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# Current measurements on insulating materials used in aeronautic HVDC cables

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## Abstract

*With the prospective of a more electric aircraft, new technologies are already developed or under development. It is for example the case with the replacement of hydroelectric or pneumatic power actuators by electric actuators. HVDC energy-networks are thought to replace HVAC technologies in the transport of electricity, and an increase of power density along these cables will also push the actual systems to their limits. In this context, knowing the electric field distribution within the cable insulating system becomes essential to prevent any electric breakdown, leading to a decrease of reliability of the electric system. To do so, it is then necessary to understand the behaviour of the cable polymeric insulation when submitted to an electrothermal stress. This work focuses on the experimental characterization of insulating materials presently used in aeronautic cables. Current measurements have been performed on Kapton (Polyimide-PI) and Polytetrafluoroethylene (PTFE), for different electric fields and temperatures. The results show a non-linearity in field for both materials.*

## I. INTRODUCTION

Electrical energy uses to take a minority place since the beginning of the aeronautics history compared with the mechanical, pneumatic and hydraulic energies. With the increase of the size of planes and the needs in embedded power, the aeronautical electricity networks undergo permanent progress. Actually, electrical energy takes a more and more important part, to the detriment of the other energies. Electric equipment are more and more numerous and nowadays, there are more than 500 km of cable in an A380 aircraft. This transition is not without consequences and thus requires the control of new technologies to meet the requirements of a high electric power.

Therefore, to obtain high power levels, new architectures of electrical distribution are put in place [1], and particularly high voltage direct current (HVDC) (540 V DC in addition to the "classical" 28 V DC).

Studies on terrestrial HVDC cable for the transport of electricity [2] show that the use of HVDC can lead to an accumulation of space charge within the insulation material. This accumulation is at the origin of a local distortion of the electric field. This space charge accumulation and hence electric field distortion can be increased by the use of multi-layer polymeric insulations of different nature, with the appearance of interfacial charges. This makes the prediction of the electric field distribution more difficult, and can bring, if the electric field becomes higher than the design field, to the breakdown of the material, i.e. the interruption of the distribution of energy. These phenomena can also take place in aeronautic cables with the use of the HVDC technology. Multi-layer polymeric insulations are also used in such cables, and the specific cable geometry also implies a field and temperature gradient, increasing the field distortion.

The aim of the present work is to characterize separately each material constitutive of an actual aeronautic cable, (polyimide and polytetrafluoroethylene) for a plane parallel geometry, and for electrical and thermal stress. To do so, current measurements have been performed for two different protocols, on each material. These results also allow us to determine the electrical conductivity variation as a function of field and temperature for each material.

## II. MATERIALS AND EXPERIMENTAL PROTOCOLS

### A. Materials

The materials used in the present study are a polyimide (PI) and a polytetrafluoroethylene (PTFE), both provided by Safran Group. These materials are already used as insulation in aeronautic (HVDC) cables for the transport of electricity.

PTFE is a hydrophobic semi-crystalline polymer constituted by very linear macromolecular chains and crystallizes easily. Its rate of crystallinity can reach 92 %. It can be used up to a temperature of 260°C and has good chemical properties and a good thermal stability.

As received PTFE samples are not sintered. A sintering is performed for all PTFE samples in an oven at 360°C during 5 to 10 min, in order to obtain samples as close of the real material as possible. The studied PTFE samples have a final thickness ranging from 72 to 77  $\mu\text{m}$ .

PI is constituted of aromatic cycles within its main macromolecular chain. This polymer is mainly amorphous, due to its rigid chains that refrain crystallization. This material can be used up to a temperature of 400°C, so its thermal stability makes it a favoured insulating material. It is a polar material, which absorb water. As received PI films are already coated with a FEP resin on both sides. The studied PI samples have a thickness ranging from 30 up to 36  $\mu\text{m}$ .

### B. Current measurement protocols

A gold electrode of diameter 20 mm and thickness 50 nm is deposited on both sides of each PI and PTFE samples.

The first measurement is designed to observe the impact of the electric field on the current behaviour for each sample. It consists in applying electric field steps of polarization/depolarization of 3 hours each, with increasing electric fields ranging from 1 kV/mm up to 120 kV/mm for PI (180 kV/mm for PTFE), at a constant temperature. A new sample is used for each temperature level. The tested temperatures are 20, 50 and 90°C. For each measurement, the current is recorded through a Keithley 617 ammeter with a 2 s dwelling time. All the measurements are performed in air at atmospheric pressure. The temperature regulation is managed using a temperature-controlled fluid circulation.

The aim of the second measurement is to see the impact of temperature on the current behaviour for each sample (PI and PTFE) for low and high applied electric fields. For this purpose, the protocol consists in applying one polarization/depolarization cycle (3h/3h) at a given temperature, ranging from 90°C up to 200°C.

### III. EXPERIMENTAL RESULTS

Current measurements for the first protocol are presented in Figure 1 for a PI sample at 50°C. The current shows a continuous decrease with time, for all the tested applied electric fields. For each applied field, the current transient seems to have two slopes: a fast decrease phase at short times and a phase of slow decrease in the longer times. This change in the current slope appears earlier with the increase of the applied field. For high applied fields, a stabilization of the current is observed for longer times.

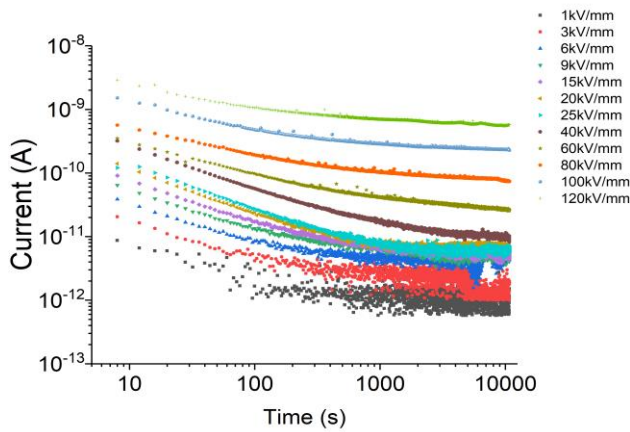


Fig. 1: Current measurements as a function of time for different electric fields at 50°C on a 36 μm thick PI film.

The increase of the current in the material with electric field is not linear for a fixed value of temperature. Figure 2 shows the current density in PI as a function of the applied electric field for different temperatures (20, 50 and 90°C). The value in current is a mean value over the last minute of the transient presented in Figure 1. The feature J-E shows two regions separated by a threshold situated at around 40 kV/mm, for the three temperatures. For low electric fields (lower than 40 kV/mm), there is a small increase in the current with the temperature increase. However, this feature does not hold at higher fields, where the current values overlap.

Current measurements up to 200°C for low and high electric field (20 and 100 kV/mm) were measured on PI samples in order to see the impact of temperature on the electrical conductivity. Figure 3 shows the current as a function of temperature for two values of the electric field. At 20 kV/mm, for temperature below 120°C the conductivity seems invariant. From 140°C and above, the conductivity increases. However, for a field of 100 kV/mm, the threshold takes place at around 90°C.

The same kind of trend has been measured for PTFE.

These results allow determining the existing relation between electric conductivity, temperature and electric field.

This law, determined for each material, will serve as input data for the implementation of a macroscopic bi-

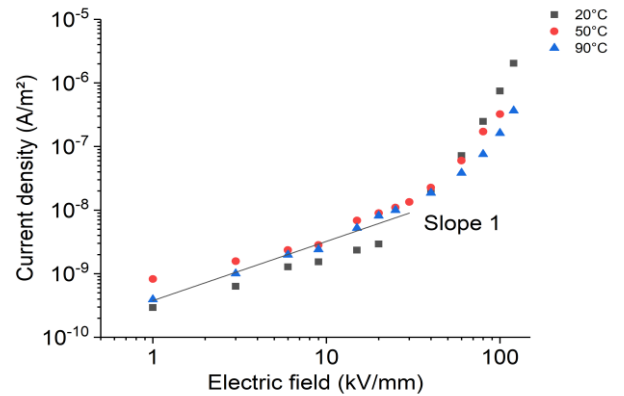


Fig. 2 : Current density versus electric field for different values of temperature (20, 50 and 90°C) for PI.

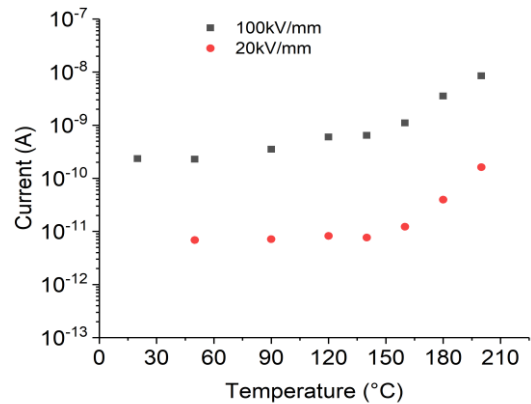


Fig. 3: Current on PI versus temperature for applied fields of 20 and 100 kV/mm.

layer model to study the current behaviour and the interfacial charging phenomena in a HVDC aeronautic cable as a function of the electric field and temperature gradients.

### IV. CONCLUSION

Current measurements have been performed for PI and PTFE materials, both used as insulation in HVDC aeronautic cables, in order to characterize their behaviour as regards electric field and temperature. The current/field characteristics show a threshold in field at around 40 kV/mm for PI and 100 kV/mm for PTFE. According the results on PI, the threshold in temperature is at around 140°C and 90°C respectively for 20 kV/mm and 100 kV/mm. These results will allow defining a relation for conductivity, depending on the electric field and temperature for both materials. The next step will be to develop a macroscopic model for HVDC aeronautic cables, where the temperature and field are no more constant within the dielectrics, and see the impact of conductivity on the internal electric field in real conditions.

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