AVALANCHE LOCALIZATION AND ITS EFFECTS IN PROPORTIONAL COUNTERS*

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Abstract

Avalanche development around the anode wire in a gas proportional counter is investigated. In the region of proportional gas amplification, the avalanche is found to be well localized on one side of the anode wire where the electrons arrive along the field lines from the point of primary ionization. Induced signals on electrodes surrounding the anode wire are used to measure the azimuthal position of the avalanche on the anode wire. Practical applications of the phenomena such as left-right assignment in drift chambers and measurement of the angular direction of the primary ionization electrons drifting towards the anode wire are discussed.

Introduction

Early studies on the spatial development of the avalanche relative to the anode wire were concentrated on the radial development, whereas in modern application of multivire proportional chambers (MWPC) and multivire drift chambers (MWD), knowledge of the angular extent of the avalanche around the anode wire becomes important not only for a more precise understanding of the gas multiplication process but also for improvement of particle position measurements by adding another information, the direction of electron drift to the anode wire.

At the beginning of MWPC development, observation of induced signals on adjacent wires led to the assumption that the avalanche surrounds the anode wire uniformly at least as high gas gain. However, more recent studies of induced signals have indicated some asymmetry in the avalanche development around the anode wire.

In this paper, we report on an investigation on the question whether the avalanche is confined to one side of the anode wire or spreads around the anode wire by measuring positive ions of the avalanche. Indeed, it was found that the avalanche is well confined to one side of the anode wire in the proportional region of gas amplification. Since the avalanche is localized, induced signals on electrodes surrounding the anode wire contain some information on the azimuthal position of the avalanche. Therefore we studied the formation of induced signals due to the localized avalanche in detail. Applications of the avalanche localization phenomena to MWPC’s and MWD’s are also discussed.

Avalanche Localization

The first method which has been applied to study the localization of the avalanche is to measure positive ion signals at potential wires in a MWDC. The principle of the method is shown in Fig. 1. A collimated source is placed near the potential wire PW. Electrons liberated by the ionization drift toward the anode wire along the field lines and are multiplied in the strong field near the anode wire. If electrons do not spread around the anode wire through these processes, positive ions created in the avalanche are also localized and trace back the same field lines in opposite direction as the electrons drifted. An arrival of positive ions in the strong field around the potential wire PW gives induced signal on PW. If the avalanche surrounds the anode wire, positive ions will also drift to the potential wire PW on the side of the anode wire where no primary ionization is produced.

Field line configuration in a drift chamber.
A: anode wire (30 µm dia., 1.75 kV), PW and PW: potential wires (100 µm dia., - 0.2 kV) and C: cathode planes (ground).

Signals on potential wires PW and PW. Amplifier differentiation time constant: t = 100 µs. Reversed polarity.

Typical signals on PW and PW are shown in Fig. 2.

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Details are given in Ref. 3.

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A large signal of positive ions is seen on FN in addition to the immediate induced signal at the beginning, but a signal of positive ions is not visible on FN. For higher gas gain, however, it becomes visible and the ratio of these positive ion signals \( R = A(FN)/A(FW) \) is used to determine the azimuthal spread of the avalanche around the anode wire.

![Graph](image)

**Figure 3**

Ratio between amplitudes of positive ion signals on FN and FW, \( R = A(FN)/A(FW) \), as a function of the avalanche size for \(^{90}\)Sr \( \beta \)-rays, \(^{55}\)Fe \( x \)-rays, and \(^{241}\)Am \( \gamma \)-rays. Gas: Ar(90%) + CH\(_4\) (10%).

The results of \( R \) for Ar(90%) + CH\(_4\) (10%) are shown in Fig. 3 as a function of the avalanche size \( Q \), which is expressed as an equivalent number of electron charges collected on the anode in \( 1 \mu s \). In the proportional region, \( Q < 3 \times 10^7 \) for \(^{90}\)Sr \( \beta \)-rays and \(^{55}\)Fe \( x \)-rays, it can be concluded that the avalanche is well confined to one side of the anode wire. By increasing the voltage, one leaves the truly proportional region which is characterized by a first Townsend process. Then two effects become noticeable, the gas multiplication starts to be aided by photon propagation and the development of space charge reduces the effective field near the anode wire which saturates the gas amplification. In this semi-proportional region, the localization phenomena depend on such factors as the voltage, the gas mixture and the density of primary ionization. In general, the photon process tends to spread the avalanche around the anode wire since the photon does not follow the field lines. The effect of photon quenching can be seen, for example, in CH\(_4\) where the spread is much suppressed compared to Ar(90%) + CH\(_4\) (10%) at the same gain. For \(^{241}\)Am \( \gamma \)-rays, \( \beta \) is less than 15 up to \( Q = 3 \times 10^7 \), where the effect of photon process is still small because of lower electric field and therefore lower gas gain.

The second method used to obtain information of the avalanche localization was to measure the center of gravity of induced charges on the cathode in a MMPC with a high precision delay line placed orthogonal to the anode wire. If the avalanche is localized to one side of the anode wire as described above, the measurement of the center of gravity of induced charges relative to the anode wire gives us an approximate indication of the radial distance of the avalanche from the anode wire. Figure 4 shows a typical measurement for \(^{55}\)Fe \( x \)-rays in Ar(90%) + CO\(_2\) (20%), where two distinct locations of the position spectra correspond to avalanches which started either from the left or the right side of the anode wire. Observed distances between the two peaks, \( X \), are shown in Fig. 5 for Ar(90%) + CH\(_4\) (10%).

![Graph](image)

**Figure 4**

Position spectra of avalanches measured with the \(^{55}\)Fe \( x \)-ray source 2.5 mm on either side of the anode wire, gas: Ar(80%) + CO\(_2\) (20%), HV: 2.3 kV and spatial resolution: \( \approx 83 \mu m \) FWHM. Distance between peaks: 190 \( \mu m \).

![Graph](image)

**Figure 5**

Measured distance, \( L_{X} \), between left and right avalanches as a function of the avalanche size for \(^{90}\)Sr \( \beta \)-rays, \(^{55}\)Fe \( x \)-rays and \(^{241}\)Am \( \gamma \)-rays.
(a) Gas: Ar(90%) + CH\(_4\) (10%) and (b) "magic gas" Ar(69.3%) + Isobutane (30%) + Freon 1381 (0.7%).
where \( f(x,y) \) is a weighting function depending on a given electrode system, only on a location \((x,y)\) of \( q \). Following Green's reciprocal theorem, \( f_t(x,y) \) is expressed as

\[
Q_t = q \cdot f_t(x,y)
\]

where \( f_t(x,y) \) is a weighting function depending, in a

**Figure 6**

Square chamber 25.4 mm \( \times \) 25.4 mm \( \times \) 90 mm. A: anode wire (25 mm dia.), U and D: cathode strips for induced signals. Collimated x-rays are injected parallel to the anode wire.

**Figure 7**

Induced signals on cathode strips \( U \) and \( D \), when the \( ^{55} \text{Fe} \) x-rays are injected on the side of cathode strip \( U \). Amplifier differentiation time constant: \( \tau = 2.5 \) ms.
where $\mu$ is the mobility of positive ions and $V$ is the applied voltage on the anode. By using $\mu = 1.7 \text{ cm}^2/\text{kv} \cdot \text{ms}$ for CH$_4$ ions in Ar (90%)/CH$_4$ (10%), $Q_\theta(t)$ and $Q_\phi(t)$ are calculated for positive ions moving along the $Y$-axis from the anode toward the cathode $U$, and are shown in Fig. 10.

There is no big difference in amplitude at the beginning and, as positive ions leave the anode, $Q_\phi(t)$ starts to decrease, however, $Q_\theta(t)$ continues to increase. Thus the signal shape observed in the real chamber is well expressed with this method.

Azimuthal Position of the Avalanche

As the induced signals, especially the difference signal $Q_\phi(t) - Q_\theta(t)$, contain information on the azimuthal position of the avalanche, we extend the analysis into two dimensions. Because of the radial field around the anode wire, it is convenient to use the $(r, \theta)$ polar coordinates. Using the relation $f_\theta(r, \theta + \pi) = f_\theta(r, \theta)$, the difference of induced signals is given by

$$Q_\phi(t) - Q_\theta(t) = q \cdot \left[ f_\theta(r, \theta) - f_\theta(r, \theta + \pi) \right]. \tag{4}$$

Since the diameter of the anode wire is small compared to the distance between the anode wire and the cathodes, it can be treated as a line charge with an infinitesimal diameter. Then $f_\theta(r, \theta)$ can be considered to be built up by the weighting function $f_\theta^0(r, \theta)$ for an electrode arrangement without the anode wire and the superposition of a very steep weighting function of the anode wire. As the latter is symmetric around the anode wire, eq. 4 can be rewritten in good approximation as

$$Q_\phi(t) - Q_\theta(t) \approx q \cdot \left[ f_\theta^0(r, \theta) - f_\theta^0(r, \theta + \pi) \right]. \tag{3}$$

$f_\theta^0(r, \theta)$ near the anode wire is approximated as

$$f_\theta^0(r, \theta) \approx \frac{2E}{\mu r} \left| \begin{array}{c} \theta = \pi \\ \frac{\pi}{2} \end{array} \right|, \quad r \cdot \sin \theta \quad (r, \pi/2) \tag{5}$$

More exact treatment of the anode wire of radius $r_1$ would include the effect of the dipole charge on the anode wire. But the angular dependence of the difference signal remains unchanged.
Finally, by the use of eq. 3, we get

\[ Q_1(t) - Q_2(t) = 2q \cdot \left( \frac{3r^4}{\pi^3} \right) \left( \frac{2\mu V}{\Delta x(r_a/r_f) \cdot \tau + \tau^2/2} \right) \cdot \sin^2 \theta \]

This clearly explains the characteristic features of the difference signal. The amplitude of the difference signal is proportional to the steepness of the weighting function without the anode wire and varies as \( \sin \theta \). The time development is in good approximation proportional to \( 1/\sqrt{\tau} \).

![Figure 11](image1.png)

**Figure 11**

Pulse shape of difference signals, \( Q_1(t) - Q_2(t) \). Differentiation time constant \( \tau = 25 \mu s \).

(a) \( \theta = 90^\circ \) and (b) \( \theta = 270^\circ \).

Typical pulse shapes of the difference signal are shown in Fig. 11 for two angular positions of the collimated \( ^{55}\text{Fe} \) x-rays; \( \theta = 90^\circ \) and \( \theta = 270^\circ \). Pulse height spectra of the difference signal normalized with the anode amplitude are shown in Fig. 12, where source positions are (a) \( \theta = 30^\circ \), (b) \( \theta = 60^\circ \) and (c) \( \theta = 90^\circ \), and \( \tau = 5 \mu s \). Angular dependence of the amplitude of the difference signal is shown in Fig. 13, which shows a complete agreement with the expected \( \sin^2 \theta \) variation. The resolution of the angle measurement is \( \pm 5^\circ \) (FWHM) at \( \theta = 30^\circ \) which is limited here by the source collimation. These results show that the azimuthal position of the avalanche around the anode wire can be measured precisely with induced signals on a set of electrodes around the anode wire.

**Conclusion**

Our study showed that, in the proportional region of gas amplification, the avalanche is well localized on one side of the anode wire. By increasing the applied voltage, the avalanche starts to spread around the anode wire to some extent by the photon process. Investigation of induced signals from the localized avalanche shows that the information on the azimuthal angular position of the avalanche can be extracted from the measurement of induced signals on a set of electrodes.

As the avalanche is formed by electrons which drifted toward the anode wire along known DC field lines, the measurement of the azimuthal position of the avalanche determines the particular drift path of electrons from each point of primary ionization. This

![Figure 12](image2.png)

**Figure 12**

Pulse height spectra of the difference signals, \( Q_0(t) \), normalized with the amount of anode charge. Angular positions of \( ^{55}\text{Fe} \) x-ray source are (a) \( \theta = 30^\circ \), (b) \( \theta = 60^\circ \) and (c) \( \theta = 90^\circ \). Gas: \( \text{Ar}(90\%)+\text{CH}_4(10\% \), HV: 1.7 kV, signal gate time: 5 \( \mu s \).

![Figure 13](image3.png)

**Figure 13**

Angular dependence of the amplitude of the difference signal for \( ^{55}\text{Fe} \) x-rays.

is very useful for practical applications. The read-out of induced signals on potential wires or neighboring cathodes in MWDC's make it possible to solve the left-right ambiguity with high precision. It is also useful for the half-gap discrimination in MWDC's for x-ray imaging. As demonstrated in this paper, the precise measurement of the angular position of the avalanche makes it possible to determine the azimuthal angle of the primary ionization point in a single counter. This combined with measurements of the electron drift time and the avalanche position along the anode wire, could locate three dimensional coordinates of the interaction point for, e.g., x-rays and neutrons.

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**Note:** A related study of the avalanche localization phenomena in MWDC is also reported by G. Charpak at \( \#2 \) at this conference.
References