

DISCHARGE MECHANISM IN VOIDS AT SUB-ATMOSPHERIC PRESSURES

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Abstract : The physical processes occurring during partial discharges (PD) in voids in solid dielectrics are complicated due to the lack of knowledge of void shape, location and gas pressure. Fast oscilloscopic techniques are needed to measure the build up and decay of current as a function of time for single discharges. The purpose of the present work is to investigate the mechanism of the discharge in artificial voids in thin polypropylene (PP) films at different sub-atmospheric pressures. Efforts have been made in this work to distinguish Townsend-like and streamer-like discharges on the basis of the discharge pulses recorded in terms of rise time, pulse width and peak current for the various void dimensions and pressures studied.

Introduction

PD in voids in solid dielectrics have deleterious effects on the electrical performance of the insulation as they are the sources of discharges taking place at low voltages. The dielectric strength of the void depends on the kind of gas in the void, the gas pressure and the dimensions of the void. PP film is being widely used as dielectric in high voltage insulation. One of the prime cause of insulation degradation is PD in voids created between two adjacent films. Moreover, there is a probability that these voids may be at different sub-atmospheric pressures due to the process of vacuum impregnation. The purpose of the present work is to investigate the possibility of the discharge mechanism inside the void for various void parameters.

The charge carrier motion between electrodes induces current in the electrode leads. However, the rapid changes of the discharge, as may occur in the early phases of breakdown in PD, may or may not show up in the external current since when a discharge is to be studied by means of current measurement, a clear correlation between the current measurements and the internal events is needed [1]. The time resolution of these measurements is limited by the bandwidth with which the current can be monitored. In order to preserve the shape of the discharge pulse and relate it to the physics of the discharge process a time-resolved detection system is needed [2]. In the present work two distinct types of discharges are identified, named large rise time (RT) pulse and sharp rise time pulse, and mechanism

responsible for their development has been proposed.

Experimental Setup

The experimental setup for PD measurements is shown in Figure 1. The sub-divided electrode arrangement is same as that used before [3]. The radius of the measuring electrode should be small to reduce stray capacitances but not too small since otherwise the moving charge carriers also induce a current in the ground connection of the surrounding ring, thus reducing the current through the measuring resistor. The diameter of sub-divided electrode was 2 cm and 6 cm for measuring disk and guard electrode respectively with 0.1 cm annular gap spacing between them. The value chosen for the measuring resistor was 25 Ω formed by two terminating 50 Ω resistors at either end of a 50 Ω co-axial transmission line (RG 214 cable) of one metre length and was fed to a 1 GHz Tektronix TDS 684A digital storage oscilloscope.

Electrical grade biaxially oriented 20 μm thick and 11 cm diameter PP films have been used with an artificial cylindrical void of 0.2 cm (finite void) and 2.2 cm (infinite void, considering 2 cm diameter of the measuring electrode and 0.1 cm annular gap between measuring disk and guard electrode) diameter made at the centre as shown in Figure 2. Four to ten films are used depending on the void depth (i.e., 80 to 200 μm) required for the middle stack of films while the top and bottom electrodes are pasted with one plane film each using petroleum jelly. Proper care is taken to see that no air bubble exists either between the films or between the film and electrode. The middle stack of films of required void depth is so placed over the bottom electrode, so as to have sufficient gap between the stack and the pasted film of the top electrode. The single stage rotary pump connected to the chamber is used to create the required void pressure inside the chamber. Few minutes are allowed for the required pressure to stabilise inside the chamber. Afterwards, the micrometer head of the Wilson seal arrangement is adjusted to place the sample tightly between the two electrodes. Now the void pressure is the same as the chamber pressure. The experiments were carried out at inception voltage and room temperature at void pressures of 100, 200 and 400 torr.

Experimental Results

The current pulse produced by an avalanche and measured as a voltage drop across the measuring resistor is composed of the fast electron component followed by the slow ion drift component. The characterisation of PD pulses is done on the basis of the rise time, pulse width and peak current of the recorded oscillograms. The rise time measured in this work corresponds to 10% to 90% of the peak amplitude. The pulse width measured at 50% of the pulse height is approximately equal to the fall time of the discharge pulse. PD current pulse magnitude is calculated from the peak current of the measured voltage waveform across the 25 Ω resistance.

The variations of the rise time, fall time and peak current of the PD pulses are shown in Tables 1, 2 and 3 respectively for the various void dimensions and pressures studied. The experimental values quoted are the average of five measurements. In the present work, two distinct types of discharge pulses are seen each with its own characteristic features. The large rise time pulses are attributed to Townsend-like discharge pulses which are characterised by large transit time of electrons and ions with a small peak value of current, while the sharp rise time pulses are characterised as streamer-like discharge pulses which have short transit times and large peak values. It is to be noted that both large and sharp rise time pulses are observed for 2 mm void diameter at 100 and 200 torr void pressures for the various void depths studied. However at 400 torr, while for 80 μm void depth both Townsend-like and streamer-like pulses are observed but for 120 and 200 μm void depths only sharp rise time pulses (streamer-like) are observed. In the case of infinite void diameter, pulses of both types are observed for the various void depths and pressures studied. Typical PD pulses are shown in Figure 3.

Discussion and Conclusion

It is generally accepted that breakdown in short gaps with metallic electrodes is governed by the Townsend mechanism. Since the most common range of physical void diameters ranges roughly from about 0.1 to 3.0 mm, one would expect the above mechanism to apply for the various void inclusions in the insulation systems. However, because of the highly distorted electric field configuration in voids having dielectric boundaries, there is every possibility that breakdown process is determined by the streamer mechanism [4]. The discharge mechanism will however depend on the gas pressure.

Whatever be the breakdown mechanism, it involves substantial ionisation within the void and the resulting

charges tend to distribute so as to oppose the applied field within the void. Thus the resultant field within the void will drop substantially, almost to zero. The charge flow in the circuit due to the drop in the field within the void, produces the PD signal. The next discharge takes place if voltage further rises or at the zero phase of the a.c. voltage or if the charges are cleared and the voltage again increases. In all such cases discharges occur when the voltage equals the inception voltage and the process is repetitive. The overall difference in the pulse shapes of the two discharge mechanisms results primarily from the fact that in the Townsend discharge maximum number of ions and electrons are created near the anode, so that the slow moving ions have to traverse the entire gap in moving to the cathode. Whereas in the streamer discharge, both the ions and electrons are produced throughout the gap and hence ion movement to cathode is fast.

Devins [5] has shown that streamer-like discharges have larger discharge magnitudes than Townsend-like discharges and the pulse width is proportional to the void height for Townsend-like discharges. Further it is shown that the pulse width closely corresponds to the positive ion transit time. Morshuis [2] has shown that Townsend-like discharge pulse is characterised by its width of about 60 ns while streamer-like discharges are characterised by short transit times of about 390 ps. The optical method used also reveals that Townsend-like discharge covers a large area of the void surface. Fromm and Kreuger [6] have shown that the Townsend-like discharge has a small peak value with large pulse width (about 55 ns) while streamer-like discharge has a large peak value and short pulse width.

In the present work, for infinite void diameter at sub-atmospheric pressures, the pulse width is found to vary from 74.94 ns to 322.41 ns and 8.32 to 33.18 ns for large and sharp rise time pulses respectively. It is also observed that the pulse peak current for large rise time pulses is much lower compared to sharp rise time pulses. Hence large rise time pulses are characterised as Townsend-like discharges whereas sharp rise time pulses are characterised as streamer-like discharges. This characterisation agrees well with the observations of others [2,5,6]. The behavior of the discharge mechanism for 2 mm void diameter at 100 and 200 torr void pressures is found to be similar to that of the infinite void diameter. But at 400 torr, Townsend-like discharge is not observed for 120 and 200 μm void depths while both discharge mechanisms are observed for 80 μm void depth. It can be concluded from the observations made that there exists a critical void parameter (diameter to depth ratio) and pressure at which there is a transition from Townsend to streamer discharge mechanism.

References

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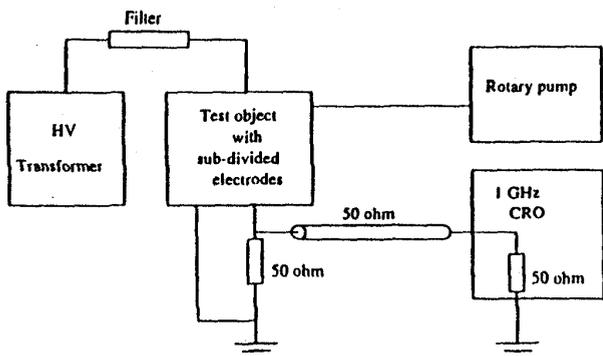


Figure 1 Experimental setup for PD measurements

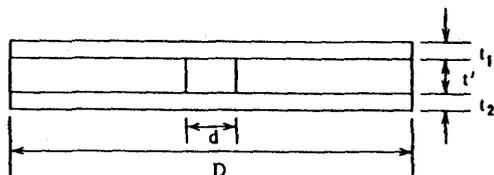


Figure 2 Sample

$t_1 = t_2 =$ thickness of the top and bottom films = 20 μm
 $t' =$ thickness of the films containing the void
 $d =$ diameter of the void
 $D =$ overall diameter of the sample

Table 1 Variation of rise time

Pressure/ Void Depth		Large RT Pulses (ns)				Sharp RT Pulses (ns)			
		Positive Pulse		Negative Pulse		Positive Pulse		Negative Pulse	
		2mm Dia	Inf Dia	2mm Dia	Inf Dia	2mm Dia	Inf Dia	2mm Dia	Inf Dia
100 torr	80 μm	33.39	136.27	33.20	124.14	8.85	8.32	8.67	11.83
	120 μm	33.07	130.46	37.66	148.56	10.96	9.95	11.32	10.22
	200 μm	35.69	117.40	34.11	100.10	10.58	11.29	10.18	13.58
200 torr	80 μm	23.99	105.16	21.96	80.56	5.74	5.31	5.58	5.42
	120 μm	21.14	77.43	17.99	77.31	6.96	3.80	6.79	4.11
	200 μm	19.51	62.39	13.69	68.34	6.21	2.54	6.32	3.02
400 torr	80 μm	12.44	47.12	11.63	59.38	1.11	3.93	1.11	3.28
	120 μm	---	37.38	---	38.88	2.19	2.28	2.11	2.28
	200 μm	---	32.71	---	33.56	2.41	2.19	2.13	2.18

Table 2 Variation of fall time

Pressure/ Void Depth		Large RT Pulses(ns)				Sharp RT Pulses (ns)			
		Positive Pulse		Negative Pulse		Positive Pulse		Negative Pulse	
		2mm Dia	Inf Dia	2mm Dia	Inf Dia	2mm Dia	Inf Dia	2mm Dia	Inf Dia
100 torr	80 μm	57.69	253.77	53.76	322.41	37.35	23.73	45.54	29.93
	120 μm	55.18	265.16	54.49	269.24	37.94	27.38	40.49	28.27
	200 μm	59.97	174.48	56.30	176.98	37.21	33.18	37.99	30.14
200 torr	80 μm	50.21	166.74	38.86	182.94	32.07	17.39	22.69	18.06
	120 μm	46.09	126.34	41.38	167.18	22.64	12.57	22.47	12.07
	200 μm	49.59	125.94	38.13	122.70	18.16	15.17	20.70	15.62
400 torr	80 μm	30.05	105.58	31.87	102.40	12.15	14.95	13.53	14.01
	120 μm	---	88.06	---	86.62	8.19	8.32	7.74	9.26
	200 μm	---	74.94	---	90.43	10.09	11.93	9.58	11.91

Table 3 Variation of pulse peak current

Pressure/ Void Depth		Large RT Pulses(mA)				Sharp RT Pulses (mA)			
		Positive Pulse		Negative Pulse		Positive Pulse		Negative Pulse	
		2mm Dia	Inf Dia	2mm Dia	Inf Dia	2mm Dia	Inf Dia	2mm Dia	Inf Dia
100 torr	80 μm	2.21	1.80	2.45	1.98	6.28	3.11	7.56	7.42
	120 μm	3.52	2.12	5.00	3.39	11.44	13.37	13.02	22.18
	200 μm	5.47	1.41	7.22	1.42	17.98	39.55	20.22	40.32
300 torr	80 μm	3.77	3.13	4.97	3.78	20.86	16.17	23.95	18.74
	120 μm	7.98	4.77	10.00	2.93	26.06	33.62	27.78	36.77
	200 μm	8.78	2.21	12.49	2.47	38.59	18.38	37.22	13.95
400 torr	80 μm	18.05	1.48	14.75	2.82	37.73	16.27	37.02	11.75
	120 μm	---	3.05	---	3.28	108.32	37.38	104.68	41.50
	200 μm	---	1.95	---	4.45	115.20	42.98	110.84	43.87

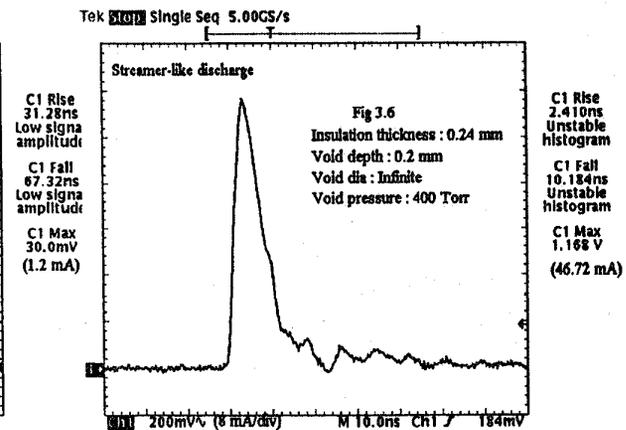
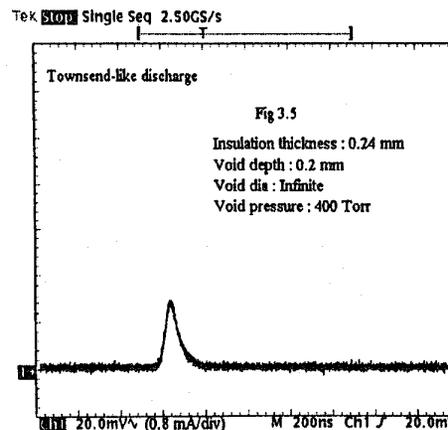
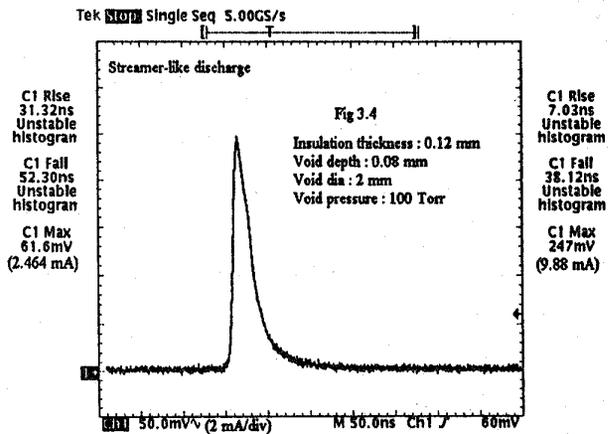
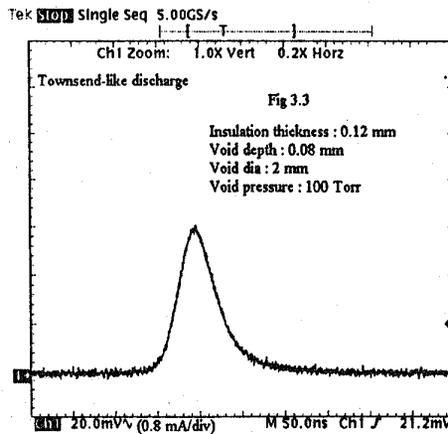
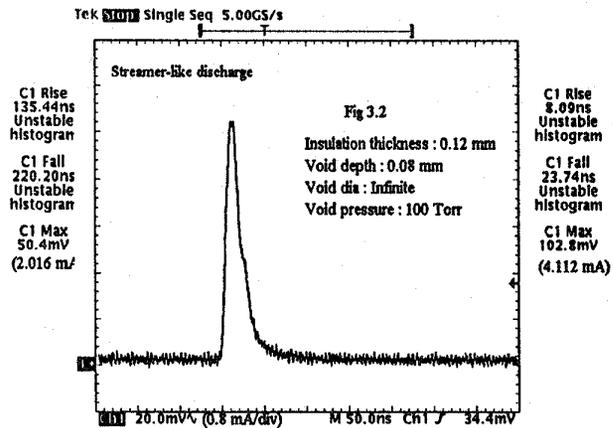
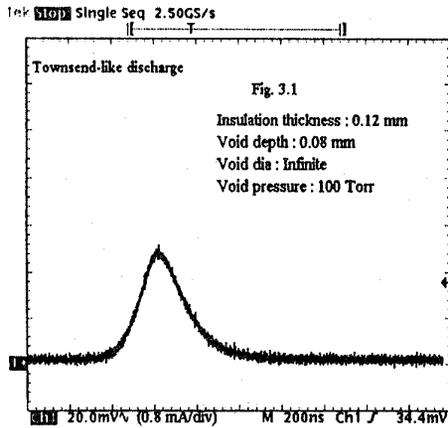


Figure 3 : Typical Partial Discharge Pulses