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Development of glass resistive plate chambers for INO experiment

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ABSTRACT

The India-based Neutrino Observatory (INO) collaboration is planning to build a massive 50 kton magnetised Iron Calorimeter (ICAL) detector, to study atmospheric neutrinos and to make precision measurements of the parameters related to neutrino oscillations.

Glass Resistive Plate Chambers (RPCs) of about $2\,m \times 2\,m$ in size are going to be used as active elements for the ICAL detector. We have fabricated a large number of glass RPC prototypes of $1\,m \times 1\,m$ in size and have studied their performance and long term stability. In the process, we have developed and produced a number of materials and components required for fabrication of RPCs. We have also designed and optimised a number of fabrication and quality control procedures for assembling the gas gaps.

In this paper we will review our various activities towards development of glass RPCs for the INO ICAL detector. We will present results of the characterisation studies of the RPCs and discuss our plans to prototype $2\,m \times 2\,m$ sized RPCs.

1. Introduction

India-based Neutrino Observatory (INO) collaboration is proposing to build a massive magnetised Iron Calorimetric (ICAL) detector in an underground laboratory to be located in South India, to study atmospheric neutrinos and to make precision measurements of the parameters related to neutrino oscillations. Since ICAL will be able to distinguish neutrino events from anti-neutrino events by detecting the sign of the produced muon, it will be possible to study the earth matter effect and thereby the neutrino mass hierarchy problem. This detector is also being planned to be used as a very long base line detector during the neutrino factory era in future.

The detector choice for the experiment was to use magnetised iron as target mass and glass Resistive Plate Chambers (RPCs) as active detector medium. The detector should have large target mass of 50–100 kton and should be modular for ease of construction. Good tracking and energy resolutions, good directionality (translating to a time resolution of better than a nano second) and charge identification of the detecting particles are the other essential capabilities of this detector, which is proposed to compliment the potentials of other existing and proposed detectors.

ICAL is a 50 kton magnetised iron tracking calorimeter, comprising of about 140 layers of low carbon 60 mm thick iron plates [1]. The iron absorber will be magnetised to a strong field of about 1.5 T. Sandwiched between these layers are glass RPCs, which are used as the active detector elements. Lateral dimensions of this cubical geometry detector are $48\,m \times 16\,m \times 12\,m$. The geometry and structure of INO magnet is largely fixed by the principle of ICAL detector [2]. Its purpose is two fold; providing target nucleons for neutrino interactions and also a medium in which secondary charged particles can be separated on the basis of their magnetic rigidity. About 27,000 RPCs of dimensions $2\,m \times 2\,m$ will be deployed in this detector and inserted into the 25 mm slots provided between iron layers. While the ICAL detector concept is shown in Fig. 1, its main features are summarised in Table 1.

2. Initial work on development of RPCs

An aggressive R&D program to develop and characterise large area glass RPCs was undertaken.

We have started our detector R&D work by fabricating several dozen glass RPCs of dimensions $30\,cm \times 30\,cm$. A gas mixing unit capable of mixing four individual gas components and control the mixed gas flow through the detector chambers has been designed and developed [5]. All the prototype chambers have been tested

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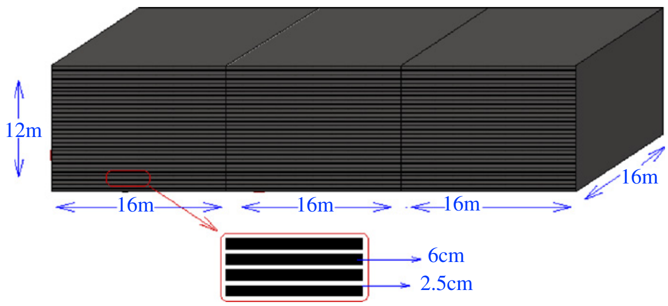

Fig. 1. Concept of ICAL detector.

Table 1
Salient features of ICAL detector.

No. of modules	3
Module dimension	16 m × 16 m × 12 m
Detector dimension	48 m × 16 m × 12 m
No. of layers	140
Iron plate thickness	60 mm
Gap for RPC trays	25 mm
Magnetic field	1.5 T
RPC unit dimension	2 m × 2 m
Readout strip width	30 mm
No. of RPCs/road/layer	8
No. of roads/layer/module	8
No. of RPC units/layer	192
Total no. of RPC units	27,000
No. of electronic channels	3.6×10^6

for their performance using a scintillator paddle-based cosmic ray muon telescope. A data acquisition system for RPC testing has been designed and developed using NIM and CAMAC electronics. The data collected by the on-line systems is analysed using standard physics analysis software packages such as PAW and ROOT. Apart from this, various slow monitor parameters such as ambient temperature, relative humidity, gas flow into the RPC, applied high voltage, chamber current etc. are also recorded.

We have started our studies by looking at some of the basic operating characteristics of the chambers, such as RPC pulse profiles, voltage–current relationship, individual counting rates of the RPC and so on. We have established a reliable way of monitoring the stability of the chamber based on its noise rates. We have obtained chamber plateau efficiencies of over 90% for various gas mixtures. We have made detailed measurements on the charge–time linearity, time response as well as the time resolution of the RPCs and obtained a typical timing resolution of about 1.2 ns while the RPC is operating on its plateau.

While the results we obtained were consistent with those reported in the literature, we have faced a serious problem when we operate the RPCs continuously. We have noticed that their efficiency drop suddenly, while their noise rates and chamber currents shot up. The chamber could not be revived. We broke open a damaged chamber and scanned the inner surfaces of the electrodes under Atomic Force Microscope (AFM) and Scanning Electron Microscope (SEM). The structures shown in the AFM and SEM scans were found to be rich in Fluorine, confirming the reasoning that Freon (R134a) gas contaminated with moister, forms Hydro Fluoride (HF), which actually damages the RPC.

3. Muon tracking using an RPC stack

We had fabricated 10 RPCs using the same materials and fabrication procedures and parameters as those described earlier. Float glass of thickness 2 mm and size 30 cm × 30 cm was used. The RPCs were mounted as a stack such that the signal pickup strips of all the chambers were well aligned geometrically. The chambers were operated in the streamer mode, using a mixture of Argon, Isobutane and Freon (30:8:62 by volume). The operating high voltage for the tests was kept at 8.6 kV. Using the above stack, we could record some interesting cosmic ray muon induced tracks (Fig. 2). Muons arriving at different angles could be captured simply by relocating the telescope window. This has demonstrated that indeed these prototype chambers are capable of effectively tracking cosmic ray muons. The information recorded in these tests was also used to extract other parameters of interest, such as efficiency, noise rate and timing of individual RPCs and their long term stability.

4. Long term stability tests of INO RPC prototypes

While the problem of sudden aging in the glass RPC prototypes was being investigated, a few RPCs of dimension 40 cm × 30 cm were fabricated, using glass procured from Japan. The fabrication and test procedures were similar to those of the earlier prototypes. These new chambers were being operated in avalanche gas mode, in which a gas mixture of Freon (R134a) and Isobutene in the proportion 95.5:4.5 by volume was used. The chambers are being operated at a high voltage of 9.3 kV. Since the pickup signal strength in avalanche mode is much smaller to that in streamer mode, external amplification has been provided by preamplifiers of gain 10. Rest of the electronics and data acquisition chain is again the same as that used earlier.

A comprehensive monitoring system for periodically recording the RPC high voltage currents as well as the ambient parameters such as temperature, pressure and relative humidity—both inside and outside the laboratory has been designed and implemented. Using this data with the RPC test data, several correlations between the ambient parameters and the RPC operating characteristics could be established.

As can be seen from the plots in Fig. 3, the performance of these chambers, characterised by their efficiency, leakage currents and noise rates, have not changed over a period of three and a half years. We have stopped these long-term stability runs at the end of last year. These tests have indicated that the aging problem associated with the previous RPCs is related to the quality of glass used to fabricate those RPCs as well as their operating mode. We have again this year fabricated a large area RPC using local glass and tried to operate the chamber in streamer mode using the streamer gas mixture. But the chamber's efficiency dropped suddenly after surviving barely for a few weeks. This has reconfirmed our earlier conclusion on the issue of detector aging.

5. Development RPC materials and assembly procedures

RPC fabrication involves deploying a large number of materials as well as many assembly procedures. So, production of high performance and reliable chambers involves choosing the right type and quality of materials as well as optimisation of various assembly and quality control procedures involved in the fabrication. Materials such as glass used for electrodes, individual gases used for mixing and flowing the gas mixtures for the operation of the chambers, spacers, buttons, gas nozzles (Fig. 4) etc. which are needed for the assembling the chamber, resistive coat on the electrodes, epoxies used for gluing together different types of materials, pickup panels used for external signal pickup from the chambers, polyester films used for insulating the pickup panels from the resistive coated electrodes, to name some. We have