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Factors affecting the precision of measurements with the usage of proportional counters

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Abstract. In all measurements with the usage of proportional counters the pulse height and its distribution are measured. From this one can calculate energy losses and their distribution along the particle track position in 2D. The pulse height at the output of electronic circuit, co-working with the proportional counters, depends on: gas gain, energy deposited inside a counter and parameters of the readout electronics. However, it is only the first approximation. Careful studies show that output pulse height depends on the place of radiation absorption along and across the counter. The measured effect is as high as a few percent across and along the counter. Those effects were observed for both cylindrical and rectangular geometry. The pulse height depends not only on the registered count rate but also on the speed of its change. All the above effects are a few percentage effects, but can strongly affect the correctness of measurement made with the usage of proportional counters.

Key words: proportional counter • gas gain • count rate effect

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Introduction

Among all the amplifiers of energy deposited by a particle on its passage through the matter, the proportional single wire counter is a simple and quite well known detector. When it is coupled with a sensitive electronic amplifier, a few, even single electron from the ionization of a particle can be observed, which create ionization avalanche in the high electric field near the surface of the anode wire. The amplitude properties of pulses produced by many primary electron-ion pairs, n_0, provided that space charge effects are not large enough to disturb the electric field, each avalanche is independent, the total charge Q generated by n_0 primary pairs is

$$Q = n_0 \cdot e \cdot A \tag{1}$$

where: A is the average gas multiplication factor that characterizes the counter operation, n_0 is equal to $n_0 = E/W$, E is the energy deposited by the registered particle in the detecting medium, W – energy required to produce one electron-ion pair, e – elementary charge. The proportionality between the deposited energy and the charge generated is achieved for values of A between 10 and 10^5. The proportionality is strongly affected by form of the electron avalanche in the vicinity of the anode wire, the so-called self induced space charge effect. This process usually manifests itself when the ionization density is high or for extremely high value of gas gain A. The amplitude of the output signal of electronic circuit, U, connected to the proportional counter is

(2) $$U = f(\tau, t_r) \cdot A_e \cdot (E/W) \cdot e \cdot A$$

where: $f(\tau, t_r)$ – factor depends on pulse rise time t_r and the time constant τ of electronic circuit; A_e – electronic gain. For fixed applied high voltage, i.e. A = const, for E = 5.9 keV (Fe-55 source) for constant A_e, the measurements of U as the function of the position of radiation absorption along and across the counter body have been made for cylindrical and rectangular in cross detectors.

The increase of radiation intensity measured by a proportional counter leads to undesirable changes of its parameters such as, pulse high 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" and are very well known. It should be pointed out that during the rapid change in count rate the final position of the peak is reached after some time. Time dependence of peak position is also presented.

Measurements and results

Scan across the counter

Pulse height at the output of electronic circuit has been measured as a function of position of a strongly collimated Fe-55 source for a cylindrical and box counter. Details of counter geometry and type of working gas are given in the description of Figs. 1, 2 and 3. In Fig. 1 for a Kr-based mixture for all the applied high voltage wide maximum is observed up to distance of 15 mm from the anode wire. For a higher distance than 15 mm, more rapid decrease is observed. Quite different behaviour was measured for a counter filed with Ar as a main gas for a large box counter and a very thin straw tube. In both cases a clear minimum exist in the center just in the place of anode wire. The increase in peak position depends on counter geometry and applied HV and can be up to 4%.

Listed effects can be explained by:

– Interaction of a primary photoelectron with an electric field in the counter. Interaction of the photoelectron with a strongly non-uniform electric field in counters results in an increase of its energy except for the interaction in counter volume directly above the anode wire. In this volume for X-ray absorbed very close to the anode wire even a decrease of photoelectron energy can take place.
– Longitudinal and transversal diffusion of a primary cloud of electrons during their drift from the interaction point to an electron multiplication region. For a higher drift distance, one can avoid overlapping of a single electron avalanche (elimination of electric field distortion due to space charge effect).
– Decrease in U for a high distance from the anode wire is caused by a low field near the cathode wall and the lost of primary electrons when the range of photoelectron is higher than the distance between the measured radiation interaction point and the counter body.

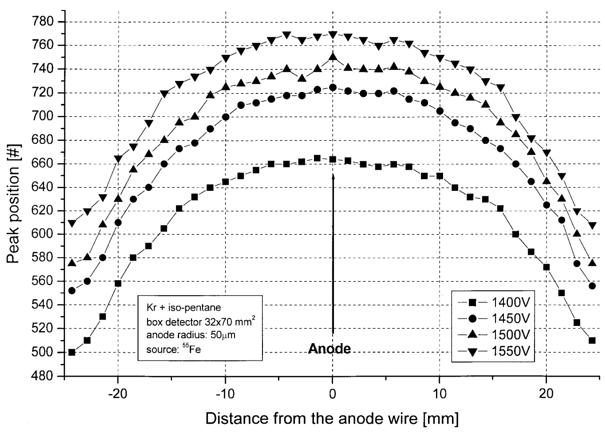

Fig. 1. Pulse height amplitude vs. Fe-55 source position across box counter filled with a Kr-based mixture for different values of applied high voltage and electronic gain.

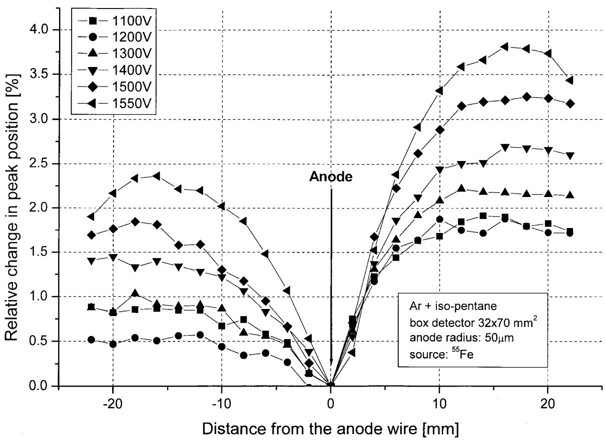

Fig. 2. Relative change in pulse height vs. Fe-55 source position across box counter filled with an Ar-based mixture for different values of applied high voltage. The ordinate is the relative change in pulse height from the value corresponding to the position of source at the center of counter.

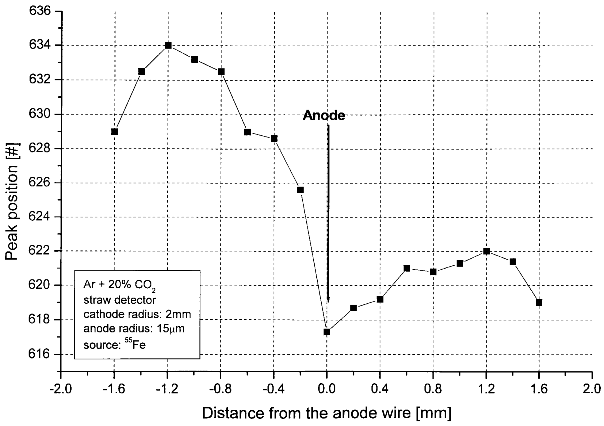

Fig. 3. The same as in Fig. 1, but for a straw counter flushed by an Ar + 20%CO_2 mixture.

Difference in the behaviour between the Ar and Kr-based mixtures can be caused by the difference in the range of primary photoelectron. At this moment, this is not well understood and studies of counters filed with Ne and Xe-based working gas are now under progress.

Scan along the counter

In straw-tube counters (cylindrical detecting element 4 mm in diameter and up to 150 cm in length) the

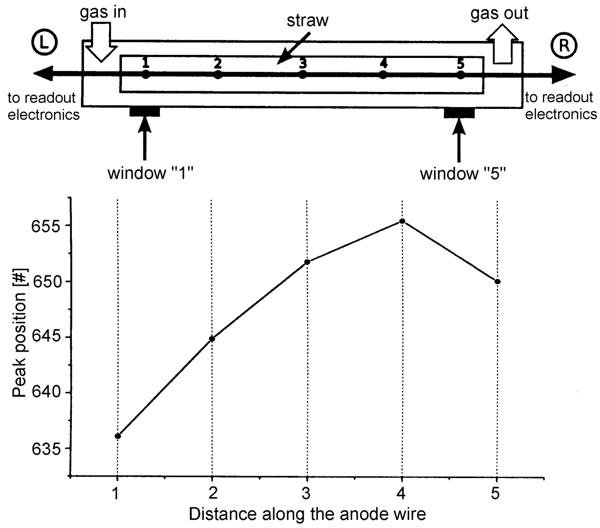

Fig. 4. A schematic drawing of the "special straw" set-up and an examplary result.

slope of output pulse height along the anode wire was reported in Ref. [1].

To study this problem, a "special straw" was built. "Special straw" it is just a straw to which the electronic readout can be connected to both sides. The straw was 50 cm in length. It was closed in a glass pipe, so the straw was flushed with the working gas inside and outside. In the glass pipe five windows were made (see Fig. 4) the outer ones are ten centimeters from the ends of the straw. The distance between the outer windows is 30 cm. The gas flow was always in the same direction, from window 1 to window 5. The spectra for the Fe-55 source for all windows have been collected and the slope was defined as:

$$\text{slope} = \frac{PP(5) - PP(1)}{PP(1)} \cdot 100\% \qquad (3)$$

where: PP(5) and PP(1) is the peak position for the Fe-55 source placed on windows 5 and 1, respectively.

For electronic readout on L and R sides the slopes are:

HV = 1230 V L slope = 1.20% R slope = 0.56%
HV = 1310 V L slope = 1.46% R slope = –0.2%
HV = 1400 V L slope = 1.90% R slope = –1.17%.

The obtained experimental results and a simple calculation (not shown here) indicate that the slopes in *U* are caused by propagation of the signal in the straw, straw itself is a long line. It is not the dumping of the signal, but the change in the pulse shape. For the pulses generated far from the frond-end electronic, the pulse rise time is shorter.

Performance under high count rate

The increase of radiation intensity measured by a proportional counter leads to undesirable changes of its parameters such as pulse height and energy resolution, both of them significantly decrease [2, 3, 6, 8] 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 proportional counters. Only one attempt to explain the resolution variation with count rate has been made. Hendricks' [5] concept considers the pulse amplitude shift as arising from the continuous decrease in gas amplification factor resulting from the presence of slowly moving positive ions in the avalanche multiplication region. According to Mahesh [9], the decrease in the pulse height is caused by 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. Spielberg and Tsarnas [11] suggested that the primary mechanism for the shift is the buildup on the anode wire of loosely bounded 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. Bednarek [2, 3] 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 the mean pulse rise-time, while the resolution variations were found to be due to the changes in the spread in the rise time.

Our results presented in Figs. 5 and 6 are in agreement with the concept of Spielberg and Tsarnas. It is indicated by a long time needed to reach stable peak

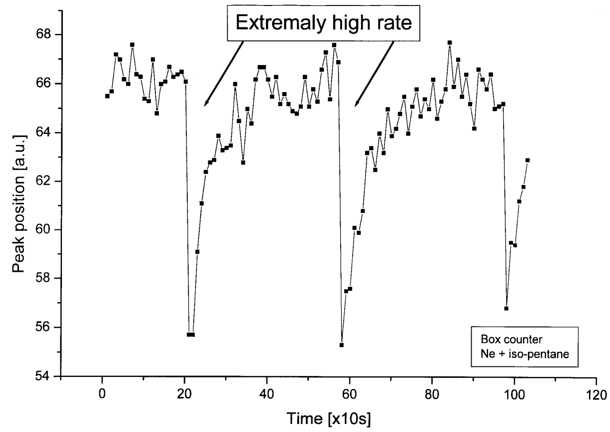

Fig. 5. Time evolution of pulse height of 5.9 keV X-rays after a very rapid decrease in count rate for box counter filled with a Ne + *iso*-pentane mixture.

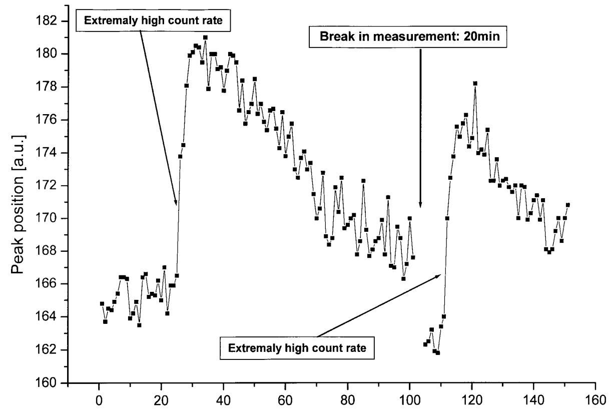

Fig. 6. Time evolution of pulse height of 5.9 keV X-rays after a very rapid decrease in count rate for box counter filled with a Xe + Kr + H_2 mixture.

position after a rapid change in count rate. The drift of positive ions takes a few ms, so the deformation of electric field due to space charge of positive ions cannot explain such a long lasting effect. The loosely bounded layer of polarized molecules not only increases the effective anode radius, but also increases a local, in electron amplification region, concentration of quenching agent. In dissociation process of *iso*-pentane the following individuals (molecules or radicals) can be produced: CH_4, CH_3, C_2H_2, C_2H_4, C_2H_6, C_3H_2,… all of them are good quenching agents [4]. After a rapid decrease in count rate, all those individuals, generated in the vicinity of anode wire, slowly diffuse out. In general, the increase in admixture concentration leads to the decrease of gas gain, i.e. the output pulse height. An opposite effect is observed in a counter filled with Xe + 2%Kr + 12%H_2, namely an increase in peak position is observed (Fig. 6). For this special mixture, the gas gain increases with increasing quenching agent concentrations, see Fig. 8.4 in Ref. [7].

General remarks

Single anode gaseous detectors are still in used. The proper selection of the filling gas composition can fundamentally improve their parameters such as energy and time resolution, performance under high gas gain and high count rate [10]. There are some inconveniences of the usage of such simple detecting elements. The output pulse height depends on both the place of radiation absorption and the type of working gas. Not only the change in count rate, but also the speed of this change affects the counter performance. The knowledge of all the above effects, not only qualitative but also quantitative, gives the possibility to correct them in off-line analysis.

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