Influence of discharge conditions on the charge decay characteristics

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Abstract. A simplified analysis of the charge decay processes for samples equipped with different types of grounding electrodes was given in the paper. It was shown, that the electrical properties of the back electrode (injecting or blocking) may strongly influence the charge decay process for plane parallel dielectric samples. The theoretical expectations were confirmed by experimental investigations. It was shown, that the half-time (time parameter characterising charge decay process) may reach, for the sample with blocking back electrode, the value of one order of magnitude higher in comparison to that obtained for other electrode types (injecting or side electrode). It was pointed out that in practical situation charge decay for the plane parallel samples may be much slower than that predicted basing on the measurements carried out according to the current standards.

1. Introduction
Charge decay characteristics have been applied since many years in studying physical nature of charge transport in solid dielectrics [1-4] as well as in technical estimation of applied dielectrics [5,6]. In case of investigations of transport processes the pre-charging and following discharging processes are usually precisely described and adjusted for the particular experiment. It is not so in case of application of decay characteristics for technical estimation of materials (e.g. antistatized materials). Not looking on the specific discharge mechanisms depending on the physical nature of charge transport processes appearing on the surface as well as in the volume of the sample, one can find some typical dependencies or influence of the discharge conditions on the shape of decay curves. The last is probably one of reasons for which some of standards used nowadays [5] includes carrying of the investigations of discharge characteristics in different discharge circuitry.

2. Theoretical expectations
Let’s consider the case with a dielectric sample charged only in the central part of its surface as it was shown in the figure 1. The sample may be discharged in three different circuits.

The sample shown in the figure 1 is equipped with the back electrode, which enables free current flow through its surface (injecting electrode). The time constant of the discharge process for the case when discharge current flows through the volume of the sample in direction normal to its surface is equal to the Maxwell’s time constant value:

\[ \tau_N = \frac{\rho \varepsilon \varepsilon_0}{\varepsilon} \]  

(1)
where: $\rho_v$ – volume resistivity of the sample’s material, $\varepsilon$ - relative electrical permittivity of the material of the sample, $\varepsilon_0$ – permittivity of the free space.

Model of the sample equipped with the side electrode only was shown in the figure 2. For this case one can expect that the discharge current will flow practically only tangentially to the surface of the sample.

Assuming \( \frac{r_2}{r_1} = e \), where $e$ – is the base of natural logarithm, $r_1$ – radius of the charged part of the sample surface, $r_2$ – internal radius of the side electrode, $d$ – sample thickness, the appropriate time constant, the discharge process (serviced by discharge current flowing tangentially to the sample surface time constant) is given by the formula:

$$\tau_p \approx \rho_v \varepsilon_0 \frac{r_1}{\pi d}$$  \hspace{1cm} (2)

Relations (1) and (2) were obtained with application of many assumptions (e.g. neglecting influence of the surface conductivity) and should be treated only as very rough approximations.

The situations shown in the figures 1 i 2 illustrate the cases described in the appropriate standards e.g. [5]. Let’s consider the case shown in the figure 3. The sample is equipped with the back electrode which does not allow to neutralise the charge reaching it (blocking electrode) and to flow freely the discharge current in direction normal to the sample’s surface. In the first, very rough approximation, one can propose the following discharge mechanism. The serious normal component of the electric field will drive charge (carriers) to the bottom of the sample and next - tangentially – to the side electrode. One can show, that for the last model the time constant characterizing discharge process described above, will be given by the following expression:

$$\tau_{EB} \approx \rho_v \varepsilon_0 \frac{r_1^2}{2d^2}$$  \hspace{1cm} (3)

The above relation was obtained for thin samples, with their geometry fulfilling the condition $r_1 \gg d$. 

Figure 1. Model of plane-parallel sample charged only in its central part. Explanations in the text.

Figure 2. Model of the plane–parallel dielectric sample equipped with the side electrode and charged in its central part. Explanations in the text.
Time constants characterizing discharge processes given by formulas (1), (2) and (3) describe the differences in the shape of appropriate discharge curves which can be observed for the same sample but discharged in different conditions. Comparison of the time constants leads to the general dependencies:

\[ \tau_N < \tau_p < \tau_{EB} \]  

\[ \frac{\tau_p}{\tau_N} = \frac{1}{\pi \varepsilon d} ; \quad \frac{\tau_{EB}}{\tau_N} = \frac{1}{2} \frac{r_1^2}{d^2} ; \quad \frac{\tau_{EB}}{\tau_p} = \frac{\pi \varepsilon r_1}{2 d} \]  

The expressions given above were obtained by the assumption, that the discharge process may be modeled by simple R-C equivalent circuits. In reality the R-C parameters should be treated as distributed. The last leads e.g. to a non-exponential character of particular discharge curves.

3. Measurements

Measurements of discharge characteristics were carried out on samples of fabrics and polymeric foils. Samples were initially corona charged by application of needle-corona electrode with the radius of 10 \( \mu \)m, placed in a distance of 15 mm above the sample surface. The corona electrode was supplied from dc high voltage power supply with the voltage regulated up to 20 kV. Charging time was regulated by high voltage switch, controlled by a timer. Measurements and registration of the surface potential was carried out by application of the electrostatic voltmeter TREK 347-3HCE equipped with a vibrating measuring head TREK 6000B-15C, voltmeter MERATRONIK V553 with the interface 1542/550 (A/D converter) and PC. Surface potential was measured after finishing the charging period and shifting the sample from polarization position to the measuring one. The shifting time was in the range of 10-20 ms. The surface potential of the sample was recorded every 100 ms. The samples were mounted on the surface of sample holder in a manner appropriate to the applied discharge models shown in figures 1 to 3. Thin layers of soft and conducting fabric was applied as the “injecting” back electrodes. 6 \( \mu \)m thick PET foil was used as a blocking layer in case of “blocking” back electrode.

4. Results

An example of results obtained for the sample of PP fabric containing relatively uniformly distributed antistatic agent in its volume was shown in the figure 4. According to the relation (4) the faster decay appeared for the sample equipped with “injecting” back electrode. Slower decay was observed for the sample equipped only with side electrode, when the expected discharge current flown parallel to the sample surface. The slowest decay was observed for the sample with blocking back electrode. Discharge characteristics in each case do not exhibit an exponential character. That is why for the mutual comparison of discharge processes the parameter called half-time (time for which the value of the surface potential decreases up to \( \frac{1}{2} \) of its initial value) was chosen. The half-time values for the investigated cases where 1.1, 1.7 and 9.2 s for injecting, side and blocking back electrodes respectively.

![Figure 3. Model of the plane–parallel dielectric sample equipped with the side and back-blocking electrode. Explanations in the text.](image-url)
Serious differences in discharge characteristics were observed especially for hydrophobic materials (commercial PP folis). In case of antistatized materials, for which the discharge process occurs mainly due to a surface current flow only, the decay curves for different discharge conditions run practically the same way.

4. Conclusions

Discharge characteristics for the thin and plate-parallel samples with discharge due to charge flow in their volume depend basically on electrical properties of the back electrode. As it comes from the simplified equations confirmed by the obtained results of appropriate measurements the characteristic time parameters (half time) may differ for the particular discharge circuit one order of magnitude. The huge influence of electrical properties of the back electrode is visibly diminished for the samples with high surface conductivity.

Discharge curves obtained for the case with blocking back electrode characterise the worst situation for the particular material from the point of view of dissipation of a stored charge in real situations. The last conclusion suggests introducing some serious changes into appropriate standards elaborated for the uniform estimation of antistatic properties of materials. One should emphasise, that the discharge process appearing in reality may occur much more slowly then the predicted on the base of investigations limited only to the commonly considered cases.

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References

[1] G. M. Sessler G M 1980 Electrets, Topics in Applied Physics 33 Springer Verlag Berlin
[2] M. M. Perlman M M, Sonnostine T J, Pierre J A, 1976 J. Appl. Phys. 47 5016-21
[3] Molinie P, 1999 J. Electrostatics 45 265-73
[4] Wintle H J, Pepin M P 2000 J. Electrostatics 48 115-26.
[5] BS 7506: Part 2:1996, Methods for Measurements in Electrostatics
[6] Chubb J N, Malinverni P 1993 J. Electrostatics 30 273-84