / increase in the number of luminous points (fig. 5 and 6). The end of this stage is distinguished by the appearance of a ring shape formed by the luminous points on the surface of the insulation of the center cable. This is accompanied by further disturbances of electrical signals with current peaks that can

reach amps in intensity. The average value of power dissipated in the fault around to 6 W.

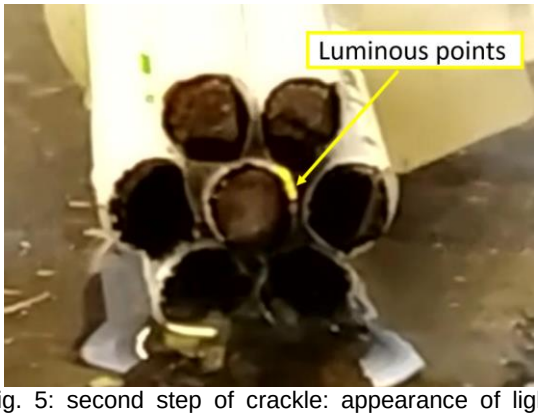


Fig. 5: second step of crackle: appearance of light points,

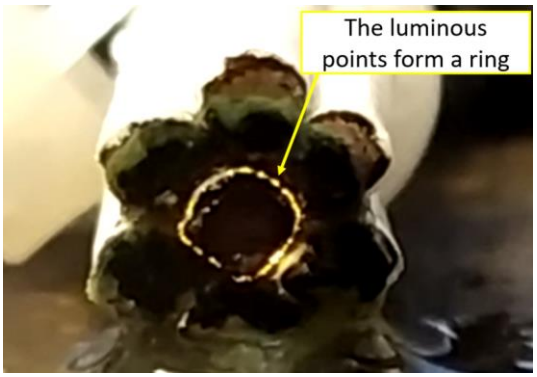


Fig. 6: second step of crackle (evolution): increase in the number of luminous points

Third step: appearance of luminous points on the surface of the anode core, a higher fault current intensity than for the other steps with current peaks of the order of magnitude up to a few amps. This step is also characterized by decomposition of the anode. (fig. 7), and this is the step that causes more degradation on the wire harness due to the decomposition of anode core like in the fig. 8, The average value of power dissipated in the fault around to 10 W.



Fig. 7: third step of crackle: appearance of luminous points on the surface of the anode core and degradation of the anode.



fig. 8: damage caused by the crackle on the harness

- **Electric arc phase:** One of the phases which systematically follows that of the crackling phase is when an electric arc appears between the central cable and one or more external cables. The fault voltage drops for reach values in the range [20 - 40] VDC during the arc phase. During this phase, the power dissipated in the fault is the maximum value observed during the various stages in the development of the fault.

Overview

The chronological evolution of the fault depend mainly on the level of voltage. The figure below synthesizes the various possible evolutions that we have observed among the various phenomena that may occur.

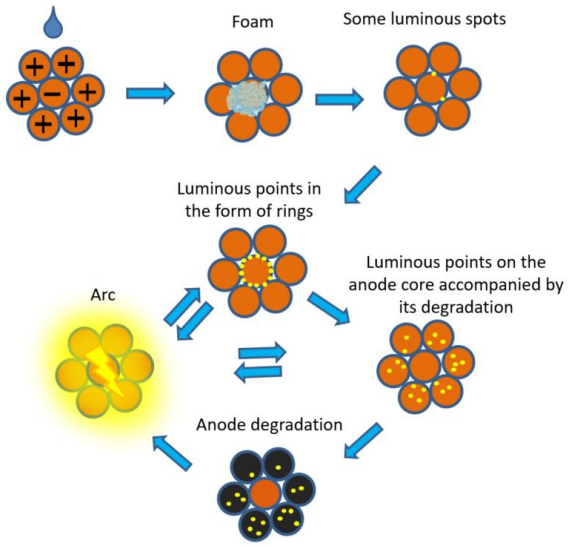


Fig. 12: summary diagram of the main stages in the development of crackle phase

The open circuit has been very rarely observed. It is caused by the decomposition of the anode core (during the third step of crackle phase) in the case of positive polarity.

Conclusion and perspective

The chronological evolution of the crackle phase which precede the arc phase have been described in detail. This precursor phase of the arc, which can last from a few milliseconds to several minutes, is more "discreet" in terms of electrical signals than the arc phase itself, but can cause significant damage. This highlights the possible advantages in detecting this phenomenon to prevent damage. The long-term objective of this study was to undertake work on fault detection modes. The detailed description of the results will be published soon.

References

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