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ТЕХНИКА ЯДЕРНОГО ЭКСПЕРИМЕНТА

THE SIMULATION RESULTS OF SIGNAL FLUCTUATION FOR MICROMEGAS-LIKE GASEOUS DETECTOR

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In the present paper, the mean signal value and its fluctuations were investigated for the well known Micro-Mesh Gaseous Structure (Micromegas) filled with argon-based gas mixtures. The number of primary electrons and ions in the conversion gap were calculated using the FLUKA code for incoming electrons. The signal resolution is a function of the energy loss or the number of produced primary electrons and its fluctuation in the detector volume. The signal generations were made with a Single Particle Monte Carlo simulation technique in the amplification gap region. We assumed a homogeneous electric field inside both the conversion and the amplification gap because the electric field shows only a small change near the openings of the microgrid. Based on the simulation, we discuss the signal fluctuations that affect the work performance of the Micromegas for different argon-based gas mixtures.

1. INTRODUCTION

The Micro-Mesh Gaseous Structure (Micromegas) is a gaseous parallel plate detector that consists of a conversion gap, where primary particles are produced by the ionizing particle, and a thin amplification gap, where the avalanche process takes place. Different applications of the Micromegas have been developed, ranging from particle physics experiments to medical imaging [1]. A detailed description of the Micromegas is given in [2].

An ideal detector would measure the primary signal while introducing minimal additional fluctuations. If the fluctuations introduced by the avalanche gain in the gas volume are too high, the avalanche gain may not give an overall advantage. In this work, a Monte Carlo simulation code has been developed to calculate the signal values and signal fluctuations for different operating voltages and different Ar-CH_4 gas mixing ratios for the Micromegas detector. The traditional structure of the Micromegas was addressed in the simulation. The study was conducted with a structure consisting of a 15×15 cm^2 drift region with thickness 3 mm and an amplification region with thickness 100 μm [3].

2. SIGNAL GENERATION AND FLUCTUATION

A charged particle passing through a gas volume loses its energy by ionizing the gas atoms and producing primary electron-ion pairs along its trajectory. Once inside the strong electric field in the gas volume, the primary electron can obtain sufficient energy to produce electron-ion pairs. After such re-ionization, the number of the electrons multiplies and the avalanche starts. The avalanche continues to grow until all of the electrons are collected on the electrode [4]. If n_0 is the number of primary electrons in a homogenous electric field, the number of electrons at a distance dx under the avalanche conditions is given by:

$$n = n_0 e^{\alpha dx}. \quad (1)$$

Therefore, the gas multiplication factor or the gas gain is given by:

$$M = \frac{n}{n_0} = e^{\alpha dx}, \quad (2)$$

where α is the first Townsend coefficient that depends on the electric field strength, the temperature and the gas mixture ratio [5]. Once the electric field E and the pressure P are known, the following approximate formula can be used to calculate the first Townsend coefficient α:

$$\alpha/P = A\exp(-BP/E), \quad (3)$$

where A and B are constants that depend on the gas mixtures [5]. The fundamental limit of the energy resolution of gaseous detectors is determined by the combined effects of two factors: the statistical fluctuation in the number of electrons released in the primary ionization and the avalanche fluctuation in the gas amplification. The limit is given by the following relation [6]:

$$\left(\frac{\sigma_s}{S}\right)^2 = \frac{\sigma_{N_i}}{N_i} + \frac{1}{N_i}\left(\frac{\sigma_M}{M}\right)^2, \quad (4)$$

where S is the average number of charge carriers collected or the mean value of the signal; σ_s is the standard deviation of S; N_i is the average number of primary electrons; σ_{N_i} is the standard deviation of N_i; M is the mean avalanche gain; σ_M is the standard deviation of M.

3. SIMULATION AND RESULTS

The number N_i of electron-ion pairs formed by a charged particle passing through the gas volume is proportional to the energy loss of the incident charged particle:

$$N_i = E/W, \quad (5)$$

where W is the energy required to produce the electron-ion pair and E is the energy loss of the electrons passing through the gas volume. In this study, the ionization energy losses have been calculated using the simulation code FLUKA for incoming electron energy of 1 GeV in different methane concentrations [7]. The energy losses in the conversion gap as a function of the methane concentration are shown in Fig. 1.

The number of primary particles was computed by Eq. (5). The signal was simulated by tracking a large number of individual primary electrons produced in the conversion gap and by following the generated electrons through the amplification gap according to the signal generation mechanism described in section 2. For each electron, the production of ionization and excitation in the amplification gap is a random process and the electron behavior contributes to the overall variation in the avalanche gain. Thus, the avalanche gain has been simulated for each electron on an interaction-by-interaction basis, using a set of cross sections for electron impact ionization and excitation computed with the Magboltz program [8]. Figure 2 shows the simulated signal values (the collected number of electrons) for different operating voltages and different Ar-CH_4 concentrations. The signal gives a maximum peak at the certain voltage and this maximum signal values decrease with increasing methane concentration because the impact ionization probability for the electrons in high methane concentrations is relatively low.

The signal fluctuations were measured from the standard deviation of the signal distribution. Figure 3 is a plot of the relative fluctuations in the signal, σ_s/S, calculated for different operating voltages and different Ar-CH_4 concentrations. The behavior of the relative fluctuations is almost the same among the different concentrations and the differences are caused by the voltage variation. Figure 4 shows that the signal relative fluctuations at the maximum signal values for the different Ar-CH_4 gas mixture ratios. The relative fluctuation quickly increased up to 300 V and remained roughly constant afterwards. This behavior confirms that the early stage of development of the avalanche dominates the final value of the fluctuation.

The Micromegas-like detectors with small gap are known to have better energy resolution. In this paper has been seen that the influence of the gas mixture on the signal fluctuation is less than the operating voltage.

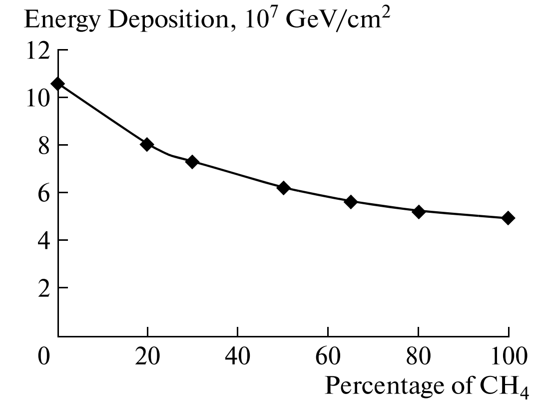

Fig. 1. The energy deposition as a function of CH_4 concentration.

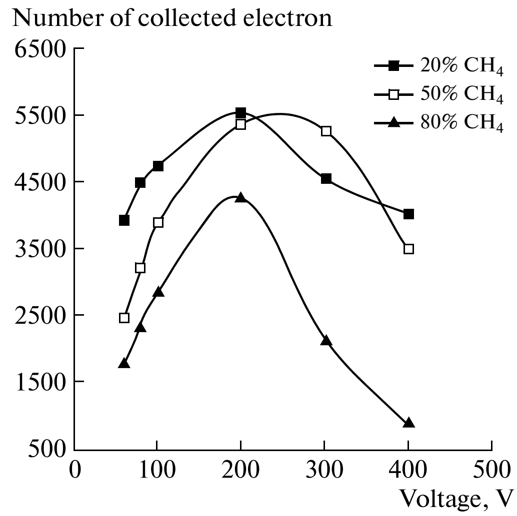

Fig. 2. Signal height versus the operating voltages for different Ar-CH_4 concentrations.

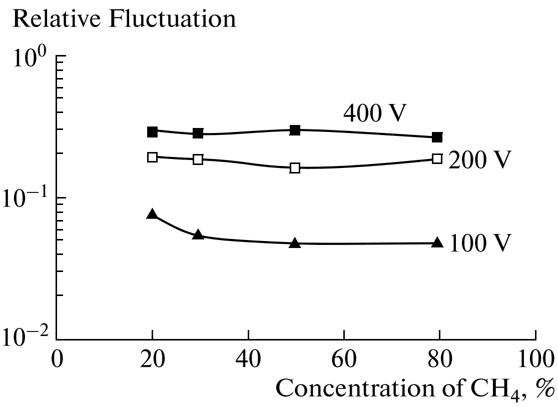

Fig. 3. Relative fluctuation versus concentration of CH_4 at the different voltages.

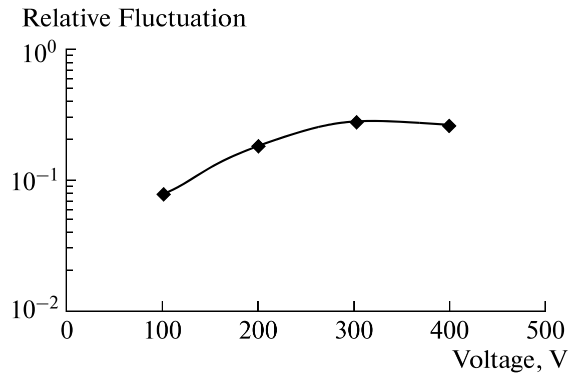

Fig. 4. Relative fluctuation as a function of operating voltage.

We can conclude that the higher CH_4 proportion in the gas mixture will decrease the signal value. Based on the simulation results, the relative fluctuation remains unchanged after 300 V. This result is important to determine the optimum operating voltage at the gas detector. Our calculation shows that the typical Micromegas design has a lower signal fluctuation than the wire chambers that were mentioned earlier in our simulation work [9] and J. Miyamoto's paper [6].

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