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An extensive aging study of bakelite Resistive Plate Chambers

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Abstract

We present recent results of an extensive aging test, performed at the CERN Gamma Irradiation Facility, on two bakelite Resistive Plate Chambers (RPC) detectors. With a method based on a model describing the behavior of an RPC exposed to a large particle flux, we have periodically measured the electrode resistivity ρ of the two detectors over 3 years. We observed a large increase of ρ with time, from initial values of about $10^{10}\ \Omega\,\mathrm{cm}$ to more than $200 \times 10^{10}\ \Omega\,\mathrm{cm}$. A corresponding degradation of the RPC rate capability, from about 3 kHz/cm^2 to less than 200 Hz/cm^2, was observed. The reversibility of the process, using a humid gas mixture, has also been studied.

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Keywords: RPC; Detector; Current; Resistivity; Bakelite; Humid gas

1. Introduction

The main challenge for Resistive Plate Chambers (RPC) in the last decade has been the improvement of the rate capability, to make suitable these detectors for the newcoming LHC experiments (see [1–3]). Standing particle flux densities up to few kHz/cm^2 [4–6] has been achieved by operating in avalanche mode, rather than streamer mode, and by using bakelite electrodes with resistivities as low as $10^9\ \Omega\,\mathrm{cm}$.

We present the latest results of a three years aging test on two bakelite RPCs performed at the Gamma Irradiation Facility [7] at CERN. The test has been made in the framework of the R&D for the LHCb experiment to verify the stability of the detector performances with time, in particular their rate capability. Since this is directly related to the RPC resistivity, a simple method [8] has been developed to measure the electrode resistivity on line.

2. Experimental setup

Two identical detectors ($50 \times 50\ \mathrm{cm}^2$ with a 2 mm gas gap) were built using bakelite plates (2 mm thick) of nominal resistivity $\sim 10^{10}\ \Omega\,\mathrm{cm}$,

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and treated internally with linseed oil. Both detectors were operated in avalanche mode with the same gas mixture, normally 95% $C_2H_2F_4$, 4% i-C_4H_{10} and 1% SF_6.

The tests have been performed at the Gamma Irradiation Facility, a test area where particle detectors are exposed to an adjustable photon flux from an intense radioactive source (^{137}Cs). The test setup is schematically shown in Fig. 1.

Normally during the aging test both detectors (RPC A and RPC B) were placed in position 1, very close to the source and almost continuously exposed to radiation. Only during the first year of test, the RPC B was placed far from the source (position 2) to serve as a reference. Position 3 was used to perform efficiency measurements with the X5 muon beam. In this case the signals from the detectors were read out on 3 cm wide strips using fast electronics.

We computed the irradiation dose of the RPCs by the accumulated charge per surface unit, measured in C/cm^2.

3. Resistivity measurements

The model describing the behavior of the RPC under high flux conditions has been presented in [8]. It assumes that the physical properties of an RPC detector depend on the effective voltage across the gap V_{gap} (see Fig. 2): we have $V_{\text{gap}} = V_0 - IR$, where V_0 is the nominal applied voltage from the power supply, I is the current drawn by the RPC and R is the total resistance of the two electrodes, related to the bulk resistivity by the Ohm's law $R = \rho d/S$, where d is the total thickness of the electrodes and S their surface. The model predicts that increasing the photon flux the current reaches a saturation value and depends linearly on the applied voltage (see Fig. 3) through $I = (V_0 - V_T)/R$, where V_T is the minimum voltage to start the avalanche.

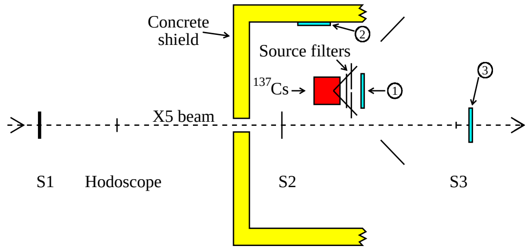

Fig. 1. Schematic view of the test setup (not to scale). The positions of the RPCs corresponding to the various measurements are indicated (1–3).

The resistance R can thus be measured by the slope of this curve. A systematic set of measurements of RPC electrode resistivity was performed using this method.

In order to compare measurements taken at different temperatures T, in the results we have rescaled the values of ρ to the reference temperature of 20°C, through the law $\rho_{20} = \rho\, e^{\alpha(T-20)}$.

We have measured $\langle\alpha\rangle = 0.12 \pm 0.01°\text{C}^{-1}$, in very good agreement with that obtained for the bulk resistivity of bakelite. This represents a clear hint that we are really measuring the volume resistivity of the bakelite.

The values of ρ_{20} for the first years are reported in Table 1 for the irradiated RPC A, with the accumulated charge density.

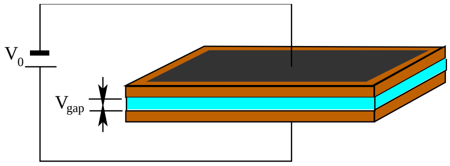

Fig. 2. V_{gap} is the voltage drop on the gas gap, while V_0 is the external applied voltage.

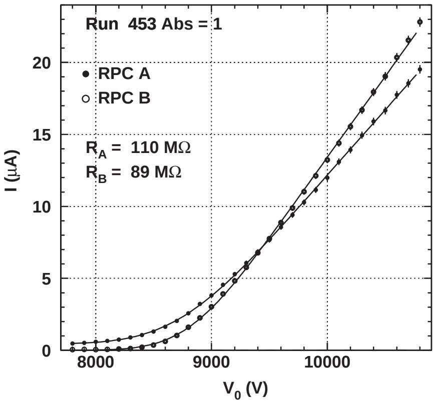

Fig. 3. Current vs. V_0 for RPC A (solid circles) and B (open circles) for a source nominal absorption factor 1.

Table 1
The time evolution of the accumulated charge density and the resistivity for irradiated RPC A from 1999 to 2001

Date	Q_{acc} (C/cm^2)	ρ_{20} (10^{10} Ω cm)
Oct 99	0	<2
Jan 01	0.076	6.6±0.5
Mar 01	0.110	8.5±0.7
Jul 01	0.361	26±2.3
Aug 01	0.42	39±4
Dec 01	0.42	69±6

The resistivity was initially measured to be about 2×10^{10} Ω cm in fair agreement with the nominal building value. Then this detector was stored during 2000. At the beginning of the test (January 2001) the resistivity had already increased by a factor 3. It increased by another factor 6 during the irradiation period (January–August), when 0.42 C/cm^2 were accumulated. The increase continued even after August, when irradiation was stopped, suggesting also a contribution not related to irradiation. This was confirmed by the reference RPC B for which we measured a resistivity of $\sim 3 \times 10^{10}$ Ω cm in October 1999, and $(13 \pm 2) \times 10^{10}$ Ω cm in August 2001, in spite of the low charge density accumulated (0.05 C/cm^2).

From 2002 the detectors were both installed in position 1 and the resistivity was measured as frequently as possible. The results are plotted in Figs. 4 and 5, respectively for RPC A and RPC B.

In the first 225 days the resistivity of both chambers continued increasing, even though, because of the high value reached, the currents drawn were tiny (about 5 nA/cm^2), so that negligible charge was accumulated during this period. It can be seen that both detectors, at the end of this period, reached roughly the same values of resistivity. These results suggest that the resistivity of bakelite electrodes tends to spontaneously increase, and that this would be the main aging effect over a long period of operation.

We do not have yet a quantitative interpretation of these phenomena, although we believe that this is related to a decrease of water content in the bakelite plates. While water evaporation from the plates is always present, it is probably enhanced both by the current flowing in the electrodes and by the flux of dry gas in the chamber. To verify this interpretation, and to check if the process could be reversed, during 2003 we started a series of measurements flushing our RPCs with a humid gas mixture.

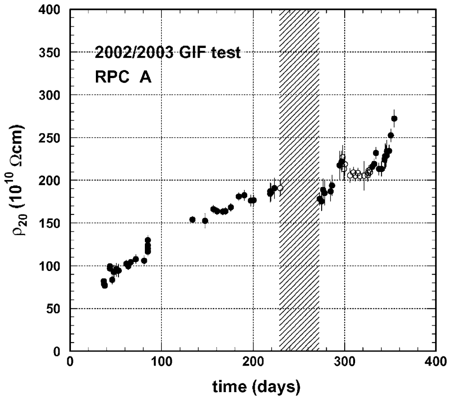

Fig. 4. The resistivity of RPC A during 2002 and 2003. Open circles indicate measurements with humid gas. The shaded region corresponds to a period of no gas flow.

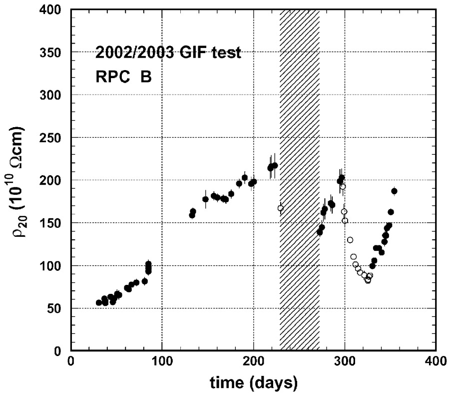

Fig. 5. The resistivity of RPC B during 2002 and 2003. Open circles indicate measurements with humid gas. The shaded region corresponds to a period of no gas flow.

1.2% of vapor water was added to the usual gas mixture, by bubbling it through a tank containing water at 7°C. The high voltage was turned on only for few minutes, during the measurements. The results are marked with open circles in Figs. 4 and 5.

Table 2
Resistivity ρ and rate capability $\Phi_{\max}$ for RPC A in three different beam tests at GIF

Date	ρ (10^{10} Ω cm)	$\Phi_{\max}$(Hz/cm^2)
Oct 99	<1	>3000
Aug 01	20	1150
Jul 02	65	350
Jul 02[a]	45	380

[a] RPC B.

In RPC A the effect was limited, while in RPC B the resistivity immediately is seen to decrease, and dropped a factor 2 in 40 days. When dry gas flow was restored the resistivity rapidly increased in both detectors, resuming the old values. Stopping the flow of dry gas also resulted in a less rapid decrease of the resistivity. The different behavior between the two detectors, nominally identical, has not been understood yet and is matter for further investigation.

4. Rate capability

The rate capability of an RPC is expected to be inversely proportional to the electrode volume resistivity. It is therefore important to check how the increase of the resistivity observed affects the performances of the detectors under high rates. In order to study quantitatively the effect, we have defined the rate capability $\Phi_{\max}$ as the maximum rate the RPC can stand providing 95% efficiency, at the maximum voltage of 10.6 kV (this guarantees a plateau of about 400 V below the threshold of streamer regime). The results of three different beam tests performed over a period of 3 years are summarized in Table 2. The value of 3 kHz/cm^2 for the first test has to be considered as a lower limit, because it was not possible to test the detector at higher rates. Considering that, the values of $\Phi_{\max}$ are in good agreement with the $1/\rho$ dependence. It is to remark that the measures in Table 2 were made between 23°C and 25°C, and that rescaling them at the reference temperature would decrease the rate capability by a factor 2.

5. Conclusions

We have been studying aging effects on bakelite RPCs for three years, applying a properly developed method which allows to measure the electrode resistivity during chamber operation. At the end of the test we found an increase of the resistivity by two orders of magnitude. We believe that although irradiation may contribute, the effect is mainly due to the drying up of bakelite. Humid gas has been flowed with different response: one detector rapidly decreased its resistivity while the other was much less affected. Restoring dry gas flow has resulted again in fast resistivity increase for both, making the method not useful to recover the detector performances. The resistivity rise caused a drop in the rate capability, from few kHz/cm^2 to less than 200 Hz/cm^2.

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