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S.M. Pratuch
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V.A. Polychronakos
I.A. Golutvin

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S.M. Pratuch F.C. Belser
J.W. Clements J.A. Horvath
G.P. Spellman C.R. Wuest

Lawrence Livermore National Laboratory, Livermore, CA

C.V. Johnson
G. Mitselmakher
Superconducting Super Collider Laboratory, Dallas, TX

V.A. Polychronakos
Brookhaven National Laboratory, Upton, NY

I.A. Golutvin
Joint Institute for Nuclear Research, Dubna, Russia

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Abstract

The GEM Detector uses 1,128 Cathode Strip Chamber (CSC) muon detectors requiring a total of approximately 10,000 precision panels in the CSC assemblies. These panels must be fabricated to extreme tolerances in order to meet the physics requirement. A fabrication technique used to produce two large panels, nominally 1 by 3 meters, is described and the resulting panel precision is reported.

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Introduction

A Cathode Strip Chamber (CSC) in the SSC GEM Detector Muon Subsystem uses honeycomb panels to precisely position cathode readout strips that define the volume of each detector layer. These panels also support and accurately position the anode wires within each detector layer. The largest panels are approximately 1.5 meters by 3.5 meters and 20 millimeters thick. Figure 1 illustrates the components of a single detector layer.

Figure 1.- Components of a single detector layer

In order to verify the current "baseline" panel fabrication process, two large panels were fabricated in a joint effort between Lawrence Livermore National Laboratory (LLNL) and Intec Composites in Bothell, Washington. The "baseline" process employs room temperature curing adhesives for bonding face sheets to the core material and includes installation of a syntactic foam as a honeycomb core edge material needed for its compressive and shear strengths in the bolt hole and other attachment regions.

The two panels are 1.1 by 3.0 meters in size; 20 millimeters thick. Each is a composite structure of two glass fiber (G-10) face sheets clad with a 17 micron thick copper layer on one side (0.79 millimeters overall thickness) and a Nomex honeycomb core (3.2 millimeter cell; $\rho=0.03 \text{ g/cm}^3$). The core material was specially ordered and sliced to a precision thickness of 18 millimeters (± 127 microns). On one face sheet of one panel, the copper material had been etched away to form lengthwise strips that define the precision cathode (active region). In this particular case, the precision cathode is actually an assembly of two halves; procured during a previous vendor survey. The two face sheet halves were spliced together using a "doubler" strip while maintaining alignment (position and parallelism) of the cathode strips on each half-sheet. Ultimately, each strip of one face sheet half will be soldered to the adjacent corresponding strip of the other half. The panels were finish-machined to required dimensions by abrasive water-jet cutting.

Upon completion, the two panels were shipped back to LLNL for inspection. The panels are now in storage at LLNL and available for continuing development.

Background

In order to fulfill the physics objective, tight tolerances have been assigned to panel flatness and thickness. Parallelism between the two glass fiber face sheets on each panel is also of importance and can be derived from the panel flatness and thickness. Panel thickness must be held to 250 microns and is easily achieved. The panel flatness requirement is much more stringent. The required panel flatness is a function of the distance between the anode wire and the panel surface (i.e., half of the detector layer gap or the anode to cathode spacing). Defining this distance as H , the panel flatness requirement, encompassing the deflection

built into the panel at the time of fabrication and that due to gravity (gravity sag), is $0.04H$ over the active width of the panel (cathode strip region). The deflection due to gravity, δ_g , is defined

$$\delta_g = fw^4$$

where the factor, f , accounts for the panel weight, stiffness and support condition. For a panel similar to that shown in Figure 1, constructed of Nomex honeycomb core, glass fiber (G-10) face sheets and adhesive, f is equal to 0.032.¹ Table 1 outlines the physics requirements for panel flatness and the corresponding tolerance for panel fabrication. Information pertaining to the GEM detector panels (inner, middle and outer superlayers, respectively) is presented in the first three rows of Table 1. The bottom row contains the values assigned to the 1.1 by 3.0 meter panels fabricated at Intec Composites.

Table 1. - Panel Flatness Requirements

Active Panel Width, m	Anode to Cathode Spacing (H), mm	Gravity Sag (over width), μm	Flatness Requirement (over width)	
			Physics, μm	Fabrication, μm
1.090	2.5	45	100	55
1.180	4.0	62	160	98
1.215	5.0	70	200	130
0.967	4.0	28	160	132

Fabrication Process

The large honeycomb panels were fabricated using a "room temperature" (RT) cure, lay-up process. That is to say, the adhesives used to bond the G-10 composite face sheets to the honeycomb core cure at room temperature. This process is reasonably well understood and has been used to fabricate panels for similar type detectors in the past. The RT process is also compatible with G-10 face sheets that have an existing etched copper cathode pattern on one surface. The major unknown is the stability of the RT adhesive over time while under stress (i.e., creep). As a rule, creep is not a concern as long as the stress in the adhesive is less than 10 percent of ultimate strength. This rule must be verified by physical tests of the materials and the assembly design being considered.

The major potential drawback to the RT process is impact on schedule and tooling requirements. Currently, each panel takes up to three days to process because each face sheet requires one day to cure properly before proceeding to the other face of the panel. (Additional time is required for setup and filling in the panel perimeter with epoxy, syntactic foam or other suitable materials.) This is not three days of labor, but mostly "idle" time required for the adhesive to cure in an undisturbed condition. Thus, tooling (a large, flat precision assembly table, vacuum bagging equipment, and other assembly fixturing) is used in an inefficient manner. Floor space requirements are 15 to 20 square meters per tooling set plus a 50 percent allowance for storage and staging of materials and other equipment.

Tooling

All bonding operations were performed on a 1.6 by 3.9 meter (5 by 12 foot) Invar platen with a flatness of 50 microns over the width.

Face Sheet Splice

The first panel included one copper clad face sheet that had been etched to provide a precision cathode plane. This face sheet consisted of two halves that required splicing. The splice was constructed as follows.

- (1) Machine 12.5 millimeter wide by 0.5 millimeter deep steps in the G-10 side of each face sheet half, along the edge to be spliced. In addition, a 25 millimeter wide by 0.38 millimeter deep doubler strip was machined from G-10 sheet material in stock.
- (2) The face sheet halves were placed on the Invar platen, G-10 side up, and positioned so that the cathode strips were aligned to ± 25 microns. Kapton tape (6 millimeter wide by 25 microns thick) was placed over the splice along its length in order to lightly hold the halves together for subsequent bonding and to keep epoxy from squeezing out through the splice line (Photo 1.). Adjacent G-10 surfaces were masked off as protection from the flow of excess adhesive.

Photo 1. - Face sheet splice.

- (3) After surface preparation (light sanding with 220 grit sandpaper followed by solvent wipe), Hysol EA 956 adhesive was mixed and applied to the bonding surfaces of the splice and doubler strip. Micro-balloons (125 micron diameter) were added to control the bondline thickness and to build up the splice region flush with the unmachined G-10 surface.
- (4) After applying the adhesive, the doubler was positioned in the splice groove and the spliced face sheet was placed under a vacuum bag. The bag was evacuated to 710 millimeters of mercury and the adhesive allowed to cure for 12 hours.

Honeycomb Core Foam Filler

The Nomex honeycomb cores for both panels were reinforced along their edges as well as four interior attachment points by filling the core cells with Ciba Giegy Furane 1617AB (Photos 2 and 3), a room temperature curing epoxy syntactic foam (density: 0.65 g/cm^3). The foam fill procedure was as follows.

Photo 2. - Honeycomb core with syntactic foam edge filler.

Photo 3. - Close-up of a reinforced section of core.

- (1) The honeycomb core was measured and each corner was marked in order to correctly position it with respect to the G-10 face sheet.
- (2) Masking tape was then applied to the honeycomb core; defining the inside edge of the region to be filled with foam. This region was initially oversized and was later trimmed to the specified dimensions.
- (3) The honeycomb core was then laid out on a piece of breather cloth. The breather cloth provided a path for displaced air to escape during foam installation.
- (4) Furane 1617AB syntactic foam was mixed in 150 gram batches and placed in SEMCO cartridges. A SEMCO gun was used to pneumatically inject foam into the honeycomb cells.
- (5) After all required areas were filled, excess foam was removed with a straight edge until flush with the tops of the core cells. The foam was then allowed to cure 8 hours at room temperature.
- (6) Once the foam had cured, 220 grit sandpaper was used to sand both the top and bottom surfaces of the foam flush with the honeycomb core.

Face Sheet Bonding

Face sheets were bonded to the honeycomb core using a room temperature curing epoxy paste adhesive; a thin film of adhesive was applied to the face sheet bonding surface. To achieve the required panel flatness, a two-step bonding operation was used in which face sheets were bonded to the honeycomb one at a time. This operation allowed the Invar platen to dictate the flatness of panel surfaces. The procedure used for bonding face sheets to the core is outlined below.

- (1) The face sheets were trimmed to match the honeycomb core dimensions (12.5 millimeters excess along the lengthwise edges and 10 millimeters along the width). Trimming was done by hand with an exacto knife. After trimming, the edges were carefully filed to remove any copper burrs.
- (2) The copper side of each face sheet was masked off with 50 micron thick polyester film, taking care that no entrapped air bubbles or wrinkles were present. This masking protected the copper cathodes from adhesive that might flow into the area during the vacuum bagging process and any other damage that could occur enroute to LLNL.
- (3) The G-10 side of the face sheet was prepared for bonding with a sanding using 220 grit sandpaper and a solvent wipe.
- (4) The face sheet to be bonded was placed G-10 side up on the Invar platen. A "Doctor Blade" was used to apply a 0.5 millimeter layer of adhesive. Hysol EA 956 adhesive with 125 micron micro-balloons (1 percent by weight; to maintain bondline dimension) was mixed. Adhesive was poured along the edge of the

Doctor Blade and continually replenished as the blade was moved to traverse the length of the face sheet, leaving a uniform coating of adhesive over the entire surface. This operation is shown being demonstrated on a small panel face sheet in Photo 4.

Photo 4. - Using a Doctor Blade to create a uniform adhesive layer.

- (5) After cleaning up any excess adhesive, the core was positioned on the face sheet. A wooden frame, using 25 by 15 millimeter rails, was placed around the laminate to protect the core edges from crushing (rounding off) during the vacuum bagging process. Photo 5 illustrates (small panel assembly shown) the manner in which the wooden frame was employed.

Photo 5. - Honeycomb core with wooden frame.

- (6) The entire assembly was then vacuum bagged and evacuated to 250 to 380 millimeters of mercury. This operation is shown in Photo 6. The adhesive was allowed to cure 8 hours.

Photo 6. - The core/face sheet laminate during the vacuum bagging operation.

Inspection Results

Prior to being sent to Intec Composites for incorporation into panels, the four face sheets were inspected at LLNL for thickness variation. The vendor, General Electric, had stated that the thickness would be constant to $\pm 10\%$ and that was in fact verified. The sheets ranged in thickness from 0.74 to 0.79 millimeters. The one face sheet that had been etched (the spliced face sheet) was also inspected to verify strip and gap widths and strip positions relative to a set of fiducials. The strip and gap width information are presented in Table 2.

Table 2. - Strip and Gap Width Information (*inspection 1*)

	Average Width, mm	Range, μm	Standard Deviation, μm
Narrow strip	1.87	(+10, -18)	10
Wide strip	2.69	(+33, -15)	15
Gap	.42	(+15, -5)	7

Upon completion, the two panels were shipped back to LLNL for reinspection (inspection 2). This time the panels were inspected for flatness as well as thickness. Also, the panel with the etched (and spliced) copper face sheet was inspected to verify that the strips hadn't moved during the fabrication process and that the cathode strips on adjacent halves were aligned adequately. The panel thicknesses were found to be well within specification at 20 millimeters (+102, -76 microns). However, the panel flatness of the two panels was found to be out of specification by 27 microns (Figure 2.) and cathode strip alignment at the face sheet splice was not within the desired specification of ± 50 microns, measuring ± 100 microns. The strip and gap dimensions were remeasured and the information is reported in

Table 3. The data suggests that the cathode strips did not move (within the accuracy of the Coordinate Measuring Machine) relative to each other during the panel fabrication process.

Figure 2. - Panel Flatness Illustration

Panel dimensions (boldface) are given in units of meters; Flatness measurements are in microns.

Table 3. - Strip and Gap Width Information (*inspection 2*)

	Average Width, mm	Range, μm	Standard Deviation, μm
Narrow strip	1.87	(+13, -8)	8
Wide strip	2.69	(+33, -15)	14
Gap	.42	(+10, -8)	7

Observations

Even though the fabricated panels were found to be slightly out of tolerance, the room temperature, two-step lay-up fabrication process was validated as a viable option for small-quantity panel production runs. Use of this process should be limited to small production quantities however because of tooling time demands and the level of craftsmanship involved. Handling large pieces of honeycomb and G-10 face sheets is awkward and requires care to ensure that the materials are not damaged. Specially designed handling fixtures for such materials would be necessary in a mass production factory. Furthermore, some skill is required during the core/face sheet bonding operation to ensure that the entire interface region is covered with a uniform layer of epoxy adhesive. (Note: The polyester film used to mask off the copper cathodes was quite effective in protecting the face sheets from the flow of adhesive during the bonding and vacuum bagging operation as well as scratches that might have occurred during handling.) However, future large panel fabrication processes would be best served if the procedure for installation of the syntactic foam edge filler was reworked. Not only was the installation process long and tedious, but the resulting reinforced area was likely the greatest contributor to the lack of panel flatness. Future designs might include pre-cast or extruded pieces that could be bonded in place during the core/face sheet bonding operation.

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