



Test of a four-gap resistive plate chamber with cosmic muons and high-rate gamma rays

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ABSTRACT

We report a new development of a phenolic four-gap resistive plate chamber (RPC) for use as a high-rate particle trigger in high-energy physics experiments. In the current study, a prototype RPC equipped with four 1-mm-thick gaps made from high-pressure-laminated (HPL) resistive plates has been designed and built. The current detector R&D aims to reduce the probability of radiation-induced degradation of the core detector components of the RPCs, the gas gaps, as well as to improve the detection rate capability. The detector characteristics of the four-gap RPC were obtained through a series of tests with cosmic muons and gamma rays and were compared with those of the typical 2-mm thick double-gap RPCs currently used in the CMS experiment at the LHC and in the PHENIX experiment at the RHIC.

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1. Introduction

Resistive plate chambers (RPCs) have been widely used as high-energy particle triggers in many large scale experiments in particle and nuclear physics [1–5] since they were introduced in the early 1980's [6]. The typical RPCs adapted for the trigger detectors in those large scale experiments were double-gap RPCs with a 2-mm gap thickness. The thin panel-shaped double-gap RPCs were capable of taking charge of the multi-layer particle triggers in the large muon detection parts of the experimental facilities.

Furthermore, the fairly accurate time response of the double-gap RPCs, with a time resolution of about 1 ns, enabled us to achieve reliable performance of the particle triggers for a maximum bunch-crossing rate of 40 MHz for the CMS experiment at the LHC. The rate capability of detection of the double-gap RPCs required to perform the LHC collision runs with a designed maximum luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ was as much as 1 kHz cm^{-2} , which was proven by intensive detector R&D using gamma-ray sources [7].

In many hadron-collision experiments, the typical resistive plates for the trigger RPCs were HPL plates made of phenol resin and craft papers. It is well understood that the rate capability of the RPCs is inversely proportional both to the bulk resistivity of

the HPL and to the size of the detector pulses. The empirically obtained optimal value for the bulk resistivity of the HPL required to perform reliable detector operations as well as to achieve the desired rate capability exceeding 1 kHz cm^{-2} is a few times $10^{10} \Omega \text{ cm}$ [8].

During the last decade, a gas mixture composed of tetrafluoroethane ($\text{C}_2\text{H}_2\text{F}_4$, R134a Freon) and isobutene ($i\text{-C}_4\text{H}_{10}$) has been typically used for the operation of the HPL-based trigger RPCs. A relatively large gain of the ionization avalanche and stability with a wide operational plateau in the high voltage (HV) region have been the great advantages of the use of the Freon-based gas mixtures.

On the other hand, it is a drawback that the large detector pulses draw large detector currents from the HV power supplies. The current drawn in a unit area of the typical 2-mm-thick double-gap RPC exceeds $300 \mu\text{A m}^{-2}$ when the signal rate per unit area reaches 1 kHz cm^{-2} [9]. Considering that the typical size of the panel-type trigger RPCs ranges from 1 to 5 m^{-2} , the detector current would exceed a practical limit ($\sim 0.5 \text{ mA}$ per high-voltage channel) even when the signal rate is below 1 kHz cm^{-2} .

Furthermore, severe degradation of detector performance was found in a systematic aging study of the prototype double-gap RPCs with a 200-mCi ^{137}Cs gamma-ray source when the signal rate induced by the gamma rays exceeded 3 kHz cm^{-2} [9]. As reported in Ref. [10], the corrosive HF^- radicals produced in the Freon-based gas mixture during the process of ionization avalanche deeply penetrate into the RPC-electrode material (HPL),

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and microscopically damaged the inner surfaces of the electrodes. As a result, it is obvious that a reduction of the size of the avalanche charges drawn in the trigger RPCs would lessen the possibility of damage as well as enhancing the detector rate capability when they are operated in the experimental conditions of a high-rate beam background. Therefore, we performed a detector R&D on 1-mm-thick four-gap RPCs for which the mean fast charge of the detector pulses was expected to be approximately one third of that drawn in the typical 2-mm-thick double-gap RPC.

In this paper, the design of the four-gap RPC and the details of the prototype detector are described in Section 2. The electronics were equipped with a time-to-digital converter (TDC) and an analog-digital-converter (ADC) to test the prototype detector, as is briefly explained in Section 3. In Section 4, we summarize the detector characteristics tested using cosmic muons and high-rate gamma rays emitted from a 200-mCi ^{137}Cs gamma-ray source. Finally, we conclude the discussions of the performance of the 1-mm-thick four-gap RPC and make a comparison with the typical double-gap RPC in Section 5.

2. Description of the four-gap RPC

2.1. Structure

A prototype RPC with the four-gap structure was constructed for the current detector R&D. A phenolic four-gap RPC consists of two 1-mm-thick double-gap gas volumes. Each double-gap gas volume was supported by three 2-mm thick phenolic HPLs and two layers of 1-mm thick coin spacers, as illustrated in Fig. 1.

Fig. 2 shows the arrangements of coin spacers that support the gap thickness and 4-mm-thick acrylic bars placed along the peripheries to seal the mixed gas. The coin spacers and the acrylic spacer bars were glued to the HPL plates using epoxy. The criterion of accepted accuracy for the 1-mm thick coin spacers was $\pm 10 \mu\text{m}$. The two-dimensional spacing of the coin spacers was $10 \times 10 \text{ cm}^2$. The HPL plate placed in the middle of each gas volume to be automatically biased at half of the applied high voltage (HV) was 44 mm smaller in both directions to allow the gas circulation and the insertion of the acrylic spacer bars.

For each gas volume, an electrode was created by painting graphite on both outer surfaces of the outer HPL plates using a silkscreen method. For the panel-type RPCs, the optimal value for

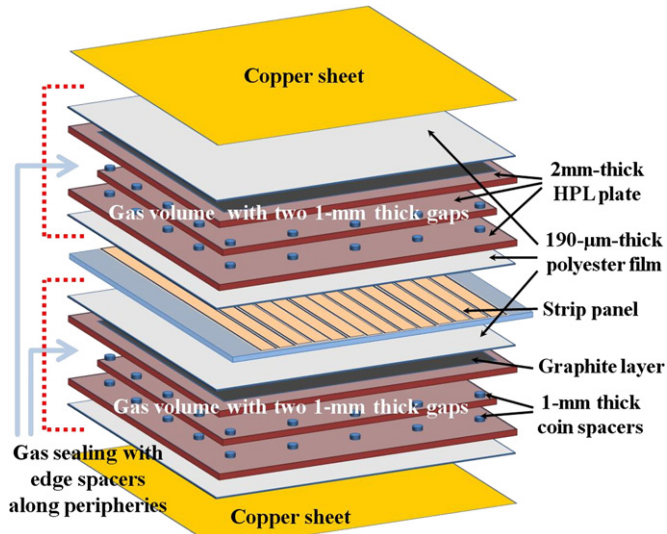


Fig. 1. Schematic diagram of a 1-mm-thick phenolic four-gap RPC.

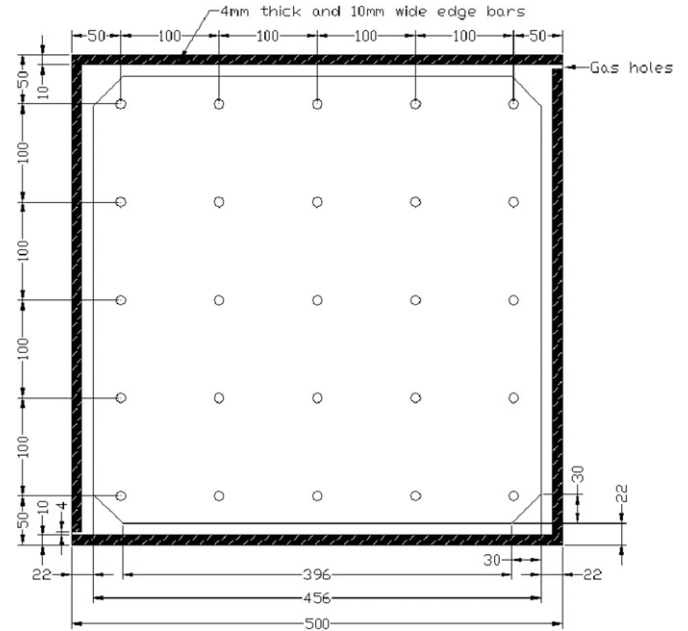


Fig. 2. Positions of coin spacers and 4-mm-thick acrylic spacer bars for supporting the gap thickness and for sealing the mixed gas.

the surface resistivity both to guarantee transparency of the induction in the copper strips and to minimize the voltage drop cross the graphite surface was $\sim 100 \text{ k}\Omega/\square$. The active area of the prototype RPC defined by the graphite-painted region was $45 \times 45 \text{ cm}^2$.

The copper strips with 27-mm pitches were attached on a $190 \mu\text{m}$ -thick polyethylene film, and were placed between the two gas volumes for the signal readouts. Eight strips lying in the middle of the prototype RPC were connected to electronics for the test with cosmic muons. In order to prevent discharges of the induced image charges, the rest of the strips were terminated to the ground with a proper impedance matching.

2.2. Bulk resistivity of the HPL

The mean bulk resistivity of the phenolic HPL samples measured and normalized at a standard temperature of 20°C , ρ_{20} , was $(0.95 \pm 0.18) \times 10^{10} \Omega \text{ cm}$ [8]:

$$\rho_{20} = \rho(T)e^{\alpha(T-20)} \quad (1)$$

where $\rho(T)$ is the bulk resistivity measured at the given temperature. Here, the temperature coefficient, α , for the typical phenolic HPL can be empirically determined by quantitative measurements [8]. For the HPL used in the current R&D, the value was determined as 0.12°C^{-1} , which is similar to the previous value [8].

3. Experimental setup

Fig. 3 shows the electronics setup for the test of the prototype RPC with cosmic muons and gamma rays irradiated by a 200-mCi ^{137}Cs source. The signals induced in the eight strips placed near the center of the RPC were linearly amplified by a factor of 10 by using a linear amplifier (CAEN N412). One of the amplifier outputs of each channel was discriminated by using a 13-mV voltage threshold (equivalent to a 1.3-mV threshold for the RPC raw pulses), and was fed into a time-to-digital converter (TDC, LeCroy 2228) after being properly delayed to satisfy a common-start-mode acquisition. The other amplifier output was also properly

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