Long term performance studies of large oil-free bakelite resistive plate chamber

R. Ganai, a,1 A. Roy, a M.K. Shiroya, b K. Agarwal, c Z. Ahammed, a S. Choudhury a and S. Chattopadhyay a

aVariable Energy Cyclotron Centre, 1/AF-Bidhan Nagar, Kolkata-700064, India
bSardar Vallabhbhai National Institute of Technology, Surat, Gujarat-395007, India
cBirla Institute of Technology and Science, Pilani, Rajasthan-333031, India

E-mail: rajesh.ganai.physics@gmail.com

ABSTRACT: Several high energy physics and neutrino physics experiments worldwide require large-size RPCs to cover wide acceptances. The muon tracking systems in the Iron calorimeter (ICAL) experiment in the India based Neutrino Observatory (INO), India and the near detector in Deep Underground Neutrino Experiment (DUNE) at Fermilab are two such examples. A single gap bakelite RPC of dimension 240 cm × 120 cm, with gas gap of 0.2 cm, has been built and tested at Variable Energy Cyclotron Centre, Kolkata, using indigenous materials procured from the local market. No additional lubricant, like oil has been used on the electrode surfaces for smoothening. The chamber is in operation for > 365 days. We have tested the chamber for its long term operation. The leakage current, bulk resistivity, efficiency, noise rate and time resolution of the chamber have been found to be quite stable during the testing period. It has shown an efficiency > 95% with an average time resolution of ~ 0.83 ns at the point of measurement at ~ 8700 V throughout the testing period. Details of the long term performance of the chamber have been discussed.

KEYWORDS: Neutrino detectors; Particle tracking detectors (Gaseous detectors)

1Corresponding author.
1 Introduction

Resistive Plate Chambers (RPCs) [1] will find possible use to track muons in the the upcoming neutrino experiments like Iron CALorimeter (ICAL) in India based Neutrino Observatory (INO) [2] in India, Deep Underground Neutrino Experiment (DUNE) [3] at Fermilab, U.S.A. INO-ICAL of dimension $\sim 48 \text{ m} \times 16 \text{ m} \times 14 \text{ m}$ will consist of $\sim 50 \text{kT}$ magnetised iron plates, each $\sim 5 \text{ cm}$ thick, stacked in 150 layers. About 30,000 single gap RPC modules each of gas gap $\sim (200 \text{ cm} \times 200 \text{ cm} \times 0.2 \text{ cm})$ sandwiched between pairs of iron plates will be used as tracking layers. The gas gap dimension of the RPC modules to be used in DUNE is $\sim (200 \text{ cm} \times 100 \text{ cm} \times 0.2 \text{ cm})$. RPCs, because of very good time resolution, will be capable of differentiating between up and down going neutrinos in INO-ICAL.

As a part of this programme, Variable Energy Cyclotron Centre (VECC), Kolkata, India, has been actively involved the R&D of RPCs using high pressure paper laminates, commonly referred to as bakelite, for almost a decade. VECC aims to develop large size ($240 \text{ cm} \times 120 \text{ cm} \times 0.2 \text{ cm}$) bakelite RPCs that might be used in the INO-ICAL or in the Near Detector (ND) of the DUNE. As these experiments will run for many years, therefore it is necessary that the long term stability of these RPCs are tested.

Long term operation of a RPC may cause ageing problems in the detector due to several reasons like the variation of the electrode resistivity, the integrated charge etc. In general there are three reasons of ageing effects in a RPC - ageing of the electrode material, aging due to the integrated charge generated in the gas gap which results in the increase in current in the detector and ageing due to irradiation on the detector. However, for low rate neutrino experiments like INO, ageing due to irradiation might not be significant but ageing due to the others remain major issue. Increase in the leakage current, bulk resistivity of the chamber, reduction in efficiency are the prominent symptoms of an aged RPC. It is therefore important to perform the long term test of a detector.

In this paper, we report the long term performance studies of a single gap RPC with $240 \text{ cm} \times 120 \text{ cm} \times 0.2 \text{ cm}$ gas gap that uses 3 mm thick bakelite sheets as electrodes.
2 Fabrication of large RPC

We have successfully fabricated a single gap (with \( \sim 240 \text{ cm} \times 120 \text{ cm} \times 0.2 \text{ cm} \) gas gap), oil-free bakelite RPC using raw materials like bakelite sheets, glue, spacers available from Indian market. Several grades of bakelites available in Indian market have been tried out for successful development of oil-free RPC. Successful fabrication and test results of a small prototype [4] encouraged us to fabricate the large RPC. For completeness, we give a brief account of the fabrication procedure. Figure 1 and figure 2 show various steps involved and a set of photographs taken while fabricating the large bakelite RPC respectively. Many challenges were faced during fabricating such a large size RPC. The most crucial challenge was to maintain the planarity of the platform on which the RPC was fabricated. For this, several layers of \( \sim 240 \text{ cm} \times 120 \text{ cm} \times 0.3 \text{ cm} \) foam were stacked one on another on the laboratory floor. Over these layers of foam, few layers of thin and soft cardboards of similar dimension were stacked. Then on those cardboards, 12 bundles of paper were placed, equidistant from each other. On the top of the paper bundles, a thick glass plate of dimension \( \sim 240 \text{ cm} \times 120 \text{ cm} \times 2 \text{ cm} \) was placed which served as the platform for fabricating and testing the RPC. The next challenge was to select a suitable glue to stick the gas nozzles, side spacers and button spacers. A detailed R&D on different glue samples was done and a suitable glue was chosen. The number of gas nozzles to be used, the number and dimension of button spacers and side spacers were also decided after detailed study. The details of the aforementioned fabrication process and test results using cosmic rays have been discussed in [5]. Figure 3 and figure 4 show the fabricated RPC. In order to tap the signals from the chamber, pick up panels which are made of \( \sim (125 \text{ cm} \times 105 \text{ cm} \times 0.15 \text{ cm}) \) FR4 sheet sandwiched between \( \sim (125 \text{ cm} \times 105 \text{ cm} \times 0.0035 \text{ cm}) \) copper sheets have been used. The copper pick-up strips are 2.5 cm in width, with a gap of 0.2 cm between the adjacent strips.

3 Long term test results using cosmic rays and discussions

A scintillator based cosmic ray test set up has been used for the test. During the entire testing period, the laboratory temperature and the relative humidity have been maintained at \( \sim 10^\circ \text{C} \) and \( \sim (35\%–40\%) \) respectively. All the tests have been performed in the streamer mode of operation of the RPC with a gas composition of Argon:Freon(R134a):Iso-butane::34:57:9 by volume. A typical gas flow rate of \( \sim 0.75 \text{ litre/hour} \) has been maintained over the entire test period resulting in \( \sim 3 \) changes of gas volume per day. The chamber was operated at \( \pm 4500 \text{ V} \) (overall 9000 V) with a signal threshold of \( \sim 20 \text{ mV} \).

Positive and negative high voltage to the chamber was applied on the top and bottom electrodes with CAEN A1832PE and A1832NE modules respectively, in a CAEN SY1527 crate. The current was monitored from the display panel of the HV supply. LEMO connectors were soldered on the copper strips of the pick-up panel to tap the signals from the chamber. The raw RPC signal was digitised using a CANBERRA QUAD CFD 454 constant fraction discriminator (CFD). A CAMAC based data acquisition system has been used in our setup. For timing measurements, a 16 channel PHILIPS SCIENTIFIC 7186 TDC module was used. The master trigger was formed with one finger (7 cm \( \times \) 1.5 cm) and two paddle (20 cm \( \times \) 8.5 cm) scintillators. The overlap area between the
Erection of a suitable assembly platform with the help of cardboard sheets, foams, paper bundles and thick glass plate

Filing the edges and chamfering the corners of the electrodes

Cleaning the electrode sheets with de-mineralised water and alcohol

Painting of surfaces with conducting paint using spray gun

Measurement of surface resistance over the entire painted surface

Placing the bottom electrode on the erected platform

Attaching the side spacers, button spacers and gas nozzles on the bottom electrode using glue

Giving ~ 1 day to settle the glue

Applying glue on the top surface of the spacers and placing the top electrode

Giving ~ 1 day to settle the glue

Turning the chamber upside down after allowing the glue to settle and re-glue the side spacers for better result

Giving ~ 1 day to settle the glue

Placing the pick up panels and flushing the gas mixture for ~3 days

Testing the module

Figure 1. Flow-chart of steps followed during fabricating of large RPC.
Figure 2. Photographs of the steps followed during fabricating the large bakelite RPC [4].

Figure 3. [Color online] Photograph of the large bakelite RPC [5].

Figure 4. [Color online] Photograph of the large bakelite RPC with pick-up panel [5].
scintillators has been used to obtain the cosmic ray efficiency. The average master trigger rate was \( \sim 0.0085 \text{ Hz/cm}^2 \).

The chamber is in gas and high voltage for more than a year. We report here the monitoring of chamber current, efficiency, noise rate and time resolution of the chamber continuously for 60 days. Data for chamber current, efficiency and noise rate have been taken every day whereas the time resolution measurement has been done once in a week’s time.

### 3.1 Current stability

Figure 5 shows the variation in current in both the electrodes. The top and middle figures show the current variation for the top and bottom electrodes respectively whereas the bottom figure shows the average current of both the electrodes. The current in both the electrodes was found to be quite stable during the monitoring period. We have calculated the bulk resistivity of the chamber from the average current values which is shown in figure 6. The bulk resistivity of the chamber was found to be \( \sim 9 \times 10^{13} \Omega \text{cm} \).

![Figure 5](image.png)

**Figure 5.** Current stability of the electrodes of the chamber over a period of 60 days as monitored from the high voltage panel. The first surface is the top electrode or the anode whereas the second surface is the bottom electrode or the cathode.

![Figure 6](image.png)

**Figure 6.** [Color online] Variation of bulk resistivity of the chamber with time.
3.2 Efficiency and noise rate

The efficiency and noise rate as a function of applied high voltage at different thresholds have been studied with cosmic ray test set up [5] as shown in figure 7 and figure 8 respectively. As seen from figure 7, the plateau was reached at $> 8400 \text{ V}$ and $\geq 9700 \text{ V}$ with an efficiency value of $> 95\%$ with a threshold of $-20 \text{ mV}$ and $-50 \text{ mV}$ respectively. Figure 8 shows that the noise rates of the chamber were found to be $\sim 0.75 \text{ Hz/cm}^2$ and $\sim 0.40 \text{ Hz/cm}^2$ with a threshold of $-20 \text{ mV}$ and $-50 \text{ mV}$ respectively. The long term tests of these parameters also have been studied over a period of 60 days. The long term test of efficiency and noise rate have been shown in figure 9 and figure 10 respectively at a threshold of $-20 \text{ mV}$. The average values of efficiency and noise rate of the chamber were found to be $> 95\%$ and $\sim 0.75 \text{ Hz/cm}^2$ respectively. The graphs showed that both remained quite stable over the entire testing period.

![Figure 7](image1.png)

**Figure 7.** Efficiency of the chamber as a function of the applied high voltage. The error bars are within the marker size [5].

![Figure 8](image2.png)

**Figure 8.** Noise rate of the chamber as a function of the applied high voltage. The error bars are within the marker size [5].

3.3 Time resolution

Figure 11 shows the variation of time resolution ($\sigma$) over the entire testing period. The details of the time resolution ($\sigma$) calculations have been discussed in [5]. The average time resolution of the chamber was found to be $\sim 0.83 \text{ ns}$. 

![Figure 11](image3.png)
Figure 9. Efficiency of the chamber over a period of 60 days. The error bars are within the marker size.

Figure 10. [Color online] Noise rate of the chamber over a period of 60 days. The error bars are within the marker size.

Figure 11. [Color online] Time resolution (σ) of the chamber over a period of 60 days.

4 Conclusions

The RPC has been successfully tested continuously with cosmic rays over a period of 60 days. The chamber remained stable in terms of leakage current, efficiency, noise rate and time resolution over the entire testing period. The average leakage current, efficiency, noise rate and time resolution of
the RPC tested with cosmic rays in the streamer mode of operation at 9000V have been measured to be $\sim 3.0 \, \mu A$, $> 95\%$, $\sim 0.75 \, \text{Hz/cm}^2$ and $\sim 0.83 \, \text{ns}$ respectively. The results obtained with this chamber make it suitable to be used for muon detection in large neutrino experiments.

Acknowledgments

The work is partially supported by the DAE-SRC award project fund of S. Chattopadhyay. We are thankful to the INO collaborators for their encouragement. We acknowledge the service rendered by Ganesh Das for fabricating the detector. We also acknowledge Ramanarayana Singaraju for his constant help throughout testing of this detector. We take this opportunity to thank Satyajit Saha and Y. P. Viyogi for their constant encouragement and all the fruitful discussions and suggestions.

References

[1] R. Santonico and R. Cardarelli, Development of Resistive Plate Counters, *Nucl. Instrum. Meth.* **187** (1981) 377.

[2] INO Project Report, M. Sajjad Athar et al. *India-based Neutrino Observatory: Project Report.Volume I, INO-2006-01* (2006) and online pdf version at http://www.ino.tifr.res.in/ino//OpenReports/INOReport.pdf.

[3] DUNE collaboration, R. Acciarri et al., Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE), arXiv:1601.02984, http://www.dunescience.org/.

[4] R. Ganai, Study of Performance of Bakelite Resistive Plate Chamber (RPC), *Springer Proc. Phys.* **174** (2016) 547.

[5] R. Ganai, A. Roy, K. Agarwal, Z. Ahammed, S. Choudhury and S. Chattopadhyay, Fabrication and Characterisation of Oil-Free Large High Pressure Laminate Resistive Plate Chamber, 2016 *JINST* **11** P04026 [arXiv:1510.02028].