

Effect of deformation due to stretching of the Gas Electron Multiplier (GEM) Foil

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Abstract. The Gas Electron Multiplier (GEM) was first introduced by Fabio Sauli in 1997, which is a thin layer of an insulating polymer, coated on both sides with copper and chemically perforated with a high density of microscopic holes. The GEM detectors, which are built using GEM foils, have been utilized for various applications due to their excellent spatial resolution, high rate capabilities and flexibility in design. Large area of triple GEM detectors are planned in experiments as it is the case in the upgrade of the CMS forward muon system. During the assembly of these detectors, the GEM foils are manually stretched to maintain the required gap configuration throughout the detector area. This stretching procedure can introduce local variation in the size or the shape of the perforated holes in GEM foil which can further vary the operational characteristics of the foil as well as the detector. Therefore, the distribution and size of the holes over a GEM foil should be uniform to achieve homogeneous functionality of the detector over the active surface. We can prevent the deformation of the perforated holes by optimizing the stretching force which is used during the assembly.

1. Introduction

The Micro-Pattern Gaseous Detectors (MPGDs) can be considered as an evolution of the Micro Strip Gas Chambers (MSGCs). One of the most common MPGD is the Gas Electron Multiplier (GEM) introduced by Fabio Sauli in 1997 [1]. A GEM foil is a thin layer of an insulating polymer, usually a 50 μm thick polyimide, coated on both sides with 5 μm of copper and chemically perforated with a high density of microscopic holes. Since their introduction GEM based detectors have been used and/or planned to be used in many experiments [2, 3, 4]. In some of these applications unprecedented large GEM sizes are considered to be used to cover very large detection areas. An example is the use of GEM detectors in future upgrade of the CMS Muon system [5] e.g. Phase-I upgrade. In order to cope with the planned increase in collision rate at future runs of the LHC, the CMS collaboration will use additional gaseous detectors in the forward end-caps, which can operate at very high rates with good performance. The upgrade project is named as GE1/1, where “G” stands for GEM, “E” for End-cap and “1/1” corresponds to first muon station and its first ring, respectively. The full ϕ coordinate and the pseudo-rapidity region $1.55 < \eta < 2.18$ will be covered by trapezoidal super-chambers (layer of 2 triple GEM detectors) [6]. This incorporates large detection area which will be covered using large size GEM detectors, although obtaining uniform response across such a large area is a big challenge. One of the challenges while operating such large areas is the planarity of the foil area



in order to keep the gas gap at the required spacing (1 to 3 mm). To achieve this goal, GEM foils have to be stretched which might affect the shape and size of the holes.

Many studies have been done in the past for optimizing the geometrical properties of the GEM using both experimental and simulation tools. However, the extent to which one can tolerate small variations in the size and shape of the holes without having a drastic change on the detector performance is not precisely known. In this paper, we investigate how stretching of the GEM foil during the assembly of the GEM detector can induce local variation in the size and shape of the holes. Further, these small variations which can occur during GEM foil production and/or detector assembly can impact the performance of the detector. As the CMS GE1/1 chambers are the largest GEM based detectors ever constructed, we are taking it as our case study in this work.

2. Motivation and Objectives

A triple GEM detector consists of three GEM foils stacked on top of each other. Potential gradient between the two GEM foils creates electric field in between which are known as Drift Field, Transfer Field(s), and Induction Field. Performance of the detector is mainly affected by variation in the gas gap which can change the electric field as well as variation of the size and shape of the GEM holes. Consequently, both cases results in variation of the gas gain of the detector (i.e. the number of electrons that reach the readout electrodes).

When a GEM detector is assembled, the GEM foil(s) are manually stretched in order to maintain the required gap configuration throughout the detector area. This stretching force applied on a GEM foil can introduce local variation in the size or the shape of the perforated holes. Deformation of microscopic holes can affect the electric field which can further vary the operational characteristics of the detector. It has been observed that even a local variation of 5% in hole diameter can lead to gain variation of up to 20% [7]. Therefore, to achieve uniform functionality of the detector over the active surface, the distribution and size of the holes over a GEM foil should be uniform.

Hence, our first goal was to study the effect of stretching forces on the GEM foil during assembly. Further, we need to find ways to limit the deformation of perforated holes by optimizing the stretching force used.

3. Methodology

In order to investigate the effect of stretching on the GEM foil, multiple models (i.e. small size & large size) of the GEM foil were created using SolidWorks software. The material properties for Kapton as well as Copper were identified and included in the simulation. The values for stretching force were also identified and applied to check the displacement, stress and strain. Firstly, a lone Kapton sheet with perforated holes was simulated to study the way this material elongates due to a force normal to the y-direction (i.e. the direction covering the thickness of the sheet). Normal forces of 0.5 N, 1.0 N and 2.0 N were applied to one side while the corresponding parallel side was fixed. The normal forces were also applied to Kapton which was covered with Copper on both sides. In this case, the distributed force was applied to the side faces of both Kapton and Copper. This study utilize the torque values (i.e. 8-10 cNm) used during assembly of GE1/1 chambers.

4. Results

In order to check the behaviour of lone Kapton, initially simulations were performed on 1 mm $\times$ 1 mm piece of Kapton foil having a thickness of 50 μ m. Stretching forces of 0.5 N, 1.0 N and 2.0 N were applied normally on one side while keeping the opposite parallel side fixed. Using SolidWorks we can quantify the corresponding stress, strain and displacement observed in the foil. Figure 1, 2 and 3 shows the variation of stress, strain and displacement according to the

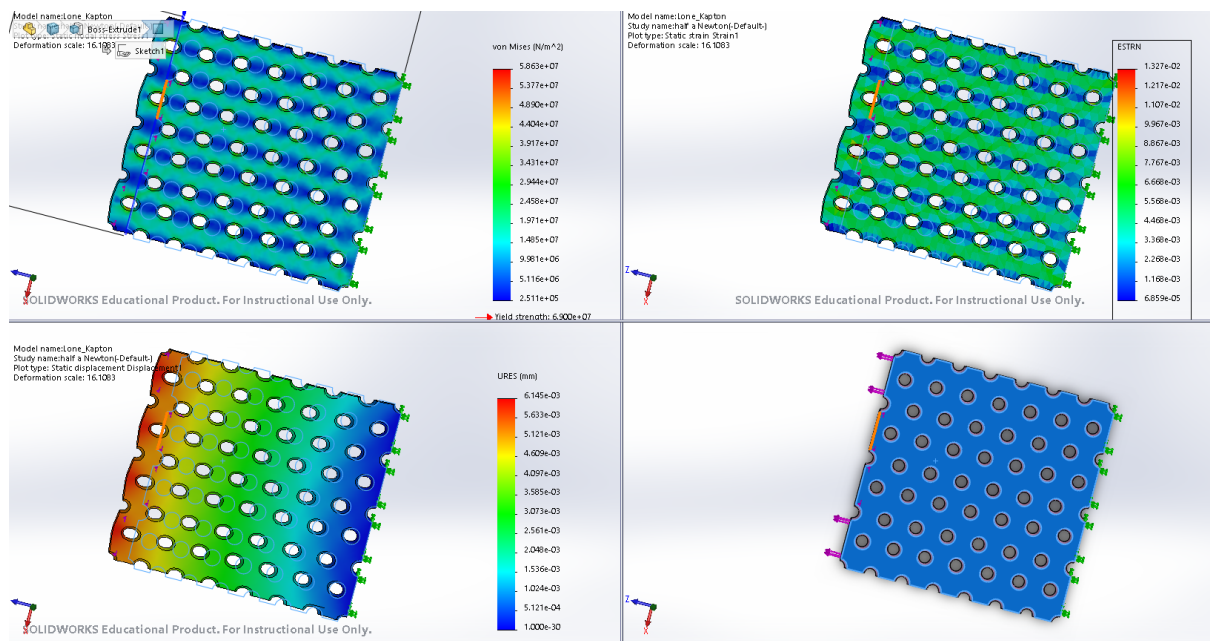


Figure 1. Sample of 1 mm $\times$ 1 mm Kapton foil showing the stress, strain, displacement observed and location and direction of applied force related to applied normal force of 0.5 N.

variation in the applied forces. The green arrows in the figures depicts the location where fixtures were applied and pink arrows (on bottom right) shows the location as well as the direction of applied force.

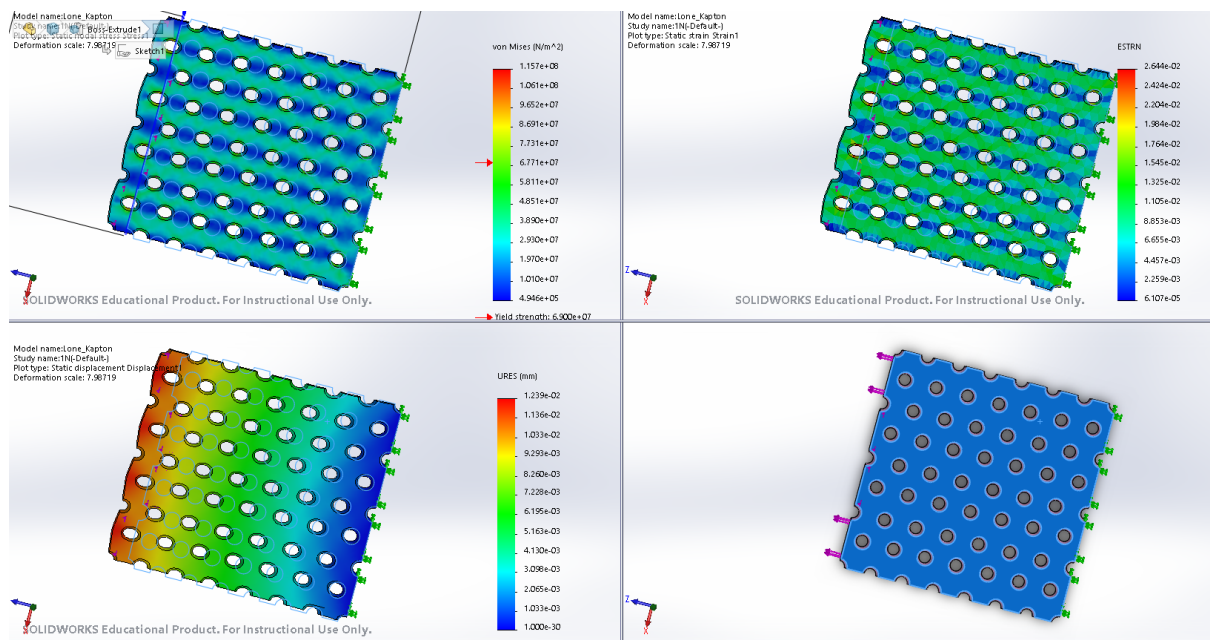


Figure 2. Sample of 1 mm $\times$ 1 mm Kapton foil showing the stress, strain, displacement observed and location and direction of applied force related to applied normal force of 1.0 N.

Comparing the results, the maximum displacement in a Kapton foil varies from 6.15 μm to

24.61 μm with the stretching force varying from 0.5 N to 2 N. Similarly, the maximum stress and strain varies from $5.86 \times 10^7 \text{ N/m}^2$ to $2.38 \times 10^8 \text{ N/m}^2$ and 1.33×10^{-2} to 5.62×10^{-2} , respectively.

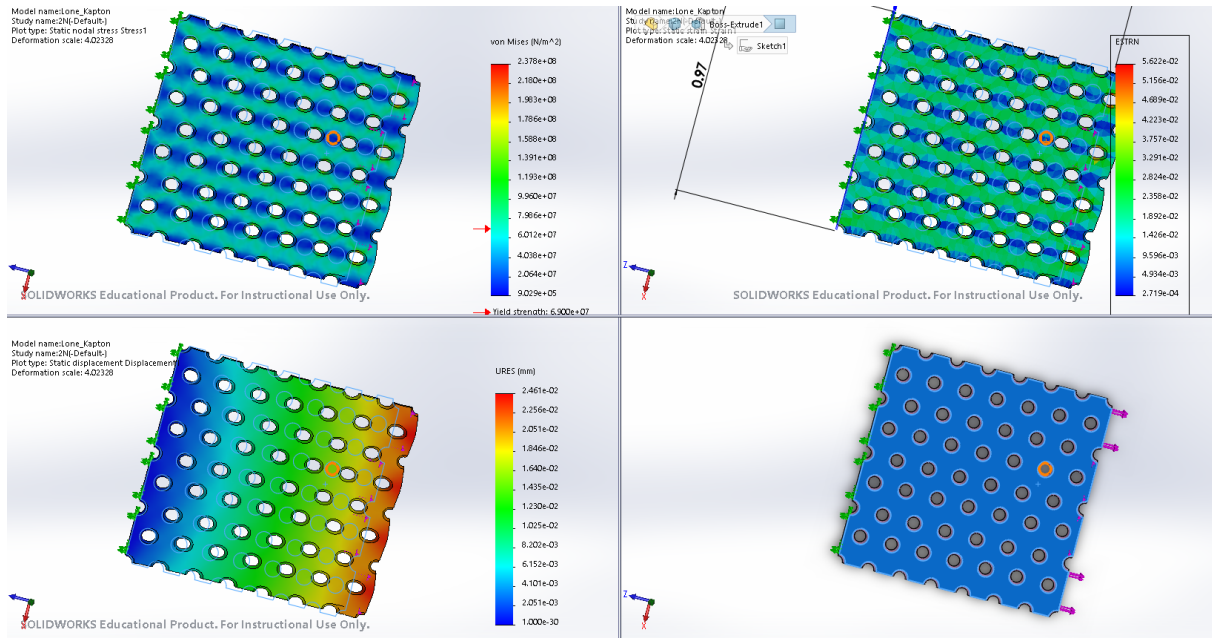


Figure 3. Sample of 1 mm $\times$ 1 mm Kapton foil showing the stress, strain, displacement observed and location and direction of applied force related to applied normal force of 2.0 N.

A trapezoidal GE1/1 short foil (with L: 106.1 cm and W: 23.0 - 42.0 cm) was also built in SolidWorks to test the normal stretching forces at appropriate locations. For simulation purpose, holes were only created in a small portion of this GEM foil, as presented in Figure 4. This was done to avoid simulation errors/crashes which occurred when the whole active area of the foil consists of holes. Figure 5 shows the test sample of 1 mm $\times$ 1 mm GEM foil and the variation of stress, strain and displacement depending upon the different location of applied forces. In this case, the maximum stress was found to be $2.49 \times 10^7 \text{ N/m}^2$, maximum strain was 0.433 and the maximum displacement was observed to be 30.18 μm .

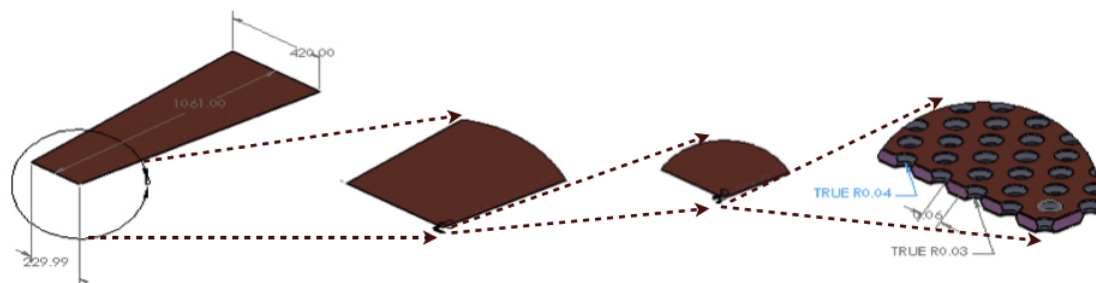


Figure 4. Finite element model built for GE1/1 chambers.

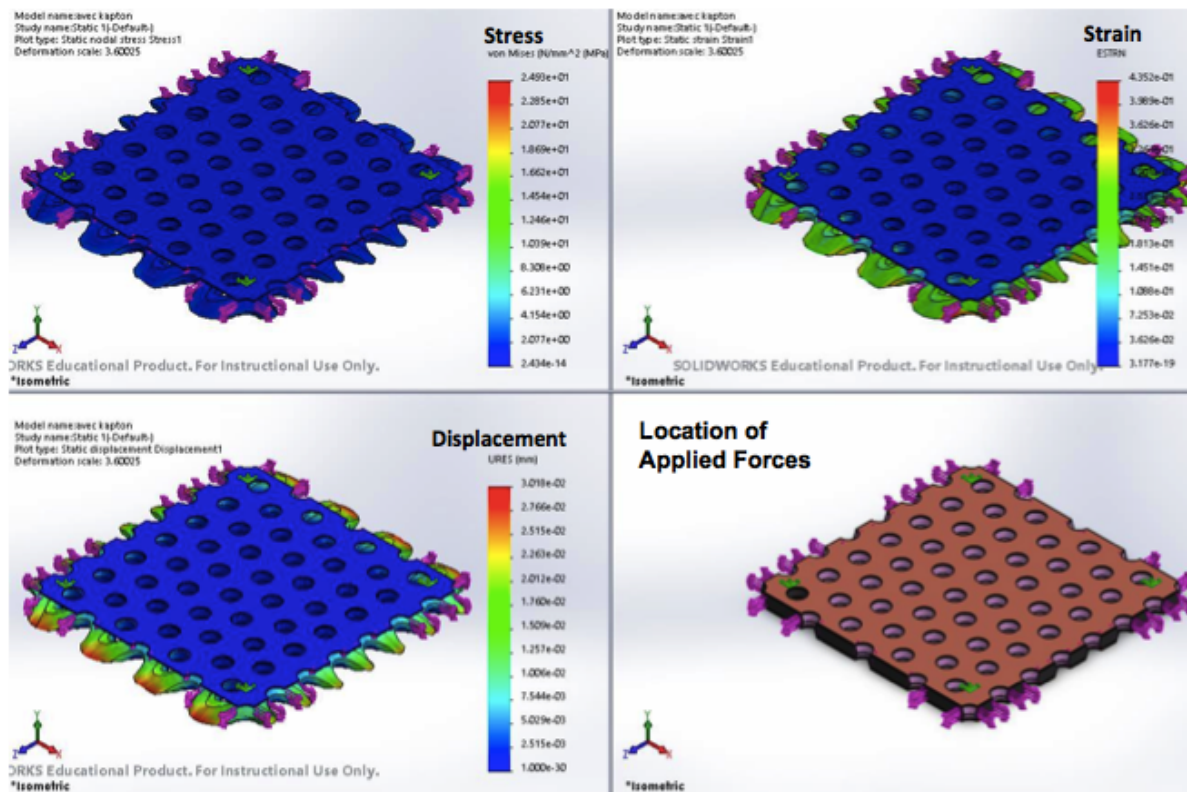


Figure 5. Sample of 1 mm $\times$ 1 mm GEM foil showing the stress, strain, displacement observed and location and direction of applied force related to location of applied forces.

5. Summary and Future Plans

A finite element model is ready for GE1/1 chambers and simulation is done to see the effect on the GEM foil due to stretching forces applied on it. As discussed above, we found the deformation in the shape and size of the holes. Our current plan is to use ANSYS and GARFIELD++ to simulate the effect of deformed holes on the gain of GEM detector. Later, we are going to modify the model for single mask etching and check displacement (both in longitudinal and transverse direction) in hole size as a function of distance from the force application point. We will further simulate and extrapolate the results for large area GEM foil to obtain better understanding. This study will prove to be useful for future detector development at CERN, specially in deciding the stretching force to be used for other planned upgrade such as the CMS GE2/1 and ME0 detectors.

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