Fabrication and Characterization of Gaseous Detector for the identification of High Energy Particles.

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Abstract. There is a vast range of gases which get ionized, produce electron-ion pairs, on the passage of high energy charged particles. Such gases are extensively used in experiments such as LHC, Belle-II, RHIC, DAFNE, etc which produce high energy particles. Panjab University established a detector assembly and characterization laboratory dedicated to gaseous detectors such as Resistive Plate Chamber (RPC) and Gas Electron Multiplier (GEM) for the LHC experiment. Here, we present the recent work on the fabrication and characterizations of the GEM detector at Panjab University.

1. Introduction

Gaseous detectors generally have two electrodes separated by the gas medium in which primary charged particles interact and produced electron-ion pairs. The GEM detector is one of the most important Micro-Pattern Gaseous Detector (MPGD) first introduced in 1997 by F. Sauli [1] at the European Organization for Nuclear Research (CERN). It records the ionization produced by charged particles in the gaseous medium consists of three GEM foils embedded between the drift board (acting as the cathode) and the readout board (acting as the anode) [2]. The GEM detector abundantly used in High-Energy Physics (HEP) experiments like CMS [3], LHCb [4], TOTEM [5], COMPASS [6] at Large Hadron Collider (LHC), Belle II [7], etc, and in medical diagnostics [8] as well as in astronomy due to their high rate detection [9] capability up to 100 MHz/cm\textsuperscript{2} with efficiency above 97\%, an excellent spatial resolution of $\sim$ 340 $\mu$m, an excellent time resolutions [10] of $\sim$ 8 ns. In most of the experiments to achieve high gain a high voltage supposed to apply across the detector which leads to an electrical breakdown problem. This problem can be avoided by using multi-layer GEM foils placed at a relative distance of a few mm in a suitable gas mixture. In this case, amplification is shared over different gem foils [11], with a relatively low voltage on each GEM foil. Panjab University has been collaborated with CMS [12] and build high-energy physics laboratory to assemble and test [13] triple-GEM detectors (referred to GE1/1 detector) that are installed in the 1\textsuperscript{st} ring in 1\textsuperscript{st} muon station in both end-caps of the CMS detector. The GEM foils and other components of production chambers are delivered from CERN.
2. Description and working principle the GEM detector

The GEM detector works in a gas medium in which gas ionization takes place due to the acceleration of electrons under the influence of the electric field. Since among noble gas Argon (Ar) is having high specific ionization and is less expensive. It can cause avalanche creation beyond the limits which leads to sparks and cause permanent damage to the detector. There is a need for a small amount of quenching gas which can be used to reduce the spark probability and to stop fake avalanche due to the emission of UV photons. The Carbon-dioxide (CO$_2$) has the properties of electro-negativity, it attracts electrons and attached to its molecules. A lot of studies have been performed on the selection of gas mixture to be used for this detector [14]. The gas mixtures of Ar and CO$_2$ are used in proportions of 70:30. Basically, a triple GEM gaseous detector is made by a drift cathode, three GEM foils, and the Printed Circuit Board (PCB) anode (or readout board). Readout board has two gas connectors located at two diagonal corners, one for gas inlet and another one for gas outlet. GEM foils are made of Kapton of 50 $\mu$m each coated with a copper layer of 5 $\mu$m on each side. The Kapton is a good insulator which remains stable in a very wide range of temperature. Each foil has equally spaced small holes perforated by chemical etching in a hexagonal pattern with 50 $\mu$m internal and 70 $\mu$m outer diameter and a pitch of 140 $\mu$m as shown in Figure 1 (Left) where the signal gets amplified as shown in Figure 1 (right). The cms triple GEM production chamber has a 3/1/2/1 mm (drift/transfer1/transfer2/induction) gas gap configuration as shown in Figure 2 which is enclosed between two electrodes with an electric field applied between them. The primary electrons produced ionization in the gap between the cathode and the first GEM foil (drift gap). In transfer region electron-ion pairs are attracted by electric filed applied on GEM foil where they get multiplied in the hole. After crossing the last GEM foil they drift to the anode in the induction gap where the signal is registered by the readout strips.

3. Assembly and quality control testing

After receiving a kit of the different parts of the production chamber from CERN, they inspected very carefully for any possible damages that happened during transport. After that next step is the assembly of the different parts of the GE1/1 detector. Many quality control(QC) test have been performed during and after the assembly such as current leakage in foil, gas leak rate of the detector, noise, effective gas gain, etc.
3.1. Pre-assembly and assembly

3.1.1. Pre-assembly: The drift board and readout are cleaned using a vacuum cleaner. All the screws and pull-outs are cleaned with an ultrasonic bath to remove any dust. Then the drift board is prepared by placing high voltage pins as shown in Figure 3 (Left), mounting resistor and capacitor as shown in Figure 3 (Middle), and pull-outs as shown in Figure 3 (Right). Spacers are prepared by fixing the brass-inserts using pressure and are used for creating gap between the foils. Readout board screwed gently with the gas connector on the readout board as shown in Figure 4 (Left).

3.1.2. Assembly: A class 100 clean room is built at PU site for the assembly. All foils are stretched in the frames and cleaned gently by using an anti-static sticky roller over the foils on both sides in order to remove the dust particles as shown in Figure 4 (middle). Then foils are tested with the MegaOhm/insulation meter by applying 550V voltage to foil by putting a negative pin on the top and positive pin on bottom high voltage (HV) pads of the foils for several minutes. The foil is accepted if the resistance of foil reaches 10 GΩ after few seconds with relative humidity less than 40%. During assembly first cleaned plexiglass is placed then 3 mm clean spacer is inserted on the guiding pins. After that GEM1 foil is placed then 1 mm spacer as shown in Figure 4 (Right). Then in a similar way, GEM2 foil, 2 mm spacer, GEM foil3, 1 mm spacer are placed to form a stack called GEM foil stack as shown in Figure 5 (Left). Plexiglass is placed on the top of the GEM foil stack using guiding pins and then uses screws to the protect GEM stack. Then the excess amounts of Kapton foils are removed using a sharp blade and detached stack from bottom plexiglass and placed it on the drift board. The chamber moved to the assembly jig and clamp the drift board to the assembly table using aluminum bars as shown in Figure 5 (Middle). After placing all the screws in place, the plexiglass and aluminum bar is removed. After that, the GEM foils and all gaps are tested at 550V and the foils are discharged after the test. To test the induction gap, the Panasonic-to-Lemo adapters are connected to one of the readout sectors and 550 V applied between GEM3 bottom and signal pad of the Panasonic-to-Lemo adapter, keeping the chamber in a vertical position as shown in Figure 5 (Right). The impedance should immediately reach 100 GΩ. All QCs results reported in this paper are obtained from a GEM detector having the ID “GE1/1_X_S_INDIYA-00YY” (where ‘YY’ stand for ‘02’, ‘07’, ‘08’, ‘09’, ‘10’, ‘15’, ‘16’, ‘17’).
Figure 4. Left: Fixing the gas connector onto the readout board, Middle: Cleaning of the GEM foil with the anti-static roller, Right: Placing the internal frame after testing.

Figure 5. Left: Assembled GEM stack, Middle: Finalizing the stretching of the stack, Right: Assemble detector and testing the induction gap

3.2. Quality control testing

3.2.1. Post-assembly QC2 test: To check again GEM foils after assembly if they are clean or not by measuring the leakage current of the GEM foils and gas gap. The leakage current is that current which flows from the top surface of the foil to the bottom due to the surface conductivity. Due to deposition of some contaminants on the surface of foil in the form of moisture or dust particles will increase this leakage. The detector is accepted if the impedance of each foil and gap is above 10 GΩ and 100 GΩ respectively and the number of sparks are zero after every minute over a period of 10 minutes. Similarly, an impedance also measured over all 24 Panasonic connectors and it should be greater than 100 GΩ. If impedance does not fulfill these criteria then there are might be some short circuit and in that case, the detectors have to be reopened and fixed the issue in the clean-room. All the 8 detectors assembled at the Panjab University site qualified the QC2-Leakage current test.

3.2.2. QC3 (Gas leak) test: If the first test goes fine, then we proceed for the QC3 test which is Gas leak test to identify the gas leak rate of the detector by monitoring the drop of the internal over-pressure as a function of the time. A typical QC3 system has 2 flow-meters, a microcontroller based Arduino chip having 3 sensors for atmospheric pressure, internal gas pressure, and temperature measurements stand prepared at the Panjab University is shown in Figure 6 (Left). The detector is connected in between the inlet and outlet of the calibrated gas system.
and filled with CO$_2$ at the rate of 5 L/h. The chambers cannot sustain internal over-pressure higher than 40-50 hPa. All chambers, except our first production chamber, were tested with an initial over-pressure of 25 hPa, and its internal pressure is monitored for 1 hour. The internal gas pressure is parametrized by $P(t) = P_0 \exp(-t/\tau)$, where $P_0$ is the initial internal over-pressure [15]. The QC3 acceptance limit is $\tau \geq 3.04$ hour, corresponding to a maximum acceptable gas leak rate of about 7 hPa/hr. All the detectors successfully passed the QC3 gas leak test because gas leak reduction rate is less than 7 hPa/hr as shown in Figure 6 (Right).

![Figure 6. Left : Front view of QC3 Gas Leak Test Stand, Right : Results from the QC3 Gas Leak Test on the GE1/1 detectors assembled at Panjab University.](image)

### 3.2.3. QC4 (High Voltage) test:

After the QC3 test, the QC4 test is performed which is a high voltage test to determine the voltage vs. current curve of the detector and to identify possible malfunctions, defects in the HV circuit, and intrinsic noise rate in GEM detector. The detector is shielded from the background noise with a ground shielding placed on the top of the readout board. The GE1/1 detector under this test is first flushed with pure CO$_2$ gas at least for 5 hours at the rate of 5 L/h. The high voltage (VSET) is provided by programmable HV power supply (CAEN SY5527) which allows the user to control the current limit (ISET), the steps to ramp up and down the voltage, the maximum voltage, and the trip time. A high voltage low pass filter was placed between the power supply and detector to reduce the electronics noise (by rejecting the high frequency noise from the power supply) so that a stable voltage can be provided to the electrodes [16]. The signal generated at the anode is processed using charged sensitive pre-amplifier connected to the bottom electrode of the third GEM foil through a decoupling RC circuit. Further to amplify and record the signal obtained from readout strips signal sent to timing filter amplifier (TFA). The output of TFA is fed into the discriminator to convert it into a rectangular digital pulse which further passes through a dual timer which generates a veto signal to avoid the fake counts. Finally, the resulting digital pulse sent to a scaler and counter unit for the rate measurement.

The discriminator threshold and the scaler clock are set to -140 mV and 60 s respectively. The total resistance ($R_{multimeter}$) of the HV circuit (divider plus HV filters) is measured using a multimeter and is used to calculate the current in the divider for every high voltage points. The current limit ISET of the power supply is set according to the expected target value plus 5 $\mu$A, and the corresponding high voltage VSET is switched on. After the operating current and voltage get stable, the values of actual voltage $V_{mon}$, the current $I_{mon}$, and the intrinsic noise rate of the detector are recorded. The intrinsic noise rate is defined as the rate of signals not arising due to ionization of the gas. The number of counts are measured using the scaler unit.
for interval of 60 s. These steps are repeated until the voltage reaches 4900 V on the detector. The detector is ramped up to 3000 V in the step of 200 V and up to 4900 V in the step of 100 V. The I-V curve is plotted, which must be a linear, and is fitted by a straight line to determine a resistance (“fitted resistance”). The reciprocal of its slope gives the resistance ($R_{IV}$) of the HV distribution system. This calculated resistance $R_{IV}$ is then compared with the value of measured resistance $R_{multimeter}$. The detector is said to pass the test if the deviation in resistance between $R_{multimeter}$ and $R_{IV}$ is $\leq 2\%$ because the deviation greater than 2% indicates a loss of linearity. The maximum intrinsic noise rate should be $\leq 100$ Hz at the value of current $\sim 999 \mu A$ and this rate is below $10^{-2}$ Hz/cm$^2$, which is a negligible value with respect to the 4.5 kHz/cm$^2$ background rate expected in CMS in standard operating conditions. Table 1 shows the value of measured resistance ($R_{multimeter}$) by multimeter, resistance ($R_{IV}$) by IV curve, and the maximum intrinsic noise rate (at the value of current $\sim 999$ $\mu A$) for all the detectors assembled at Panjab University. Figure 8 (Left) shows the monitored voltage ($V_{mon}$) as a function of the monitored current ($I_{mon}$) and Figure 8 (Right) shows intrinsic noise rate as a function of monitored current for different GE1/1 production chambers assembled at Panjab University site. All the detectors successfully passed the QC4 HV test as deviation in resistance is $< 2\%$ and maximum intrinsic noise rate is 11.88 Hz which is very less than 100 Hz. Some data points of 8 chambers are overlapped, as the I-V relation of each chamber is similar to each other.

Figure 7. QC4 HV test experimental setup.

Figure 8. Left: Results from QC4 HV test, Right: Intrinsic Noise Rate as a function of monitored current for different assembled GE1/1 production chambers.
Table 1. Results from QC4 HV test showing the value of measured resistance ($R_{\text{multimeter}}$) by multimeter, resistance ($R_{\text{IV}}$) by IV curve, and the maximum intrinsic noise rate (at the value of current $\sim 999 \, \mu$A) for all the detectors assembled at Panjab University.

| Detector ID | Resistance by Multimeter ($R_{\text{IV}}$) (MΩ) | Resistance by I-V curve ($R_{\text{multimeter}}$) (MΩ) | Intrinsic Noise Rate (HZ) |
|-------------|-----------------------------------------------|---------------------------------------------------|--------------------------|
| GE1/1_X_S_INDIA_0002 | 4.67 | 4.69 | 11.88 |
| GE1/1_X_S_INDIA_0007 | 5.00 | 5.01 | 3.50 |
| GE1/1_X_S_INDIA_0008 | 5.00 | 5.02 | 6.57 |
| GE1/1_X_S_INDIA_0009 | 5.00 | 5.01 | 5.62 |
| GE1/1_X_S_INDIA_0010 | 4.97 | 5.02 | 5.72 |
| GE1/1_X_S_INDIA_0015 | 4.96 | 5.01 | 11.30 |
| GE1/1_X_S_INDIA_0016 | 4.97 | 5.02 | 8.58 |
| GE1/1_X_S_INDIA_0017 | 5.00 | 5.02 | 8.25 |

4. Conclusion
All the QC4 tests have been performed at Panjab University and the results are consistent as recommended by the CMS GEM collaboration. In total, 8 production chambers have been assembled and tested at PU site and shipped to CERN, Geneva and successfully installed in the CMS detector. In future, Panjab university group will be receiving more kits of GEM detector for assembly and testing.

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