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TIME EVOLUTION OF PARTIAL DISCHARGES ON INSULATORS UNDER IMPULSE VOLTAGE

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ABSTRACT
Partial discharges due to impact ionization is a major aging factor of insulators. In this work, the time evolution of partial discharges on insulators under impulse voltage of 1.2/50 μs form is examined. The measurements show that the duration of partial discharges is not proportional to the peak value of the applied impulse voltage. In this case, apart from the consumption due to partial discharges, a part of the offered energy from the impact ionization is consumed on the insulator due to mechanical stress.

KEY WORDS
Partial discharges, impulse voltage, solid insulators

1. Introduction

The application of high electric fields on dielectrics has a strong effect on their electrical and mechanical properties. It is commonly accepted that the applied electric field is the dominant factor which determines the overall conductivity of dielectrics [1].

Low fields are not capable of introducing partial discharges. In this case the conductivity is very low and depends mainly on the temperature. In the high field regime, dielectrics exhibit an increased conductivity due to non-linear phenomena such as impact ionization, which take place in the pre-breakdown stages [2]. Current instabilities are observed and high mobility states are stimulated [3]. This initiation and growth of partial discharge channels is related to these phenomena and plays a very important role in the dielectric aging procedure [4].

In this work, measurements are carried out on bakelite specimens in insulating oil under impulse voltage 1.2/50 μs of both positive and negative potential, in order to be examined the time evolution of partial discharges.

2. Measurement circuit and measurement procedure

A simplified diagram of the measurement circuit is given in Figure 1. This experimental set-up is standard in high voltage techniques [5, 6].

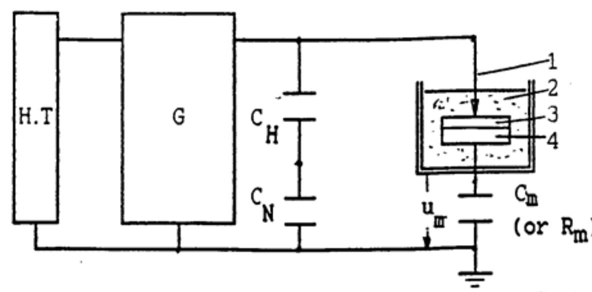

Figure 1. Simplified diagram of the measuring circuit:

H.T.	High voltage transformer
G	Impulse voltage generator
C_H, C_N	Voltage divider for the measurement of the high impulse voltage ($\hat{U}_H$ is the peak value)
C_m	Measuring capacitor for the detection of the potential steps corresponding to the partial discharges (u_m)
1	Tip electrode made of bronze (diameter 5 mm, tip radius 0.9 mm)
2	Insulating oil
3	Solid organic insulator sample in the form of a disk (thickness 1 mm, 2 mm, diameter 150 mm)
4	Plate electrode made of bronze (diameter 150 mm, thickness 5 mm)

The electrode configuration comprises of a metal tip-plate electrode assembly (tip radius R=0.9 mm) in order to establish a strongly inhomogeneous electric field. The solid insulator samples were made by bakelite, prepared in disk form with a diameter of 150 mm and a thickness of 1 mm and 2 mm. The specimens were in mechanical contact with the electrodes. The electrodes were made of bronze and were immersed with the specimen in a common insulating oil (transformers' oil). The applied pulses were of the form of 1.2/50 µs of both positive and negative potential. A measurement capacitor C_m was connected in series with the sample towards the electric earth. The applied impulse voltage and the potential profile across C_m were monitored on an oscilloscope. A great number of oscillographs of the potential profiles were taken for various impulse voltage peak values. The first measurements were recorded as soon as the partial discharges were detected, and then the measurement procedure continued, increasing incrementally the applied peak impulse voltage. Ten new specimens were tested at each impulse voltage peak value in order to be achieved reliable results and conclusions. The mean value of the measurements carried out is given in the figures below.

The outbreak of partial discharges at the solid-liquid dielectric combination brings out the formation of discrete potential steps at the potential build-up across C_m. This provides the required information about the duration of partial discharges versus the peak value of the applied voltage and the max value of the field strength.

3. Results and Discussion

A typical oscillograph of the applied voltage pulse $u_k(t)$ and the potential profile $u_m(t)$ across the measurement capacitor C_m is given in figure 2.

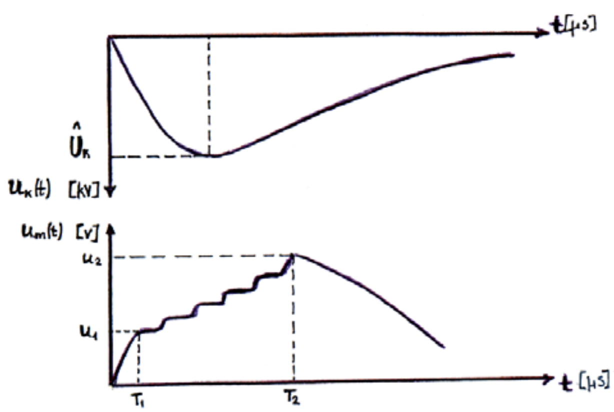

Figure 2: Potential steps during the aging of bakelite samples, under the application of impulse voltages of the form 1.2/50 µs.
$\hat{U}_k$: Impulse voltage peak value [kV]
T_1: starting time of partial discharges [µs]
T_2: ending time of partial discharges [µs]

The potential steps at $u_m(t)$ indicate the presence of partial discharges at the solid-liquid dielectric combination. In all cases, the applied electric field strength E at the tip electrode has been evaluated using the analysis for a conical tip [7].

According to this, the electric field peak value $\hat{E}$ is given by the expression:

$$\hat{E} = 2\,\hat{U}_k / [r \,.\, \ln(4d / r)] \qquad (1)$$

where r is the tip radius (0.9 mm) and d the distance between the electrodes (1 mm).

The increment of the charge ΔQ, can be estimated by the difference of the charges:

$$\Delta Q = Q_1 - Q_2 \qquad (2)$$

where Q_1 is the charge at the outbreak of the partial discharges and Q_2 is the charge at the end of the partial discharges. Q_1 and Q_2 are given by:

$$Q_1 = C_m \cdot u_1 \qquad (3)$$

$$Q_2 = C_m \cdot u_2 \qquad (4)$$

where u_1 and u_2 are the values of the impulse voltage of the outbreak and of the end of the partial discharges correspondingly:

The following figures show the duration of partial discharges ΔT (T_2-T_1) for each measurement group of the applied voltage ±1.2/50 µs and specimen (bakelite of 1 mm and 2 mm).

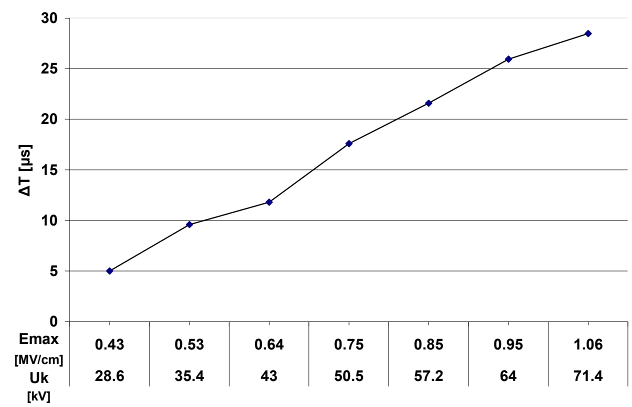

Figure 3: Duration of partial discharges for bakelite 1 mm and impulse voltage +1.2/50 µs versus the max absolute value of field strength E_{max} and the peak value of the applied voltage $\hat{U}_\kappa$

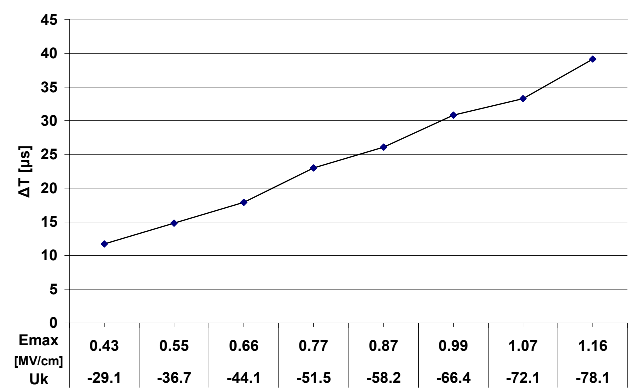

Figure 4: Duration of partial discharges for bakelite 1 mm and impulse voltage -1.2/50 µs versus the max absolute value of field strength E_{max} and the peak value of the applied voltage $\hat{U}_\kappa$

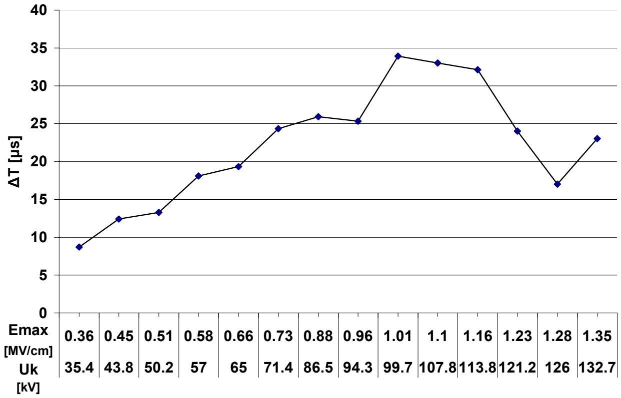

Figure 5: Duration of partial discharges for bakelite 2 mm and impulse voltage +1.2/50 µs versus the max absolute value of field strength E_{max} and the peak value of the applied voltage $\hat{U}_{\kappa}$

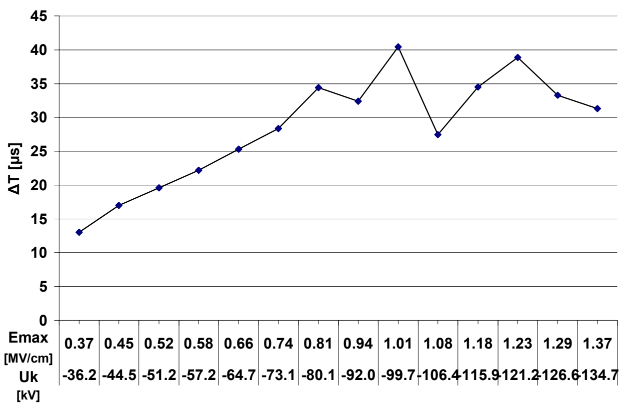

Figure 6: Duration of partial discharges for bakelite 2 mm and impulse voltage -1.2/50 µs versus the max absolute value of field strength E_{max} and the peak value of the applied voltage $\hat{U}_{\kappa}$

The above figures show that the duration of partial discharges is not proportional to the peak value of the applied impulse voltage, as it may be presumable. In most cases, the duration is increased as the applied voltage is increased. However, there are high voltage values in which a reduction of the duration of the partial discharges is observed. This phenomenon is more intense on the specimen of the 2 mm width.

The reduction in the duration of partial discharges means that there is a reduction in the rate of the charge increment, although the voltage is higher. Partial discharges are construed as the production of free electrons due to impact ionization [8, 9]. In the cases of the charge decrement, the energy seems to be offered for the mechanical stress of the specimen by Coulomb forces. Consequently, there is an alternation between the factors of insulator ‘s aging (Coulomb forces, partial discharges), till the final aging of the insulator.

The differences of the results for the two different width of the specimen show that the partial discharges are related more with the environment than the material of specimen itself.

4. Conclusion

In this work, measurements are carried out on solid dielectrics immersed in insulating oil under impulse voltage 1.2/50 µs, in order for the time evolution of partial discharges to be examined. The measurements show that there are cases where the duration of the phenomenon is decreased although the applied voltage takes higher values. Consequently, the rate of charge increment is decreased. That means that the energy is offered to the mechanical stress of the insulator. It seems that during the process of insulator’s aging under impulse voltages, the offered energy from the impact ionization is consumed on the insulator alternatively due to the mechanical stress and the partial discharges.

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