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A Monte Carlo Simulation of Multi-gap Resistive Plate Chamber and Comparison with Experimental Results*

RUAN LI-Juan SHAO Ming1) CHEN Hong-Fang LI Cheng WANG Xiao-Lian
WU Jian XU ZI-Zong HUANG Sheng-Li
(Department of Modern Physics, University of Science and Technology of China, Hefei 230027, China)

Abstract A model simulating the main aspects of avalanche growth and signal development in Resistive Plate Chambers (RPCs) is presented. The model has been used to compute the charge distribution and time distribution of Multi-gap RPCs. The comparison between model simulation and experimental results is also discussed.

Key words Monte Carlo simulation, MRPC, charge spectrum, time distribution

1 Introduction

Resistive Plate Chambers (RPCs) were developed in 1980s[1], and were originally operated in streamer mode. This operation mode allows us to get high detection efficiency (> 95 %)and time resolution (~ 1 ns), with low fluxes of incident particles. At higher fluxes (> 200 Hz/cm^2), RPCs begin to lose their efficiency. A way to overcome this problem is to create RPCs in an avalanche mode[2].

The Multi-gap Resistive Plate Chamber(MRPC) was developed 6 years ago[3]. It consists of a stack of resistive plates, spaced one from the other with equal sized spacers creating a series of gas gaps. Electrodes are connected to the outer surfaces of the stack of resistive plates while all the internal plates are left electrically floating. Initially the voltage on these internal plates is given by electrostatics, and they are kept at the proper voltage due to the flow of electrons and ions created in the avalanches.

MRPC, as a new kind of detector for the time of feIight system, operated in an avalanche mode with a non-flammable gas mixture of 90 % F134A, 5 % isobutane, 5 % SF$_6$, can fulfill all these requirements: high efficiency (> 95 %), excellent intrinsic time resolution (< 100 ps)[14—18], high rate capability (~ 500 Hz/cm^2), high modularity and simplicity for construction, good uniformity of response, high granularity/low occupancy and large acceptance.

In the first paper[7], the simulation was used to compare with the available experimental data, and explained the results of the detection efficiency and signal amplitude. However when it concerned charge distribution, the agreement between the simulation and the experimental data was not very well.

2 Model

A detailed description of the model used in the simulation was reported in some papers[4—7], here just the main items will be repeated. The program starts from considering an ionizing particle which crosses the gas gaps and generates a certain number of clusters of ion-electron pairs. The electrons contained in the clusters drift towards the anode and, if the electric field is sufficiently high, give rise to the avalanche processes.

The primary cluster numbers and the avalanche growth are assumed to follow, respectively, simple Poisson statistics and the usual exponential law . Avalanche gain

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* Supported by National Natural Science Foundation of China(10155002)
1) E-mail: swing@ustc.edu.cn

fluctuations have been taken into account using a Polya distribution[8]. After the simulation of the drifting avalanches, the program computes, by means of Ramo theorem[9], the charge q_{ind} induced on the external pick-up electrodes (strips or pads) by the avalanche motion. Under certain approximations, this is given by the formula:

$$q_{ind} = \frac{q_e}{\eta d}\Delta V_W \sum_{j=1}^{n_{cl}} n_j M[e^{\eta(d-x_j)} - 1],$$

where q_e is the electron charge, η 1st effective Townsend coefficient $\eta = \alpha - \beta$ (α and β are Townsend coefficient and electron attachment coefficient, respectively), d the gap width, x_j the jth cluster initial distances from the anode, n_j the number of initial electrons in the considered jth cluster, M the avalanche gain fluctuation factor, $\Delta V_W / d = E_W$ is the normalized weighting field. In addition to q_{ind}, the current $i_{ind}(t)$ induced on the same electrodes by the drifting charge $q_{drift}(t)$ may be computed as

$$i_{ind}(t) = \Delta V_W \frac{v_d}{d} q_{drift}(t) M e^{\eta v_d t},$$

where v_d is the electron drift velocity (so the distance over which the avalanche developed at time t is $v_d \cdot t$, t initially equals to 0), and $q_{drift}(t)$ is the drifting charge induced on the pick-up electrodes at time t. The computation of i_{ind} allow us to reproduce the whole information coming out from MRPC, such as time distribution.

3 Charge spectrum simulation

The almost Gaussian charge distribution obtained with the MRPC is a key ingredient to its performance. If the avalanches grew following Townsend's formula the charge distribution would be exponential in shape. Thus the space charge effects must be considered in the simulation.

The input parameters for the simulation program are α, β, the average distance between clusters λ and the probability distribution of the number of electrons per cluster. These pieces of information can be obtained, for a given gas mixture and given conditions (pressure and temperature) and electric field, by the programs HEED[10] and MAGBOLTZ[11,12]. In addition, a maximum number of electrons in an avalanche (cutoff value) is specified.

In a given gap, we generate a number of clusters with distances exponentially distributed with average distance λ. For each cluster, we then generate a certain number of electrons, according to the distribution obtained by the program HEED. Each electron from the primary cluster will give rise to a number of electrons, generated according to an exponential probability law.

For each cluster, the avalanche growth is stopped when the total charge reaches a certain cutoff value, as originally suggested in Ref. [13] to take into account space charge effects in the avalanche development. This cutoff value has been set to be 1.6×10^7 electrons.

In Fig. 1 we show the results of simulations, Fig. 1 (a) is the simulated curve of the 1st effective Townsend coefficient η versus the electric field, which is generated by MAGBOLTZ. The curve shows that the correlation between η and the electric field is almost linear when MRPC is operated at high electric field for the gas mixture. Fig. 1(b) the charge spectrum for a 6 gap chamber and (c), (d) for a 10 gap chamber compared to experimental data[14,15], and the number under each plot shows the electric field E in the gas for MRPC. In both cases the gap size is 220μm. The gas mixture was 90 % F134A, 5 % isobutane and 5 % SF_6 in normal conditions of pressure and temperature. The value of λ used was 0.1mm, derived from HEED program.

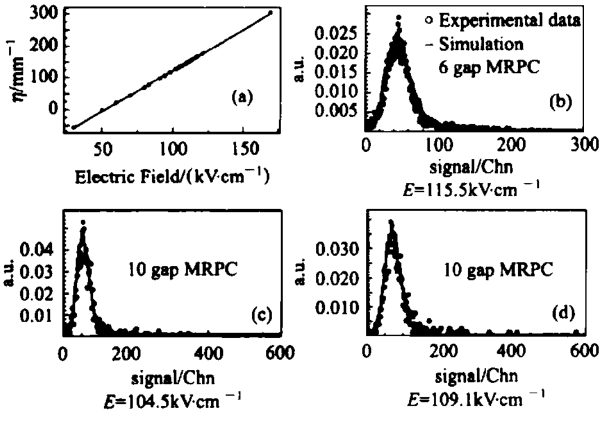

Fig. 1 Simulated 1st effective Townsend coefficient curve and normalized charge distribution for a 6 and 10 gap MRPC.

The charge distribution has an almost Gaussian form, especially for the 10 gap MRPC. The left side of the distribution (very few events at values near zero) is due to the fact that the MRPC operates at high gain $\eta d \sim 30$. This means that avalanches starting in the middle of the gap width, which only avalanche over half the distance, give a detectable signal. The charge distribution is the superposition of several probability distributions which, according to the central limit theorem, will tend to a Gaussian form. The right side of the charge distribution (the fact that the tails are not very long) indicates that indeed the space charge effects stop the development of the avalanche.

4 Time distribution simulation

We then proceed to simulate the time distribution of these chambers. The electron drift velocity can be obtained from HEED. When the total induced charge signal is over threshold, the time is recorded. In this paper, the threshold is 13 FC for the 6 gap MRPC and 26 FC for the 10 gap MRPC. Fig.2 is the simulated results for a 6 gap chamber. Fig.2(a) is the simulated curve of the electron drift velocity versus the electric field, which is generated by MAGBOLTZ. Fig.2 (b) is the time distribution of a 6 gap MRPC. The intrinsic time resolution is only 19 ps or so. If we consider other contributions, such as front-end electronics 30 ps, TDC resolution 25 ps, fanout start signal 10 ps, beam size(1cm) 15ps, we can get the MRPC resolution is $\sqrt{(20^2+30^2+25^2+10^2+15^2)} = 47\text{ps}$. This value is similar to the experimental result[14,15]. For a 10 gap MRPC, the intrinsic time resolution is about 15 ps.

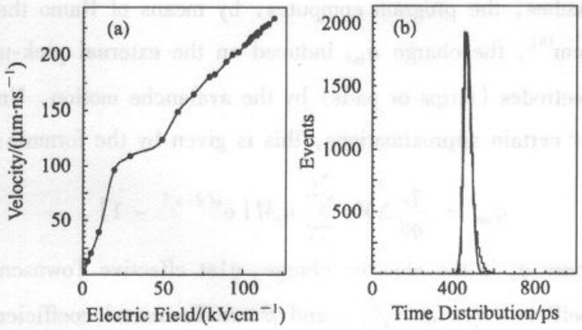

Fig.2 Simulated results of a 6 gap MRPC.

From the simulation, we can get the bottom line of MRPC time resolution ~20ps. And we need to keep control of all these contributions to ensure best time resolution.

5 Conclusions

A model describing the basic processes taking place in RPCs in avalanche mode has been studied. The agreement between the simulation and the real data is very good where it concerns charge spectrum and time distribution.

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多气隙电阻板室蒙特卡洛模拟与实验的比较

阮丽娟　邵明[1]　陈宏芳　李澄　汪晓莲　伍健　许咨宗　黄胜利
（中国科学技术大学近代物理系　合肥　230027）

摘要　介绍了一个在电阻板室雪崩增长与信号发展的模型，模拟了多气隙电阻板室的电荷谱和时间分布谱，并与试验做了比较．

关键词　蒙特卡洛模拟　多气隙电阻板室　电荷谱　时间谱

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1）E-mail：swing@ustc.edu.cn