INFLUENCE OF MEMORY ON THE STATISTICS OF PULSATING CORONA

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INTRODUCTION

It has been shown in the recent work of Van Brunt and Kulkarni (1990) that the well known pulsating negative corona (Trichel pulse) discharge in electronegative gases is a stochastic process in which memory effects play an important role. A complete understanding of this phenomenon cannot be achieved without information about these memory effects which are associated with the influence of negative-ion space charge and metastable species from previous discharge pulses on the initiation and growth of subsequent pulses. The purpose of this paper is to illustrate how information about memory can be obtained from measurements of various conditional discharge pulse-amplitude and pulse-time-separation distributions. The discharge phenomenon is represented here by a random point process corresponding to the set $\{q_1, q_n, \Delta t_{n-1}\}, n = 2, 3, 4, \cdots$ of pulse amplitudes, q_n, and time separations, Δt_{n-1}. Here Δt_{n-1} is the time separation between the nth and (n - *1*)st discharge pulses.

MEASUREMENTS

The results reported here were obtained using a measurement system previously described (Van Brunt and Kulkarni, 1989) which allows a direct, "real-time" determination of the set of conditional and unconditional pulse-amplitude and pulse-time separation distributions: $p_0(q_n)$; $p_0(\Delta t_n)$; $p_1(q_n|q_{n-1})$; $p_1(q_n|\Delta t_{n-j})$, $j \geq 1$; $p_1(\Delta t_n|\xi)$, $\xi = q_n$ or Δt_{n-1}; $p_2(q_n|\Delta t_{n-1}, \xi)$, $\xi = q_{n-1}$, or Δt_{n-2}. These distributions are defined such that $p_0(q_n)dq_n$ is the probability that the nth discharge pulse, for arbitrary n, has an amplitude between q_n and $q_n + dq_n$ independent of previous pulse amplitudes or time separations; $p_1(q_n|\Delta t_{n-1})dq_n$ is the probability that the nth discharge pulse has an amplitude in the same range if this pulse is separated from the previous pulse by a fixed time separation Δt_{n-1}; and $p_2(q_n|\Delta t_{n-1}, q_{n-1})dq_n$ is the same with *both* Δt_{n-1} and q_{n-1} fixed.

The results reported here apply to a self-sustained discharge in a $Ne/5\%O_2$ gas mixture at an absolute pressure of 100 kPa ($\sim$ 1 atm). Polished stainless-steel point and plane electrodes were used, where the point electrode served as the cathode for a dc gap voltage, V_a, of 6.5 kV. The point-to-plane gap spacing was 2.0 cm and the radius of curvature at the tip of the point electrode was 0.15 mm. The pulse amplitude is expressed in units of picocoulombs (see Van Brunt and Leep, 1981).

RESULTS AND DISCUSSION

Examples of the results obtained for the various conditional and unconditional distributions are shown in Figs. 1–5. Data for the different sets of distributions were obtained at different times so that the cathode surface conditions that apply, for example, to the results in Fig. 1

Gaseous Dielectrics VI, Edited by L.G. Christophorou and
I. Sauers, Plenum Press, New York, 1991

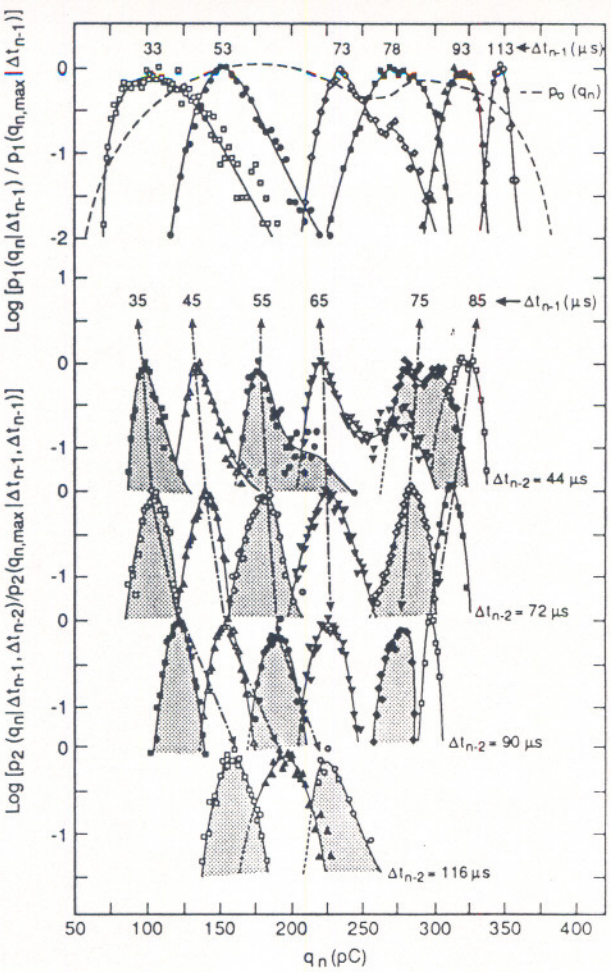
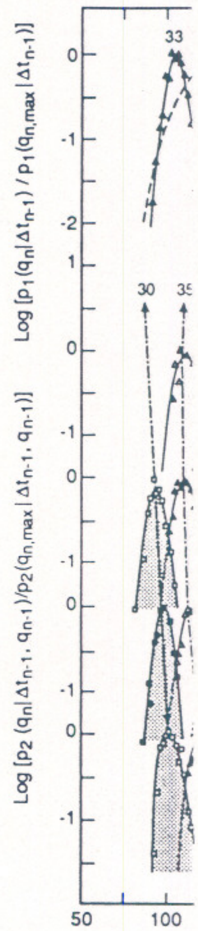


Fig. 1. Measured unconditional and conditional discharge pulse-amplitude distributions $p_0(q_n)$, $p_1(q_n|\Delta t_{n-1})$, and $p_2(q_n|\Delta t_{n-1}, q_{n-1})$ for the indicated fixed values for Δt_{n-1} and q_{n-1}. The distributions have been normalized to the maxima.

differ slightly from those that apply to Fig. 2. This accounts for the difference in $p_0(q_n)$ shown in these two figures. A detailed interpretation of the results presented here would go beyond the scope of this report. However, salient features of the data and certain important conclusions that can be derived therefrom should be noted. A reasonably complete discussion of the physical bases for the stochastic behavior of the Trichel-pulse phenomenon has been given by Van Brunt and Kulkarni (1990).

The fact that the second-order conditional distributions, p_2, differ from the corresponding first-order distributions, p_1, which in turn differ from the corresponding unconditional distributions, p_0, indicates unequivocally that the set of random variables $\{\Delta t_n, q_n, \Delta t_{n-1}, q_{n-1}, \Delta t_{n-2}, \cdots\}$ associated with adjacent pulses are not independent. For example, it is seen from Fig's 1 and 2 that q_n has a strong positive dependence on Δt_{n-1}. This dependence can be related to the influence of moving negative-ion space charge from previous pulses in suppressing the magnitude of the electric field at the cathode when the next pulse develops. It is also seen from Figure 1 that the amplitude, q_n, of a pulse can be either positively or negatively dependent on the amplitude, q_{n-1}, of the previous pulse. The sign of this dependence can be explained in terms of the competing effects of negative-ion space charge and metastable species in respec-



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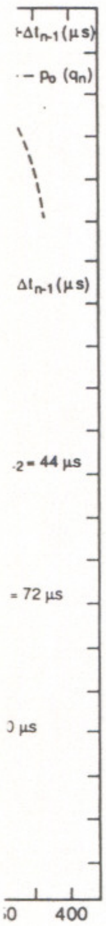

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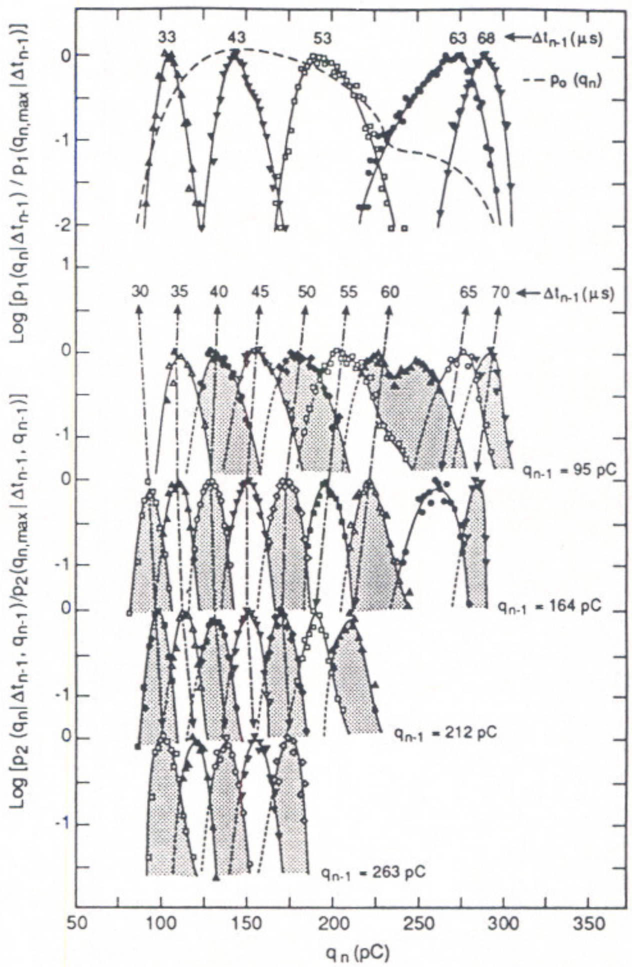


Fig. 2. Measured unconditional and conditional discharge pulse-amplitude distributions $p_0(q_n)$, $p_1(q_n|\Delta t_{n-1})$, and $p_2(q_n|\Delta t_{n-1}, \Delta t_{n-2})$ for the indicated fixed values for Δt_{n-1} and Δt_{n-2}. The distributions have been normalized to the maxima.

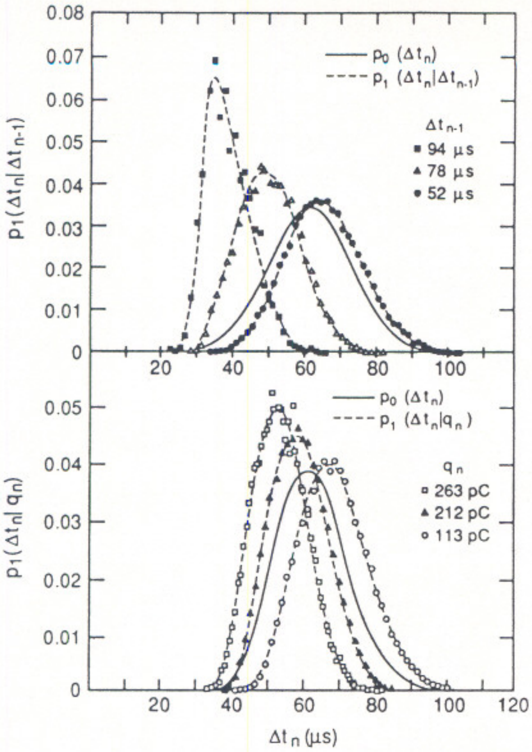


Fig . 3. Measured unconditional and conditional discharge pulse-time-separation distributions $p_0(\Delta t_n)$, $p_1(\Delta t_n|q_n)$, and $p_1(\Delta t_n|\Delta t_{n-1})$ for the indicated fixed values for q_n and Δt_{n-1}. The distributions have been normalized to the areas under the curves.

tively retarding or enhancing the growth of the next pulse. The negative dependence of Δt_n on q_n (and Δt_{n-1}) implied by the conditional time-separation distributions shown in Fig. 3 can be understood in terms of the influence of metastable species from the previous pulse in enhancing the probability for initiating the next pulse by ejecting electrons from the cathode surface during field-assisted quenching.

Because of the correlations among the amplitudes and time separations of successive pulses, the distributions shown in Figures 1–3 are all related. It can be shown, for example, from the law of probabilities that $p_0(q_n)$, $p_0(\Delta t_n)$, and $p_1(q_n|\Delta t_{n-1})$ are related by the integral expression

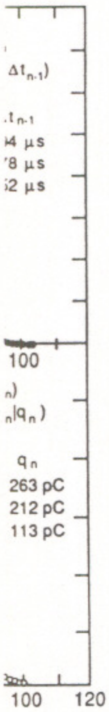
$$p_0(q_n) = \int_0^\infty p_0(\Delta t_{n-1}) p_1(q_n|\Delta t_{n-1}) d(\Delta t_{n-1}), \tag{1}$$

and the distributions $p_0(q_n)$, $p_0(\Delta t_n)$, $p_1(q_n|\Delta t_{n-1})$, $p_1(\Delta t_n|q_n)$, and $p_2(q_n|q_n, \Delta t_{n-1})$ are related by

$$p_1(q_n|\Delta t_{n-1}) = p_0(\Delta t_{n-1})^{-1} \int_0^\infty p_0(q_{n-1}) p_1(\Delta t_{n-1}|q_{n-1}) \times p_2(q_n|q_{n-1}, \Delta t_{n-1})\, dq_{n-1}. \tag{2}$$

Equation (1) indicates that if q_n is dependent on Δt_{n-1}, then any externally-induced change in the time-interval distribution, $p_0(\Delta t_n)$, will necessarily be reflected as a change in the amplitude distribution, $p_0(q_n)$.

Since, as seen from the data in Figs. 2, 4, and 5, the profiles for $p_2(q_n|\Delta t_{n-1}, \Delta t_{n-2})$ and for $p_1(q_n|\Delta t_{n-j})$, $j = 2, 3, 4$ do not match the profile for $p_0(q_n)$, it can be stated that q_n



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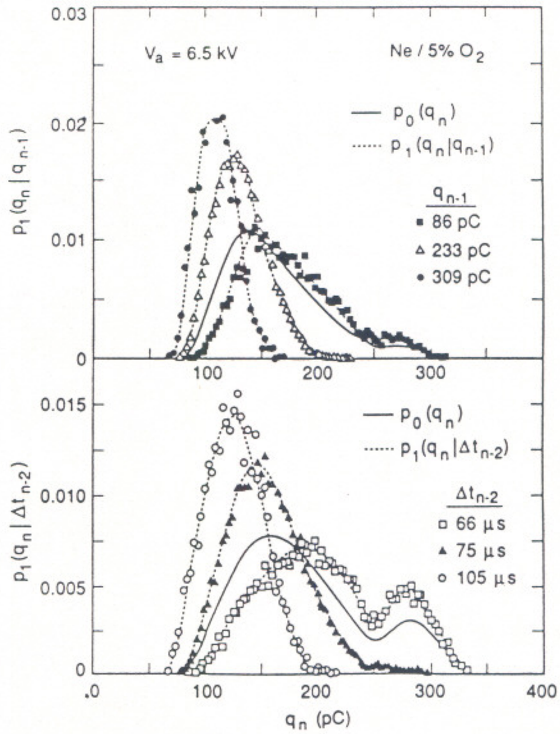

Fig. 4. Measured unconditional and conditional discharge pulse-amplitude distributions $p_0(q_n)$, $p_1(q_n|\Delta t_{n-2})$, and $p_1(q_n|q_{n-1})$ for the indicated fixed values for Δt_{n-2} and q_{n-1}. The distributions have been normalized to the areas under the curves.

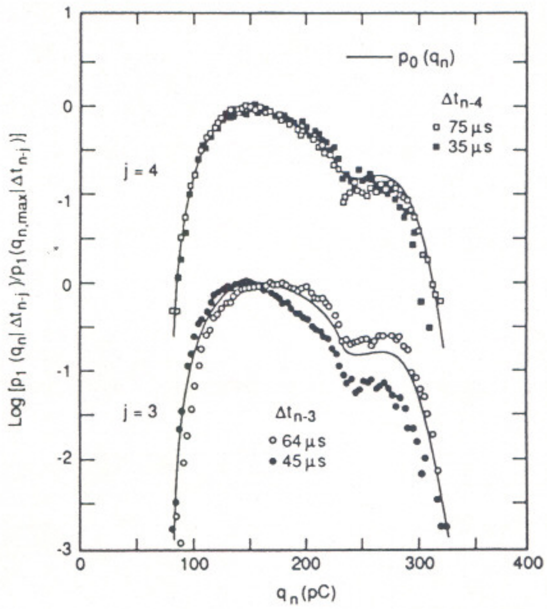

Fig. 5. Measured unconditional and conditional discharge pulse-amplitude distributions $p_0(q_n)$, $p_1(q_n|\Delta t_{n-3})$, and $p_1(q_n|\Delta t_{n-4})$ for the indicated fixed values for Δt_{n-3} and Δt_{n-4}. The distributions have been normalized to the maxima.

depends on $\Delta t_{n-j}, j > 1$, and therefore, the process is one for which memory extends back in time beyond the most recent event, i.e., the process is non-Markovian. This observation is consistent with results reported in the recent work of Steiner (1988). It can, in fact, be shown (Van Brunt and Kulkarni, 1990) that because of the relatively strong dependence of q_n on both Δt_{n-1} and q_{n-1}, it is possible for memory to propagate indefinitely back in time.

ACKNOWLEDGEMENTS

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DISCUSSION

R. T. WATERS: What are the effects of gas type on your corona statistics?

R. J. VAN BRUNT: The kinds of stochastic behavior exhibited here for neon–oxygen gas mixtures are also observed for other mixtures like air, nitrogen–oxygen, sulfur hexafluoride–oxygen, and pure oxygen. This behavior is, in fact, ubiquitous and inherent to the Trichel–pulse phenomenon independent of gas mixture.

I. GALLIMBERTI: Did you do any covariance analysis on the stochastic process that could show how far the "memory" of one single event extends in time on the subsequent ones?

R. J. VAN BRUNT: We have carried out a covariance analysis in the sense that we used our data on conditional distributions to compute correlation coefficients to determine the degrees of correlation among the amplitudes and time separations of successive Trichel pulses. This is discussed in our recent paper (R. J. Van Brunt and S. V. Kulkarni, Phys. Rev. A, Oct. 15, 1990). This kind of analysis was also carried out in the work of J. P. Steiner (Ph.D. Thesis, Purdue University, 1988) which again showed that memory indeed propagates far back in time for this discharge phenomenon.

L. NIEMEYER: The interrelations between the probability distributions of different orders indicate that there is redundance. Can one devise, based on statistical theory, a systematic strategy of the sequence in which one has to measure the different distributions? As an example, if one wants to check for a memory effect, what are the necessary distributions to assess the existence/nonexistence of this effect?

R. J. VAN BRUNT: It is true that there is a certain redundancy built into our measurements in as much as we look at distributions that are related. We have done this to determine that the distributions are all self consistent and to determine which distributions might provide the most interesting information about the physical mechanisms of the process. In the design of practical partial–discharge measurement systems to assess stochastic behavior, one could use a subset of the distributions considered in this work. One could, for example, build a four channel system to simultaneously measure $p_0(q_n)$, $p_0(\Delta t_n)$, $p_1(q_n|\Delta t_{n-1})$ and $p_1(\Delta t_n|q_n)$ that might be adequate for some applications.