Fabrication and Characterization of Glass Resistive Plate Chamber (RPC)

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Introduction to RPC and operational principle

Fabrication of RPC detector

Measurement of surface resistivity of graphite coated glass

Preparation of pickup panel

Characteristic impedance of pickup panel

Leak test of RPC

Assembly of all components including readout electronics (preamplifier)

Characterization of RPC: dark current, noise rate and efficiency as a function of applied HV

Cosmic muon spectrum using existing RPC stack
1.1 INTRODUCTION

The Resistive Plate Chamber (RPC), introduced in 1981 by R. Santonico and R. Cardarelli, is a gaseous particle detector based on the principle of “Spark Chamber”, utilising a constant and uniform electric field produced by two parallel electrode plates which are made up of a material with high bulk resistivity. Its working concepts are based on the detection of gaseous ionization produced by charged particles traversing the active area of the detector, large avalanche of electron under a strong uniform electric. A gas mixture namely R134a, iso-C₄H₁₀ and SF₆, which is ionised by charged particles traversing the detector, is flown through the gap between the electrodes. The electrodes which we are using in this experiment are glass electrodes, coated with a layer of graphite on outer side.

The RPC’s are preferred over scintillators because of the following advantages:-

1) They can be made to have a large area but at a minimal material cost.
2) These are easy to assemble and they possess simple read-out electronics.
3) They exhibit better time resolutions than scintillators and long term stability.
4) Moderate position resolution and give good detection efficiency.

The glass RPC’s have been proposed as the active element in the iron calorimeter detector for the India-based Neutrino Observatory. Almost all big high energy physics experiment presently operational are used RPC either for trigger or timing measurement, whereas INO is going to us this for both triggering and tracking of charge particles. Single and double gap RPCs have also found application in cosmic ray experiments as well as in Astro particle physics.

1.2 PRINCIPLE OF OPERATION OF GLASS RPC:-

The basic principle of working of a RPC is based on the principle of Spark Chamber i.e. “ionisation”. Spark chambers consist of metal plates placed in a sealed box filled with a gas such as helium, neon or a mixture of the two. As a charged particle travels through the detector, it will ionize the gas between the plates. A trigger system is used to apply high voltage to the plates to create an electric field immediately after the particle goes through the chamber, producing sparks on its exact trajectory. In counters with metallic electrodes the spark discharges the total capacity of the plates, leading to high temperature and burning of the electrodes. The damaged surface gives spontaneous breakdown at lower fields. A possibility of avoiding the deficiency consists in using material with high resistivity (ρ=10⁹-10¹⁰ Ω-cm) for one of the electrodes. The spark then only discharges a small area of the condenser around the primary ionization.
RPC is similar to spark chamber, but the high resistance of glass/Bakelite between high voltage plates quenches spark arching. The glass RPC is consisting of two parallel electrodes made up of float glass with a volume resistivity of about $10^{12}$ Ω-cm. The two electrodes, 2-3mm thick, are mounted 1-2mm apart by means of highly insulated spacers. A suitable gas mixture is flown at the atmospheric pressure through the gap while an appropriate electric field is applied across the glass electrodes through a resistive coating on their outer surfaces. An ionizing charged particle traversing the gap initiates a streamer in the gas volume that results in a local discharge of the electrodes. This discharge is limited to a tiny area of about 0.1cm$^2$ due to the high resistivity of the glass electrodes and the quenching characteristics of the gas. The discharge induces an electrical signal on external pickup strips on both sides orthogonal to each other, which can be used to record the location and time of ionization. The discharge area recharges slowly through the high resistivity glass plates and the recovery time is about secs. The duration of discharge is typically ~ ns. This discharge is quenched by the following mechanisms:

1.) Prompt switching off of the field around the discharge point, due to the large resistivity of electrode.

2.) UV photon absorption by the quencher (iso-butane is a common quencher) preventing secondary discharges from gas photo ionisation.
3) Capture of outer electrons of the discharge due to the gas with high electron affinity (e.g., SF$_6$), which reduces the size of the discharge and possibly its transversal dimensions.

Because of the large difference between the duration of discharge and recovery time, the electrode plates behave like insulators so that only a limited area of ~0.1cm$^2$ around the discharge point remains inactive for the dead time of the detector. The motion of electron during avalanche process induces an electrical pulse which is picked up by the pick-up panels, made up of copper strips, through graphite painted high voltage electrodes. The velocity of positive ion is very low and consequently produced induced signal is negligible and for all practical purpose induced signal due to the motion of positively charged ions are neglected. The same electron produces induced signal in both pickup panels and that is opposite due to the motion of electron opposite with respect to two plates. The copper strips are insulated against the high voltage by thin insulator layer, e.g., mylar sheets. The electric signal is then properly picked up by the “read-out electronics” and analysed.

1.3 MODES OF OPERATION:-

Based on the applied electric potential and the ionisation phenomenon, the modes of operation of a RPC are classified as follows:-

a) Avalanche mode.

b) Streamer mode.

a) Avalanche mode: A charged particle passing through the gaseous medium produces primary ions. These ions, being accelerated by the electric field, collide with the gas molecule to produce secondary ionization. The external field opposes the electric field of the ionising particles and the multiplication process stops after sometime. Then the charges drift towards the electrodes and are collected there. Due to reduction of electric field across the gap (and consequently the gas amplification), a robust signal amplification is required at the front end electronic level. The substantial reduction of the charge produced in the gap improves the rate capability by more than an order of magnitude, allowing application of RPCs to high rate experiments.

This mode corresponds to the generation of a Townsend avalanche followed by the release of primary charge by the ionizing radiation. It operates at a lower voltage and the gain is less. Typical pulse amplitudes are of the order of a few mV in this avalanche mode with an electron multiplication $\sim 10^6$. 
b) Streamer mode: In this mode of operation, applied electric field is large and consequently electron gain may go up to \(10^8\). The secondary ionization continues until there is a breakdown of the gas and a continuous discharge takes place. Typical pulse amplitudes are of the order of 100-200 mV. The electric field inside the gap is kept intense enough to generate limited discharge localized near the crossing of the ionizing particle. Due to the relatively long relaxation time of the resistive electrode, this mode is not suitable in most of the collider experiments, where event rate is very large, but adequate for cosmic ray and low-rate accelerator experiments.

- Though all experiments with RPC operates with these mode, there is no sharp boundary between these two mode. RPC operating in avalanche mode may also form streamer. This probability is reduced with the increase of fraction of electronegative gas. While the statistics of avalanche multiplication predicts a shape following a power law, measurements show a peak that becomes more pronounced at higher voltages.

1.4) EQUIVALENT CIRCUIT OF RPC:- At low voltage, multiplication is very low and resistivity with the gas gap, \(R_{gap}\) is very high and the conduction of charge mainly goes through the spacer and button, \(R_{spacer}\). As the applied field in more and more, increase of free electron in gas due to large multiplication reduces the resistivity of gas and most of the current goes though the gas. This is very clear from the I-V plots of RPC, in the lower region, the slope is gives the \(R_{spacer}\), while at higher applied volt, it gives the value of the resistance of electrodes, \(R_{plate}\).
Fabrication of RPC’s

Resistive Plate Chambers (RPC) can be fabricated and tested easily, without much special tools, which is very common for the other detectors in the experiment of high energy physics. A complete RPC detector is made of mainly these three subcomponents, a glass gap, pickup panel and electronic chain containing amplifier and discriminator in front end and digital backend, which collect analog signal from front-end and send digitized signal to data acquisition system. In this project, a prototype RPC glass gap will be built along with pickup panels. The following steps will be followed to fabricate the RPC gas gap.

a. Cutting and Cleaning of glass

We will use commercially available float glass to make up the resistive electrodes of the RPC. The glasses were cut to the required size with the help of a diamond cutter. The edges are chamfered to make a 45° angle. The glass sheets will be cleaned thoroughly by alcohol followed by labolene and distilled water. The glasses are then left for drying. The next step is to introduce the button and side spacers. The edge spacers are as shown figure. The edge spacers are fitted in with a nozzle creating a gas inlet.

The button spacers and the edge spacers ensure a gap of 2mm between the glass plates. The four chamfered edges are fitted with corner edge spacers. Side gas nozzles used to create one inlet and one outlet. The spacers were cut according to the size of the RPC.
b. **Conductive coating**

The Glass plate is now covered with masking tape covering a distance of about 1cm measured from the edge of the glass. This is done to prevent the conductive coating from being sprayed at the edges. It not only increases the conductivity of the glass but also allows for the uniform application of high voltage over the area of the RPC. The conductivity is chosen in such a way that it can produce nearly uniform electric field throughout the chamber, without much screening the induced signal, which is picked up by pickup panel and passed to electronics. Thus before going to make the glass gap, it is important to measure resistivity of both top and bottom glass, this will be done using a square jig of copper and brass (5cm x 5cm). Optimum surface resistivity is \( \sim 1-1.2 \Omega/\square \). Conductive paint specially developed by M/s Nerolac is sprayed by using a spray gun. Measured resistivity in 5×5 points will be tabulated in the following table.

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**c. Gluing the glass with the spacers**

The glue is used for stabilizing the glass plates with the spacers was 3M Scotch-weld epoxy adhesive DP190 Gray in a duo-pack cartridge. Since the size of the RPC is small, it was decided to use four button spacer in the between the plates. A small drop of glue binds the buttons with one sheet of glass. The other glass plate is rested on top of the buttons with the help of suction cups, so that the glue is not spilled and the glass sits neatly in line with the one under it. The glue is then applied to the gap between the spacer and glass.
After a period of 8 hours, the RPC is turned over and the glue is applied to the other side. After 8 Hours RPC gas gap had become ready for leak test.

d. Gas leak test and estimate the leak rate

To test if there are any leaks during the application of glue a pressurized gas leak test was done. The RPC is filled with R134a/N\textsubscript{2} gas which is connected to the RPC with a needle valve which helps in slowly increasing the pressure in the RPC. A pressure of 30 mm of water column was maintained using Adriano based leak test setup. and it was found that the RPC has to keep at this pressure for almost 8 hours revealing that there are no leaks. This experiment will use a leaky RPC and measure leak rate with a very short time. Fill the following table and calculate leak rate.

<table>
<thead>
<tr>
<th>Time</th>
<th>Pressure in mmWC</th>
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</table>
Gas cylinder

RPC

Manometer
**Pickup Strips and characteristic impedance**

The RPC is now sandwiched between two honeycomb pickup panels placed orthogonal to each other and then packed in an aluminum case. The pickup panel consists of 8 strips copper foil on one side of a layer of 5mm of foam and aluminum on the other side. Each strip is of width 2.8 cm with a gap of 0.2 cm in between two adjacent strips. Each strip is terminated with a 50Ω impedance to match the characteristic impedance of the preamplifier. A layer of Mylar sheet of thickness 100 μm is placed between the resistive coating and the pickup panel to provide insulation.

The characteristic impedance ($Z_0$) of a transmission line is the resistance it would exhibit if it were infinite in length or no loss of signal. This is entirely different from leakage resistance of the dielectric separating the two conductors, and the metallic resistance of the wires themselves. It is important to have a fixed impedance of transmission line (independent of length), such that it match with the input impedance of readout electronics to reduce the reflected signal. Signal reflection and distortion can be avoided between cables by matching their impedances to each other. The NIM1 standard requires that all input and output device impedances and cables impedances be 50Ω. Thus, the materials of RPC pickup panel and its design is also optimised to have characteristic impedance of 50Ω. If two cables of impedances $R$ and $Z$ are connected to each other, the value of the ratio of their difference to their sum, $(R-Z)/(R+Z)$ gives the ratio of reflected signal with respect to incident signal and matching these impedance one can avoid any loss of signal due to reflection.

But there are times when two cables or devices of two different impedances need to be interconnected to each other. When this need arises, the principle of termination is used. Termination is the addition of supplementary impedance(s) to the impedances of two devices or cables to adjust the load seen by both of them at their interface. Termination can be done either in series or in parallel or a combination of both. This technique is used here to determine the characteristic impedance of the RPC pickup panel, where a varying resistance is used to ground the strips and reflected of signal between the junction of strip and the varying resistance is used to measure the characteristic impedance of RPC strip. The flowing figure shows the electric connections,
To start with, we have to first set the wave generator to give us a negative pulse of duration 10ns and amplitude of 300mV. Now the wave generator has an input impedance of 50ohm and the wire connecting to through T-connector to oscilloscope and to pick up strip. Pickup strips are grounded through a potentiometer. A typical reflected signal is shown in the following fig for improper impedance matching. Measured the ratio of reflected signal peak and original signal peak for the following value of resistances,

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<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
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<th>80</th>
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Then choose ranges, where you have minimum ratio, e.g., it is in 40Ω and 50Ω, then take reading in smaller variation of R to have more accurate value of characteristic impedance

<table>
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<tr>
<th>50+1</th>
<th>50+2</th>
<th>50+3</th>
<th>50+4</th>
<th>50+5</th>
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**Characterization of the RPC**

The RPC is then kept on an aluminum plate and is connected to the pre amplifier board. The RPC is introduced into a system of continuous gas flow for more than a day so as to flush out the air from it. The gas mixture used is given in the table.

<table>
<thead>
<tr>
<th>Gas Constituents</th>
<th>Percentage</th>
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<td>R134a</td>
<td>95.2</td>
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<tr>
<td>Isobutane</td>
<td>4.5</td>
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<tr>
<td>Sulphur Hexafluoride (SF6)</td>
<td>0.3</td>
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The use of gases depends on the following factors:

- low working voltage
- high gain
- good proportionality
- high rate capability.

Tetrafluoroethane (known as Freon), which is widely used, has shown these specifics. But here we use R134A (as Freon) which is eco-friendly. Isobutane acts as the quenching gas which absorbs the extra photons that are generated. We use SF$_6$ (Sulphur-hexafluoride) to control the excess number of electrons and help to localized signal to have precise position information of traverse charge particle.

**a. I-V characteristics and noise rate**

In this setup, gas mixture is fixed for the operation of RPC in avalanche mode. To have the best performance, first we need to find the operating HV. This can be done using information of dark current in the RPC and the noise rate of RPC signal as a function of applied HV. The gain of the preamplifier is ~80 and the discriminator threshold of signal is ~30mV. Variation of dark current and noise rate in few strips with applied HV will be used to identify that the chamber is useful for any experiment or need to change/correct a component. Typical operational HV of this chamber is ~10kV. A good RPC should have dark current less than 50ns and noise rate per strip less than 50Hz.
b. Measuring Efficiency

But, final test of the RPC is done by measuring the detecting efficiency of charge particle, e.g., cosmic ray muon. Typically, efficiency is measured with the help of scintillator paddles. Scintillator paddles are optical fibers/wave guide are connected to a photomultiplier tube. The photons generated in the scintillator are propagated in all direction, but all sides except side of the PMT, it was covered with highly reflective material, e.g., Tyvek, thus eventually all photon, except the loss due to self-absorption and loss at surface propagated towards the photomultiplier tube which converts them into electrical signals. These paddles are arranged in line with a particular strip of the RPC pickup panel. The presence of a muon trajectory is ensured by the trigger paddles and efficiency of the RPC is determined by the fraction of events, where RPC signal is above the threshold value of the discriminator. Before doing this we must ensure that the noise rate of the RPC is very less.

But, during this experiment, both noise rate/dark current and efficiency are measured together. The following setup is used to do that.

![Diagram](image)

Three Scintillator paddles are arranged on top and below of the RPC under test as mentioned above. Care should be taken that the alignment of the telescope is accurate to avoid inefficiency due to wrongly triggered event where muon does not pass through the RPC. These Paddles are supplied with high voltage from the HV distribution box. HV for RPC is supplied separately. Signal outputs of Paddles are directly taken to the discriminator module. Threshold adjustment for the discriminator and width...
adjustment for the pulse shaper can be done in the same module. RPC pulses are small - in the order of few mV. So, RPC pulses are amplified by using an HMC Preamplifier with a gain of about 80 and then fed to the Discriminator.

1. Before starting the experiment make sure that the RPC is flushed with appropriate gas for sufficient time.
2. Ramp Up the Voltage of the RPC detector in steps of 100V for both the polarities.
3. At each step, wait for few minutes so that the current stabilises.
4. Connect the raw signal output from RPC detector to Oscilloscope and look for appropriate pulse and noise level.
5. Remove cables from oscilloscope and connect to AND logic module to get following logical signals.
   a. 1f = RPC
   b. 3f = P1 . P2 . P3
   c. 4f = RPC . P1 . P2 . P3
6. Note down the observed Current and set Voltage values at each step and plot as a function of HV
7. Fit the two regions of the IV characteristics, understand the reasons for the same and fit the curves and obtain the resistance values.
8. Plot the strip count (1f) as a function of applied HV and that should be similar to the figure given below, where rate is increases rapidly with the increase of HV.
9. Efficiency is calculated as (4f) × 100/(3f) at each HV operation and that should be looks like the following plot, initially the efficiency is zero and gradually increased to nearly 100%.

![Noise rate of strips as a function applied HV](image1.jpg)  ![Efficiency as a function of applied HV](image2.jpg)
Cosmic muon angular distribution using existing RPC stack

In this experiment, we will use previously prepared 12 RPC detectors of size 1m×1m with 32 strips in either side. These strips are also having same 3cm pitch and connected with the same electronics of the small detector. Cosmic muon events are self-triggered by this RPC stack and using the information of all strips, the muon trajectory is reconstructed with a precision of position in few mm and angular resolution of $\leq 1^\circ$. This detector is continuously collecting data of cosmic muon and those data will be used to measure position dependent efficiency of those detector as well as time resolution of the detector. Typical zenith angle distribution of this RPC stack is shown in the following figure. Make plots of position and time resolution of RPC detectors. Also measure the zenith and polar angle distribution of cosmic muon.

[Graph showing zenith angle distribution of cosmic muon in RPC stack]

Zenith angle distribution of cosmic muon in RPC stack.