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Final results from an extensive ageing test of bakelite Resistive Plate Chambers

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Abstract

We present the final 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 behaviour of an RPC under high particle flux conditions, we have periodically measured the electrode resistivity ρ of the two RPC prototypes over 3 years. We observed a large spontaneous increase of ρ with time, from the initial value of about $10^{10}\,\Omega\,\mathrm{cm}$ to more than $200 \times 10^{10}\,\Omega\,\mathrm{cm}$. A corresponding degradation of the RPC rate capabilities, from more than $3\,\mathrm{kHz/cm^2}$ to less than $200\,\mathrm{Hz/cm^2}$, was observed; the reversibility of the process, using a humid gas mixture, has also been studied. We also present a study of the effects of humidity on the bakelite resistivity using two $10 \times 10\,\mathrm{cm^2}$ bakelite samples.

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

1. Introduction

In order to make the Resistive Plate Chambers (RPC) detectors suitable for the forthcoming LHC experiments [1–3], it has become necessary to improve the rate capability: a good efficiency at particle flux densities up to few $\mathrm{kHz/cm^2}$ [4–6] has been achieved by operating in avalanche mode and by using bakelite electrodes with resistivities as low as $10^9\,\Omega\,\mathrm{cm}$.

In this paper, we present the final results from a 3 years ageing test performed on two bakelite RPCs at the Gamma Irradiation Facility [7] at CERN in the framework of the R&D for the

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LHCb experiment; the main goal was to verify the stability of the detector performances with time and especially the rate capability. Since variations of the electrode resisitivity directly affect the RPC rate capability, it is very important to be able to monitor this parameter during the chamber operation and a simple method [8] has been developed to measure the electrode resisitivity on line.

The variations of the electrode resisitivity can be due to changes in the environmental parameters such as temperature and humidity [6,9] and to study these effects we have performed a separate test on two bakelite samples.

2. Experimental setups

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 $\sim 10^{10}\,\Omega\,\mathrm{cm}$, 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 ageing 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 $\mathrm{C/cm}^2$.

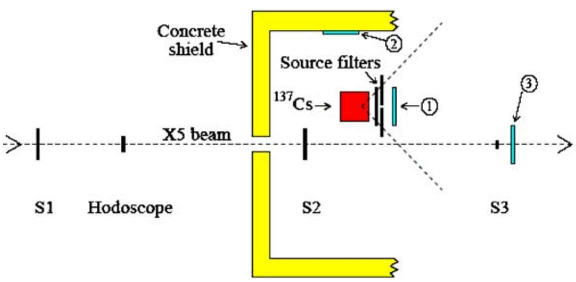

Fig. 1. Schematic view of the test setup (not to scale). The positions of the RPCs corresponding to the various measurements are indicated (1–3).

The study of bakelite resistivity started in August 2003 and went on for about 60 days. Two bakelite samples $10 \times 10\,\mathrm{cm}^2$ were kept in a thermostatic chamber used to control the temperature. A vacuum pump was also used to perform some resistivity measurements in a vacuum bell.

3. Rate capability and resistivity measurements

The rate capability of an RPC is expected to be inversely proportional to the electrode volume resisitivity. In order to study quantitatively the effect, we have defined the rate capability as the maximum rate the RPC can stand providing 95% efficiency at the maximum voltage of 10.6 kV (to guarantee a plateau of about 400 V below the threshold of streamer regime). The results of some rate capability measurements are shown in the next figures: in August 2001 we measured the RPC A rate capability to be $\sim 640\,\mathrm{Hz/cm}^2$ when its resisitivity was $\sim 40 \times 10^{10}\,\Omega\,\mathrm{cm}$ at 20°C (Fig. 2), while in July 2002 we measured the rate capability to be $\sim 200\,\mathrm{Hz/cm}^2$ when its resisitivity was $\sim 110 \times 10^{10}\,\Omega\,\mathrm{cm}$ at 20°C (Fig. 3).

By measuring continuously the bakelite resistivity during the ageing test, using the method of Ref. [8], we could confirm that the reduction in rate capability was clearly related to an increase of the bakelite resistivity. The measurements also allowed to obtain the bakelite temperature coefficient needed to rescale the values of ρ to the reference temperature of 20°C, through the law $\rho_{20} = \rho e^{\alpha(T-20)}$. We have measured $\langle\alpha\rangle = 0.12 \pm 0.01\,^\circ\mathrm{C}^{-1}$, in very good agreement with that obtained for the bulk resistivity of bakelite (see later). 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

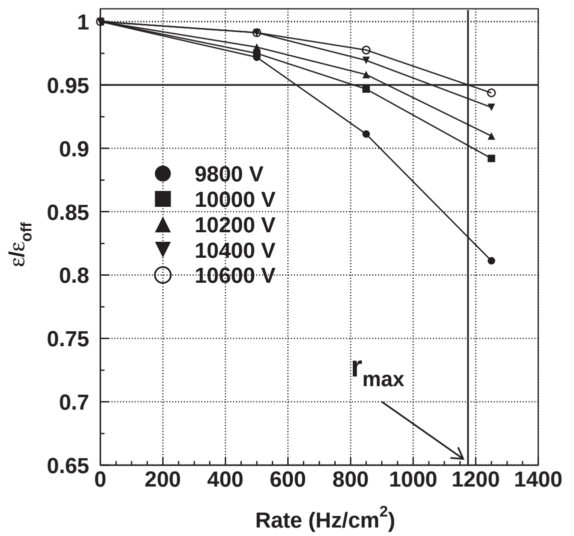

Fig. 2. Normalised efficiency with respect to the rate for five different applied external voltage at 25°C in 2001.

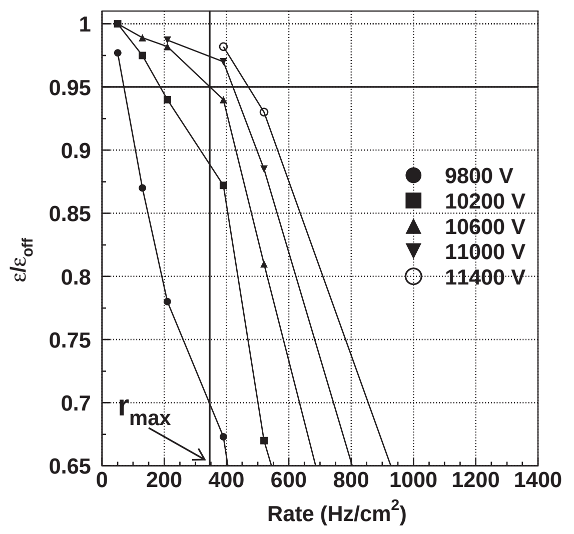

Fig. 3. Normalised efficiency with respect to the rate for five different applied external voltage at 24.5°C in 2002.

reported in Table 1 for the irradiated RPC (A), with the accumulated charge density.

The observed resistivity increase even after August 2001, when irradiation was stopped, suggests also a contribution not related to irradiation. This was confirmed by the reference RPC (B)

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}($10^{10}\,\Omega$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

for which we measured a resistivity of $\sim 3 \times 10^{10}\,\Omega$cm in October 1999, and $(13 \pm 2) \times 10^{10}\,\Omega$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. 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 ageing effect over a long period of operation.

4. Effect of water vapor

Since it is well known that the bakelite resistivity strongly depends on the water content, a possible explanation is that the observed effects are simply due to water evaporation, possibly 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. 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 just for few minutes, during the resistivity measurements.

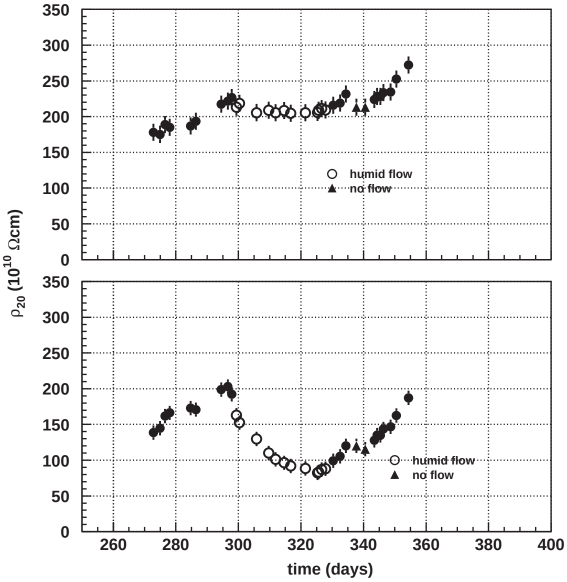

Fig. 4. The resistivity of RPC A (top) and RPC B (bottom) during 2002 and 2003. Open circles indicate measurements with humid gas.

The behaviour of resisitivity during the whole test is plotted in Fig. 4. The measurements performed with the humid gas mixture are marked with open circles. In RPC A a small effect was observed, while in RPC B the resistivity immediately is seen to decrease, and dropped a factor 2 in 20 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 behaviour between the two detectors, nominally identical, has not been understood yet and is matter for further investigation.

5. Study of bakelite resisitivity

In order to better clarify the effect of water content on the bakelite resistivity, we performed a study on two $10 \times 10\,\mathrm{cm}^2$ samples (a and b). The resistivity was continuously measured for about two months. During the first 3 weeks we performed a measurement of the temperature coefficient in two different environments. In the unconditioned enviroment the samples were kept in the thermostatic chamber at 50% humidity; the temperature coefficient was measured and we found a consistent value with values previously measured: $0.14 \pm 0.02°\mathrm{C}^{-1}$ for sample a and $0.12 \pm 0.02°\mathrm{C}^{-1}$ for sample b. In the humid air enviroment the samples were kept in the thermostatic chamber at 100% humidity and the temperature coefficient was measured: $0.10\pm 0.02°\mathrm{C}^{-1}$ for sample a and $0.09 \pm 0.02°\mathrm{C}^{-1}$ for sample b. The temperature coefficient thus showed a clear dependence on the humidity percentage (see also Ref. [6]). We used these values to rescale at 20 °C the resistivity measured in a 100% humid air enviroment at four different temperatures (see Fig. 5).

Even if rescaled using the correct temperature coefficient, the resisitivity still showed a decreasing behaviour: for example, between day 49 and day 51, it reached a 35% lower value. Our hypothesis is that the resisitivity decrease depended on the progressive water absorption. This hypothesis seemed to be also confirmed by the resistivity measurements shown in Fig. 6: when, after 22 days

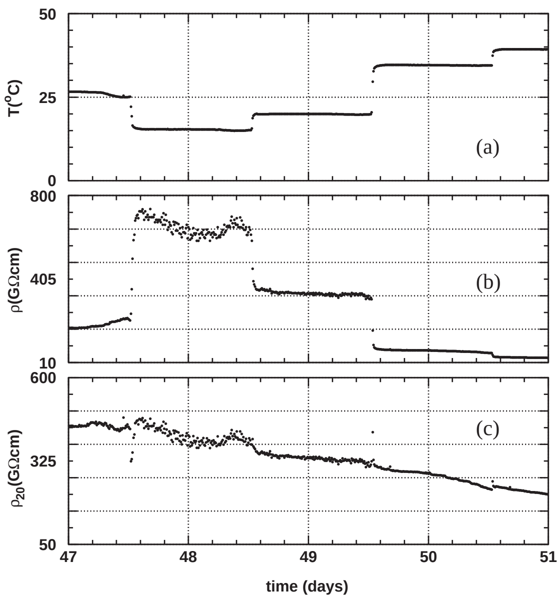

Fig. 5. (a) Temperature, (b) uncorrected resistivity, and (c) corrected resistivity with respect to the time in days for sample a in humid air environment.

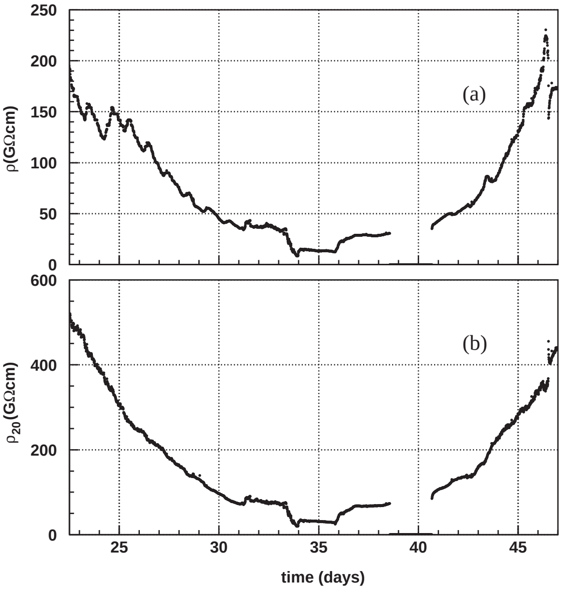

Fig. 6. (a) Uncorrected resistivity, and (b) corrected resistivity with respect to the time in days for sample a at $T \simeq 26°C$.

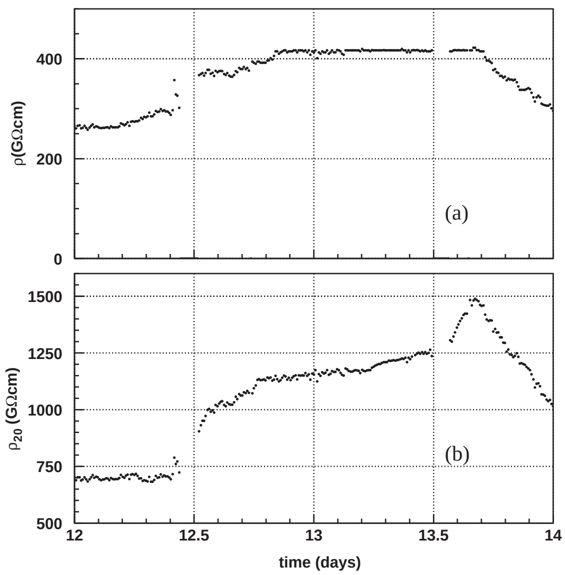

Fig. 7. (a) Uncorrected resistivity, and (b) corrected resistivity with respect to the time in days for sample a in the vacuum bell at $T \simeq 28°C$.

of test, the sample a was left in the thermostatic chamber in 100% humid air and constant temperature, the resistivity decreased rapidly; but, when the thermostatic chamber was opened during day 35, the previous value was rapidly restored.

Finally we used the vacuum pump also in order to perform some resistivity measurements in the vacuum bell (see Fig. 7). When the vacuum was created[1] after 12.5 and 13.5 days, the resistivity increased rapidly.

6. Conclusions

We have extensively studied ageing effects on RPC detectors for three years. At the end of the test we observed a resistivity increase by two orders of magnitude. We believe that, although irradiation may contribute, the effect is mainly related to the drying up of bakelite. Even if drying humid gas has resulted in a resistivity decrease, after restoring the dry gas flow the resistivity increased again rapidly. Therefore, periodic conditioning with humid gas is not useful to recover the detector performances. This is confirmed by a study performed on two bakelite samples in different environmental conditions; the measurements confirmed the strong dependence on the environmental parameters of the bakelite resistivity, especially on the humidity percentage, and also showed the fast response of the electrical bakelite characteristics with respect to the variations of the environmental conditions.

[1]A silica gel was used to absorb humidity.

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