Design and Test of a Gluing High Rate MRPC

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Abstract—MRPC has become a preferred triggering detector in many heavy-ion experiments, because it has a high efficiency and excellent time resolution. The Compact Muon Solenoid (CMS) at LHC is considering using trapezoid MRPC for muon system upgrading. But the size of MRPC is limited by the production technology of low resistive glass at present. We designed a prototype of large MRPC and its electrodes are developed by gluing two pieces of glass plates. The glued area is about only 1 mm. The mosaicked MRPC has five gas gaps with 0.25 mm width and the dimension of the detector is 2547 cm\textsuperscript{3}.

To estimate the glues impact, we made a simulation of the weighting field in readout electrodes using Ansoft Maxwell and analyzed the induced signals. Simulation demonstrates that the efficiency of the 1 mm glue area is still higher than 93\% and the affected region is less than 1\% of the total area.

This MRPC was tested by cosmic ray with working gas of 90\% Freon, 5\% iso-butane and 5\% SF\textsubscript{6}. The results proves that the detector efficiency is about 94.2\% at HV=6.9 kV and the time resolution is around 73 ps. This detector was also tested at GIF++ on this August. The performance in different radiation flux was studied. The efficiency can reach 96\% and the other performance is also excellent.

I. INTRODUCTION

The multi-gap resistive plate chamber (MRPC) is originally designed for muon trigger detectors and has got extensive development in LHC experiments ever since. MRPC is developed from Resistive Plate Chamber (RPC) and has a more excellent time resolution and higher efficiency. With the increasing of accelerator luminosity, high rate MRPC will have even more applications and is capable to replace RPC in some areas. In Compact Muon Solenoid (CMS) experiment at CERN, MRPC is supposed to be a promising updatder of RPC as trigger detector to better satisfy accelerator energy around 14 TeV, 100 times of the present.

RPC system lies on both barrel and endcap area of the CMS detector. Every single RPC module is made by two bakelite plates [1] which are needed to be large but thin. However, the size of high rate MRPC is restricted to 30*32 cm\textsuperscript{2} owing to the production technique. Present large MRPC in TOF detector is achieved by piling up hundreds of MRPCs, which makes the system much thicker than a single module [3]. Thus, thin and high rate MRPC with large size is in need.

We have done research and experiments on a prototype of gluing MRPC. A simulation of weighting field based on Maxwell was completed and the detector was also tested by cosmic ray and beam at GIF++ August 2015. Results demonstrate that this large gluing prototype of MRPC is proved to be well performed and cheap.

II. SIMULATION OF WEIGHTING FIELD

A. Principle of weighting field theory

The real electric field in gas gaps of MRPC is always calculated by dividing the high voltage applied on graphite layers by the total gap width, because in typical MRPC, bulk resistivity of gas and glass are $10^{12}\Omega\cdot cm$ and $10^{10}\Omega\cdot cm$ (10$^{10}\Omega\cdot cm$ for low resistive plate) which means the voltage drop on plates are one in a thousand (one in 100 thousand) of that in the gas gap. Value of the real field is around 10 kV/mm and this determines the circumstance of avalanche, in other word, Townsend and attachment coefficient.

When original or avalanche particles move toward a resistive plate, induced signals can be measured on read-out electrode. According to the Ramo theory [7], the induced current is

$$I(t) = \frac{E_w}{V_w} \dot{X} q$$

where $X$ represents the charge trajectory in the detector, $q$ is the charge released in the gas gap, $E_w$ is called weighting field, which is the electric field in the gas gap when removing the charge and setting the voltage of read-out electrode to be $V_w$ and others 0. For strip
read-out plates, the Z component of weighting field in one gap can be given by solving Maxwell equations as [8]

$$E_z(x, z) = V_w \varepsilon_1 \frac{2}{\pi} \times \int_0^{\infty} d\kappa \sin(\kappa x) \sin\left(\frac{\kappa w}{2}\right) F_1(\kappa, z)$$

(2)

where \(\varepsilon_1\) is the relative permittivity of plates, \(w\) is the strip width and \(F_1\) is a function related to relative permittivity and width of every layer. Weighting field acts like a weighting factor which reflects how much the capacitors of gas and plates affect detectors performance. By setting a threshold \(Q_0\) in detection, Reigler deduced the efficiency function [9]

$$eff = 1 - e^{-\left(1 - \frac{2}{\alpha}\right) \frac{V_w}{\alpha \eta Q_t} 1/\alpha \lambda}$$

(3)

where \(\alpha\) is Townsend coefficient, \(\eta\) is attachment coefficient, \(\lambda\) is average distance between clusters, \(d\) is gap width and \(e_0\) is electron charge. (3) indicates that, by simulating display of \(E_w\), the efficiency can be estimated.

B. Simulation model and results

The analytic solutions of weighting field are difficult to achieve mathematically, so simulation is always a good method to obtain numerical values of the weighting field. ANSYS Maxwell is a common commercial software dealing with electromagnetic problems. By solving quasi-static approximation Maxwell equations, it can be used to simulate the weighting field in a given MRPC gap. Majumdar has done similar simulations of RPC weighting field previously with neBEM [10]. We have built the same model as explained in ref [10], and get a totally same result. In order to study on the weighting field on MRPC, we built a 3D model of 5 gap gluing MRPC and the XZ plane is shown in Fig.1. The readout strip is set across the glue to better research on the glues influence.

Parameters of all the components are listed below:

The dimensions of two different glasses are 25cm20mm and 25cm27cm. 1 V voltage is applied on to the central top readout strip while the others are kept 0.

Simulation presents that in normal region, \(E_x=E_y=0\), \(E_z=5.32\) V/cm, but in the glue region, none of the 3 components of electric field is 0. According to section 2.1, we define Z component of electric field the weighting field. The first Fig.2 shows weighing field in 5 different gas gaps (1-5, top-bottom) around gluing region which is from 270 mm to 271 mm. Since the tendency in every gap is similar, the average is taken and shown in second of Fig.2. Weighting field drops from 5.32 V/cm to 4.12 V/cm and the affected area is 2.2 mm. The real electric field in gap is \(V/5d=11\) kV/mm, and from Fig.4 in [9], the Townsend and attachment coefficient is around 140/mm and 10/mm respectively. We assume that efficiency of the normal region can reach 94%, and when the weighting field is 5.32 V/cm, a charge threshold can be obtained. Substituting the weighting field around the glue into (3) when other variables are given, we can get an efficiency still around 93%. This proved that the influence of this 1mm glue is small.

III. DEVELOPMENT AND TEST OF GLUING MRPC

A. Production

Supported by the simulation results, we designed a five gap gluing MRPC with 0.7 mm-wide low resistive glass (1010cm) electrodes. As showed in Fig.3, the dimension of gluing module is 47.1251.9cm3, the same as the simulation model. Corresponding plates are stuck by an optical glue, previously used to sticking light-sensitive diode and halogen crystal in detectors. Parameters of every component in gluing MRPC are shown in Table.1 Parameters of Gluing MRPC component Table.1. Signals of gluing MRPC are read out using only one PCB board, 12 strips, double side. The whole MRPC is enlarged but
Fig. 1: XZ plane of MRPC Model

<table>
<thead>
<tr>
<th>Component</th>
<th>Width (mm)</th>
<th>Relative permittivity</th>
<th>Bulk Conductivity (s/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read-out Strip</td>
<td>0.1</td>
<td>3.5</td>
<td>5.8 × 10^-7</td>
</tr>
<tr>
<td>Insulated layer</td>
<td>0.18</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>Graphite</td>
<td>0.05</td>
<td>1</td>
<td>7 × 10^-4</td>
</tr>
<tr>
<td>Resistive plate (Glass)</td>
<td>0.7</td>
<td>8</td>
<td>10^-8</td>
</tr>
<tr>
<td>Glue</td>
<td>1</td>
<td>4.3</td>
<td>0</td>
</tr>
<tr>
<td>Gas</td>
<td>0.25</td>
<td>1.006</td>
<td>0</td>
</tr>
</tbody>
</table>

TABLE II: Parameters of Gluing MRPC component

<table>
<thead>
<tr>
<th>MRPC Component</th>
<th>Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honey Comb</td>
<td>255 × 472 × 6</td>
</tr>
<tr>
<td>PCB</td>
<td>320 × 540 × 0.7</td>
</tr>
<tr>
<td>Mylar</td>
<td>260 × 480 × 0.18</td>
</tr>
<tr>
<td>Gluing Glass</td>
<td>250 × 470 × 0.7, 250 × 200 × 0.7</td>
</tr>
<tr>
<td>Glue</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Gap</td>
<td>0.25 × 5</td>
</tr>
</tbody>
</table>

Fig. 3: Diagrammatic sketch of Mosaic MRPC. (1) Honey Comb Board; (2) PCB Board; (3) Mylar; (4) Low Resistivity Glass; (5) Graphite; (6) Fishing Line; (7),(8) Stud & Nut; (9) Separator; (10) Block; (11),(12) Screw & Nut

Fig. 4: Photos of Gluing MRPC

is still thinner than 2cm, suitable for CMS upgrade. The first picture in Fig. 4 shows the process of adding glue and the second is a photo of gluing glass. Glass has better planeness when the liquid glue is dried naturally than baked in oven, which costs much less time than the former. Fishing line in second Fig. 4 goes across the glue to reduce the possibility of break in glue due to unbalanced forces.
B. Cosmic ray test and results

Cosmic ray tests have been done to test how the mosaic MRPC functions practically. The detector is put into a sealed box to supply its typical working gas—96% C₄H₂F₄, 3.7% iso-C₄H₁₀, and 0.3% SF₆. NINOs FEE is used and TOT signals are read out and processed. Experiment setup is shown in Fig.5, gluing MRPC is laid between some scintillators, which are read out by 5 PMTs. Scintillators and MRPC are aligned vertically, so if cosmic ray triggers both the top and bottom scintillators, then it must pass through the gluing MRPC. Scintillators are smaller than MRPC and are placed in the middle, which covers the area of the separator. Fig.6 shows the efficiency plateau curve of the gluing MRPC. Triangle symbols represent the efficiency data of the experiments and the square symbols represent the cluster size data. Red and blue curves in Fig.6 are the fitting curve. Cluster size means the average number of strips that is triggered by one cosmic particle. The maximum cluster size is 1.8 in experiments. When the voltage reaches 7kV, the efficiency can reach 94.6%. Plateau begins from 6.9kV while the efficiency is 94.2%, demonstrating that this gluing MRPC has a high efficiency.

Setting the working voltage to be 6.9kV, we collect and select nearly 10000 vertical incidences. Slewing corrections are made to reduce the systematic error caused by amplitude and the time over threshold. Fig.7 shows the PMT time display both before and after slewing correction. Fig.8 and Fig.9 shows the time display of signals on 2 read-out strips of MRPC. The slewing correction on MRPC considers also the influence of PMTs. Noises on the display is cut off before fitting. Each unit in above figures is 25 ps. We get the time resolution of strip 3:

$$\delta = \sqrt{3.349^2 - 1.766^2} \times 25 = 71.1\text{ps} \quad (4)$$
and time resolution of strip 4:

\[ \delta = \sqrt{3.442^2 - 1.766^2} \times 25 = 73.9\text{ps} \] (5)

So the experiments prove that the time resolution of gluing MRPC is under 74ps which is approximately equal to that of a simple MRPC. Time resolution results indicate the capability of gluing MRPC to be a large triggering MRPC in CMS experiments.

C. Beam test

The gluing MRPC has been tested at the Gamma Irradiation Facility (GIF++) which is located in Super Proton Synchrotron at CERN. The GIF experiment is in the X5 beam and it allows detectors to be tested using a muon beam at around 150 GeV/c while irradiated by 662 keV photons from $^{137}$Cs source. The setup of the beam test is shown in left of Fig.10, and the right of Fig.10 is a photo of detectors.

The left in Fig.11 shows the efficiency of gluing MRPC as a function of applied voltage. It proves that the detector still has an efficiency higher than 96% at the HV=9.8kV, capable of detecting in heavy-ion experiments. The right in Fig.11 shows the efficiency versus source intensity which is aimed to measure the variation of detector performance when the source intensity changes. Gluing MRPC has behaved stable when intensity increases. In future a larger MRPC glued by more than 4 plates will be studied and tested.

IV. Conclusion

Detector signals induced on the read-out electrode is related to the weighting field in gas gaps, explained by Ramos theorem. So understanding the performance of this new style MRPC cannot ignore research on the weighting field.

The large area MRPC glued with two or more glasses is proved to have good performance in detecting particles with low costs. Simulation of Maxwell indicates that 1 mm glue causes little influence of the detector—the efficiency loss is less than 1% and the affected area is less than 0.5% comparing to the total size. Besides, cosmic
ray tests have been processed, showing that the efficiency of the mosaic MRPC reaches 94.6\% at high voltage of 6.9kV and the time resolution is better than 74ps. This detector was also tested at GIF++ August 2015. The performance in different radiation flux was studied. The efficiency measurement proves that it can reach 96\%. Method of mosaic MRPC is demonstrated to be feasible and has a bright prospect.

REFERENCES


