Low resistance bakelite RPC study for high rate working capability

T. Dai, a L. Han, c S. Hou, b M. Liu, c Q. Li, c H. Song, c L. Xia a and Z. Zhang c

a Argonne National Laboratory, Downers Grove Township, U.S.A.

b Institute of Physics Academia Sinica, Taipei, Taiwan

c University of Science and Technology of China, Hefei, Anhui, China

d University of Michigan, Ann Arbor, U.S.A.

E-mail: h.song@cern.ch

ABSTRACT: This paper presents series efforts to lower resistance of bakelite electrode plate to improve the RPC capability under high rate working condition. New bakelite material with alkali metallic ion doping has been manufactured and tested. This bakelite is found unstable under large charge flux and need further investigation. Alternatively, a new structure of carbon-embedded bakelite RPC has been developed, which can reduce the effective resistance of electrode by a factor of 10. The prototype of the carbon-embedded chamber could function well under gamma radiation source at event rate higher than 10 kHz/cm². The preliminary tests show that this kind of new structure performs as efficiently as traditional RPCs.

KEYWORDS: Resistive-plate chambers; Trigger detectors

1 Corresponding author.
1 Introduction

Resistive Plate Chamber (RPC) [1] has been widely used in particle and nuclear physics and astronomy experiments as trigger or time-of-flight detectors, due to its excellent timing capability, low cost and ability to easily scale to large areas. However, for traditional glass or bakelite RPC, large resistances of chamber electrode plates prevent accumulated avalanching charge from dispersing, which would diminish the effective high voltage field and result in limitation of RPC rate capability as $\sim 1 \text{ kHz/cm}^2$. To confront the challenge of future high energy and high luminosity collider physics such as ATLAS forward Muon trigger upgrade, novel technology needs to be developed to lower effective resistance of RPC electrode plates. Efforts of strengthening RPC rate capability are reported in this paper. The resistance of electrode plate can be described as

$$R = \frac{\rho \cdot d}{s}$$

where $\rho$, $d$ and $s$ are the material bulk resistivity, thickness and area of the RPC electrode plates respectively. It’s natural to have two ways to reduce the effective resistance of the RPC plates, namely lowing the resistivity of the materials or diminish the thickness of the plates. New materials doped with alkali metallic ion are produced to develop low resistivity bakelite plates, and long term stability and aging behavior under high charge flux imitation of the new bakelite are studied and summarized in section 2. Another attempt is to develop a new structure of RPC chamber, i.e. carbon-embedded bakelite plate, which is produced by coating a layer of carbon layer into normal bakelite layers to reduce the effective thickness of electrodes. A detailed description of the RPCs made with new structure bakelite is presented in section 3. Results of cosmic and high rate capability tests are presented in section 4, and discussion is made in section 5.
A new type of bakelite plates is manufactured by doping sodium ion into the epoxy resin during production process. Bulk resistivity of the new bakelite can be lowered to $10^8 \sim 10^{10} \Omega \cdot \text{cm}$ from traditional glass or bakelite plates of $10^{12} \Omega \cdot \text{cm}$. The plates are stored still in superclean room for 3 months, under conditions of temperature $15 \sim 30^\circ \text{C}$ and humidity $25\% \sim 50\%$. The bulk resistivity of plates are monitored frequently by measuring current through the specimens at $HV = 500 \text{V}$, shown as figure 1. A press machine with conductive sponges, which can generate pressures up to $\sim 10 \text{atm}$, is employed to keep the test electrodes in well contact with the specimen. It takes about 30 minutes for the current flow through the plate to reach a stable value during measurement. The resistivity and measuring conditions of temperature and humidity versus time are depicted in figure 2. As expected, the resistivity of new material varies significantly with temperature change, and is stable under still storage over 120 days.

To imitate the aging behavior of the new material under high rate working condition, the bakelite plates are connected in series with the direct current circuits and kept charging continuously for more than 30 days. The charge flux in total reaches about $2 \text{C/cm}^2$, which is equivalent to working at a high rate of $10 \text{kHz/cm}^2$ for one month. Figure 3 shows that the bulk resistivity of the new bakelite increases by a factor of 30.

An alternative way to lower resistance of RPC plates is to reduce the effective thickness of their electrodes. A carbon layer of $10^5 \sim 10^6 \Omega \cdot \text{cm}$ is sprayed uniformly between two phenolic resin bonded paper laminates of RPC plates with different thickness, and is used as electrodes by connecting to HV or ground. A sketch view of the chamber made with the carbon-embedded new structure bakelite is depicted in figure 4, where thick external laminate is used as supporter and the internal thin one faces to gas gap. By diminishing the effective bakelite plate between gas gap and electrodes, the resistance of the whole chamber would be reduced proportionally by a factor 10.
Figure 2. The black circle, red square and blue triangle present the bulk resistivity of new bakelite material, and the temperature and the humidity of measurements in 120 day still storage.

Figure 3. The black circle, red square and blue triangle present the bulk resistivity of new bakelite material, and the temperature and the humidity of measurements in 30 day continuous charging.

Figure 4. Side view of RPCs made with carbon-embedded electrode bakelites.
4 Chamber tests

Two types of RPC chambers are manufactured for cosmic and high rate tests.

- Type-A: made of low resistivity bakelite of $10^{10} \Omega \cdot \text{cm}$, the thickness of plates is 1.5 mm.
- Type-B: made of traditional bakelite of $10^{12} \Omega \cdot \text{cm}$ with carbon-embedded electrodes of 0.2 mm thickness internal plates.

All the chambers are $40 \times 40 \text{ cm}^2$ in area, and with 1.2 mm gas gap, using a gas mixture of 94.7\% C$_2$H$_2$F$_4$, 5\% iC$_4$H$_{10}$ and 0.3\% SF$_6$.

4.1 Cosmics test results

A 7-layer cosmic ray test system is built at Argonne Lab with readout developed for digital hadronic calorimeter prototype. Each layer covers $32 \times 48 \text{ cm}^2$ area, which is detected by $1 \times 1 \text{ cm}^2$ readout pads. The system works in self-triggered running mode, which can filter out cosmic muon signal by requiring time stamp coincidence among layers and noise distribution can be automatically recorded. Two Type-A chambers and two Type-B chambers have been studied. The efficiency of Type-A chambers reaches the platform at 7000 V with a cluster size of 3, as shown in figure 5. The noise rate of these two Type-A chambers is about 20–30 Hz/cm$^2$, shown in figure 6. The results of Type-B chambers are presented in figure 7 and figure 8, which are consistent with those of Type-A chamber and demonstrate the new structure of carbon-embedded electrode chamber can work as efficiently as normal RPC.

![Figure 5](image1.png)

**Figure 5.** Cluster multiplicity (left) and efficiency (right) of cosmic ray signal versus HV of two Type-A chambers.

4.2 CERN GIF test results

The high rate capability tests were carried out with Cs$_{137}$ $\gamma$ source at GIF in CERN, and the setup of the radiation test is depicted in figure 9. The photon source could be switched on and off with lead sliding filters. Cosmic muon events were triggered by coincidence of scintillators which were either shielded or far away and thus insensitive to the $\gamma$ source. Cosmic muon signals yielded in RPC chambers were picked up by strips of 1.27 mm in width, and read out by ATLAS MDT DAQ system.
Figure 6. Noise rate on x-y plane of two Type-A chambers at HV = 6.4 kV. The hot spots are located at internal supporters of the chambers.

Figure 7. Cluster multiplicity (left) and efficiency (right) of cosmic ray signal versus HV of two Type-B chambers.

Figure 8. Noise rate on x-y plane of two Type-A chambers at HV = 6.4 kV. The hot spots are located at internal supporters of the chambers.

Both Type-A and Type-B RPCs have been tested at GIF. The cluster size of signal decreases obviously while the source is on, because of the accumulation effect of avalanching charge under high rate condition, as shown in figure 10. The rate capabilities of Type-A and Type-B RPCs have been proved that can reach 7 kHz/cm². The stronger the source strength, the weaker the effective field applied on the gas gap of RPC chamber is, and the smaller avalanching signal can be developed. This effect can be observed clearly in figure 11, where the ADC outputs of signals
Figure 9. Side view of GIF test setup.

Figure 10. Multiplicity of Type-B chamber, red: full source, black: no source.

Figure 11. ADC outputs with different strength of source for Type-B (left) and Type-A (right) chambers.

diminish with less shielding from the source. On the other hand, it’s encouraging to see that the signals of the carbon-embedded electrode Type-B chamber might be more distinctive than those of traditional Type-A RPC chamber.
5 Conclusions

Two methods of strengthening RPC high rate capability have been investigated. Low resistivity bakelite with sodium ion doping was manufactured, but aging results showed that the recipe might be not stable enough for long period work under high rate condition. Alternatively, a new structure of carbon-embedded bakelite RPC has been developed, which might be able to decrease the resistance of electrode plate by an order. The preliminary studies demonstrated that this kind of new structure could perform as efficiently as traditional RPCs, and the prototype chamber is the first one that functioned under CERN GIF high rate environment.

References

[1] ATLAS collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, 2008 JINST 3 S08003.

[2] S. Palestini, The muon spectrometer of the ATLAS experiment, Nucl. Phys. Proc. Suppl. 125 (2003) 337.

[3] R. Santonico and R. Cardarelli, Development of resistive plate counters, Nucl. Instrum. Meth. A 187 (1981) 377.