Manifestation of aging effects in gas proportional counters

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Studies of the behavior of cylindrical proportional tubes, 25 mm and 32.1 mm in diameter, under sustained irradiation were carried out with Ar/iso-pentane 95:5 and Ar/CO_2/N_2/iso-pentane 70:10:10:10 gas mixtures. The influence of aging on the decrease of gas gain and on the so-called count rate effect was studied. Special attention was paid to the performance of aged counters operated at high gas gain and at high counting rate. A very strong impact of aging on the count rate effect was observed. The decrease of gas gain was found to be a linear function of the collected charge.

1. Introduction

Aging of gaseous detectors designates a permanent decrease of the observed signal amplitude as the total accumulated charge increases. This degradation of the response is most often due to solid deposits on the anode wire, which eventually lead to a breakdown of the operational stability of the detector. The aging of gaseous detectors is a complex process, which depends upon a large number of parameters (gas mixture, type of radiation, gas gain, concentration of impurities, gas exchange rate, ...), which very often get out of hand. Most of the aging studies of gas counters are performed at much larger dose rates than those encountered under standard operation conditions for proportional counters [1].

In our measurements, iso-pentane containing mixtures were used to age the counters within a short time at a current density below 1 μA/cm. The detectors were exposed to radiation coming from ^{109}Cd and ^{90}Sr sources. Four cylindrical, proportional counters were investigated [2]. Below, the detailed information on the design of the counters and their operating conditions is presented:

- Counters 1 and 2: Ar/iso-pentane 95:5 working gas; ^{90}Sr – source; brass cathode, 25 mm in diameter; W/Au anode, 100 μm in diameter, current density – 0.3 μA/cm, working gas pressure $p = 0.9$ Bar, HV = 1800 V, gas gain $\approx 7 \cdot 10^3$.
- Counter 3: Ar/CO_2/N_2/iso-pentane 70:10:10:10 working gas; ^{90}Sr – source; brass cathode, 32.1 mm in diameter, W/Au anode, 40 μm in diameter, current density – 85 nA/cm, $p = 0.9$ Bar, HV = 1150 V, gas gain $\approx 10^4$.
- Counter 4: ^{109}Cd – source; current density – 20 nA/cm; all other parameters the same as for counter no. 3.

The impact of aging on gas gain, shape of the pulse height spectra and on the so-called "count rate effect" was experimentally studied. Special attention was paid to the performance of aged counters operated at high counting rate and at high gas gain. The main scope of this work is to study which detector parameter is sensitive to aging.

2. Influence of aging on gas gain

The change in gas gain was determined from the measured change in the ^{55}Fe pulse height distribution. Denoting by k the amplification factor of the amplifier one can write the following expresion for the pulse amplitude U at the output of a spectroscopic circuit:

$$U = f(\check{l}, t_r) \cdot k \cdot (\tfrac{E}{W}) \cdot A$$

where $f(\check{l}, t_r)$ is a factor depending on, among others, the time constant for pulse shaping $\check{l}$ and on the shape of the pulse; t_r is the pulse rise-time;

W is the mean energy loss needed to produce an ion-electron pair in the given gas; A is the gas gain. If the shapes of all the pulses produced in the counter are identical, i.e. t_r = const, then for a given energy E deposited in a detecting system with parameters $\check{l}$, k and W this states that the amplitude is a function of the gas gain factor A only, ($U = f_1(A)$).

Most of the parameters which describe the growth of electron avalanches in an electric field, especially $\frac{\alpha}{p}$ (α - Townsend's first ionisation coefficient, p - gas pressure) are explicit functions of the electric field strength E_r. In a cylindrical counter of diameter $2r_k$ with an anode of diameter $2r_a$ placed along the axis of the cylinder, the electric field strength E_r is given by the standard formula:

$$E_r(r) = \frac{V}{r\ ln(\frac{r_k}{r_a})}$$

where V is the voltage applied between the cathode and anode. Thus, $U = f_1(A(V, r_a))$ for all other parameters kept constant. One of the indications of aging is the increase of the anode wire diameter caused by the layers of insulative or conductive deposits. This leads to a strong non-uniformity and decrease of E_r followed by reduction in gas gain.

For instance, an appearance of a 0.5 μm thick layer on an anode wire, 25 μm in diameter, can reduce the gas gain by (20 - 40)% [4]. In case of an insulating layer, the anode is shielded and the layer is negatively charged up. This leads to further reduction in gas gain due to the decrease of V.

The relative decrease in gas gain as a function of collected charge for counters 1 and 2, measured at different values of HV is shown in Figs. 1 and 2. It is seen that the relative decrease in the ^{55}Fe peak position is a linear function of collected charge; the effect is much stronger for higher HV. For fixed collected charge, the relative decrease in the ^{55}Fe peak position is also a linear function of applied HV (Figs. 3 and 4).

3. Influence of aging on count rate effect

The increase of radiation intensity measured by a proportional counter leads to undesirable changes of pulse height and energy resolution. It has been found that both the pulse height and the energy resolution significantly decrease with increasing radiation intensity. These changes are called "count rate effect". At present, there are four different concepts explaining the count rate dependence of the pulse amplitude shift in aged proportional counters. Hendricks' [5] concept considers the pulse amplitude shift as arising from the continuous decrease in the gas amplification factor, resulting from the presence of slowly moving positive ions in the avalanche multiplication region. Spielberg and Tsarnas [8] suggested that the primary mechanism for the shift is the build-up on the anode wire of a loosely bound layer of polarizable molecules, or molecular fragments of quench gas, which effectively increases the diameter of the anode wire, thereby decreasing the gas gain for a fixed applied voltage. In both above mentioned concepts, the quality of the anode surface is important and can strongly affect the measured change in the pulse height. According to Mahesh's concept [6], [7] the decrease in the pulse height is caused by the quasi-columnar recombination of primary ions, and by the volume recombination taking place in the avalanche near the anode. Both effects affect the pulse height by decreasing the number of the electrons reaching the anode. Bednarek [9], [10] showed that the gas gain is still constant over a large range of count rate, and the changes in the pulse amplitude observed were found to be due to the variation of mean pulse rise-time, while the resolution variations were found to be due to the changes in the spread in the rise time. The hypotheses proposed by Mahesh and by Bednarek are independent of the anode surface quality.

To determine the influence of aging on the count rate effect, the following counter parameters were measured:

- Energy resolution as a function of count rate for different values of collected charge.
- Relative changes in the peak position (MnK - line) as a function of count rate for different values of collected charge.
- Changes in the shape of the pulse height

spectra were also monitored.

Selected, representative results are shown in Figs. 5 and 6. The energy resolution R for new counters is nearly independent of the intensity of registered radiation, but depends strongly on the count rate for aged counters. For instance, at a flux of incoming photons of $\sim$ 10 kcps $R = 16\%$ for a new counter (for ^{55}Fe - line); for a collected charge of $Q = 1.38$ C, $R = 26\%$ but for $Q = 3.54$ C, $R = 38\%$. Pulse height spectra for different photon fluxes are presented in Fig. 7. It should be pointed out that for a count rate $I = 490$ cps, $R = 27.3\%$, but for $I = 710$ cps a second peak starts to appear. It is clearly seen from Figs. 5, 6, and 7 that for a count rate below 400 cps, R is aging-independent.

4. Conclusions

- The decrease in gas gain for fixed HV is a linear function of the collected charge.
- The decrease in gas gain, for fixed collected charge is also a linear function, but of applied high voltage.
- The count rate effect of aged counters strongly depends on the collected charge and the applied high voltage; for low gas gain and low intensity of registered X-ray photons the energy resolution is below 27%, while for a gas gain higher than $5 \cdot 10^3$ and a count rate higher than 0.7 kcps a double peak is measured.
- We observed a strong impact of aging on the count rate effect.

It should be emphasized that all counters were aged at low current density.

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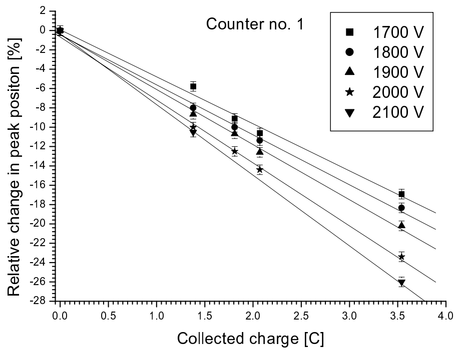

Figure 1. The relative decrease in the ^{55}Fe peak position from the value corresponding to the new counter as a function of collected charge and of applied HV for counter 1 (filled with a mixture of Ar/iso-pentane 95:5).

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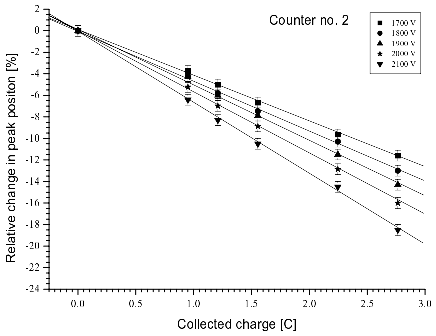

Figure 2. The same as Fig. 1 but for counter 2.

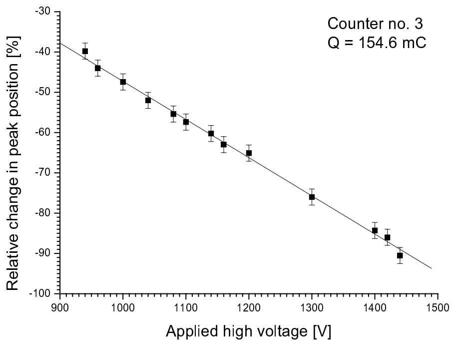

Figure 3. The relative decrease in the ^{55}Fe peak position from the value corresponding to the new counter as a function of applied HV for counter 3 (filled with a mixture of Ar/CO_2/N_2/iso-pentane 70:10:10:10).

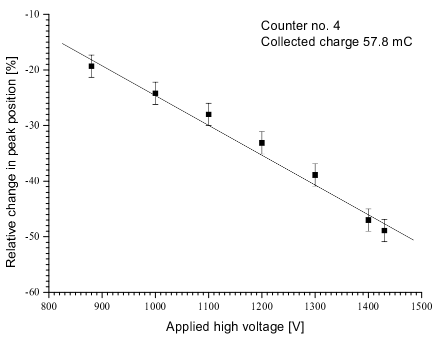

Figure 4. The same as Fig. 3 but for counter 4.

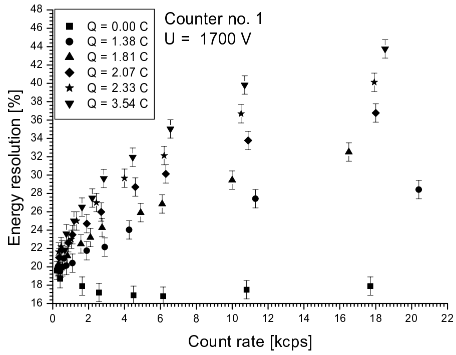

Figure 5. Energy resolution as a function of the count rate for different values of collected charge for counter 1.

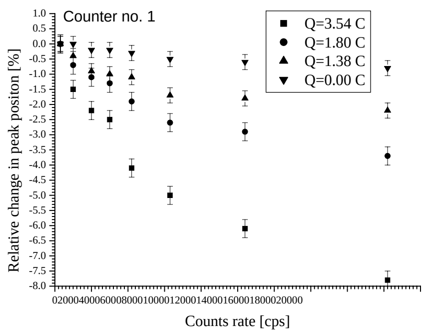

Figure 6. The relative decrease in the ^{55}Fe peak position as a function of count rate and of collected charge for counter 1. The ordinate is the relative decrease in pulse height from the value corresponding to the count rate below 400 cps.

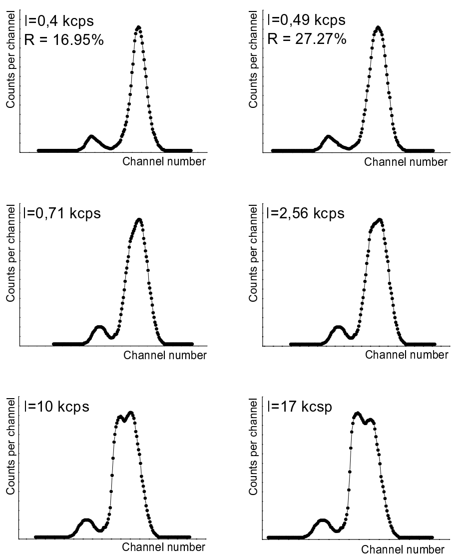

Figure 7. Pulse height spectra for counter 1 at fixed collected charge $q = 1.47$ C and applied HV $= 2100$ V, but for different counting rates I.