TRANSITION FROM TRICHEL-PULSE CORONA TO DIELECTRIC BARRIER DISCHARGE

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INTRODUCTION

When a dc voltage of sufficiently high level is applied to a point-plane electrode gap in an electronegative gas such that the point electrode is negative with respect to the plane, a pulsating corona discharge occurs. The discharge pulses in this case are known as Trichel pulses after G. W. Trichel who reported the first observation of this phenomenon in 1938 [1]. The properties of these pulses have been studied extensively in air and other electronegative gas mixtures [2 4]. Recent investigations by Van Brunt and Kulkarni [5] have shown that the phenomenon is inherently a stochastic process in which memory effects play an important role. The "memory effects" result from the influence of residuals such as negative-ion space charge and metastable excited species from previous pulses on the initiation and growth of subsequent pulses. As a consequence of memory effects, the amplitudes and time separations of successive pulses can be strongly correlated.

The present investigation was undertaken to examine the influence that thin circular solid dielectric barriers placed on the planar anode surface have on the stochastic behavior of Trichel pulses. It is shown that charging of the dielectric surface by the corona discharge introduces another memory effect that becomes increasingly significant as the point-to-plane gap spacing is reduced. At a sufficiently short gap distance, the charge on the dielectric causes the field at the point electrode to drop below the level required to sustain a corona discharge and at that point Trichel pulses cease.

MEASUREMENTS

The experiments were carried out using a recently described [5,6] technique which allows direct, "real-time" measurements of various conditional and unconditional pulse-amplitude and pulse time-separation distributions from which the degree of correlation among the amplitudes and time separations of successive discharge pulses can be quantitatively determined. The electrode-gap configuration used to obtain the results presented here is shown in Figure 1. A PTFE dielectric of 1.0 mm thickness and of diameter D was placed on the plane electrode and centered on the point-to-plane axis. The point-to-plane spacing, d, could be varied from 0 to 10 cm. A very sharp stainless-steel point electrode with a radius of curvature at the tip of less than 0.01 mm was used to insure that, at a sufficiently high gap voltage, V_a, the discharge could be

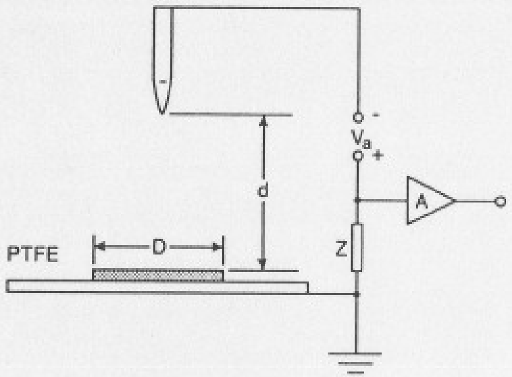

Figure 1. Electrode configuration.

sustained by field-induced electron emission. The measurements described here were performed using "room air" in the gap.

The corona-discharge current pulses were detected electrically using a preamplifier, A, connected to an impedance, Z, in series with the discharge gap as shown. The output of A was fed to the computer-controlled measurement system previously described [5,6]. In the work to be described here, the system was used to measure the unconditional pulse-height and pulse time-separation distributions, $p_0(q_n)$ and $p_0(\Delta t_n)$ respectively, and the conditional pulse-height distribution $p_1(q_n|\Delta t_{n-1})$, where q_n is the amplitude of the nth pulse and Δt_n is the time separation between the nth and $(n+1)$st pulses. The system was calibrated [5,7] so that pulse amplitude could be expressed in units of pico coulombs (pC).

The conditional distribution $p_1(q_n|\Delta t_{n-1})$ is defined such that $p_1(q_n|\Delta t_{n-1})dq_n$ is the probability that the nth pulse has an amplitude between q_n and q_n+dq_n if this pulse is separated from the previous pulse by a *fixed* time separation Δt_{n-1}. If it is found that $p_1(q_n|\Delta t_{n-1}) \neq p_0(q_n)$ for at least some allowed values of q_n and for all allowed Δt_{n-1} such that $p_0(\Delta t_{n-1}) \neq 0$, then q_n and Δt_{n-1} are dependent variables and correlations will exist among successive pulses. The distributions $p_0(q_n)$, $p_0(\Delta t_n)$, and $p_1(q_n|\Delta t_{n-1})$ are related from the law of probabilities by the integral expression

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

This means that the pulse-amplitude and pulse time-separation distributions will not be independent if there are correlations among successive pulses, i.e., changes in $p_0(\Delta t_n)$ will be reflected in corresponding changes in $p_0(q_n)$.

RESULTS AND DISCUSSION

Figure 2 shows the measured critical point-to-plane gap separations, d_c, below which the Trichel-pulse discharge ceases for different indicated values of D. For $d < d_c$, a pulsating discharge still occurs, but the time separation between pulses becomes very long (many seconds) and is evidently controlled by the rate of surface charge dissipation on the dielectric. It is seen that the larger the dielectric diameter, D, and the lower the applied voltage, V_a, the larger will be the critical distance d_c at which the corona extinguishes.

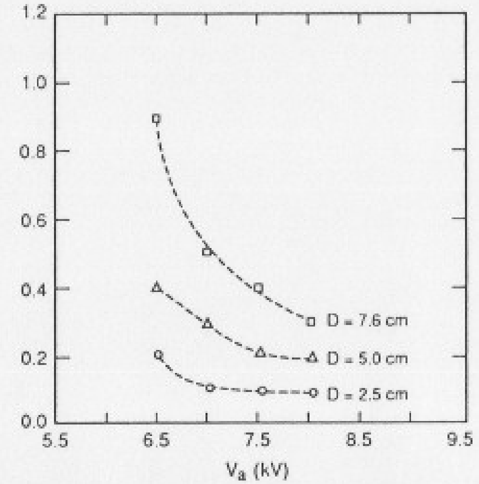

Figure 2. The measured critical point-to-plane gap spacing, d_c below which the Trichel-pulse discharge ceases as a function of applied gap voltage and for the different indicated diameters of the PTFE insulator.

Examples of measured $p_0(q_n)$ and $p_0(\Delta t_n)$ at different indicated distances d and for $D = 5.0$ cm and $V_a = 6.5$ kV are shown in Figure 3. The distributions, $p_0(\Delta t_n)$, indicate a previously observed [5,6,8] critical minimum time separation, Δt_c, between successive pulses. The rate of decrease in $p_0(\Delta t_n)$ for $\Delta t_n > \Delta t_{n,max}$, where $\Delta t_{n,max}$ is the maximum in $p_0(\Delta t_n)$, is controlled by the rate of electron emission at the point electrode [5] and is thus strongly dependent on the local electric field. It is known [5,8] that Δt_c also decreases exponentially with the field near the cathode. Examples of data for Δt_c versus d at different indicated values of D are shown in Figure 4. The fact that both Δt_c and the width of $p_0(\Delta t_n)$ go through a minimum at a particular $d > d_c$ indicates that the electric field at the cathode goes through a maximum at this separation. This maximum does not occur when the dielectric is removed.

Examples of measured conditional distributions $p_1(q_n|\Delta t_{n-1})$ at different indicated values of Δt_{n-1} and d and for $V_a = 10.1$ kV and $D = 7.5$ cm are shown in Figure 5 together with the corresponding unconditional distribution $p_0(q_n)$ indicated by the dashed line. A strong positive dependence of q_n on Δt_{n-1} is seen from these data. This behavior is consistent with that previously reported [5,6,9] and can be explained by the effect of moving negative-ion space

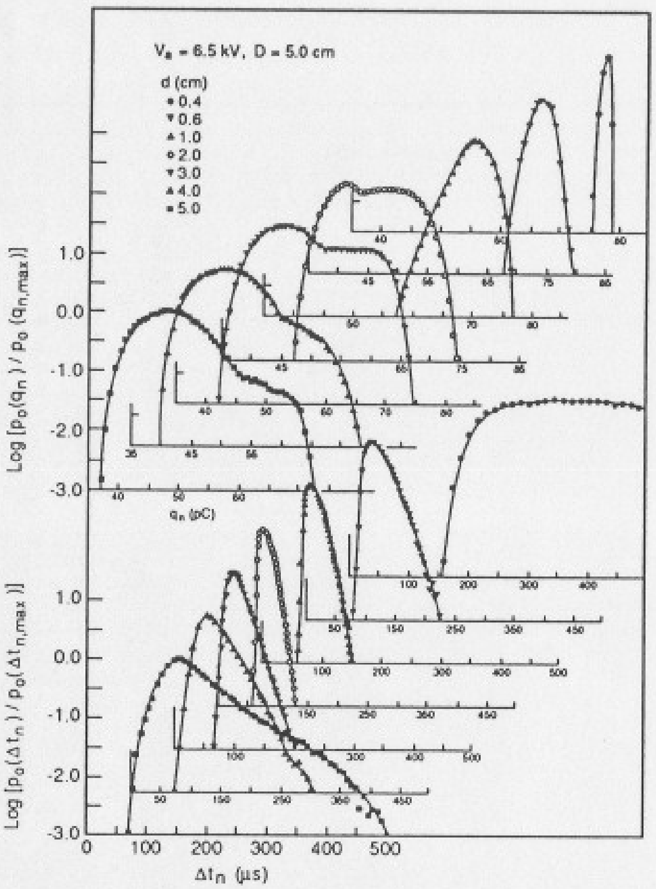

Figure 3. Measured pulse-height and corresponding time-interval distributions at $V_a = 6.5\,\mathrm{kV}$, $D = 5.0\,\mathrm{cm}$, and for the different indicated gap spacings. The distributions have been normalized to the maxima.

charge clouds from previous pulses on the electric field at the cathode when the next discharge pulse develops [2]. The unconditional pulse-height distributions $p_0(q_n)$ shown in Figure 3 are determined by the profiles of the corresponding $p_0(\Delta t_n)$ distributions and the dependence of q_n on Δt_{n-1}. These distributions are found to be consistent with Eq. 1 above.

Figures 6 and 7 show plots of $\langle q_n(\Delta t_{n-1})\rangle$ versus Δt_{n-1} where

$$\langle q_n(\Delta t_{n-1})\rangle = \int_0^\infty q_n p_1(q_n|\Delta t_{n-1})\,dq_n. \tag{2}$$

These results again indicate the strong dependence of q_n on Δt_{n-1} and are consistent with previous results [5,10] except at short distances ($d \lesssim 0.6\,\mathrm{cm}$) at which a change in slope becomes evident, particularly for longer time separations. This is indicated more clearly by the data in Figure 7. For $\Delta t_{n-1} < \Delta t_\ell$, the dependence of q_n on Δt_{n-1} is due predominantly to the negative-ion space charge effect which is a prominent characteristic in the stochastic behavior of Trichel pulses in the absence of the dielectric barrier [5,10]. The slope of the $\langle q_n(\Delta t_{n-1})\rangle$ versus Δt_{n-1} decreases significantly at Δt_ℓ. It is speculated that at $\Delta t_{n-1} = \Delta t_\ell$, the negative ions have been deposited on the dielectric, and for $\Delta t_{n-1} > \Delta t_\ell$, the dependence of q_n on Δt_{n-1} is governed by the rate of charge dissipation or migration on the dielectric surface.

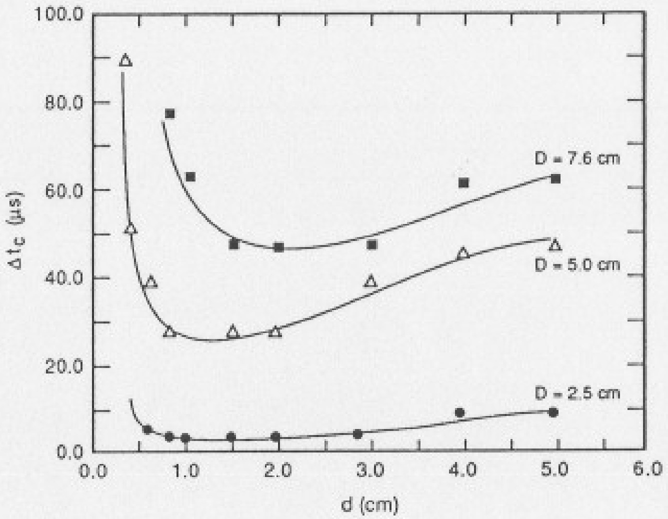

Figure 4. Minimum possible pulse time separation, Δt_c, versus gap spacing for $V_a = 7.5\,\mathrm{kV}$ and the different indicated insulator diameters.

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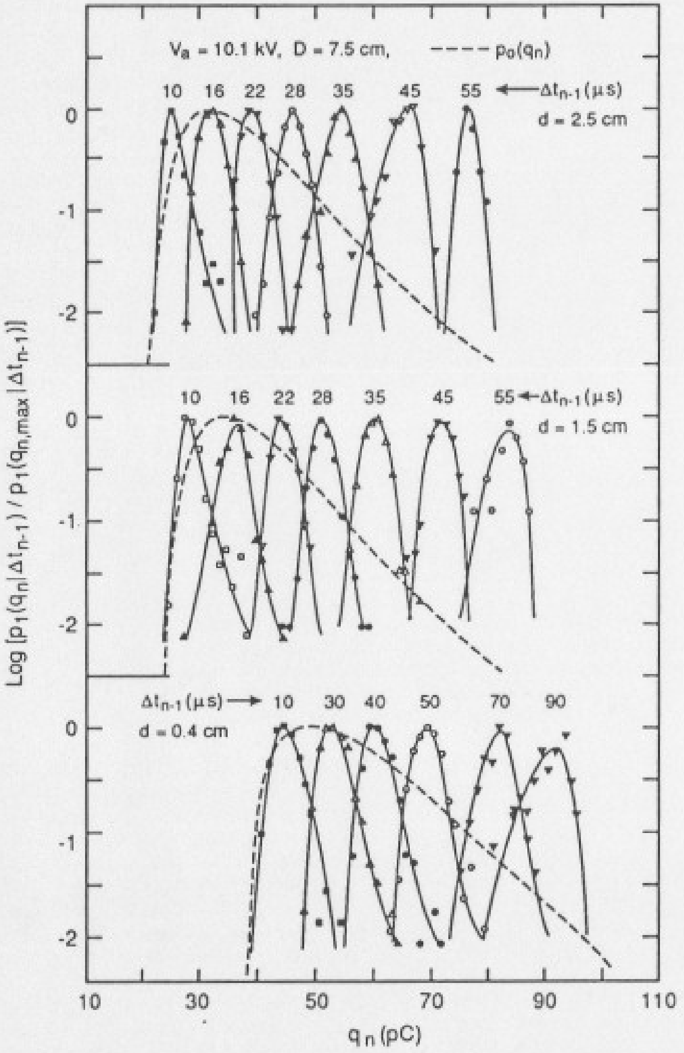

igure 5. Measured conditional pulse amplitude distributions $p_1(q_n|\Delta t_{n-1})$ at he different indicated values for Δt_{n-1} and gap spacing, and the corresponding nconditional pulse-amplitude distributions $p_0(q_n)$ shown by the dashed lines. he distribution have been normalized to the maximum values.

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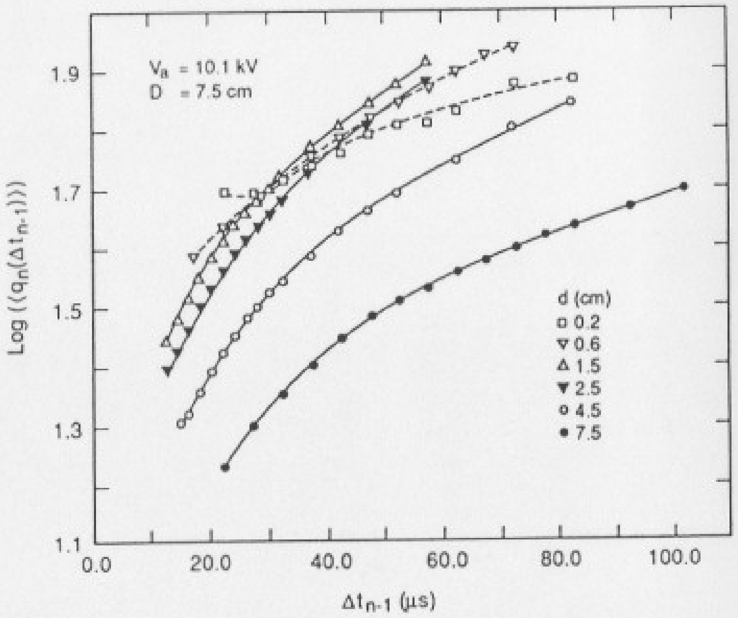

Figure 6. The expectation value $\langle q_n(\Delta t_{n-1})\rangle$ versus Δt_{n-1} at $V_a = 10.1$ kV and $D = 7.5$ cm for the different indicated gap spacings.

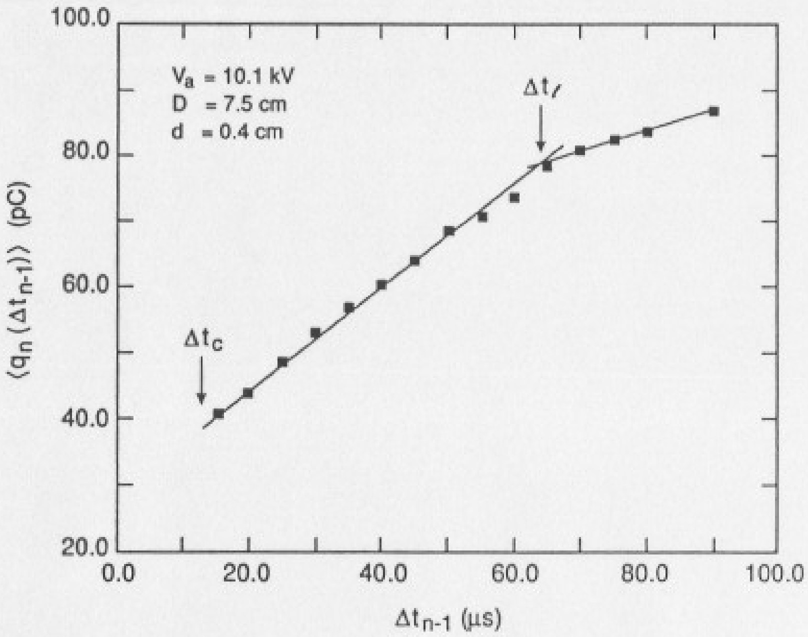

Figure 7. The expectation value $\langle q_n(\Delta t_{n-1})\rangle$ versus Δt_{n-1} for $V_a = 10.1\,\mathrm{kV}$, $D = 7.5\,\mathrm{cm}$ and $d = 0.4\,\mathrm{cm}$.