CMS Conference Report

20th January 2000

Medium-term stability of a Parallel Plate Avalanche Chamber with a bakelite electrode operated in high radiation flux

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Abstract

A gas detector made of three parallel electrodes (bakelite electrode and two metallic mesh electrodes) and working in proportional mode allows monitoring of the gas gain under various intensities of X-rays over long period of time. The detector performance, when irradiated with an intense radiation flux, and possible effects of variation of the bakelite electrode conductivity on a medium-term stability of operation are reported. The results shown in this paper were obtained for detector filled with Argon/Isobutane gas mixture.

Presented at *V-th International Workshop on Resistive Plate Chambers and Related Detectors*,
Bari, Italy, October 28-29, 1999

Submitted to *Nucl. Instr. and Methods*

1 Introduction

Many experiments will be equipped with Resistive Plate Chambers (RPC) [1] – gas detectors allowing large detection system construction at moderate cost. Large scale experiments at LHC require good stability of operation of the detectors (i.e. efficiency, time resolution) over many years of operation under high radiation flux [2]. It is well understood that the dynamic voltage drop across the gas gap due to the avalanche current becomes significant even at moderate avalanche rates when a RPC is made out of high resistivity bakelite [3, 4]. A good stability of electrical characteristics of the electrodes' material is one of critical parameters for proper operation at high rates. Several bakelite laminates, provided by different manufacturers, exhibit strong dependence of the specific resistivity on the ambient temperature and the water content. The effect of the resistivity growth with time was observed when a constant polarizing voltage was applied for a long time period [5]. It was demonstrated that low resistivity bakelite plates ($10^8 - 10^{10} \Omega\text{cm}$) are suitable for stable and fully efficient operation of RPCs at high counting rates [6, 7], however the data concern the short and medium-term stability of the detector only. The effect of the reduced efficiency at high radiation flux of high resistivity RPCs was measured [8, 9]. Quantitative investigation of the gas gain as a function of avalanche rate during long-time exposures is crucial for good understanding of the detector operation since it provides a measurement of the electrodes' resistivity fluctuation in the working conditions of the detector. Measurements performed by P. Fonte et al. [10] cover wide range of rates (up to 10^7 Hz/cm^2) and electrodes' material resistivities ($4 \cdot 10^7 - 4 \cdot 10^{11} \Omega\text{cm}$), address short-term effects only.

2 Experimental setup

In order to study the impact of the avalanche rate on the gas gain we have constructed a proportional parallel plate chamber (PPAC) with the electron collecting electrode made out of resistive material (Fig. 1). The chamber has only one resistive electrode made of $10 \text{ cm} \times 10 \text{ cm} \times 2 \text{ mm}$ bakelite plate. The mechanical construction allows changing the anode plate, thus measurements with different resistive materials are possible. For measurements reported, the bakelite plate¹⁾ having volume resistivity of $3 \cdot 10^{10} \Omega\text{cm}$ has been chosen. High voltage is applied to the bakelite surface by means of conductive electrode – 80 mm in diameter, made of $50 \mu\text{m}$ aluminium foil that was integrated to the bakelite surface during the production process. The cathode plane made of stainless steel mesh, was placed at 2 mm distance from the bakelite surface. This electrode was used for the pulse read-out. Second mesh plane was positioned at 6 mm distance from the readout plane and was used to form a drift collection electric field. Thin mylar window was closing the gas volume. The detecting structure allows to amplify the primary electron charges due to X-ray conversion in the drift region. The monitoring of the gas gain can be easily done due to characteristic peak-shaped charge distribution obtained under irradiation with mono-energetic X-rays. The peak-sensing ADC (LeCroy 2259B, 11 bits, 1 mV resolution) was used for the pulse-height measurement. Thus one can investigate the standard RPC operation using pulse-height analysis. The detector was operated in the gas flow mode. A single wire proportional counter, installed in the same gas line, served as the gas gain stability monitor (Fig. 2), since the gas gain depends on ambient temperature and pressure and on the gas composition

¹⁾ The bakelite was specially developed according to our specification by IZO-ERG S.A., Gliwice, Poland.

Figure 1: Schematic view of the PPAC with a bakelite electrode.

Figure 2: Experimental setup for monitoring of the gas gain in the PPAC irradiated with X-rays.

fluctuations. Pulse-height of low intensity 5.9 keV X-rays from ^{55}Fe source was used as a reference. Additional proportional wire counter, with thin beryllium window and with gas volume sealed, served to monitor the stability of the radiation flux from the X-ray generator with the copper target. The size of the beam spot in the PPAC drift plane was about 10 mm. In this work we report on the measurements performed with 70 % Ar + 30 % Isobutane gas mixture. The PPAC was operated at amplification voltage of 4900 V which provides the gas gain of about $4 \cdot 10^3$ (the avalanche consists of about 10^6 electrons) at lowest rates. For each intensity of X-rays charge distributions and counting rates of three detectors were measured every hour. Intensity of the incident X-ray flux was controlled by the copper absorbers placed in the bottom colimator shown in Fig. 2.

3 Results

An example of the pulse-height distribution from PPAC for low intensity of X-ray flux is shown in Fig. 3. The main peak corresponding to the copper fluorescence line can be seen. The pulse-height spectra for high X-ray flux are also displayed in the figure. The effect of the amplitude decrease with increased rate, as well as further reduction of the signal during long-time operation can be observed.

The results of the measurements with different fluxes of X-rays, numbered from I to VII, are plotted in Fig. 4 in chronological order. The average intensity corresponding to each series of data taking is marked at the top of the figure. The data presented were not corrected for changes of ambient pressure and temperature. Pulse height fluctuations observed at the lowest rates correspond to the variation of pulse amplitude in the monitor counter and are partially due to low statistics of the single data set. At rates above 100 Hz/cm^2 clear effect of the avalanche current becomes visible - immediate reduction of the pulse-height followed by further slow decrease of the gas amplification during the exposure (curves II and VI). Comparison of measurements II and III indicates the detector recovers after heavy irradiation applied during extended time period. Between the two measurements the detector was active and only the radiation flux was stopped. However, a discrepancy by a factor of 1.5 was observed between measurements I and IV performed at very similar counting rates. It may indicate the effect of avalanche-induced

Figure 3: Charge distributions for two intensities of 8 keV X-rays (110 Hz/cm^2 and 1030 Hz/cm^2 , low and high flux, respectively); the effect of the pulse height decrease after 115 hours at high flux is displayed.

Figure 4: Measurements of the gas amplification stability for several intensities of X-ray beam. Average intensities are shown at the top of the figure.

changes of the electrical properties of the bakelite electrode, which influences the rate capability of the detector.

In Fig. 5 the evolution of normalized pulse-height is shown as a function of the irradiation time for selected radiation rates. At highest rates the pulse height is reduced by a factor of 2 after 100 hours of exposure. During the time separating measurements VI and VII the irradiation was stopped and the high voltage in the PPAC was switched off for about 50 hours. This time does not seem to be sufficient to recover completely the initial level of the bakelite conductivity as the initial value of pulse height of the measurement VII corresponds to the last value measured during the run VI.

The pulse height measured at the beginning of an irradiation as a function of the avalanche rate per unit area is shown in Fig. 6. The effect of the dynamic reduction of the gas amplification due to avalanche rate can be seen. The difference between initial values of pulse height measured during exposures II and VI can be attributed to an increase of the effective bakelite resistivity during the operation of the PPAC under high counting rate.

Figure 5: Dependence of the relative gain on time for several counting rates.

Figure 6: Initial values of pulse-height from the bakelite PPAC as a function of rate of avalanches per unit area; the line is drawn to guide an eye.

4 Discussions and conclusions

The systematic decrease of the gas gain in the PPAC with time of irradiation was observed for high rate of avalanches. The mechanism responsible for this reduction is not well understood. It could be attributed to the effects like: polarization of the bakelite plates in the presence of the electric field, local charging up of the bakelite surface, deposit of a thin layer of polymers on the anode plane. Further systematic studies are needed with various resistive materials and with other gas mixtures.

Acknowledgements

The authors wish to thank the State Committee for Scientific Research of Poland for financial support (grant 2 P03B 054 16). Our special thanks are addressed to H. Czyrkowski, R. Dąbrowski and Z. Sałapa for technical support.

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