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Construction Techniques for Large Size Gaseous Detectors for High Energy Physics Experiments

Sampsonidis D., Lampoudis C., Kompogiannis S. andKarkanias I.
School of Physics/Aristotle University of Thessaloniki,.
Center for Interdisciplinary Research and Innovation (CIRI-AUTH),
Thessaloniki, 10th km Thessaloniki-Thermi Rd, GR 57001, Greece.
Corresponding Author: Sampsonidis D.

Abstract: *The MicroMegas technology was selected by the ATLAS experiment for the upgrade of the Innermost station of the forward Muon Spectrometer, in order to maintain the precision tracking properties in the upcoming luminosity upgrade of the Large Hadron Collider. A large surface of the forward regions of the Muon Spectrometer will be equipped with 8 layers of MicroMegas modules forming a total active area of 1200 m^2. The New Small Wheel is scheduled to be installed in the forward region of $1.3 < \eta < 2.7$ of the ATLAS detector and will have to operate in a high background radiation environment, while reconstructing muon tracks as well as furnishing information for the Level-1 trigger. The precision tracking requires fully efficient MicroMegas chambers with spatial resolution down to 100 μm, a rate capability up to about 15 kHz/cm^2 and operation in a moderate (highly inhomogeneous) magnetic field up to B=0.3 T. The required tracking is linked to the intrinsic spatial resolution in combination with the demanding mechanical accuracy. This paper describes in detail the procedures used in constructing the drift panels of the LM2 chambers in the Aristotle University of Thessaloniki, as well as the Quality Assurance/Quality Control (QA/QC) processes followed.*
Keywords*, LHC**,** Gaseous Detectors, Micromegas.*

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I. INTRODUCTION

The Large Hadron Collider (LHC) [1, 2] at CERN will be upgraded in several stages (Phase-1, Phase-2). After the second long shutdown (LS2) in 2019-2021 the luminosity of the accelerator will be increased up to 2-3×10^{34} cm^{-2}s^{-1}, which will allow ATLAS detector [3] to collect data at a rateup to 100 fb^{-1}/year. In order to take advantage this foreseen high luminosity of the LHC efficiently, the innermost stations of the forward region of the ATLAS muon spectrometer (Small Wheel - SW) will be replaced by a New Small Wheel (NSW) [4] during the Phase-1 upgrade. The muon spectrometer has to retain the ability to reconstruct particle tracks with high precision,in particular, the offline track reconstruction requires a spatial resolution of about 100 μm per detector layer and an angular resolution of approximately 1 mrad for the online track segment reconstruction for the L1 trigger at background rates up to 15 kHz/cm^2. For this purpose a new set of detectors have been designed and are being constructed for the NSW, implementing two technologies, one primarily devoted to the L1 trigger function (small-strip Thin Gap Chambers, sTGC [5]) and one dedicated to precision tracking (MicroMegas detectors - MM [6]). The MM detectors have outstanding precision tracking capabilities due to their small gap (5 mm) and strip pitch (450 μm).This paper describes in detail the procedures used in constructing the drift panels of the LM2 chambers in the Aristotle University of Thessaloniki, Greece, as well as the processes followed during Quality Assurance/Quality Control (QA/QC) steps, including the related results.

II. THE DESIGN OF THE NEW SMALL WHEELS

The NSW of the ATLAS muon spectrometer will be comprised of two wheels equipped with sTGC and MM chambers. The wheel has eight large and eight small sectors (wedges) partially overlapping and fixed on a metallic circular structure called spacer frame, as shown in Fig. 1 (left). A single sector consists of two MM wedges attached on both sides of the spacer frame and sandwiched by two sTGC wedges as shown in Fig. 1 (right). MM and sTGC chambers in the wedges have four active detector layers forming quadruplets. Therefore theNSW has eight layers of MM and eight layers of sTGC detectors. Each MM wedge issegmented in two parts of different size trapezoids, each covering a different region in η. This results in four types of MM chambers: SM1 and SM2 as Small Sectors Modules, LM1 and LM2 as the Large Sectors Modules, corresponding to chamber sizes of 2 m^2 and 3 m^2 respectively. The construction of the four different MM modules has been shared between four laboratory consortia, one for each type of chambers: INFN, Italy for the SM1, Germany for the SM2, Saclay, France for the LM1, while for the LM2 construction, the work is shared among Greece, Russia and CERN. In this text we present the construction of the drift panels for the LM2 modules based on the assembly procedure developed at CERN as well as the quality control procedures followed during the construction, which is the responsibility of the Aristotle University of Thessaloniki.

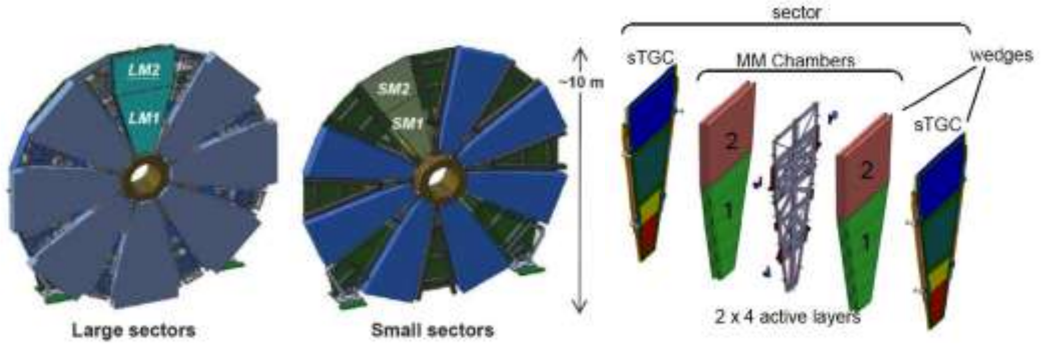

Figure 1: Overall view of the New Small Wheel. Left: Views of the wheel, highlighting the modules large sectors LM1 and LM2 and the modules of the small ones SM1 and SM2. Right: Exploded view of a Large sector, with two sTGC and two MM quadruplets on both sides of the spacer frame

A MM chamber consists of four gas gaps forming a quadruplet of MicroMegas detectors. The MM chambers need to fulfill mechanical requirements in order to be able to reconstruct a muon momentum with a resolution of 15% at 1 TeV in ATLAS. This implies an excellent mechanical precision of construction requiring strict quality control of all parts and special construction methods. The anode plane is based on printed circuit boards (PCB), with photo-lithographically etched copper strips and a layer of resistive strips on a Kapton foil glued on the copper strips for the discharge protection. The resistive strips have a resistivity of 10 to 20 MΩ/☐. The readout strips have a pitch of 450 μm. The mesh, which is stretched with a tension of 7-10 N/cm, is supported by 128 μm high pillars, which guarantee the uniformity of the amplification gap. The cathodeis also a PCB having a copper surface. The desired accuracy on η coordinate determines the precision of the strip positioning expected to be on the level of 30 microns r.m.s..Fig. 2 (right) shows a schematic view of a quadruplet. Five panels, providing the required stiffness, bound the four active MM gaps. The panels are trapezoidal in shape. Each quadruplet has two readout panels (four detection planes). There are two drift panels having one side covered with copper implementing the cathodes for the outer gaps and one central drift panel having both sides covered with copper. The mesh is glued on the drift panels on an appropriate mesh frame and attached to the pillars when the quadruplet is assembled.

A panel is a stiff light structure consisting of an aluminum frame, aluminum honeycomb 10.1 mm thick with 6 mm hexagonal cells, sandwiched between two outer surfaces by 0.5 mm FR4 material of the PCBs. The frame consists of aluminum bars with 10.0 mm thickness, perimetric and cross as reinforcement bars with four special aluminum corners, which also implement the gas inlet and outlet to the MM gap. Main components of the panel are the aluminum mesh frame and the woven mesh. All the aluminum parts are tested to fulfill the mechanical requirements for the thickness and possible bending deformations using specialized tooling.

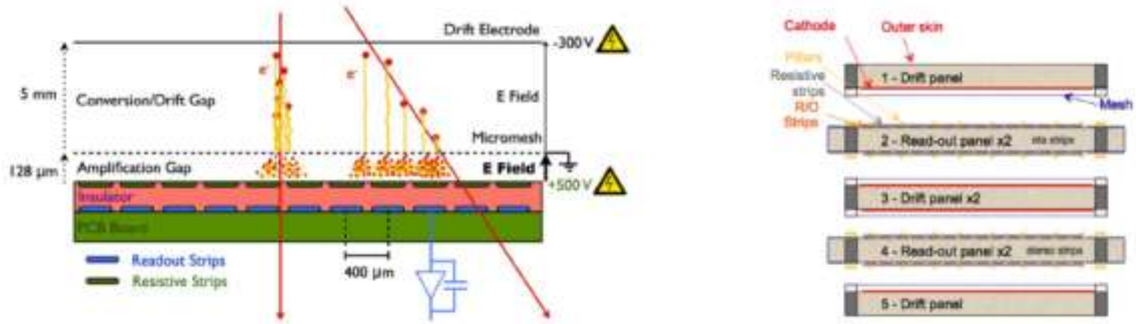

Figure 2: Left: A scheme of a single MM layer. Right: A schematic view of the five panels of a MM forming a quadruplet.

III. THE DRIFT PANEL PRODUCTION

According to the described structure of the quadruplet, two external and one central drift panels are produced for each LM2 Module (quadruplet) in a clean room, at the Aristotle University of Thessaloniki. The nominal tolerancefor the panel planarity is 37 μm in r.m.s., equivalent to 110 μm of mechanical tolerance.

The building of the bare drift panel is accomplished by the use of specialized tables constructed at CERN. This involves a pair of ultra flat tables, namely vacuum tables, made mainly from carbon fiber and perforated aluminum honeycomb. Surface induces high precision holes for alignment purposes. Hereafter table I is the permanently positioned table and table II the movable one that comes on top of table I during the gluing of the drift panel. On the third flat table, namely assembly tool, several high precision holes were drilled on the surface to be used as reference spots to insert special pins, in order to align aluminum bars and parts.The first step for each panel construction is the assembly/preparation of the aluminum frame. This is a two-step process, starting by gluing together the top and bottom bars (the parallel) with the corner parts on the assembly table using dowel pins. At the second step all the bars are indexed on table I using dowel pins and glued without any mechanical constraints (Fig. 3, left). The aluminum frame including the transverse bars is divided in three areas as shown in Fig. 3 (left). Additionally, a layer of silver paste is applied over the glued parts to guarantee the electrical conductivity.

The panel construction is done using the vacuum table method in one step. The PCBs are indexed on the vacuum tables via precision holes, using dowel pins (with a 5 mm diameter in the case of a PCB equipped with copper and 6.5 mm in the case of a bare PCB). An under-pressure of about 100 mbar is applied, sucking all PCBs, thus following the planarity of the ultra flat vacuum tables (30 μ). A 70 μm thick Kapton tape is attached on the PCBs junctions for sealing purposes and the interconnection inserts are glued on the PCB placed on table I. The volume formed by the aluminum frame and the underlying PCBs is filled by three honeycomb pieces, cut to the proper sizing to avoid any mechanical constraints. Three small cables attached between the honeycomb pieces and the aluminum frame assures electrical conductivity. Asimulation of the gluing process is performed prior, but with no use of glue (the so called “dry-run”) to ensure that table II stands properly on the high precision spacers and the panel will have the nominal thickness. This step confirms the QC measurements already performed on all associated mechanical parts.

A total amount of 3 kg of glue is distributed by hand on the PCBs as well as on the aluminum frame. For the proper spread of the glue on the area of the PCBs that the aluminum frame will lay, a calibrated limbo tool is used that ensures the application of a layer of glue, so to have 140 μm thickness. The frame is positioned on the PCBs standing on the vacuum table I and indexed using pins on the four corners. After positioning the honeycomb pieces (Fig. 3, right) on table I, the table II is placed on top of the first one standing on ten high precision spacers which define the panel thickness, as shown in Fig. 4. The under-pressure is maintained for 20 h during glue curing. Next day, the upper table is removed and the bare panel is completed.The finalization begins with some minor fixing of the panels. At first, the PCB in excess is removed, using a rotary tool and finishing with sandpaper.

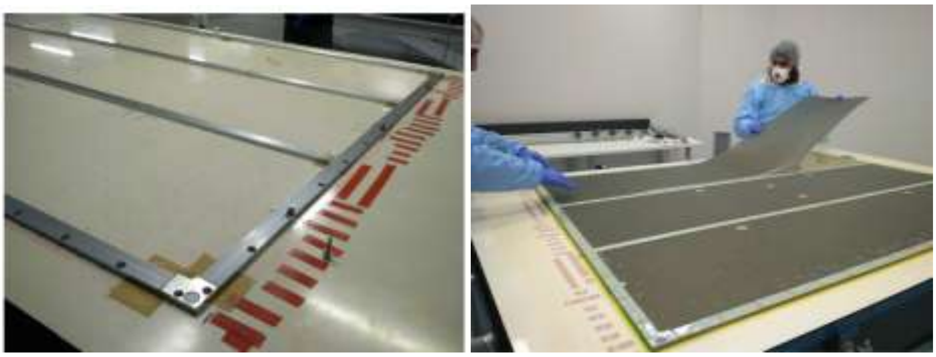

Figure 3: Left: The aluminum frame of the drift panel. Right: The positioning of the honeycomb during the drift panel construction.

The mesh frame is then screwed and glued on the drift plane, at 19 mm distance from the edge, with the required accuracy of ±200 μm in the plane and ±25 μmin height, guaranteed both by using rulers during the assembly process and the precision of the mesh frame profile. The proper amount of glue applied, is controlled using a 3D printed tool. The mesh grounding is assured by the proper contact of the mesh and the mesh frame, while the mounting screws used, guarantee the electrical conductivity between the mesh frame and the panel frame. Next the interconnection drift spacers are glued with a special tool (Fig. 5, left) by applying 0.6 N m with a torque screwdriver. Prior to this, in the case of the external drift panels, the interconnection bushings are glued to provide the thread to the interconnection spacers.

Figure 4: Left: Table II on top of Table I during drift panel construction. Right: The precision spacers between the two tables.

Following, the gas distribution pipes are mounted and glued in several points in contact with the inner of the mesh frame parallel sides. To ensure conductivity with the mesh frame, three corrugated aluminum pieces are placed between the gas pipes and the mesh frame, covered partly with glue.Finally, the HV connectors are glued on the outer side of the aluminum frame of the panel and soldered to the copper of the PCB. Soldering is also implemented to bridge the three PCBs cathode. In order to avoid any interference with the applied electric field, all soldered spots are covered by a thin layer of glue. In all above mentioned steps, extra care is given to eliminate any potential risk to create electrical conductivity between the cathode and the grounding via the glue.

Figure 5: Left: The special tool developed for the interconnections spacers gluing. Right: The interconnection spacer after gluing.

IV. QUALITY ASSURANCE OF THE NSW MICROMEGAS DRIFT PANELS

All panels are measured for their planarity and thickness. For these measurements a limbo tool has been developed, which consists of a rigid aluminum profile, instrumented with four height gauges (Fig. 6, left). The measurement of the thickness is performed on the vacuum table with the vacuum ON, having an under pressure of about 100 mbar, while the measurement for the planarity is performed without vacuum. The gauges are calibrated on a granite bar beforeevery measurement and then the panel surface is scanned by taking measurements at a grid of 152 points in total. Storing the measurements via a USB to a PC, data are recorded and analyzed to produce the planarity and the thickness of a panel. Fig. 6, right, shows the planarity results of cathode (copper) side of a panel. The r.m.s. is 14 μm well within the specifications.Outside the copper zone, the thickness is controlled all along the perimeter of the assembly holes in a total of 62 points with the use of a digital micrometer. This set of measurements is additional to the panel thickness measurements and the values are expected to be in the same range (~ 11.41 mm).

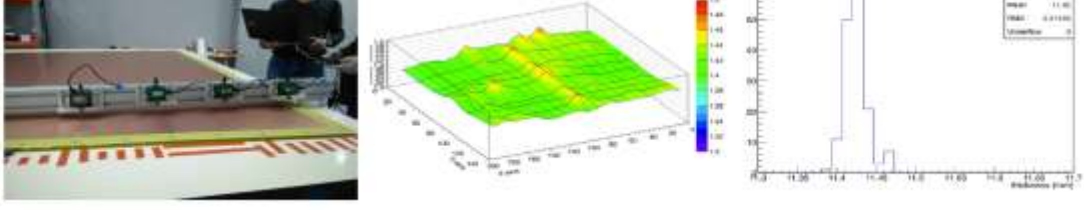

Figure 6: Left: Planarity and thickness measurement with the limbo tool. Center: Contour plot of the thickness measurements. Right: Distribution of the panel thickness.

To ensure the quality of the constructed panel, a set of additional measurements have to be performed. These measurements concern the height of the parts glued to the panel, adding height that is critical for the performance of the detector.The mesh frame height is measured at 66 points with a digital indicator. A nominal value of 5.060mm is expected with a tolerance from5.035 to 5.085 mm.

The interconnection spacers height is also a subject of measurement. A set of 5 spots are measured (1 in the center and 4 in the edges, with 90° spacing) on each spacer, in order to avoid any possible inclination. The nominal value is 5 mm with a 50 μm range tolerance. In case of excess of this limit, treatment with fine sandpaper is required (to avoid contact with the mesh). Before the mesh gluing on the drift panel, the gas leakage test is performed, adopting the pressure drop method [7], to ensure the tightness of the panel.

In order to simulate the exact conditions of the 5 mm gas gap volume of a MM chamber, a rigid aluminum surface panel, in permanent contact with the 7 mm EPDM o-ring, are used forming an extremely tight setup (Fig. 7, center).

The sequence of the gas tightness test for a drift panel is the following:

- Each panel under test before clumped on top of the reference set up (Fig. 7, left), is thoroughly cleaned along the o-ring contact line.
- Six dedicated interconnection caps equipped with o-ring are screwed on both sides of the interconnection holes, tightening the interconnection areas of the panel and reducing the volume expansion of the panel when the active area is filled with Argon.
- The created volume is filled with Ar gas reaching roughly 5 mbar of over-pressure, p_{over}, following a constant flow rate , f_{in}, of about 6 bar L/h measured by a digital flow-meter in the interest of measuring the volume expansion factor k.

The expected pressure rise rate, S_{exp}, due to the gas input flow is calculated as

$$S_{exp} = \frac{f_{in}}{V_{\alpha}} \times 1000 \left(\frac{\text{mbar}}{\text{h}}\right) \qquad (1)$$

whereV_{α} is the active volume of the gap, that for the case of LM2 MM is≈ 15.5 L, while the slope of the measured pressure rise is fitted by a first order polynomial and expresses the experimental pressure rise rate, S_{meas}. The ratio of these two values (i.e. the expected over the measured pressure rise rate) represents the volume expansion factor k (eq. 2).

Figure 7: Left: The o-ring, placed between the mesh frame and the gas gap aluminum frame. Center: The gas tightness setup. Right: The pressure drop is monitored and fitted.

$$k = \frac{S_{exp}}{S_{meas}} \qquad (2)$$

The pressure drop is monitored typically for about 24 h and the data are corrected for temperature variation, for the ambient pressure fluctuations and an exponential or first order polynomial fit is performed to the pressure drop rate. The gas leakage of each drift panel under test is calculated from eq. 3 which is derived from the ideal gas law.

$$\text{Gas Leak} = \frac{\Delta p_{atm}}{p_0} + \frac{\Delta p_{over}}{p_0} + \frac{\Delta V}{V_0} + \frac{\Delta T}{T_0} \qquad (3)$$

Long term room temperature monitoring, proved that it was exceptionally stable, within a range of 0.1 °C that permits the approximation of ignoring the temperature variation term, so eq. 3 becomes

$$\text{Gas Leak} = \frac{\Delta p_{atm}}{p_0} + \frac{\Delta p_{over}}{p_0} + k\frac{\Delta p_{over}}{p_0} = \frac{\Delta p_{atm}}{p_0} + (k+1)\frac{\Delta p_{over}}{p_0} \quad (4)$$

In eq. 4, factor$\Delta p_{over}/p_0$ is the slope of the measure drop, implemented with an exponential or first order polynomial fit. The permitted gas leak rate ofthe NSW chamber is set to the value of 0.6 mbar/h (at an overpressure of 3 mbar) in order to avoid contamination of the gas volume with oxygen that would affect the ionization rate. Thus, each panel needs to satisfy this requirement.

V. MESH ASSEMBLY

The electrical transparency of the stainless steel micromesh, necessary for the passage of the drift electrons, depends on both its mechanical structure as well as on the ratio between the amplification and drift electric fields. In order to ensure the homogeneity of the amplification gap and avoid sags between the pillars, the mesh must be stretched to a certain tension value and glued on the drift panel. The nominal distance between the mesh and the anode is guaranteed by the precise pillars height in combination with the proper mesh tension. This adopted method, called floating mesh, is a novel technique, in contrast with MMs of smaller dimensions that had been built with the so called bulk technology. In the floating mesh concept, the quadruplet can be reopened since the mesh is not glued to the read-out PCB. The mesh used in the NSW project is made of 28 μm diameter wires, woven with 325 lines per inch (corresponding to a pitch of 78 μm).During the assembly, initially the mesh is stretched to the desired tension, then six holes are created at the interconnections pass through points, and finally it is glued on the drift panel.

More specifically, for this procedure a dedicated stretching tool (~2×2.7 m^2) was developed and build, capable of stretching the LM2 size meshes. This device is equipped with a total number of 24 clamps, each 37 cm long, mounted along the four sides. The mesh is firmly attached under the array of clamps. Each clamp can be manually pulled in the outwards direction via a screwing bolt, thus increasing the tension of a specific zone. The tension homogeneity is achieved by the fine tuning capability of the clamping system to apply tension to the mesh and to enable the user to adjust the tension to the nominal tension value, which is in the range of 7-10 N/cm with a uniformity better than 10% on the drift panel. Heavy duty iron frames are used to transfer the stretched mesh after being glued onto, with a specific adhesive.

The mesh tension is subject to changes during the different steps of the process. In particular a typical decrease of 1 N/cm occurs when the mesh is released from the clamping system or after cutting the mesh during the final gluing onthe drift panel.

The mesh tension is monitored and controlled in multiple steps of the process, keeping record of mapping. The tension meter is an analogue gauge (GRUNIG Tetkomat 7150). A total number of 35 pixels areas are measured in both x and y directions on the transfer frame, while 24 spots of the final drift panel. For external drift panels measurements are performed on flat tables, while for central drift panels shims are used to secure the mesh. Before final gluing both mesh on transfer frame and bare panel are washed following the protocol developed and approved by the MM community. To avoid remnants from the water on the mesh (such as Calcium) and stains on both the mesh and the copper of the panel, compressed air is used to dry out the washed mesh and the panel.

The final step in the drift panel completion is the transfer and gluing of the pre-stretched mesh on the panel mesh frame. A dry-run test is performed in order to confirm the precise alignment between the passivated holes and the interconnection spacers of the drift panel. The relative position between the transfer frame and the drift panel is properly fixed. In addition during this test, the mesh tension is controlled and proper adjustments are applied during the gluing if necessary (adding extra weight).

After glue curing overnight, the mesh on excess out of the mesh frame, is cut out with a sharp scalpel and polished with sandpaper, so the final product is ready for the last certification control.

VI. FINAL TESTS, STORAGE AND TRANSPORTATION

All structural parts and components of the panel that participating in the grounding scheme are under control for the electrical conductivity. The final test that has to be performed on the drift panel to assure the electric insulation between the mesh and the copper of the PCB (cathode electrode) is the electrical measurements. When applying 500 V the current measured has to be less than 10 nA.For each drift panel, a final thorough visual inspection is done as part of a final full evaluation and all findings are listed and documenting. This report accompanies each panel until reaching the intermediate destination of JINR in Dubna, Russia. There, the read-out panels are constructed and the 5 panels of each Module are assembled in a quadruplet. The completed quadruplet is then transported to CERN for the final tests and the installation to the NSW.

VII. CONCLUSION

The Micromegas detectors will be used in the NSW upgrade of the ATLAS Muon Spectrometer enabling to retain its excellent performance after the next LHC upgrade. The construction method as well as the Quality Assurance of the drift panels of the LM2 chambers which are produced in the Aristotle University of Thessaloniki, Greece, has been presented.

VIII. Acknowledgements

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