Experimental investigation of discharges for charged plastic or plastic-coated materials

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Abstract: The paper will present experimental investigation of discharges to charged plastic plates with and without groundplane on the back side. The plates were charged using the corona discharge. The charge distribution on the surface was acquired using a scanning system. Then, a grounded electrode was moved to the charged surface until a discharge occured and the new charge distribution was acquired. Furthermore, the discharge current pulse was measured. With the acquired charge distribution values the transported charge and the area of the discharged surface were determined. The transported charge can also be determined using the measured current pulse. Additionally, theoretical work was performed to develop a model that allows the calculation of the dissipated power and energy during the discharge.

Introduction

Due to the increasing use of plastics or plastic-coated materials different kinds of problems, like charging and discharging, can occur. Isolated surfaces are considerably charged by material separation, flowing liquids or electrical fields. For this reason discharges can develop between the charged surface and a near grounded conductive object. These transient gas discharges are locally limited.

In the last fifty years these brush discharges have been investigated. Heidelberg [1], [2], Lövstrand [3] or Gibson and Lloyd [4] investigated this kind of discharges referring to the generation of ignition of gas-air mixtures.

Among others, Lichtenberg [5] or Toepler [6] have shown that unter certain conditions ‘Lichtenberg figures’ can occur. These surface discharges are able to discharge considerably larger charged areas with a high discharge energy.

An easy model for the charge and discharge phenomena of insulating materials could facilitate the dimensioning of devices and systems. On the one hand, the conditions influencing the size of the discharged area have to be determined. On the other hand, an easy model is needed to estimate the dissipated power and energy during the discharge process.

Therefore, new measurement data are needed. In addition, some parameters, like thickness, size and kind of material, form of electrode and others are varied.

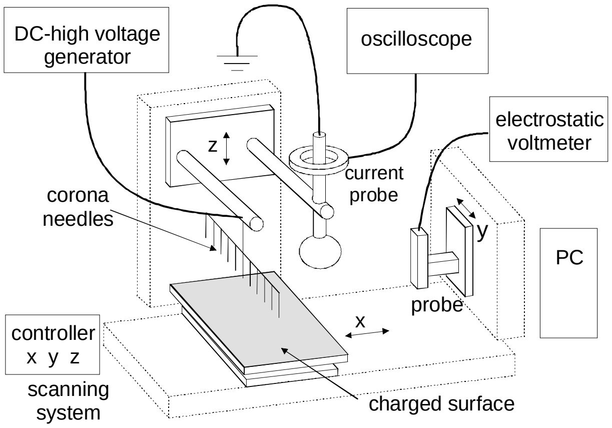

Figure 1: measurement setup

Measurement setup

The charging and discharging of insulating materials depend on the climatic conditions, like relative humidity and temperature. Therefore, the experimental arrangement is set-up in a climatic chamber for constant climatic conditions.

All components are controlled by a PC using a program written in Lab Windows. The test object and the probes are moved by a scanning system, consisting of three stepping motors. The test object is situated on the x-axis and the probe of the electrostatic voltmeter is situated on the y-axis (figure 1). With this arrangement a two-dimensional recording of the charge distribution is possible. The x-y-coordinates are determined by the pulses of the stepping motor.

The discharge distribution is calculated from the potential on the test surface, which can be measured using an electrostatic voltmeter connected to a probe. The probe adapts the potential on its housing to reduce the electrostatic field to zero. The potential of the probe housing is transmitted via a monitor output and an A/D-converter to a PC.

The distance of the corona needles and the grounded sphere to the test object is varied along the z-axis. An equal distribution of the surface charge can be obtained by shifting a line of needles over the complete surface. The charge density decreases on the border of the plate. Therefore, a margin of 10 mm on each side of the plate is not taken into account by the scan. The high voltage is provided by a DC-high-voltage-generator (35 kV; 4 mA).

The pulse of the discharge current is measured with a 1 GHz digital oscilloscope and a current probe. This probe has a bandwidth from 100 kHz to 1 GHz. The measuring data are stored on a PC for further evaluation.

Measurement procedure

First, the test surface is charged using the corona discharge. In the initial position, the voltage of the line of needles is increased to the final value (15-18 kV). Then, the distance of the needles to the test surface is reduced to 5 mm for coated materials or 1 mm for other. After the needles have been moved over the complete surface they are brought back to the initial position and the voltage is reduced to zero.

In a second step, the charge distribution is acquired. The test object and the probe are moved to the start position with a probe to surface distance of 2 mm. The data of the first line are recorded by moving the test surface until the probe reaches the other end of the plate. Then, the probe is shifted to the next grid point and the test object is moved back. Like this, the complete surface is scanned with a grid of 0.5 mm.

When the scan is completed, a grounded electrode is moved step by step or continuously in z-direction to the charged surface until a discharge occurs. The pulse of the discharge current is measured and the new charge distribution is acquired. By further approach of the electrode, additional discharges can occur. Futhermore, the approach of the grounded electrode can also take place in horizontal direction at surface level.

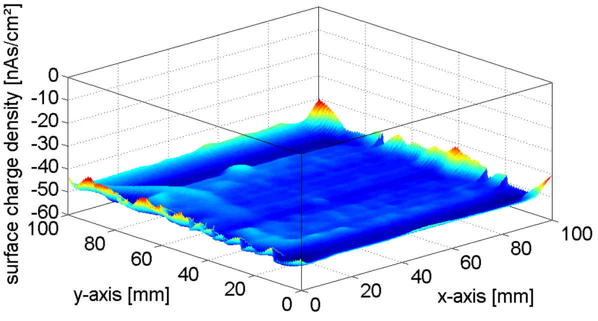

Figure 2: constant distribution of the surface charge on the PVC-plate

Finally, the measured data are analyzed. With the acquired charge distribution values the transported charge and the area of the discharged surface can be calculated. Additionally, the transported charge can be determined from the current pulse.

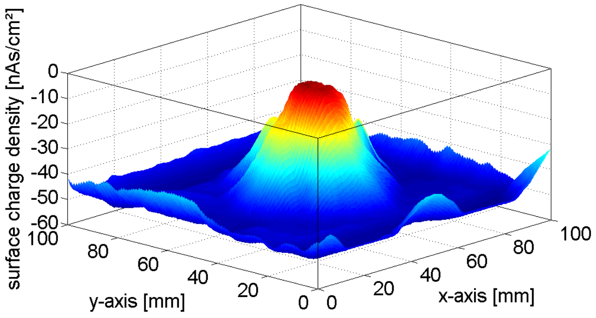

Figure 3: typical surface charge distribution after several discharges

Experiments

As a first example a PVC-plate (12 cm x 12 cm; tickness 1 mm) with copper on the back side is used. Due to the conductive plate on the back side, the surface charge density is about 20 times higher than without ground plane, where the theoretical maximum value would be 2.7 nAs/cm². In figure 2 a relatively constant distribution of the surface charge with an average value of 50 nAs/cm² is presented. Typically 90% of the measured data are in the range between ± 5% of the average value.

Figure 3 shows a typical charge distribution after the surface has been discharged by a sphere with a diameter of 30 mm. With a slow step by step approach of the sphere a brush discharge can be recognized. By further approach a number of additional discharges, typically 3 or 4 rarely up to 10, can occur.

A cutaway view of such a distribution is shown in figure 4. The initial distribution and selected distributions after different numbers of discharges are illustrated.

If the sphere is approached faster with a continuous velocity of about 50 mm/s, only one bigger discharge occurs. Figure 5 shows a cut of this distribution.

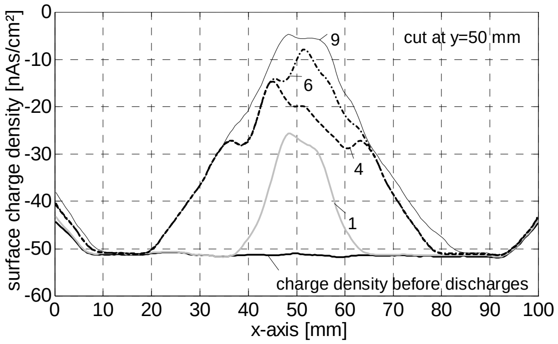

Figure 4: surface charge density at y=50mm before discharges and after the 1., 4., 6., 9. discharge

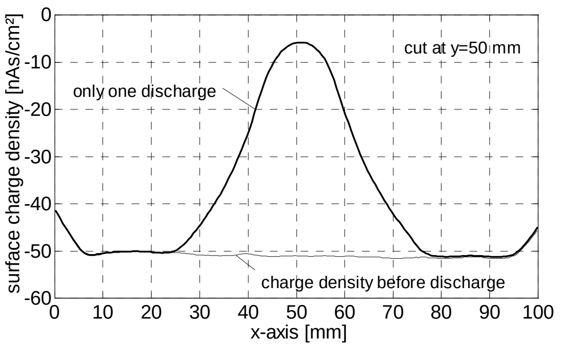

Figure 5: surface charge density at y=50mm before discharge and after only one discharge

In case of several discharges the measured current pulses of all discharges have a similar shape and differ only in the amplitude. Two typical measured current pulses are presented in figure 6. The rise time is approximately 5 ns and the duration of the discharge is typically some 100 ns. In case of only one discharge the current peak is higher (about 2-4 A) but the pulse shape is similar.

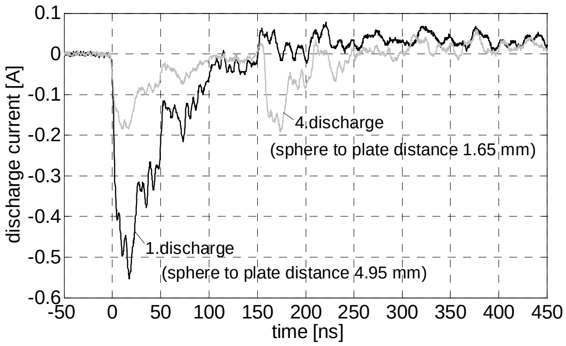

Figure 6: the 1. and 4. discharge current pulse of several brush discharges

From the acquired charge distribution or the measured current pulse the transported charge can be determined. In the case of several brush discharges the transported charge is about 0.25-0.45 µAs in total. The charge of each single discharge is in the range of 0.03-0.08 µAs. If only one single discharge occurs, the transported charge is approximately 0.25-0.6 µAs.

As a second example a PVC-foil (12 cm x 12 cm; tickness 0.18 mm) with a copper layer on the back side is used. Since the foil is very thin, a much higher average value of the surface charge density of approximately 260 nAs/cm² can be obtained with the same corona voltage as in the case of the PVC-plate. The initial charge distribution is similar to the distribution in figure 2 but higher.

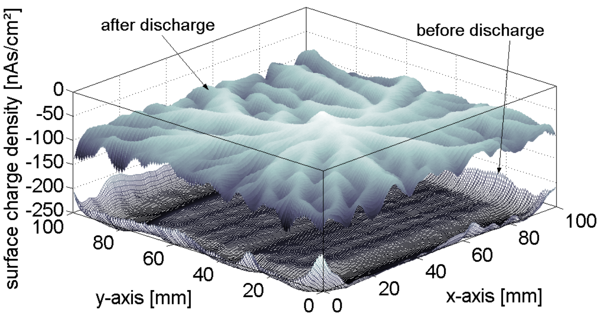

Figure 7: typical surface charge distribution after a surface discharge ('Lichtenberg figure') and the initial distribution

The charge distribution, which can be measured after discharging the surface by a sphere with a diameter of 30 mm, has the appearance of a "Lichtenberg figure" (figure 7). The complete surface is discharged except for a small remaining residual charge. Along the discharge channels the remaining residual charge is smaller than in between.

Figure 8 shows the measured current pulse for this discharge. At the beginning, a brush discharge occurs which initiates the following surface discharge. The discharge shorts the charged surface to the grounded backplane.The high tangential electric field strength on the surface causes the following surface discharge. The surface discharge has a peak current of about 20 A and the transported charge is approximately 18-20 µAs.

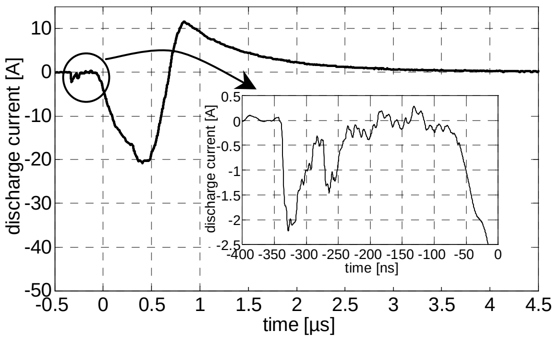

Figure 8: discharge current pulse at a surface discharge and the zoom of the typical brush discharge before the surface discharge

Model

In order to estimate the area of the discharged surface the difference of the charge distribution before and after the discharge is approximated with a cylinder of equal charge. The result is an equivalent circle area A_e (equivalent radius R_e) with a constant equivalent surface charge density σ_e (figure 9). An algorithm to determine the optimal adaptation will be investigated in the future. Up to now, the equivalent charge density is calculated with an estimated value of $\sigma_e = 0.8 \cdot \sigma_{max}$.

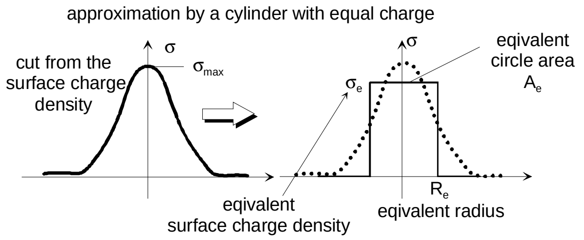

Figure 9: approximation of the surface charge density with a cylinder of equal charge

Figure 10 shows the equivalent circuit for the discharge arrangement. The capacitance C_A represents the capacitance between the grounded sphere and the constant charged eqivalent area A_e. C_{D0} is the capacitance to the ground plane inside the dielectric. The capacitances are estimated with equation 1 (approx. by a plate capacitor). The inductance of the cable is represented by the inductance L, estimated to 1 µH. The discharge channel between the sphere and the plate is approximated with a time-varying resistance R_G.

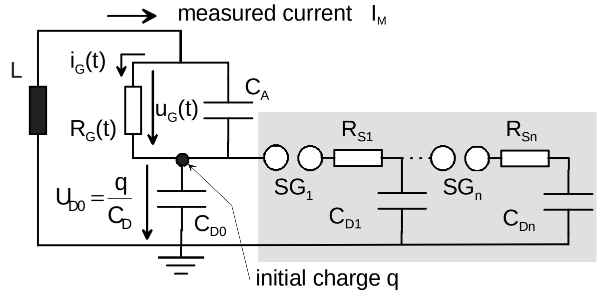

Figure 10: equivalent circuit of the discharge measurement setup

$$C_D = \varepsilon_0 \varepsilon_r \cdot \frac{A_e}{h} \qquad C_A = \varepsilon_0 \cdot \frac{A_e}{d} \tag{1}$$

$$u_G(t) = -U_{D0} - L\frac{di_M(t)}{dt} - \frac{1}{C_D}\int i_M(t)dt \tag{2}$$

$$i_G(t) = i_M(t) \cdot (1 + \frac{C_A}{C_D}) + C_A L \frac{d^2 i_M(t)}{d^2 t} \tag{3}$$

$$W = \int p(t)\, dt \qquad p(t) = i_G(t) \cdot u_G(t) \tag{4}$$

The slow linear slope of the surface discharge current in figure 8 can be explained by a continuous addition of surface elements. An element is represented by a spark gap SG, a resistance R_S and a capacitance C_D. In futher investigation the parameters of this elements will be determined.

With the measured current I_M and the initial charge q on the eqvivalent area A_e all elements of the circuit can be calculated. In this case the gray part of the circuit is disregarded. Then, equations 2-4 allow the determination of the dissipated power and energy in the resistance R_G.

The results of the three different forms of discharges are put together in table 1: brush discharge with several (M1) and only one (M2) discharge and surface discharge (M3) (typical example).

Table 1: result list

	max. current	circle area/radius	charge	energy
	[A]	[mm²/mm]	[µAs]	[mJ=mWs]
M1	0.56	284 / 9.5	0.059	0.28
M2	5.5	734 / 15.3	0.321	2.74
M3	21.0	10000 / 56.4	18.1	160

Conclusion

The measurement setup and the measurement procedure for the investigation of discharges for charged plastic or plastic-coated materials were introduced.

By means of two coated test plates, the investigation of discharges were presented referring to the thickness of the plastic. Further investigation will include other parameters as well.

A first model was derived, which allows the determination of the dissipated power and energy in the discharge gap. The model will be improved and optimized in the future.

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