ELECTRICAL DISCHARGE IN DIELECTRIC STRUCTURES

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Abstract

Based on investigations on partial discharges under different physical conditions and when using different dielectric barriers, it was found that the discharge in the gas gap confined by dielectrics has a pulse character under all conditions. The discharge current is shown to consist of discrete pulses whose shape and frequency depend on the dielectric parameters, the type of gas in the gap and the pressure. One of the main reasons for the deterioration of the electrophysical properties of dielectrics is the development of electric discharges in dielectric structures consisting of dielectrics with significantly different properties. Therefore, the study of the influence of the properties of dielectrics and the electrophysical parameters of these dielectrics on the mechanism of development of the discharge under conditions of electric discharge is an urgent issue [1-3].

Keywords: Dielectric, microstructure, electrophysical parameters, electron-optical converter, discharge.

I. Introduction

Knowledge of microstructures and mechanisms of discharge formation, as well as the nature of physical and chemical processes occurring both in the volume of the gas medium and in the place of contact of microdischarges with the dielectric surface, is important for solving problems related to the creation of solid dielectrics operating under partial discharge conditions.

To reveal the microstructure, a spatial (optical) view of the discharge in the space between dielectrics under different electrophysical conditions was obtained. A special experimental apparatus was used, which allows to simultaneously record the electrical and optical picture of the discharge with the help of an oscillograph and an electron-optical converter (EOC) and a multi-frame optical time loop.

At present, it is not possible to fully understand the influence of the electrophysical properties of dielectrics on the microstructure and the mechanism of development of partial discharges.

The experimental apparatus used by us to study the electric discharge in the gas gap confined by dielectrics allowed simultaneous recording of electrical (current and voltage pulses, volt-coulomb properties) and optical scenes. The studied discharge was generated in an experimental core with disc-shaped electrodes made of stainless steel. Depending on the purpose of the research, the surface of the electrodes of the core is covered with different polymer dielectrics. The thickness of the polymer layers and their composites varies from 20 to 200 μm. The polymers are filled with various inorganic materials: semiconductors, magneto-piezoelectrics and semiconductor oxides. The electrodes are equipped with fixing means that create a reliable contact between the metal electrode and the dielectric. With the help of a micrometric screw it was possible to change the distance

between the electrodes from 0 to 15 mm with an accuracy of 10 μm. A high voltage with a frequency of 50 Hs was applied to the core under investigation.

The optical picture of the discharge was recorded by means of electron-optical time-lapse photography with multi-frame electron-optical converters (EOTC). The use of electron-optical converters, which provide multiple amplification of the image, is determined by the poor illumination and short lifetime of individual microdischarge channels. In our experiments, the maximum optical resolution reached 20 double lines/mm per frame across the entire screen of the EOCH converter.

The obtained optical images (EOC) (figure 1) show that the geometrical dimensions and microstructure of the channel of individual microcavities are highly dependent on the electrophysical parameters of the dielectrics bounding the gas gap. Naturally, it can be assumed that the value of the local residual voltage after the occurrence of an individual microdischarge in the air gap depends significantly on the dielectric properties.

Table 1 shows the average value of the diameter of the microdischarge channels for some dielectric anodes (positive electrode coated with dielectric as dielectric anode) and cathodes (negative electrode coated with dielectric). Other conditions being equal (constancy of the voltage amplitude at the electrodes, the thickness of the air gap), if polymer layers (PE, PP) are used as a dielectric, the diameter of the microdischarges near the anode is always the same as that of dielectrics with high dielectric permittivity, i.e. composites obtained on the basis of dielectrics dispersed with barium titanate ($BaTiO_3$) or non-organic dielectric particles of the LZT-19 type are smaller than those used.

PVDF + 20% vol. $BaTiO_3$ or PP + 10% vol. QST - 19 as a dielectric anode, i.e. the number of microdischarges in each series or in each hole of the gas gap (figure 1, b and c) is less than in the case with polymer layers (PP, PE) as anodes, i.e. dielectrics with low electrical conductivity and low dielectric permittivity (figure 1, a).

The amplitude of the applied voltage affects the number of micro-discharges in each series and therefore the amplitude of the voltage pulse generated during the perforation of the air gap.

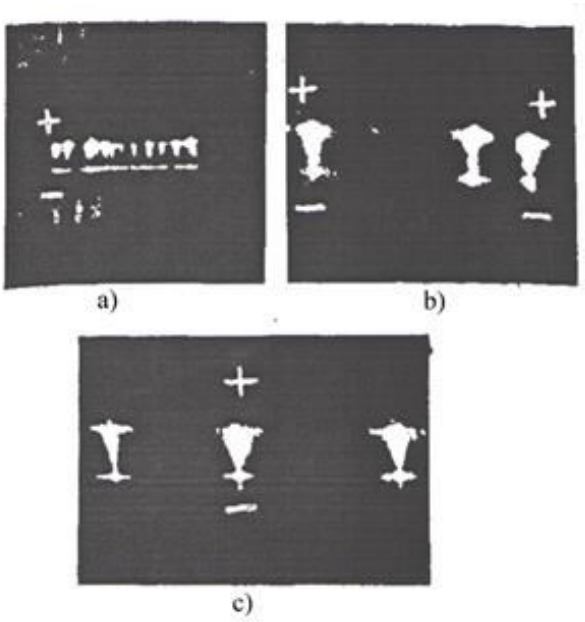

Figure 1: *Optical view of the discharge.*
a) PP - air gap - PP; ε = 2,3; b) PP + 20% vol. LZT-19 - air gap - PP + 20% vol. QST-19; ε = 10;
c) PVDF + 20% vol. LZT-19 - air gap - PVDF + 20% vol. LZT-19; ε = 18

Dielectric anode and cathode thickness 200 μm; thickness of the air gap between two-phase composites d = 4,5 mm.

Table 1: *Dependence of the diameter of the channel of individual microdischarges near the anode on the type of dielectric limiting the air gap*

Thickness of the air gap d, mm	Dielectric anode and cathode types			
	Diameter of micro-discharges D, mm			
	PVDF 20 % vol. $BaTiO_3$	PE	PP	PP+20 % vol. LZT - 19
1	1,15	07,	0,6	0,86
2	1,3	0,92	0,84	1,1
3	2,2	1,2	1,00	1,5
4	2,6	1,43	1,3	2,0
5	3,0	1,53	1,45	2,2
6	3,64	1,8	1,8	2,36

With a change in the thickness of the air gap between the dielectrics, the illumination brightness and geometrical dimensions of the microdischarge channels change. For example, with an increase in the thickness of the air gap under the same conditions, the diameter of the microdischarge channels near the dielectric anode increases significantly (table 1). In addition, under the conditions of our experiments, with an increase in the air gap, the number of microdischarges in the series, that is, with each puncture of the discharge gap, also decreases.

The study of the optical picture of the discharge showed that the properties and thicknesses of the dielectric anodes and cathodes have a significant influence on the optical picture of the microdischarge channel. The brightness, geometrical dimensions and shapes of the discharge channels depend significantly on the dielectric permittivity ε_g of the dielectric anode. The dielectric permittivity (ε_g) of the polymers was modified by dispersing them with barium titanate $BaTiO_3$ or LZT-19 particles.

The formation mechanism of different microdischarge channels in the polymer-air gap-polymer dielectric structure was considered, and it was found that the microdischarge channels expand near the dielectric anode when the positive electrode is coated with dielectric. It is known that the following can cause the microdischarge channels to widen:

1. Expansion due to thermal diffusion of electrons in the cross-sectional direction of the microdischarge channels.

2. Expansion due to electrostatic repulsion of the electron cloud.

3. Expansion due to the field of charges sitting on dielectric surfaces.

After that, by comparing the experimentally found values of D_{mb} - for EOCH grams with the calculated values of the microdischarge diameters, it was concluded that the expansion of microdischarges near the dielectric anode cannot be determined by the thermal diffusion of electrons and repulsion of the electron cloud. The subsequent expansion of the microdischarge channels is associated with the distortion of the electric field of charges sitting on dielectric surfaces in the air gap.

Indeed, with the passage of the first current, electrons settle on the surface of the dielectric anode and form a point of charge of any density there. The electric field of charges is characterised by both normal accumulation, directed against the external field, and tangential accumulation, determined by the unequal density of charges located at the point along the dielectric surface. It is believed that the presence of tangential accumulation of the field helps to attract charges from the centre of the microdischarge channel to the edges, i.e. leads to a noticeable bending of the trajectory of electrons near the dielectric anode.

Although the effect of the expansion of microdischarge channels near the dielectric anode has been extensively described, the reasons for the appearance of dark patches in the overall structure of microdischarge channels near the dielectric cathode have not been sufficiently investigated.

We found that when the air gap and dielectric thicknesses are unchanged, the structure of the microdischarge channel mainly depends on the dielectric permittivity of the walls. The obtained optical images show that the dark areas near the cathode decrease significantly with increasing ε_g. From the above, it can be concluded that the decrease of the dark field near the cathode with increasing εg can be explained as follows. In the polymer - air gap - polymer system, the voltage takes such a value that ionisation processes start in the air gap, after which the starting current is initiated from the place where the field intensity is greatest - from the dielectric surface of the cathode. As a result of the development of the initial flood, charges accumulate on the dielectric anode and cathode surfaces bounding the air gap at any $\Delta S^{/}$ - surface of the dielectric. In the air gap where the flow occurs, the electric field (ΔE) is the superposition of two fields: external (E_p) and the field of charges sitting on the surface of the dielectric (E_{ot}), i.e.,

$$\Delta E = E_p + |-E_{ot}|$$

We can estimate the capacitance of a dielectric barrier with area $\Delta S^{/}$, dielectric permittivity ε_g and thickness d_g as follows:

$$\Delta C^{/} = \frac{\varepsilon_0 \varepsilon_g \Delta S^{/}}{d_g} \quad (1)$$

The $\Delta q^{/}$ - load on the considered $\Delta S^{/}$ area creates a voltage increase $\Delta U^{/}$ equal to $\Delta q^{/}/\Delta C^{/}$. At this time, the voltage in the air gap will drop very low. As can be seen, the degree of voltage drop in the air gap after the initial onset of flooding when d_g = const is mainly determined by the dielectric permittivity ε_g. During the formation of the microdischarge, the formation of a flood of electrons along the channel continues until the field of settled charges reduces the value of the external field, so that after this value the development of ionisation processes is not possible [4-6]. Therefore, at a certain density of electric charges transported by means of an initial current to the surface of the dielectric barriers, the voltage drop slows down with an increase in εg in the air gap, and hence the number of currents generated from the same point increases on the surface of the dielectric cathode, which leads to the complete disappearance of individual micro-discharges. The increase in the number of electron flows with increasing ε_g is probably the main reason for the large retention of the dielectric anode surface (figure 1 b,c).

Let us look at possible reasons for the disappearance of the dark field in the microdischarge channel near the dielectric cathode with increasing dielectric permittivity. This topic is also important for determining the criteria and understanding the mechanism of electrical breakdown of dielectrics under the influence of discharge. Based on the experimental results obtained, several hypotheses can be proposed.

1. If the air gap is bounded by different types of dielectrics, the degree of decrease of the main (external) area near the dielectric electrodes at a constant value of the settled charges differs. Near the dielectric-covered electrode, which itself has a large dielectric permittivity (when d_g = const), the decrease in the base area during each current is smaller. We consider that after a discharge, the surface of the dielectric walls is not equipotential and the field is differentiated in the air gap near the electrodes due to the variation of ε_g, γ_s and d_g in the dielectric. Therefore, the electrons initiating the overflow processes can only obtain sufficient energy to excite and ionise the atoms of the gas after travelling a certain distance from the dielectric cathode surface in the air gap. This minimum distance can be distinguished as a dark area in the optical appearance of the microdischarge channels (figure 1, a).

2. The number of electron streams generated along the channel of an individual microdischarge, which ultimately leads to the formation of a microdischarge, can greatly influence the dimensions

of the dark field. The number of electron flows along the microdischarge channel can be determined using simultaneous plotting of electrical and optical images of the evolution of the discharge in the air between the dielectric walls as follows:

a) First we determine the value of the Q - charge in the half-period (T/2) of the applied voltage according to the oscillogram of the discharge and determine the number of micro-discharges according to the optical picture n in the period T/2. Then, the value of the charge Δq carried by the individual microdischarges is determined as follows:

$$\Delta q = \frac{Q}{n} \tag{2}$$

Knowing the value of the Δq charge, the number of N_s currents along the microdischarge channel is determined:

$$N_s = \frac{\Delta q}{2\Pi_e e_e} \tag{3}$$

where e_e - is the charge of an electron,

Π_e - is the number of electrons in a separate current and is determined by the following expression:

$$\Pi_e = n_0 \cdot exp\left(\int_0^d d \cdot dx\right) = n_0 e d_{or} \cdot d \tag{4}$$

Where n_0 - is the effective electron number,

α - is the Townsend coefficient and

d - is the thickness of the air gap in the polymer-air gap-polymer system.

In our experimental conditions, the value of α or is determined from the dependence graph α/p = f(E/p). As mentioned above, with the development of microdischarge, the charges sitting on the dielectric anode and cathode reduce the value of the electric field in the air gap during the formation time, and therefore the value of the pulse ionisation coefficient becomes an unstable quantity. Therefore, for a given value of α, E_{or} in the dependence α/p = f(E/p) should be assumed as follows:

$$E_{or} = \frac{U_d + U_b}{2d} \tag{5}$$

where U_d - is the breakdown voltage of the gap in the polymer-air gap-polymer system,

U_b - is the breakdown voltage of the individual microdischarge determined from the following expression:

$$\Delta q = \frac{\Delta s}{s}\left(C_g + C_b\right)\left(U_d + U_{sön}\right) \tag{6}$$

Here C_g and C_b are the dielectric and air gap capacitances, respectively.

b) The number of electron flows during the formation of local discharges is expressed as follows:

$$N_s = \frac{t_{mb}}{V_e^{-1} d} \tag{7}$$

where V_e is the electron drift velocity. The value of V_e is determined from the experimental graph V_e = f(E_{or}/P) and t_{mb} is determined from the discharge voltage pulse oscillogram.

The intensity of the electric field is determined by the electric strength of the gas gap between the dielectric barriers, which is a constant quantity when the thickness of the gap d remains constant

and does not depend on the amplitude of the voltage applied to the polymer gas gap-polymer dielectric structure. The amplitude of the applied voltage mainly determines the number of discharges in the sinusoidal voltage period (figure 2).

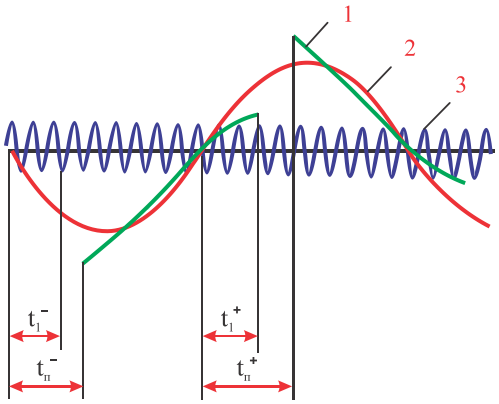

Figure 2: *Oscillograms of applied voltage and discharge voltage pulses:*
1 - discharge voltage pulses in the sinusoidal voltage period;
2 - variation of the applied voltage;
3 - calibration voltage (T = 1000 μs)

II. Conclusion

Thus, the application of EOC and simultaneously obtained electrical (figure 2) and optical (figure 1,a) images are used to reveal the microstructure of the electrical discharge in the dielectric - gas gap - dielectric system, their causes. The electrical corrosion of polymers and the formation of new electret, piezo and pyroelectric properties in them allow their proper utilisation.

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