Features of Streamer Discharge in Geiger-Muller Counters

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Abstract: ***The paper considers one of the understudied aspects of the use of low-voltage halogen counters of the Geiger-Muller, associated with the choice of the operating point voltage in the middle of the plateau of the counting characteristics. It is shown that the difficulties can be caused in determining of the beginning of counting characteristics by the appearance of streamer discharge pulses in a zone of limited proportionality to the transition to a stable corona discharge. The use of the Raether criterion to estimate the necessary and sufficient conditions for the appearance of a streamer makes it possible to introduce some clarity into the essence of this phenomenon.***

Keywords: Streamer discharge, Geiger-Muller counter, Electron multiplication

1. Introduction

It is well known [1] from the physics of a gas discharge in nuclear radiation detectors that a region of limited proportionality exists between the region of proportionality gain and the Geiger regime. The boundaries of the region of limited proportionality are strongly dependent on a numbers of reasons, the main ones being the composition and pressure of the gas filling, as well as the type and angle of incidence of the ionizing radiation. It is assumed that the limitation in the growth of the pulse amplitude in a given region is determined mainly by the influence of the electric field of a positive charge slowly leaving the zone near anode. With a relatively large coefficient of gas amplification in the area under consideration (about 10^5) the amplitudes of the pulses from particles with different ionization become approximately equal. However, it should be noted the presence of unusual pulses with a sufficiently large amplitude and short duration. This fact becomes especially noticeable when the anode of the counter is irradiated by alpha particles perpendicular to its axis. With an increase in the voltage at the anode of counter a signal of this kind begins to appear from other sources of irradiation at different angles of flight. Impulses of this kind are called as an “increased pulses”. Waveforms of this these pulses shows that they represent essentially other form of gas discharge which does not correspond to either proportional mode or Geiger mode [2]. It is necessary to point the fact that appearance of abnormally big pulses, approximately by 100 times exceeding signals in the proportional mode was marked in operation in case of a research of electronegative impurity in a gas mixture on operation of the wire chamber of Charpak construction [3]. This position sensitive detector of the charge particles represented a set of the planes from wire electrodes that serve as an anode and a cathode are similar to the design of a cylindrical proportional counter.

According to the conclusions given in work [4], the origin of the “increased pulses” can be related to the nature of the Self-Quenching Streamer (SQS) discharge in the gas volume of the detector with a large content of the photon-quenching additive. From the same positions it is possible to explain the facts of the delay and uncertainly in the time of recording events relative to the moment of entry of ionizing particles.

Features of the SQS-mode of discharge in the Geiger – Muller counter.

In order to better understand the problem under consideration it is useful to note the main parameter of the Geiger counter , namely the voltage of the counting start as V_0, at which at least one electron is produced due to secondary processes at the cathode of the counter. In this case there is a delay between the time of the primary ionization and the data of registration of this event in the form of a pulse in the external circuit. It can be caused by various reasons and have an undefined value. This delay of the pulse is influenced by at least three effects. The first of these is related to localization of primary radiation, which can produce an electron anywhere on the detector. After some time of drift it can initiate an avalanche reproducing process in a zone with high electric field strength near the anode. Maximum drift time has an electron formed near the cathode and minimum drift time belongs to an electron created near the anode. The second type of delay occurs due to different slope of the front pulse depends mainly on the parameters of the external reading circuit. Both of these processes result in a relatively short delay time (near 10^{-7}sec.).

The third type of signal delay is associated with the capture of the primary electron by an electronegative gas molecule. The negative ion passes the maximum distance from the cathode to the anode in a much longer time interval (10^{-4} sec.). This effect becomes noticeable in the presence of gas admixtures with a sufficiently large coefficient of adhesion of electron (e.g., oxygen and halogens).

This should take into account the fact, that different stages of the gas discharge in Geiger-Muller counters are mainly determined by the properties of the filling gas mixture. For example, a transition from a region of limited proportionality to an increase in the voltage may result in a corona discharge if there is no component in the gas mixture absorbing UV photons. If there is a significant fraction of the quenching component, a streamer mode can be formed.

According to the conclusions from paper [5], the occurrence of SQS –mode is determined by two conditions: necessary and sufficient. The necessary condition follows from the formula of Rether [6]:

$MAC= A \cdot N_0 \leq 10^8$ electrons,

where:

MAC- maximum charge of the Townsend avalanche,

A-coefficient of gas amplification,

N_0-number of primary electrons

This formula is empirically derived for the case of the maximum formation of an avalanche in the process of Townsend multiplication of electrons in gases.

A sufficient condition is determined through experimental data in accordance with the law of similarity, existing in the gas discharge physics, which suggests the presence of a pulse precursor in the transition from one mode of the discharge to another.

Thus, taking the above mentioned circumstances, one can imagine the following sequence of events in case of delay of the pulse and the associated uncertainty in the position of working point on the plateau in the Geiger-Muller counter. After passing the primary ionizing particle or gamma quantum in the discharge gap a pulse proportional mode with small amplitude of the order of several millivolts and duration of no more than a few tens of nanosecond take place. Then a pulse-precursor with an uncertain delay time appears with the amplitude one or two orders higher them pulse amplitude in a proportional mode and with a time of the order of several hundred nanoseconds. This delay in the appearance of the pulse-precursor is in the range from several hundred nanoseconds to several hundred microseconds.

According to the above, it can be assumed in this case there is a transition to the streamer mode, when this sufficient condition is presented as a probabilities process of formation of secondary or “seed” electrons in the gas volume of the counter. It can be occurs due to inelastic collisions II-kind in accordance with the conclusions of Meek [7]. Since the life time of excited and metastable states of the atoms in the gas is sufficiently long for a period of time, up to several seconds, the reason for the delay in the appearance of the precursor pulse becomes clear.

The ionization wave resulting from the secondary process of electron multiplication in the detector gas volume reaches the cathode surface and releases the negative charge induced from the previous avalanche, closing the space between the two oppositely charged regions by means of a thin luminous cord or streamer. Since this process is not connected with positive feedback, typical for the operation of the Geiger-Muller counter, due to hard ultraviolet radiation and ion bombardment of the cathode surface, there is reason to believe that in the zone of limited proportionality the origin of the “increased” pulses and the uncertainty in the time of their appearance also, they are connected with the solution of the Raether criterion. In this case the correspondence to the necessary condition is ensured by a large gas gain ($A>10^6$), and a sufficient condition can be represented as the probability of finding of creating “seed” electrons by the nature of such phenomena in a gas as metastable or non-metastable Penning effects and other reactions in inelastic collisions of the II-kind [8.9]. In according to the experimental data the uncertainty in the counting start time in low-voltage halogen counters due to appearance of “increased” caused by streamers can range from 5 to 50 microseconds. This fact, apparently, is decisive when choosing the position of the operating point in the middle of the plateau of the counting characteristic in order to ensure a high efficiency of registering the flows of charged particles and to reduce the number of false positives.

2. Conclusion

The appearance of “increased” pulses in the region of limited proportionality in low-voltage halogen counters can be explained if the implementation of the Rheter rule is considered as a necessary condition for the development of a prebreakdown phenomenon in the view of a streamer. A sufficient condition for the appearance of a streamer may to consider as a probabilistic process of the existence or creation in a gas volume of a counter of a free or “seed” electron. Both these conditions are most often fulfilled when perpendicular irradiation occur to the anode wire of counter when a columnar recombination takes place and the emerging streamer “remembers” the direction of irradiation in the absence of photon and ion bombardment of the cathode. When the voltage reaches a value that exceeds the counting start voltage, $V_{0,}$ a corona discharge takes place over the entire length of the anode wire due to the photon and ion feedback, so that all pulses acquire the same values.

References

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