NONSTATIONARY BEHAVIOR OF PARTIAL DISCHARGE DURING INSULATION AGING

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There are two purposes for this work. The first is to present an example of a case where a pulsating partial-discharge (PD) phenomenon exhibits non-stationary behavior associated with discharge-induced "aging" of a dielectric material. The observed nonstationary behavior, which manifests itself by a time-dependence in the statistical characteristics of PD pulses, illustrates the difficulties to be encountered in defining meaningful PD pulse "patterns" that can be used for reliable defect site identification. The second purpose is to point out possible difficulties in relating measured PD pulse-height distributions to measured average PD current which are relevant to the calibration of PD measurement systems.

MEASUREMENTS

The pulsating PD phenomena investigated in this work were generated by applying an alternating voltage to a sharp, stainless-steel point electrode that touches a flat solid dielectric surface fastened to a ground plane in air as described in our previous work (Van Brunt and Cernyar (1,2)). Various conditional and unconditional pulse-height, pulse-phase, and integrated-charge distributions were measured using a stochastic analyzer (2). Results are shown here for the integrated-charge distributions $p_o(Q^+)$ and $p_o(Q^-)$, where Q^+ and Q^- are respectively the sums of charges associated with all PD pulses in a given positive or negative voltage half-cycle, namely

$$Q^{\pm} = \sum_i q_i^{\pm}, \qquad (1)$$

where $q_i^{\pm}$ is the charge in pC of the ith PD pulse in an arbitrary half-cycle. The average PD currents, I_m, were measured under the same conditions in separate experiments using a TETTEX-9120 PD measurement system.[1] The measurements were carried out for two types of cast epoxy materials (with and without Al_2O_3 filler) supplied by the Electrotechnical Institute of Warsaw.[1] Results were obtained for frequencies in the range of 50 to 400 Hz and for an applied rms voltage of 3.0 kV. In some cases, surface resistivities of epoxy materials were measured after exposure to PD in the region where the discharge had occurred as described elsewhere, Van Brunt, et al. (3).

[1]The identification of commercial instruments or materials and their sources is made to describe the experiment adequately. In no case does this imply recommendation by the National Institute of Standards and Technology, nor does it imply that the instrument is the best available.

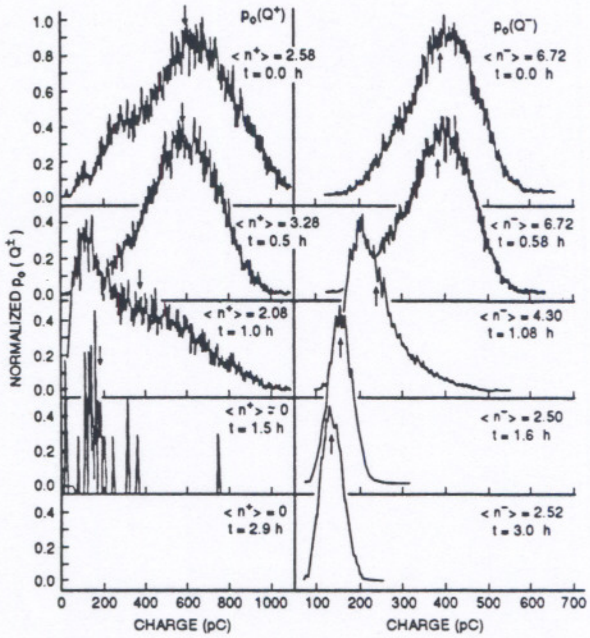

Figure 1. Positive and negative integrated-charge distributions measured for epoxy with filler at the indicated times after the 50 Hz voltage was applied. Also shown are the corresponding mean numbers of positive and negative PD pulses and the mean charge values (vertical arrows).

RESULTS AND DISCUSSION

Integrated charge-distributions

The distributions $p_o(Q^+)$ and $p_o(Q^-)$ were measured at different times during a continuous application of voltage to the point-dielectric gap. The time required for the measurement of each distribution was about 4 minutes. An example of a set of distributions measured at 50 Hz for epoxy with filler is shown in Figure 1 together with corresponding information about the times at which measurements were performed and the mean numbers of positive and negative discharge pulses per cycle ($\langle n^+\rangle$ and $\langle n^-\rangle$). The mean charge values defined by

$$Q_{av}^{\pm} = \int_o^{\infty} Q^{\pm} p_o(Q^{\pm}) dQ^{\pm} \Big/ \int_o^{\infty} p_o(Q^{\pm}) dQ^{\pm} \qquad (2)$$

are indicated in the figure by vertical arrows.

It is seen that after the voltage has been applied for about an hour, the statistical characteristics of the discharge change dramatically. At about 1.7 h, the positive PD pulses cease entirely and $|Q_{av}^-|$ shifts to a lower value. The time of positive-pulse disappearance was found to be reproducible and to decrease in direct proportion to the frequency, f, for $f \leq 400$ Hz. The surface resistivity of the epoxy was also found to decrease significantly near the discharge site. The disappearance of PD pulses associated with discharge-induced changes in surface resistivity is consistent with recent observations of Hudon, et al. (4) and with computer simulations that take into account increasing rates of surface charge decay with decreasing resistivity (3). It is interesting to note that the epoxy without filler shows much less variation of PD behavior with time (3).

Relationship between average PD current and PD pulse height distributions

In accordance with the IEC Standard (5), the "average discharge current," I_m, such as measured by the instrument used in this work is defined by

$$I_m = f(|q_1| + |q_2| + \cdots) + I_b, \tag{3}$$

where $|q_i|$ is the absolute charge associated with the ith PD event which is related to the PD current $I_i(t)$ by

$$q_i = \int_{\Delta\tau} I_i(t)dt. \tag{4}$$

The integration in equation (4) is over the duration, $\Delta\tau$, of the PD pulse. In equation (3), the term I_b corresponds to background or discharge current not accounted for by the observed pulses and therefore by equation (4).

If it can be assumed that: (1) all of the PD current is due to the recorded pulses and (2) PD pulses occur on every half-cycle, i.e., there are no "null" half-cycles, then the average current can be calculated using the integrated charge, namely

$$I_c = f(|Q^+_{av}| + |Q^-_{av}|), \tag{5}$$

which is equivalent to equation (3) ($I_c = I_m$), for $I_b = 0$. If null cycles occur, then

$$I_c = f(|\langle Q^+\rangle| + |\langle Q^-\rangle|), \tag{6}$$

where

$$\langle Q^\pm\rangle = \frac{n_o^\pm}{n_t} Q^\pm_{av}. \tag{7}$$

Here n_t is the total number of cycles observed at time t ($n_t = ft$) and $n_o^\pm$ is the number of positive or negative null cycles so that $n_t \geq n_o^\pm$, and likewise $|Q^\pm_{av}| \geq |\langle Q^\pm\rangle|$. Thus, if $I_b = 0$ and n_o^+ or n_o^- is nonzero, equation (5) will overestimate the PD current, i.e., $I_c > I_m$. If $n_o^\pm = 0$ and $I_b \neq 0$, then the current is underestimated, i.e., $I_c < I_m$.

Figure 2 shows plots of I_m, I_c, $|Q^\pm_{av}|$, and $|Q^-_{av}|$ versus time for conditions like those used to obtain the data in figure 1. It is seen that although the curves for I_m and I_c have the same shape, I_m is always greater than I_c, which suggests that $I_b \neq 0$. This is expected if there is a loss of surface charge due to conduction on the surface. There is evidence that the initial charge imbalance ($|Q^+_{av}| > |Q^-_{av}|$) is due mainly to a lack of positive PD pulses in every cycle, i.e., $n_o^+ \neq 0$.

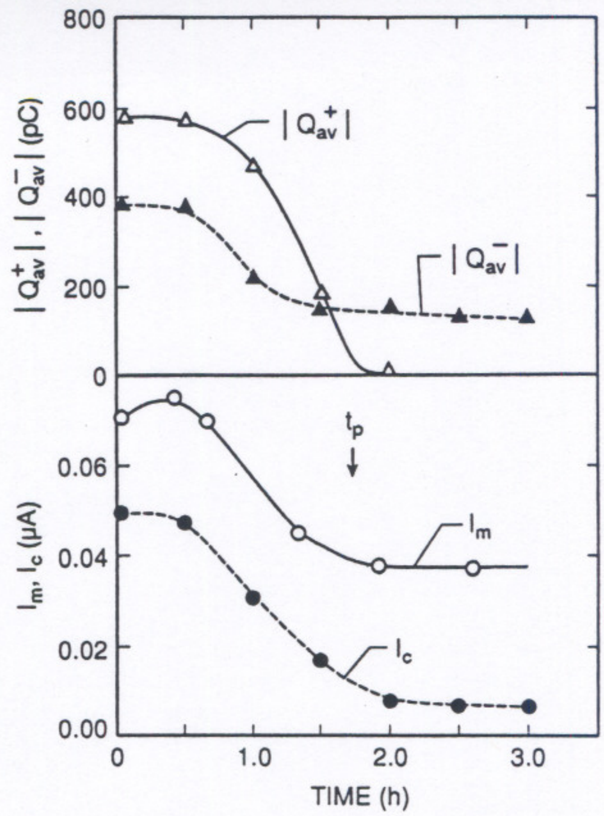

Figure 2. Time dependencies of the mean values for the integrated positive and negative charges determined from $p_o(Q^\pm)$ data such as shown in figure 1 using equation (2) and the measured average PD current, I_m, and calculated PD current, I_c, using equation (5). Indicated is the time t_p at which the positive PD pulses ceased.

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