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TEMPORAL AND SPATIAL DEVELOPMENT OF PARTIAL DISCHARGES IN SPHERICAL VOIDS IN EPOXY RELATED TO THE DETECTED ELECTRICAL SIGNAL.

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ABSTRACT

Investigations were made on the temporal and spatial developmer partial discharges(PD) in spherical voids (⌀:1-5 mm) in clear epoxy pl

Two very different types of discharges were found with respect to charge image, luminosity and propagation time. The electrical signal simultaneously displayed on a 1 GHz real-time oscilloscope, sho pulses with rise times in the ns and sub-ns range of varying magnitude shape. Pulse phase/height analyses were performed showing a un pattern for all voids.

A relationship was established between the shape of the detected pu pulse phase/height analyses and optical characteristics of the disch phenomena.

INTRODUCTION

PD testing of HV equipment with sensitive equipment often results i detection of electrical pulses of varying shape and magnitude. PD ana performed on these pulses show some unique patterns, which somet can be related to special types of defects. However, the relationship ween the physical processes taking place inside the material and the de ted electrical signal is somewhat unclear.

This report presents some of the results from investigations on PD in defined defects (1 single spherical void in clear epoxy, 1-5 mm in dia ter) under a 60Hz AC voltage, high enough to cause spontaneous disch es. In this way the development of the discharges is kept as 'natur

MEASUREMENT SYSTEM

The voids were made by injecting clean, dry air in an Bisphenol A type epoxy before curing with an acid anhydride curing agent, resulting in a natural void shape and void surface. The gas composition and gas pressure inside the void was not known, but recent investigations [2, 3] indicate that the major part is nitrogen at a slight under-pressure.

The discharge image was detected with an Imacon 790 Streak Camera via an optical lens, prism and mirror system as described in [1]. Images with wavelengths in the visible range could be recorded in single frame or in streak mode. In single frame mode, a two-directional view gave the capability to determine the spatial development of the discharge in three dimensions. The temporal development was observed in streak mode, with the image collimated in the field direction to a narrow band, hereby also capturing light emitted from points not on the optical axis and reducing geometrical effects on the streak image. Images were recorded only from PD in 3.5 and 5mm voids. The intensity of the emitted light from a 1mm void was too low for any analysis to be made.

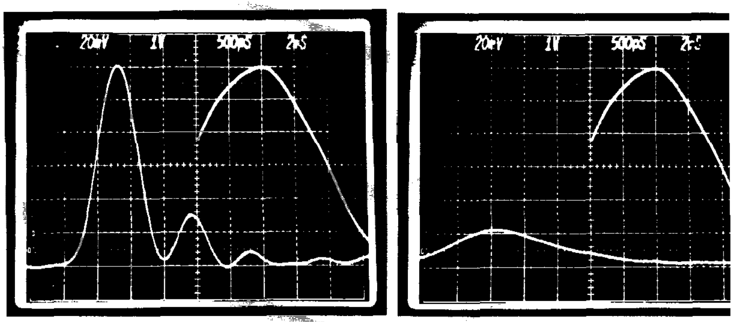
The electrical signal was detected by direct voltage measurement across a 50 Ohm impedance in the specimen ground lead. A 1 GHz real time oscilloscope measured the PD voltage pulse. In this way ultra wide band measurements (UWB, 1-750MHz) were possible. The oscilloscope also was configured to show the timing of the PD pulse with respect to the phase of the applied AC Voltage [1].

By manual reading of these data it was possible to determine pulse magnitude as well as pulse width and phase of each pulse and relate these data to a single discharge image. Thus, the apparent charge could be calculated by integrating over the pulse, giving a true phase/<u>height</u> and phase/<u>charge</u> distribution. In the following these expressions refer to the peak magnitude of the current pulses, and time integrated current pulse, respectively.

RESULTS

<u>Pulse type</u>

For all samples, two very different types of pulses were found : a fast <u>type A</u> (fig.1a) with under 500ps rise-time, 700ps pulse width and a nearly constant maximal pulse magnitude and a 'slow' <u>type B</u> (fig.1b) with more than 1ns rise-time, 2-10ns pulse width and varying pulse magnitude always 15-40dB under the magnitude of type A pulses . Similar observations have been made in previous investigations [4].



a) Fast type A pulse,
rise-time: <500ps, width: 700ps.

b) 'Slow' type B pulse,
rise-time: >1ns, width: 2-10ı

Fig.1.a-b: The two typical pulse shapes. The origin of the sine ' indicates the phase of the AC voltage at which the PD occurred.

Temporal and Spatial Development of Discharges

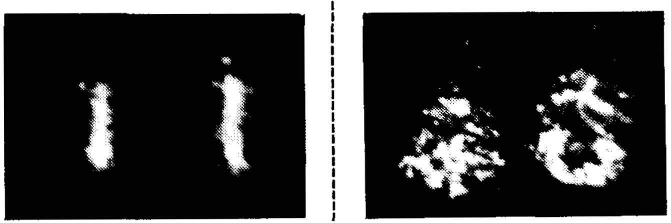
The optical investigations showed two different types of discharg shown in fig.2a-c and fig.3a-b (3.5mm void, applied voltage 19 kV, AC): Streamer-like discharges, forming a bright channel either acro: void or close to the surface; and more diffuse discharges, covering of the void with significant less intensity.

The observed streamer discharges could be directly related to th type A pulses. No difference in the electrical signal could be seen bet the discharges occurring across the void or along the void surface. A be seen from the streak image, the propagation time of the streamer discharge was less than the resolution of the recording system, i.e. <2 After 15ns the detectable light emission had ended and only mi pre-breakdown emission could be seen 1-2ns before breakdown. shape was independent of the polarity of the applied voltage.

The diffuse discharges always resulted in a slow type B pulse. No de location inside the void could be observed. The discharges were typ formed over a period of several nanoseconds with a duration of 5- and considerable less intensity. In some cases a slight motion towar

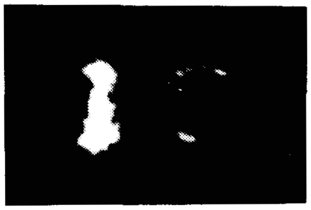
Streamer Discharges
(fast pulses,type A)

Diffuse Discharges
(slow pulses,type B)



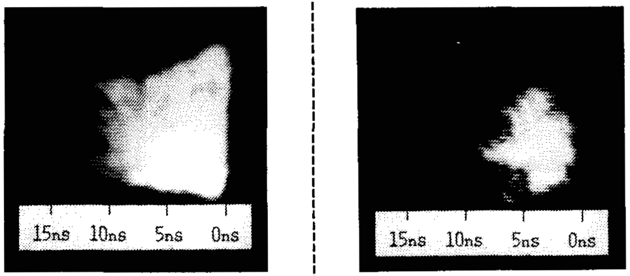
a) Streamer, Across the void

c) Diffuse, low intensity discharge covering most of the void. High optical gain.



b) Streamer, Along the surface

Fig.2a-c:
Spatial development. Images are taken from 2 directions perpendicular to each other. The surface discharge clearly illustrates the limited view field caused by the lens effect of the void.



a) Fast Streamer discharges

b) 'Slow' diffuse discharges

Fig.3a-b: Temporal development,streak image. Time origin to the right. The light intensities are not comparable since the optical gain was some orders of magnitude higher for the

PD Analyses

Fig.4 illustrates the relationship between the electrical and the op information in a pulse phase/height diagram. The analysis was base manual reading of 300 pulses and corresponding discharge images. ring patterns were typical for all void diameters, similar patterns reported from PD analyses on full size insulation [4]. As can be seen ir figure, streamer discharges and diffuse low intensity discharges directly related to a specific area in the diagram. The distribution is s metrical for both polarities. Clearly visible is the inception poin streamer discharges ca. 2ms after onset inception. A distinction betv surface discharges and discharges across the void did not show significant difference. However, at some voltages the discharges acros void tended to occur close to the inception point. Fig.4 shows s discharges that could not be categorized as one of the two main disch types. The spatial and temporal development of these discharges m was similar to the development of streamer discharges, but with intensity.

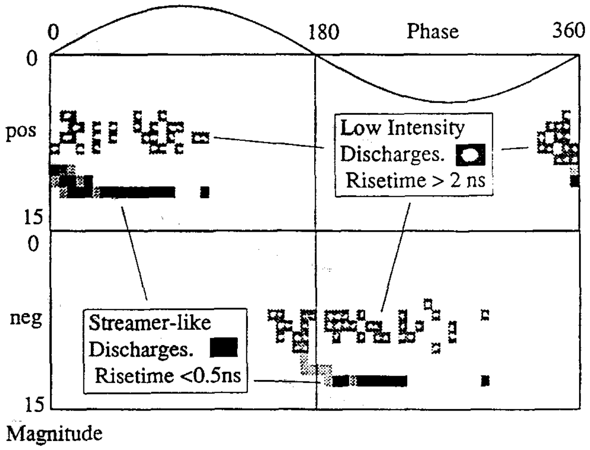


Fig.4: Relations between charge imag phase/hei analysis on detected pu from PD 3.5mm v Applied vol 19kV, 6(AC. Max. tected p current 4A, garithmic s

This pattern was only observed in the UWB detected phase/he diagram, a phase/charge analysis based on the same data showed that ring pattern had been reduced to a cluster formed charge distribution correlations between discharge image and a specific area could no established.

DISCUSSION

Characteristic for all voids investigated was the parallel occurrence of tw
very different types of discharges.

The observed streamer discharges are characterized by a sub-ns pro
pagation time, missing pre-breakdown emission and an inception poi
after the AC zero crossing. The short propagation time is most likel
caused by a strong field inside the void, possibly due to the lack of initi
electrons at PD onset voltage as verified by the late occurrence wi
respect to the AC phase. The inception voltage for the 3.5mm void w
measured 6 kV by emitting initial electrons using X-rays. That means th
the electrical stress inside the void at 19 kV may be up to 200% above t
inception field (space and surface charges not considered). Earli
investigations of discharges in a homogeneous field [6] showed a stream
propagation time in Nitrogen of about 1 ns at 100% overvoltage and r
secondary streamer to be formed. This is in very good agreement wi
observed phenomena in the present experiments. The reason for n
detected pre-breakdown emission is most likely the limited optical ban
width of the system and the absorption of the emitted light under 430n
wavelength in the epoxy [7]. According to [8] the wavelength of t
pre-breakdown luminosity in Nitrogen is under 450nm. At the moment
the breakdown the luminosity extends to the visible range and the intensi
increases by several orders of magnitude, in agreement with the observe
phenomena.

The observed diffuse discharges are characterized by a propagation tir
of several nanoseconds, a very low luminosity and their occurrence ov
a wide range in the phase/height diagram. Unless other, not considere
phenomena have influence on the development of the 'slow' diffu
discharges, these are most likely formed in a weak field, i.e. near the P
onset voltage, after previous discharges, or in a reduced field caused
space charges, surface charges or by temporary changes on the vo
surface. The diffuse discharge image and the spread pulse analysis indica
processes of high complexity. Real time detection of all discharges for
number of AC cycles would be useful to approach this problem. Anoth
interesting aspect that needs some further investigations may be t
apparent correlation between luminosity and peak current.

All optical investigations were made on large voids compared to t
critical diameter in full size insulation. Nevertheless, the electric
measurements on pulses from PD in a 1 mm void showed the same pul
shapes and the same typical patterns in the PD analyses as for the 3-5m
voids, so the assumption of similar processes taking place inside sma
voids must be considered realistic.

It should be noticed that the shown relationship between the electrical the optical information is clearly observable only with the ultra wide b (UWB) detected data (phase/height). Based on integrated data (phas charge) this relationship is not observable. This fact may be interes with respect to recognition of PD signals compared to electrical noise for identification of defect types in insulation.

CONCLUSION

The investigations on the spatial and the temporal development of PI voids in epoxy showed two different types of discharges.

a) Streamer discharges with sub-ns propagation times were observed b straight through the void and close to the void surface. They could dire be related to very fast pulses with sub-ns rise time, sub-ns pulse width nearly constant pulse magnitude. The discharge location had no influe on the electric pulse characteristics.

b) Diffuse discharges across most of the void were observed wit luminosity some orders of magnitude lower than for streamer discha and with several nanoseconds propagation time. The corresponding elec pulses on the electrodes had 5-10ns risetimes and lower and varying p magnitudes.

The recording of pulse magnitude, pulse width, and pulse phase simul neous with the discharge image in either frame or streak mode it possi to perform true phase/height as well as and true phase/charge analyses to relate each discharge type to a specific area in the phase/height d gram. The phase/height analyses showed a symmetrical ring patter reported earlier. The formation of this pattern can partly be explained the parallel occurrence of the two discharge types.

Comparison with phase resolved charge analyses showed that the detect of peak current by UWB measurements gives more information than corresponding integrated current as detected by systems of a very limi bandwidth. Moreover, the relationship between PD analysis and discha type only could be established based on the true phase/height analysi

The influence of the two types of discharges on the void surface i.e. ag of the material is not known and needs some further investigation. Bu

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