

An Aging Study of a Gas Electron Multiplier with Micro-Strip Gas Chamber Readout

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Abstract

We have performed an aging study of a Gas Electron Multiplier (GEM) readout with a Micro-Strip Gas Chamber (MSGC). The GEM is constructed from Kapton and copper, and the MSGC is constructed from semiconductive glass and gold. When the detector (GEM+MSGC) is operated in an argon-dimethyl ether (DME) gas mixture and irradiated with a 5.4 KeV photon beam, about 220 mC/cm of charge can be accumulated without degradation of the detector performance. This corresponds to about 20 years of operation at the LHC.

I. INTRODUCTION

The field of gas proportional wire counters has been revolutionized by the introduction of micro-electronic fabrication techniques to define micro-structures around which sizable gas gains can be obtained. Examples of new detectors which employ these techniques include: Micro-Strip Gas Chambers, Micro-Gap Chambers (MGC's), Microdots, MICROMEAS, the Compteur a Trous (CAT) and the Gas Electron Multiplier. For a recent review see [1].

The MSGC, invented in 1988 by Oed, was the first of the microstructure gas detectors [2]. In common with other gas microstructures, the precision and uniformity of the lithographic technique and the fine granularity it allows produce a detector with high rate capability ($\sim 10^6$ Hz/mm² at 200 μ m pitch), excellent position resolution (30 μ m) and energy resolution ($\sim 10\%$ at a few KeV) over large areas. These properties have made the MSGC the subject of intense research, in particular for use as a precision tracker for high rate particle physics experiments. MSGCs are for example being considered as part of the tracking system for the CMS experiment [3].

At high energy colliders and in certain imaging applications the MSGC is exposed to large radiation doses which can irreversibly degrade gas gain, energy resolution and position resolution and may, in extreme cases, lead to detector failure. This phenomenon is called aging. For a given set of conditions it is assumed that aging of a gas detector depends on the quantity of ions produced in the avalanche. The natural unit is therefore the accumulated charge per unit length of the charge collector (microstrip in this study).

The aging behavior of wire chambers has been extensively studied (see ref. [4]). Early aging studies of MSGCs indicated that aging progresses faster in MSGCs than in wire chambers and the life time of MSGCs became questionable [5], [6]. More recently a comprehensive study of factors affecting MSGC aging have been performed and excellent aging results have been obtained in the laboratory [7], [8], [9].

Aging studies are performed in the laboratory using low energy X-ray beams. However, the conditions found near the interaction region at a high energy accelerator are not well approximated by a low energy X-ray beam. In particular at the LHC a significant flux of neutrons and heavily ionizing particles will also be present. The latter background has been found to produce a significant problem for microstructure devices which are prone to abrupt discharge when operated with a large avalanche size and irradiated by heavily ionizing particles because avalanches are confined to a very small volume and streamers are easily developed [10], [11], [12], [13]. The discharge phenomenon can easily damage fragile strip materials and lead to partial detector failure. A large scale beam test conducted at CERN in 1997 demonstrated that long term operation of MSGC's is difficult with the appearance of breakdown and loss of efficiency in some detectors [14]. For another example see [15].

A very attractive and promising solution to overcome this problem is to separate the amplification stage of the microstructure detector from the charge collection structure. This can be elegantly achieved using a pre-amplification foil such as gas electron multipliers (GEM) [16] [17].

A GEM consists of a Kapton mesh typically 50 μ m thick coated with 5 μ m of copper on both sides of the Kapton. Holes in the mesh are conical in shape, typically 100 μ m wide at the metal level and 40-80 μ m wide in the middle of the insulator, with a pitch of 140 μ m. Application of a suitably large voltage difference between the metal layers of the GEM produces an electric field in the holes sufficient for gas multiplication.

When a GEM is inserted above a charge collecting device, such as an MSGC, in the same gas enclosure, electrons liberated above the GEM, drift into the GEM holes multiply in the high field and continue to the charge collection device which may be operated at a much lower voltage than before to achieve the same gain. Significantly, the use of printed circuit boards as charge collectors in ionization mode has also been demonstrated [18].

The use of the GEM with a MSGC and other microstructure devices is a natural choice for particle tracking in many high energy physics experiments. Due to the relatively recent introduction of the GEM, much less is known about GEM aging than is known about wire chamber or even MSGC aging. Only one GEM aging study has been reported in the literature [19]. In that work a GEM+MSGC accumulated 17 mC/cm at a current density of 4.5 nA/mm² without degradation of performance. Further aging studies of a GEM are therefore crucial.

II. EXPERIMENTAL DEVICES

A. GEM+MSGC

A schematic diagram of the GEM+MSGC is shown in Figure 1. The drift cathode is made of a stainless steel mesh and is located about 8 mm above the GEM surface and it is negatively biased relative to the GEM to create a drift field for the electrons produced by absorption of X-rays.

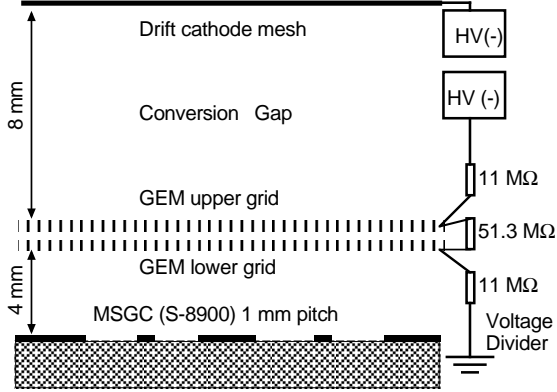


Figure 1: Schematic of the GEM+MSGC.

The GEM foil was manufactured at CERN from 50 μm thick Kapton and 5 μm copper layers [20]. The hole diameter was 80 μm with a pitch of 140 μm .

The gap between the upper GEM electrode and the drift cathode, which we call the drift or conversion region, is about 8 mm. The gap between the MSGC and the lower GEM electrode, which we call the transfer region, is about 4 mm. Although it is possible to independently apply high voltage to the GEM electrodes with separate voltage supplies, the GEM was biased through a voltage divider to guarantee a fixed potential difference across the GEM.

The MSGC was manufactured [21] on a semi-conductive glass, S-8900 [22]. The gold electrodes are alternately anodes 8 μm wide and cathodes 400 μm wide with a pitch of 1 mm. All anodes are connected together and then to a single charge sensitive preamplifier. Cathode strips are grounded and connected to a picoammeter to measure cathode ion current.

With an argon rich gas mixture most photon conversions take place in the drift region therefore most primary electrons experience two stages of amplification. First in the intense electric field in the GEM holes and second in the semi-dipole field formed by the anodes and cathodes of the MSGC. Signals from photon conversions in the lower drift region are negligible when the MSGC is operated at low gain.

B. Gas system

In the gas system high purity argon (99.999% pure) [25] and DME (99.8% pure) [26] are mixed in the ratio of 9:1. by calibrated mass flow meters, which also maintain a constant gas flow to the detector. All gas lines are made of stainless steel tubing. Several gas purification devices, present in both gas

lines, were found not to be necessary [6] and were bypassed for the present study.

The chamber enclosure housing the GEM+MSGC is made of stainless steel. Indium ribbon is used instead of conventional silicone O-rings to provide a gas tight seal. Both the chamber enclosure and the tubing of the gas system are carefully cleaned with a sequence of organic solvents to remove oil based contaminants and dirt. A detailed description of the cleaning procedure can be found in [6].

C. Detector operating characteristics

1) Drift field intensity

As the GEM upper electrode is highly negatively biased with respect to the MSGC surface, in order to successfully transfer electrons from the drift region, the drift field in the conversion gap must be sufficiently large. If, for example, the drift field is too weak, some electrons do not reach the GEM holes and are easily swept back to the drift cathode resulting in electron loss. In order to determine the appropriate drift field, the detector was irradiated with X-rays and the relative gain and count rate were studied as a function of the drift voltage (see Figure 2). For this study the operating voltages of the GEM+MSGC are: $V_{GEM} = 350 \text{ V}$ (voltage across the GEM) and $V_a = 260 \text{ V}$ (MSGC anode voltage), the MSGC cathodes were at ground. Figure 2 shows that when the drift voltage is lower than approximately 400 V, the gain and the count rate are very small. At approximately 400 V, electron collection efficiency becomes large and consequently both counting rate and gain become large and constant with drift voltage. If the drift voltage is increased beyond about 1,000 V it has been found that electrons are preferentially attracted to the upper GEM electrode causing an inefficiency. In our experiment, the drift electrode is not designed to hold a voltage in excess of 1,000 V so the electron inefficiency is not relevant. For the aging experiment the drift voltage was set to 700 V corresponding to a drift field of 375 V/cm which is sufficient to collect most primary charge.

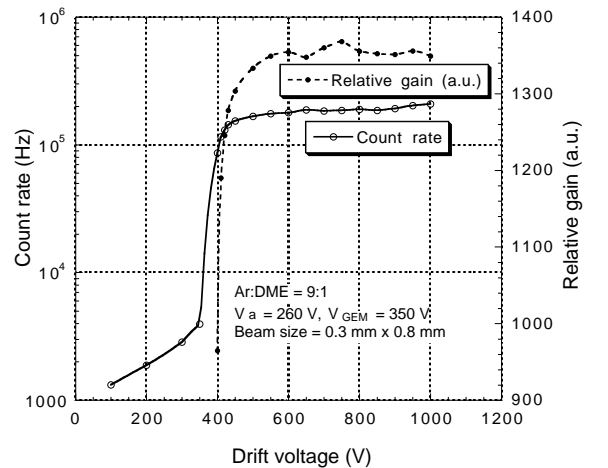


Figure 2: Relative gain (arbitrary units) and count rate as a function of drift voltage.

2) Gas gain of the GEM+MSGC

The combined gas gain was chosen to be about 1,000. The gain of the GEM was chosen to be about 100 and the MSGC was operated with very low gas gain (about 10). Thus the MSGC was operated very close to ionization mode and mainly acted as a charge collector rather than charge amplifier.

3) Approximate Rate Capability

To determine the approximate rate capability of the GEM+MSGC, the gas gain was measured as the rate of irradiation was varied. Since only slow electronics was available the gas gain was determined from the radiation-induced cathode current. The beam intensity was varied by increasing the current of the X-ray tube [6]. In this measurement the total gas gain of the GEM+MSGC is about 1,000, corresponding to an avalanche size of 2×10^5 electrons. The result is shown in Figure 3 where the ratio, R, of the radiation-induced current to the X-ray tube current is shown as a function of the X-ray tube current. As the rate limit of the detector is reached R will decline. From Figure 3 the rate limit appears at a X-ray tube current of about 10 mA corresponding to a flux of about 10^6 Hz/mm². It was shown in our previous work [6] that a 1 mm pitch MSGC has a rate capability of about 2×10^5 Hz/mm² at a gas gain of 1,000. Due to our choice of low gain of the MSGC in the GEM+MSGC combination, and hence a reduction in the number of slow moving positive ions in the vicinity of the microstrips, the rate capability of the detector is enhanced.

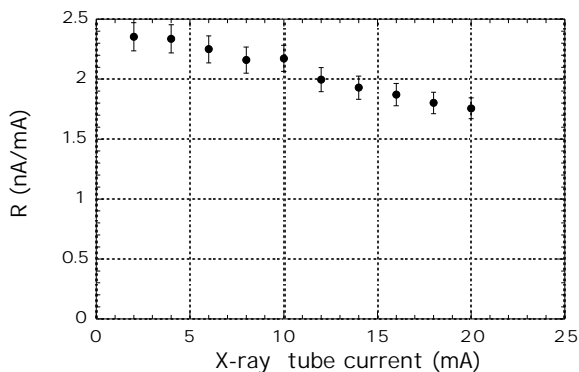


Figure 3: The ratio, R, of the radiation-induced current (nA) to the X-ray tube current (mA) as a function of the X-ray tube current.

III. EXPERIMENTAL METHODOLOGY

Radiation damage (aging) experiments are designed to establish the conditions required to minimize or eliminate performance degradation. The aging experiment was performed by irradiating the detector with an intense photon beam from an X-ray generator with a chromium target. The target material produces 5.4 KeV photons along with a high energy continuum. The beam was collimated to a size of 0.3 mm \times 0.8 mm. The experimental arrangement is shown in Figure 4. The X-ray tube current was set to 4 mA where the detector can be operated safely without saturation.

Aging produces a change in the gas gain and energy

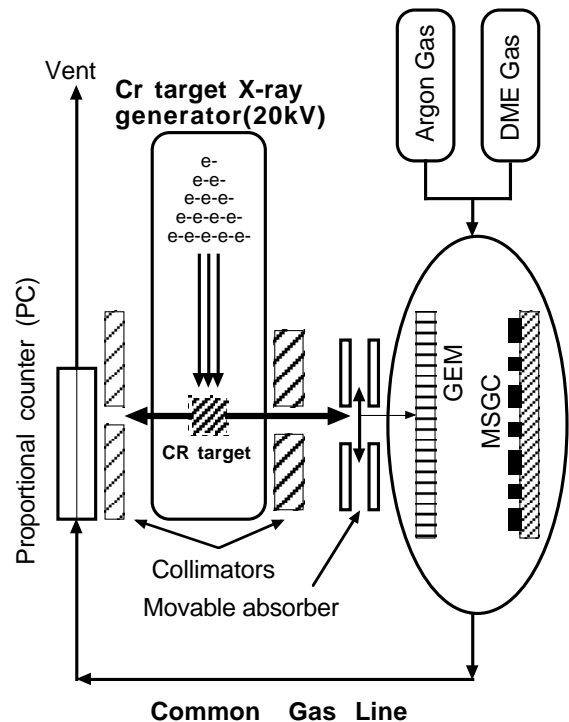


Figure 4: Experimental setup consisting of gas chambers and x-ray source with vanadium absorber.

resolution of the detector. It is therefore important that factors that could cause a change in gain that are not related to the aging process are identified and their effects quantified and subtracted. These include (1) changes in ambient conditions (pressure and temperature) which typically cause changes in gain at the 5-10% level, (2) changes in the quality of the gas, or variations in the gas mixture, and (3) variation in the output of the X-ray generator. Each of these factors is determined simultaneously by placing a single wire gas proportional counter (PC), in the *same* gas system as the MSGC (see Figure 4) and exposing the PC to a low rate (~ 100 Hz) from a second X-ray beam derived from the *same* X-ray generator. Other parameters measured were pressure, temperature, and the count rate, pulse height spectrum and radiation-induced current of both GEM+MSGC and PC. An automated mechanical absorber made of vanadium was inserted into the beam when GEM+MSGC pulse height spectra were taken. The radiation-induced current was calculated on-line by subtracting the steady state current from the measured total cathode current. The total charge accumulated was calculated after determining the ratio of the radiation-induced current diverted to the drift cathode. The aging data acquisition was automated by LabView software and the program was run on a Macintosh computer. The sequence of measurements is shown schematically in Figure 5.

IV. AGING EXPERIMENTAL RESULTS

The detector was irradiated at a current density of 63 nA/mm², corresponding to a flux of approximately 2×10^6 Hz/mm². This current density is much higher than in our

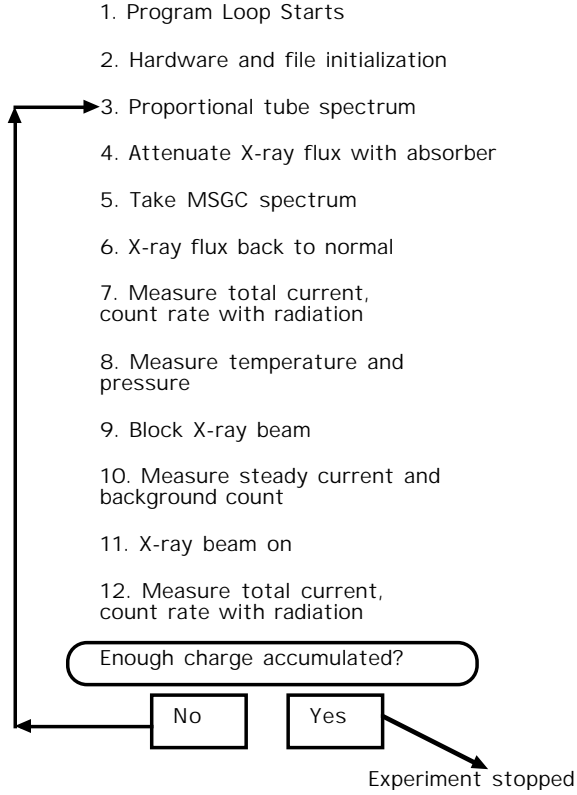


Figure 5: Data acquisition loop for aging test

previous work and is based on the assumption that the detector life time is limited by the total charge accumulated but is independent of rate of charge accumulation. This assumption appears valid for MSGC's constructed on electronically conducting substrates such as S-8900 but is not valid when the substrate is an ionic conductor [23][24]. We will investigate the effect of the rate of charge accumulation in a future study.

Relative gas gain of the detector is plotted in Figure 6 along with data from the PC and data from the pressure gauge installed in the room. Changes in the gain of the PC are correlated with changes in pressure (see Figure 6) and temperature. In this experiment changes in pressure were dominant most of the time. The response of both detectors to ambient conditions are almost identical except that the magnitude of the change in gain of the PC is slightly larger than that of the MSGC.

The GEM+MSGC data are corrected for ambient conditions using measurements made with the PC. The correction was performed in the following way. Let M_i and P_i be the GEM+MSGC gain and proportional tube gain at the i th measurement respectively, and let M'_i be the corrected value corresponding to each M_i . Let μ^M , μ^P , σ^M and σ^P to be the average GEM+MSGC gain, the average PC gain, the standard deviation of the GEM+MSGC gain, and the standard deviation of the PC gain respectively.

If at the i th measurement the following relation holds for a preselected constant C :

$$|M_i - \mu^M| \geq \sigma^M \times C \quad (1)$$

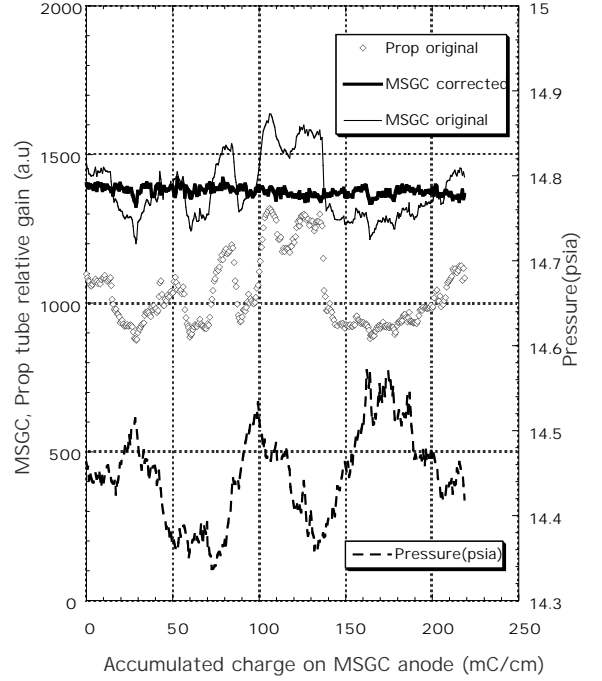


Figure 6: Relative gain of the MSGC (thin line) and PC (diamonds) as a function of the total accumulated charge. The MSGC gain after correction for ambient conditions using gain measurements made with the PC (thick line) and the atmospheric pressure during the period of charge accumulation (dashed line) are also shown.

then a correction is made to M_i and the new value, M'_i , is

$$M'_i = M_i \pm (P'_i - \mu^P) \times \frac{\sigma^M}{\sigma^P} \quad (2)$$

with the \pm sign dependent on the sign of the absolute quantity in equation (1). The fraction σ^M/σ^P is introduced to account for the slightly larger response of the PC gas gain to pressure changes. This difference probably arises because the electric field intensity around the anode wire of the PC is not as large as the electric field at the microstrip of the MSGC.

On the other hand, if the condition in equation (1) does not hold no correction is made, thus

$$M'_i = M_i. \quad (3)$$

The constant C was adjusted neither to over-compensate nor under-compensate for the pressure change.

A total of 220 mC/cm of charge was accumulated during continuous irradiation of the detector for a two week period. After applying the correction for ambient conditions the GEM+MSGC gain did not change during the accumulation of this charge (see figure 6). The energy resolution (not shown) also did not change during the charge accumulation. At the LHC it is expected that a detector should be capable of taking 10 years of data without significant degradation in performance. This corresponds to an accumulated charge of 100 mC/cm. Since the detector in this study showed no sign of degradation in performance after more than double the expected accumulated charge at the LHC, the result was deemed satisfactory and the experiment was stopped. After

the aging study was completed optical inspection with a microscope revealed no deposits on the GEM or the MSGC electrodes or surface.

The absence of degradation in detector performance with accumulated charge is attributable to two sources, (1) the gas system was carefully constructed to minimize impurities that enhance aging, (2) the MSGC was operated at relatively low gain. In our previous work a 1 mm pitch MSGC operating at the same gas gain as the GEM+MSGC in this test developed deposits on the microstrips after 150 mC/cm of accumulated charge [9]

V. SUMMARY

We have performed an aging study of a Kapton GEM with a large pitch MSGC made of S-8900 glass as a charge collector. No degradation of gain or energy resolution was observed after 220mC/cm of charge had been accumulated.

If we assume that (1) aging is solely a function of the accumulated charge, and (2) aging is independent of the nature of the irradiation producing the charge then it follows that if the low level of impurities present in this experiment were attained at the LHC, GEM+MSGC combination detectors constructed from Kapton and S-8900 glass respectively would operate without significant degradation for about 20 years.

VI. ACKNOWLEDGMENT

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