Time Decay Constants of Resistive Detectors

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Abstract. Several authors have studied the dependence of the detection efficiency or charge gain of a resistive detector on the counting rate. Most of these results assume a stationary regime and treat the dielectric as equivalent to a simple RC circuit. In order to verify the validity of this model we have investigated the transient behavior of a resistive detector with a cylindrical geometry for various counting rates. In the present work we show that the charge-signal amplitude decays with time and tends towards a constant value that corresponds to the pulse height under stationary regime. In some cases the time-decay curves can be fitted by a single exponential plus a constant term, while in others (higher counting rates) a sum of two exponentials plus a constant term is needed to fit the experimental data. The time constants show a tendency to decrease with increasing counting rate that prevents us from relating these constants to the glass-relaxation mechanisms. However, these results indicate how fast the effective relaxation of the dielectric is and also demonstrate that the resistive detector cannot be treated as equivalent to simple RC circuits.

INTRODUCTION

Several groups have investigated the drop in the efficiency of Resistive Plate Chambers (RPCs) with increasing high voltage and counting rate [1, 2, 3, 4, 5]. In our previous papers [6, 7, 8, 9] we have shown that this behavior is attributed to the voltage fall-off on the resistive electrodes, which reduces the effective electric field across the gas gap and consequently the charge gain. Our measurements were performed assuming a stationary regime and treating the dielectric as equivalent to a simple RC circuit with a time constant given by $\rho\varepsilon\varepsilon_0$, where ρ, ε, and ε_0 are the bulk resistivity, the static dielectric constant, and the permittivity of vacuum, respectively. Therefore, the reduction of the voltage available to the charge multiplication processes in the gas and consequently the rate capability of the resistive detector must depend on this time constant. Besides, the variation of the effective voltage, as well as the pulse amplitude as a function of time, is expected to be represented by a simple exponential decay. In order to verify the validity of this interpretative RC model, it was decided to study the time evolution of the amplitude of the charge signals from a cylindrical resistive detector. Advantages of this geometry are the inherently good energy resolution, i.e., the detection and measurement of small variations of gain or pulse height, and clear definition of the working regime without loss of generality of the information obtained. In this work we present data that, in a quantitative way, contribute to the clarification of the transient behavior of resistive detectors.

EXPERIMENTAL SET-UP

The experimental results shown below were obtained with a long cylindrical counter made of glass (ϕ_I = 12.7 mm, glass wall thickness 1.1 mm, and resistivity $\rho = 8.6 \cdot 10^{12}$ $\Omega\cdot$ cm) with a stainless-steel anode wire ($\Phi_1 = 50$ μm) stretched along its axis. The cathode was the glass tube covered externally with a thin-grounded layer of **Electrodag 114**. The gas mixture, Ar + 10% CH_4 (P10) was admitted into the detector in a continuous flow regime, at atmospheric pressure and at room temperature ($\approx$ 293 K). X-rays from a ^{109}Cd source (22 keV) irradiated the detector through its glass wall. To keep constant the irradiated zone of the tube, a Pb foil with a central hole of 3 mm diameter positioned just above the cylinder was used. The counting rate was changed by the variation of the distance source detector.

The anode signals were fed to a charge-sensitive preamplifier and a linear amplifier with a time constant of 2 μs. For the study of the transient effects the output of the amplifier was connected to an Analog-to-Digital

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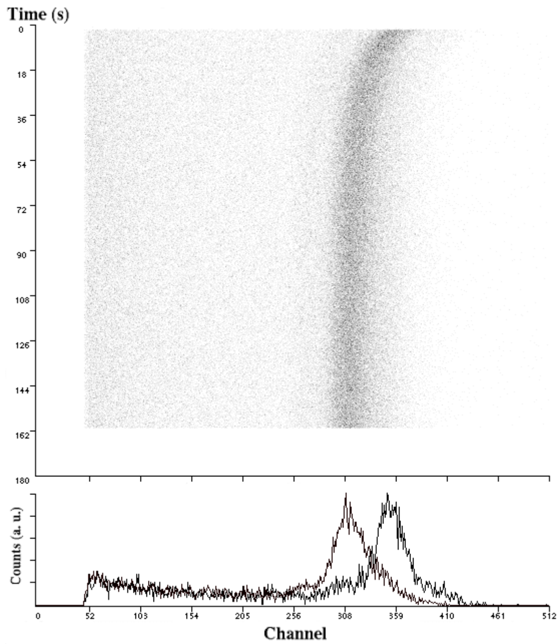

FIGURE 1. Display window of the program (GONK) where a real-time acquisition run is shown (see text for details).

Converter (ND 582). The digital data from the ADC was retrieved with an IO board (AT-DIO 32F, National Instruments) installed in a microcomputer. When new data were available, the Kernel device driver interrupted the IO board to allow storing both the amplitude of signal (or channel number) and the time from the CPU cycle counter in a buffer whenever acquisition was in progress. The data-acquisition program (**GONK** [10]) read the data from the device driver and displayed it in a two-dimensional matrix (amplitude$\times$ time histogram). Just as an illustration, Fig. 1 shows an edited display window of this program where the corresponding matrix, presented in the upper part of this figure, was obtained with the resistive detector under an irradiation rate of 522 Hz. The vertical scale is in seconds and the horizontal one in ADC channels. The fall of the channel number as a function of time can be evidenced through the pulse-height histograms (bottom of Fig. 1) obtained in the beginning and in the end of the irradiation time. In this case, the counts plotted were the sum of those stored during the two time intervals previously selected. It is also possible to represent all these data through a charge pulse-height distribution as a function of time and counting rates in a three-dimensional graph as presented in Fig. 2.

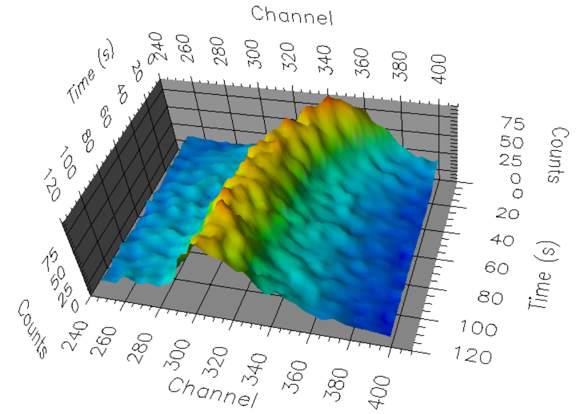

FIGURE 2. Pulse-height distribution as a function of time and counting rate obtained with the resistive detector under an irradiation rate of 522 Hz.

RESULTS

The variation of the pulse amplitude as a function of time obtained with the resistive detector under constant applied voltage ($V = 2000$ V) and counting rates of 40, 95, 200, and 522 Hz is shown in Fig. 3. The analysis of these curves shows that for the lowest counting rate (40 Hz) no rate effects should be associated with the resistive detector since the signal's amplitude remains constant with time. Nevertheless, for higher irradiation rates an expressive decrease of the pulse height was observed as a consequence of the voltage across the gas. Indeed, according to our transient behavior model, due to the finite conductivity of the resistive electrode, as soon as the irradiation starts a small current begins to flow through the gas. This results in an increase of the potential of the internal surface of the dielectric, i.e., in a decrease of the potential across the gas gap and, consequently, of the pulse amplitude. Therefore, it decays with time and tends towards a constant value that corresponds to the pulse amplitude under stationary regime.

An analysis of these data in terms of an exponential decay was attempted and it was found that for the rate of 95 Hz a simple exponential plus a constant term fits the experimental results well, whereas for the rates of 200 and 522 Hz a sum of two exponentials plus a constant term was needed. Figure 3 shows one of these fittings for 522 Hz of irradiation rate. As a result, two time constants (τ_1 and $\tau 2$) were obtained according to the expression:

$$y = y_0 + A_1 e^{-\frac{t}{\tau_1}} + A_2 e^{-\frac{t}{\tau_2}} \qquad (1)$$

where y_0 is the pulse amplitude at stationary regime; A_1 and A_2 are constants.

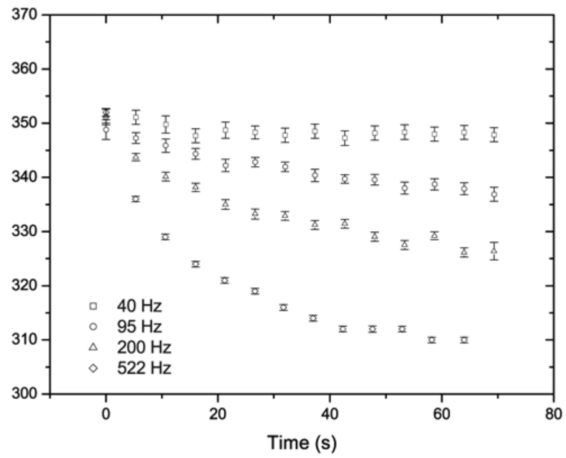

FIGURE 3. Time dependence of the amplitude of the charge signals for the resistive detector. Data were obtained for 40, 95, 200, and 522 Hz and an applied voltage of 2000 V.

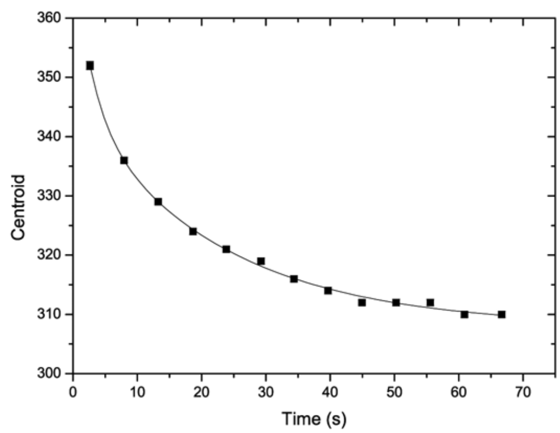

FIGURE 4. Fitting the experimental results for the rate of 522 Hz trough a sum of two exponentials plus a constant term.

The results obtained are presented in Table 1 where the time constants show a tendency to decrease with increasing counting rate. It is worth noting that the values for the slow time constant are larger up to a factor of 10 or of the order of the equivalent RC time constant (3.8 s in this case).

These results evidence that the transient behavior of resistive detectors cannot be treated as equivalent to simple RC circuits where the dielectric is considered ideal. Indeed, the glass used in these measurements features a complex relaxation mechanism and at least two processes (prompt and delayed) are responsible for the polarization of the dielectric [11]. Although the associated decay constants are not directly related to the fundamental processes, they are characteristic of a particular material and give an idea of how fast the effective relaxation of the dielectric is.

TABLE 1. Time-decay constants. All the χ^2 values were within the acceptance region.

Rate (Hz)	τ_1 (s)	τ_2 (s)	χ^2	$P(\chi^2)$ (%)
95	25.2(42)	$\cdots$	2.03	3.9
200	17.0(54)	31(19)	1.51	15
522	2.9(12)	22.5(28)	1.38	20

CONCLUSION

In the present work measurements of the transient behavior of a cylindrical resistive detector show that the time evolution of the amplitude of the charge signals can be fitted by a simple exponential for low counting rate and by a sum of two exponentials for rates higher than 200 Hz. It is also found that the decay time constants decrease with the irradiation rate and are higher (up to a factor of 10) or of the order of the assumed $\rho\varepsilon\varepsilon_0$ value. Although they indicate how fast the effective relaxation of the dielectric is, they also demonstrate that the resistive detector cannot be treated as equivalent to simple RC circuits. Indeed, the established model does not take into account, for example, the fact that the glass is not polarized instantaneously and the importance of the drift velocity of ions through the glass wall.

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