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CHARACTERISATION OF PARTIAL DISCHARGES IN MINERAL OIL

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ABSTRACT
This paper deals with the characterisation of the partial discharge currents generated in mineral oil and their consequences. The shape of these currents, the associated electrical charges and energies are analysed in function of the number of discharges, the electrode geometry and the applied voltage. Chromatographic analyses in gaseous phase of oil samples submitted to partial discharges are achieved. The energy levels of the partial discharges are investigated as well as the types and concentrations of gases that they can generate.

KEY WORDS
Mineral oil, transformer, partial discharges, current, energy, chromatography.

1. Introduction

The cycle life of a power transformer depends on the electrical, mechanical, thermal and environmental stresses to which its components are submitted during their exploitation. The insulating structure constitutes one the most important component. It consists of solids (especially paper and/or polymer) and insulating fluids and more particularly oils which also serve to evacuate the heat generated by the windings.

The failure of the insulating structures is often initiated by partial discharges resulting in changes of the physical and chemical properties of oil expressed by the formation of dissolved gases in the liquid bulk and the migration of solid particles and traces of water [1-3]. Numerous studies were reported on this topic [3-7].

The present paper is aimed at the analyse of partial discharge currents generated in mineral oil. We investigate especially the shape of these currents, the associated electrical charges and energies in function of the number of discharges, the electrode geometry and the applied voltage. A particular attention is reported on the analyse of dissolved gases resulting of such discharges versus the energy levels of these latters. We also present and discuss the currents associated to PD initiated in three different electrode geometries.

2. Experimental Technique

Two experimental devices were used. The first one consists of a test cell and an automatic setup enabling to measure the discharge voltage, the dielectric permittivity, the loss factor (tanδ) and the resistivity of oil samples. The available energy supplied by this device is not sufficient to provoke a significant deterioration of the characteristics of oil samples. It is applied through an automatic disconnecting switch for discharge currents higher than 4 mA in a lap of time lower than 1 ms. The second device enables to measure and to visualise the currents, and to generate discharges of different levels of energy (Figure 1). It consists of a test cell of 330 ml and a high voltage transformer (220V/100kV - 5kVA - 50 Hz). The voltage is applied to the oil gap through a switch which cut out when the discharge current exceeds a certain value; it's uniformly increased (2.0 ± 0.2kV/sec). A non-inductive measurement resistor is inserted in the primary circuit. It's characterised by a voltage drop of 120mV corresponding to a current flow of 12A. A digital storage oscilloscope (Tektronix - 100MHz Bandwidth) is used to record the current signals.

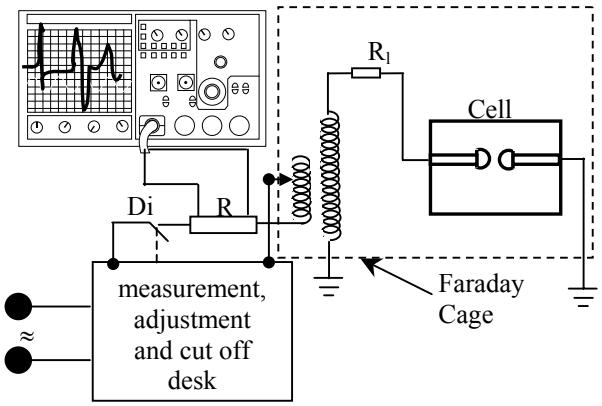

Figure1: Experimental setup

The test cell containing the electrode system was made of Plexiglas. Three electrode systems were used. The first one consists of two hemispherical electrodes of 12.5 mm, made of brass and enabling to get a quasi-uniform electric field. The gap d was set to 2.5 ± 0.05 mm, according to IEC 156/195-02 specifications. The electric field distribution in this electrode system is quasi uniform. The two other electrode configurations consist of point-

hemisphere systems made of brass. The radius tip r_p of the point electrodes were 500µm and 200µm and the diameter of hemispherical electrode was 12.5mm.

3. Results and Discussions

3.1. Energies

The tests were performed on mineral oil (BORAK 22) consistently to IEC specifications: IEC 156 for the dielectric strength, IEC 247 for tan δ, IEC 814 for the water content and ISO 4406/NAS 1638 for particle detection. The analyses of dissolved gases were achieved thanks to a chromatograph (TFGA-P200 DGA Plotting type) according to IEC 567 specifications. The interpretation of the obtained results is made by the calculation of ratios of the dissolved gases following Duvall's triangle consistently to IEC 60599 specification.

Two types of energy are measured: the first one is related to the continuous component of the current and the second one to the maximum value of pulses superimposed on this continuous component. A digital voltmeter is also used to measure the effective value of the current through the non-inductive resistor. Thus we measure the currents, the energies and the charges associated to each discharge occurring within the tested liquid.

The energies measured in each type of electrode configuration is all the more weaker as the radius of curvature of the electrode is smaller. These energies are of about 1 to 5 Joules; they correspond to luminescent discharges the duration of which are less than 5ms. Their adjustment is obtained by the simultaneous changing of the curvature radius of the sharp electrode and the discharge current obtained thanks to a device of variable resistors acting as a current divider. The system is protected against arc discharges whose energies are higher than 10 Joules. On the other hand, we observed that the initiation of a large number of discharges (about one hundred) the energy of which is lower than 0.5 J doesn't practically affect the characteristics of oil ; and no significant quantity of dissolved gases was detected except a vaporisation of water traces contained in the oil.

Figure 2 presents the variations of the discharge voltage versus the discharges number, for the three considered electrode configurations. We note that the smaller the radius curvature of the electrode thence the higher the electric field, the lower the discharge voltage is. And the mean charge of discharges is all the more higher as the radius of curvature of electrode is larger even if the corresponding initiation voltages are lower (Figure 3). The current signals are characterised by discreet positive and negative pulses of comparable amplitudes which are greatly higher than that of the continuous component on which they are superimposed. Figure 4 presents a typical discharge current obtained with a point of 200µm under a voltage of 25kV. The pulse durations are of about 40 µs.

And since the discharge (streamer) propagation velocity in mineral oil is estimated to more than 1.4 km/s [8, 9], this time is widely sufficient for the propagation of discharges up to the opposite electrode. Figure 5 presents a typical shape of positive current measured at the earthed electrode in a point-plane electrodes arrangement where the radius curvature of the point is 10µm.

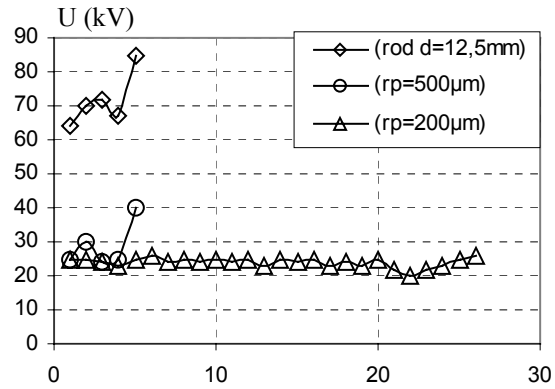

Fig. 2: Disruptive voltage versus the number of discharges for the three electrode configurations, d=2.5mm.

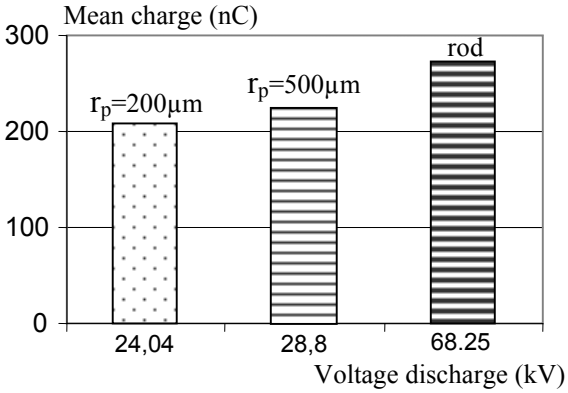

Fig. 3 : Mean charge for different voltage discharges and radius of curvature of the HV electrode.

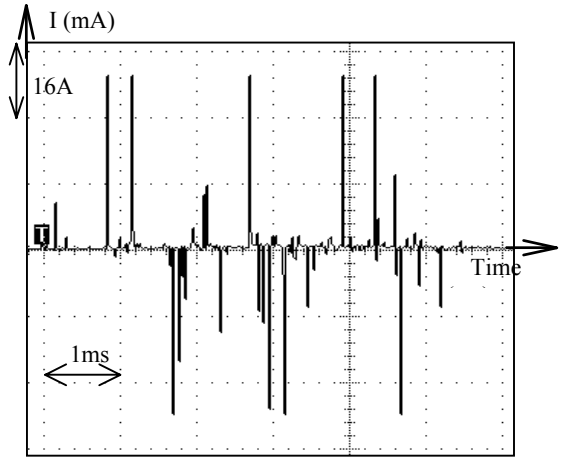

Fig.4 : Typical signal of discharge current in mineral oil. d=2.5mm ; U=25kV, r_p=200µm.

Note that the energy corresponding to such a signal is too weak due to the fact that the earthed electrode is covered by an insulating sheet used also as a protection [10].

The discharge current signals we recorded would correspond therefore to the propagation and extinction of several streamers spaced by times between 0.2 and 1.5 ms. The number of pulses characterising each recorded discharge varies between 5 for discharges of weak energy and one hundred for discharges of high energy. The duration of each event varies between 1ms for the discharges of weak energy and 12ms for the discharges of high energy.

The energies corresponding to the current pulses are much higher than that of the continuous component. Figure 6 gives the chronological variation of energy of each current peak. The stored maximal energy could exceed 5 Joules for some peaks. The mean value of the flowed energy varies between 0.2 and 1.5 J while the average charge is about 10 to 120 µC.

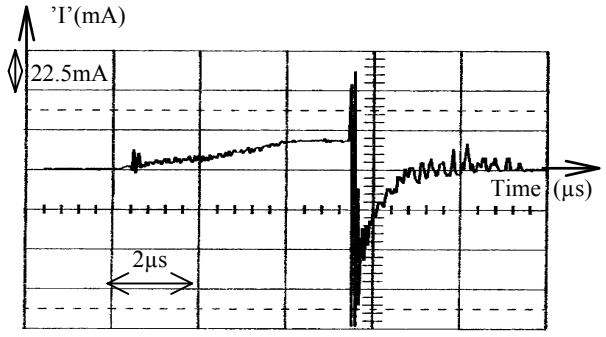

Fig.5 : Typical signal of positive streamer current in mineral oil. d=5mm ; U=24kV, r_p=10µm.

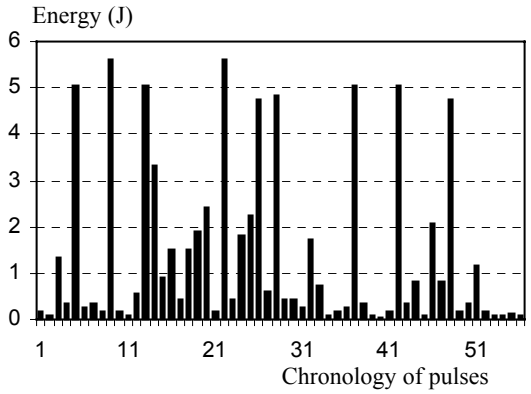

Fig.6 : Energy of the current pulses of figure 4 as a function of their chronology. d=2.5mm ; U=25kV, r_p=200µm.

3.2 . Chromatographic Analysis

The dissolved gases present in oil sample after submission to 38 discharges are analysed by chromatography in gaseous phase. And the results are treated by the calculation of the dissolved gases ratios according to IEC.60559 specification; the gases are extracted from oil samples using the "SHAKE TEST" technique. The diagnosis is achieved on two columns: A and B. The parameters characterising these columns are:

(i) Column A: it's of MS-5A-10m type where the vector gas is helium; temperature: 70°C; pressure: 31.4 pounds per square inch (psi); injection time : 50 ms; time of separation: 10s and the time of analysis: 100s.

(ii) Column B: it's of Poraplot-U-4m type where the gas vector is helium; temperature: 45°C; pressure: 19.2 psi; injection time: 50 ms; time of separation: 10s and the time of analysis: 60s.

Two gases are evidenced in each column: CO and CO_2 in column A (Figure 7 (A)) and C_2H_4 and C_2H_2 in column B (Figure 7 (B)). These analyses concern a sample of new oil previously treated and then submitted to discharges in a point-sphere electrodes arrangement under an average voltage of 28.80 kV. The temperature of oil before its injection is 24°C and the pressure 0.0 psi. Table 1 gives the concentrations of the detected gases. We observe a high quantity of acetylene indicating the advanced deterioration of the tested oil. The occurrence of two arc discharges on the 38 applied discharges to the tested oil was sufficient to create quantities of acetylene rendering this oil non conform to the use.

We also achieved another analyses of oil samples we submitted to 4 arc discharges of energy of 18 J we get in a sphere-sphere electrodes configuration under 68.25 kV. Table 2 gives the concentrations of the different dissolved gases we evidenced. We note that the quantity of acetylene is 6 times higher than that detected in the previous test.

Table 1 : Type and concentration of the dissolved gases detected through the two columns (38 discharges including two arcs)

Type of gas	Column of detection	Concentration
Hydrogen (H_2)	A	n/d <1
Methane (CH_4)	A	n/d <1
Carbon monoxide (CO)	A	3
Carbon dioxide (CO_2)	B	582
Ethylene (C_2H_4)	B	26
Ethane (C_2H_6)	B	n/d < 1
Acetylene (C_2H_2)	B	231>>3
Equivalent TCG (%)		0.02

4. Conclusion

This work allowed us to identify the limits of energy levels of discharges over which most compromising gases to the oil quality and thence to the safety of oil filled apparatus (especially power transformers) could be generated. The discharges the energy of which exceeds 15 Joules generates a great quantity (231 ppm) of acetylene (C_2H_2) indicating the break of the triple carbon liaisons of oil and its irreversible deterioration. This takes place at temperatures over 700°C. Such a quantity of acetylene is much higher than 3ppm which is the limit tolerated by IEC specifications.

In some cases, gaseous phase chromatography is not sufficient to itself, to make a formal diagnosis on oil. The furanic compounds resulting from the paper decomposition are likewise determinant.

Table 2 : Type and concentration of dissolved gases recorded through the two columns (only 4 arcs).

Type of gas	Column	Concentration in p.p.m.
Hydrogen (H_2)	A	175
Methane (CH_4)	A	70
Carbon monoxide (CO)	A	3
Carbon dioxide (CO_2)	B	433
Ethylene (C_2H_4)	B	186
Ethane (C_2H_6)	B	n/d < 1
Acetylene (C_2H_2)	B	1437 >>>3
Equivalent TCG (%)		0.50

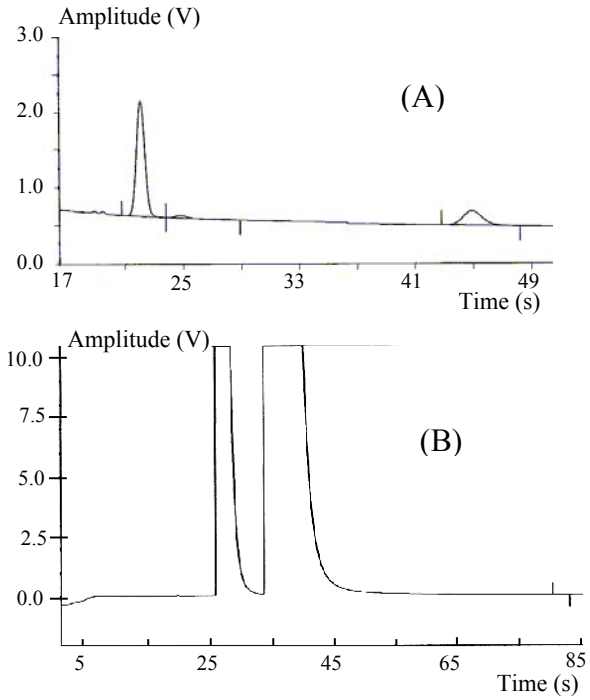

Fig. 7 : Chromatograms in each column A and B.

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