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**CSC Panel Mass Production Technology R&D Plan
for
SSC GEM Detector Muon Subsystem**

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Introduction

A Cathode Strip Chamber (CSC), in the SSC GEM Detector Muon Subsystem, uses honeycomb panels to precisely position the 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 mm thick. The panel cross-section is illustrated in Figure 1. Each panel must remain flat to 100 microns over 1.5 meters, to meet physics objectives, while serving as a key structural component of the chamber assembly.

Figure 1. - Panel cross-section

The GEM Detector uses 1,128 CSC's ("24/36/48" configuration)¹ requiring a total production of approximately 10,000 precision panels (8,088 plus spares). Mass production techniques are required which can produce the large number of panels for minimal cost and within a reasonable schedule while maintaining structural and stringent physics requirements. The goal of this R&D effort is to define, develop, and verify appropriate technologies that can be fashioned into an overall fabrication process for mass production of CSC panels. In addition, panel design features are evaluated which aid in CSC assembly and internal alignment.

Considerations for Fabrication Processes

Room Temperature Process

Presently, honeycomb panels used in a CSC are fabricated using a "room temperature" (RT) cure, lay-up process, that is to say, the adhesives used to bond the G-10 (glass fiber) 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 having 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. A simple analysis indicates this may not be a concern as long as the stress in the adhesive is less than 10 percent of ultimate strength. However, this must be verified by physical tests of the materials and assembly design being considered.

The major *potential* drawback to the RT process is impact on schedule and tooling requirements. Currently, each panel takes 3 days to process because each face sheet requires 1 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 or other suitable materials.) This is *not* 3 days of labor, but mostly "idle" time required for the adhesive to cure in an undisturbed condition. Thus, tooling (large and flat precision assembly table, vacuum bagging equipment, and other assembly fixturing) will for the most part be used in an inef-

efficient 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.

Emphasis must be placed on reducing the process cycle time. This can likely be reduced to a 2-day cycle with the development of some specialized tooling to help automate repetitive tasks. However, fabrication of the panel would still rely on bonding one face at a time. It may even be possible to reduce the cycle to one day. However, this would require something like a "room temperature mold" that precisely positions all the panel components while the adhesive cures simultaneously on both face sheets. In any case, reducing the cycle time probably increases up-front tooling costs.

A hypothetical production period of 2 years (5 days per week, two 8 hour shifts per day) would produce 520 panels per set of tooling for a *1-day cycle*. Thus, 20 sets of tooling operating in parallel would be required to produce a total of 10,000 panels during that period. (The number of shifts is not likely to limit production but rather the cycle time is the limiting factor.) If the panel process cycle can only be reduced to 2 days, 39 sets of tooling would then be required. In either case, this could have a significant impact on production logistics. The trade-off between setting up a "special" facility (rented space?) for the sole purpose of mass producing panels *versus* distributing the production among existing panel manufacturers and facilities needs to be evaluated. A cost trade-off with production schedule, cycle time, unit cost of tooling, number and "source" of panel production facilities, and finished panel unit cost must be analyzed.

The foregoing discussion has assumed the production of 10,000 identical panels. There are actually more like three different panel sizes for barrel chambers, and six different sizes for end cap chambers. Significant commonality among the different tooling requirements can be realized with careful design, but this will still add something to overall tooling costs. This is another area needing investigation to optimize panel unit cost.

High Temperature Process - Compression Molding

Compression molding (CM) is a high temperature (HT) process being considered as an alternate method for mass production of CSC panels. The panel components are bonded simultaneously using an adhesive that cures quickly at elevated temperature. A mold, duplicating the desired finished panel configuration, is used to restrain the panel components under pressure while at the curing temperature. Properly selected HT adhesives are generally more stable than RT adhesives where creep is a problem. This process is used routinely in the automobile and aircraft industries to make similar size parts. The inherent accuracy of finished parts is a function of design, material selection, and precision control of the curing cycle.

The HT process may not be compatible with G-10 face sheets having an existing etched copper cathode pattern on one surface. If the glass transition temperature of the copper-clad face sheet is exceeded during the curing cycle (which seems likely), the cathode strip pattern may "float" across the surface and out of the extremely tight locational tolerance limits. The effect of the HT process on the copper cladding needs to be evaluated.

Etching the cathode pattern *after* fabricating the panel would be an alternative. Effects, if any, of the curing cycle on the adhesion of the solid copper-cladding to the face sheets must be tested. In addition, the removal of copper from one surface of the finished panel may induce unacceptable distortions if the curing process has left residual stresses in the panel assembly. This must also be examined.

Another alternative would be to bond a thin film cathode pattern onto a finished panel made with a "bare" (no copper) G-10 face sheet on one side. Issues to be examined are: film adhesion and "local" flatness after bonding.

The HT process has the *potential* of drastically reducing cycle time to 0.5 to 1.0 hour per panel. (The automobile industry compression molds auto hood panels in a few minutes. CSC panels are more complicated and thus a much more conservative estimate is used.) One set of tooling could produce 16 to 32 panels per two shift work day or 8,320 to 16,640 during a 2 year production period. At most, two presses with interchangeable molds for producing the various panel sizes could produce all the CSC panels in less than 2 years. An alternative approach would be to split up the various size molds among a number of manufacturers and produce all the panels in a much shorter period of time. Many variations in logistics exist.

Such HT process equipment exists in the compression molding industry. The "up-front" costs will be in the molds for each panel size, possibly nine or so different sizes. (Common tooling possibilities need to be investigated.) The cost of these molds needs to be compared to the cost of multiple sets of tooling required for the RT process. The production logistics are obviously simplified when dealing with only one or two panel production stations; there is also more flexibility in selecting industrial manufacturers.

Emphasis must be placed on evaluation of the HT process compatibility with the copper-clad face sheets and the alternative methods of producing the finished cathode pattern on the panel. Again, a cost trade-off with production schedule, cycle time, tooling costs, and finished panel unit cost must be analyzed.

Other Factors Influencing Fabrication Processes

Overall chamber design (structural and physics requirements) has a significant impact on the selection of a panel fabrication process. Material choices are dictated by the structural requirements that are in turn driven by physics requirements (panel flatness and allowable chamber sag due to gravity). Various ideas have been proposed for the component designs that are used to separate the panels within a chamber assembly (i.e., precision spacer frame and gas seal) or are otherwise attached to a panel (i.e., anode wire support). These design functions are incorporated in separate components in one concept and combined to various degrees in other concepts, sometimes incorporated directly into the panel itself.

The most appropriate assembly system for a CSC must be identified, in conjunction with structural analysis of the design, for its overall efficiency and suitability for the chosen assembly method. The details of a particular panel fabrication process will be determined by the amount of integration desired in combining multiple functions into a single part. The limitations of the panel fabrication process will in turn affect how far this integration process can go before panel unit costs become unacceptable. The degree to which multiple design features can be integrated into the panel production process should be investigated at small scale first *in parallel* with a cost trade-off analysis for mass production.

R&D Plan

Parallel lines of investigation will be pursued for viable panel fabrication processes. The "baseline" process will incorporate the most mature technology existing at any given instant. Therefore, the "baseline" process will evolve over time, incorporating improvements in technology as available. This will culminate with the selection of the panel fabrication

process to be used for supplying panels to the CSC Prototype Factory. Presently, the "baseline" panel fabrication process is an RT-cure, lay-up process.

The panel R&D effort is broken into three categories; large panel development, small panel development, and panel fabrication process development. Within each of these categories, a number of parallel efforts are planned.

Large Panel Development

In order to verify the current "baseline" panel fabrication process, two large panels (nominally 44-by-118 inches) will be fabricated in a joint effort between Lawrence Livermore National Laboratory (LLNL) and Intec Composites in Bothell, Washington. The "baseline" process includes installation of a syntactic foam (paste-like consistency), honey-comb core edge material needed for its compressive and shear strengths in the bolt hole region at the panel perimeter. Alternative edge materials and installation methods will be investigated. One such alternative is to use a castable edge material to form precast precision blocks that can be assembled into a frame around the core, creating the necessary structural component.

The two large panels will be shipped to BNL where large panel development will continue. BNL plans to employ the same RT-cure, lay-up technique to produce seven or more large panels for use in the construction of a 1-gap "engineering" chamber at the SSC Laboratory and a 6-gap prototype chamber for the Fermilab Beam Test.

Small Panel Development

Two additional development tasks are planned using small panels. At LLNL, techniques for aligning one panel to another within a chamber are being studied. The current "baseline" design calls for panels to be positioned as they are surveyed under an optical microscope using precision washers indexed to fiducials (etched at the same time as the cathode circuit pattern) on the panel face sheet. This approach requires a measure of skill and is time consuming. One technique being investigated at LLNL employs an assembly fixture with precisely located and sized pins which mate to a precision pin hole and slot in the panel. The panel pin hole and slot locations are precisely indexed to the cathode strips as they are photo-etched onto the face sheet. Further studies are needed to determine the repeatability of transferring the printed circuit from the photo-etching mask to the face sheet. Concerns include; warping of the mylar photo-etching mask due to changes in temperature and humidity and degradation of the mask precision with use. Ultimately, this task would culminate in a 6-gap small chamber in which the intrinsic error of panel alignment from one panel to another within a chamber could be measured and the effects on detector efficiency calculated.

An alternative technique being investigated at LLNL is a simplified version of optical alignment. An optical microscope would be used to align panels relative to each other by sighting on the edges of the etched cathode face of each panel. The transition at the sharp edge of a circuit trace (copper to G-10 substrate) is the fiducial used for alignment. Thus, circuit patterns are aligned directly from one panel to the other without intermediate fiducial transfers as in the "baseline" optical alignment method. This assumes that etched features can extend to the edge of the panel face.

A second small panel development task is being conducted in parallel at the SSC Laboratory. In this task, the SSC Laboratory will produce a small 1-gap chamber using panels fabricated at LLNL. The chamber will be equipped with all the electrical components planned for the actual chambers and tested to see how it responds under high voltage.

Panel Fabrication Process Development

A variety of issues are to be addressed during the panel fabrication process development effort. As suggested earlier, RT panel fabrication processes in which casted edges are used must be investigated. Such a process would tremendously reduce the amount of labor and time involved in the "baseline" panel production process. The technique used to produce the first two large panels is a three day process; one day to install the syntactic foam edge filler material and two days (one day per face sheet) to bond the face sheets to the core. Using precast precision pieces to form the panel edge would cut the production time down to two days. LLNL will investigate this fabrication method as part of the small panel development effort.

Another RT panel fabrication process to be considered is casting the edge around a previously made honeycomb panel with no edge filler. In this process, the precision gap spacer frame, wire fixation bar and sealing bar, in addition to the panel edge, are cast simultaneously around the panel as it is held in place between the two mold halves. BNL will investigate this fabrication method. Furthermore, assuming that this technique proves successful, BNL will continue its investigation into the possibility of bonding the face sheets to the core during the casting process instead of before. Successful implementation of this RT process would reduce the panel fabrication time to one day per panel.

An attractive iteration on the casting method mentioned above is a HT panel fabrication process employing compression molding techniques. Similar processes are used extensively in the automobile industry. In a first set of tests that will be conducted at LLNL, the stability of the etched copper cathode strips on the glass fiber face sheet will be evaluated during the HT process cycle. If the strips "float" out of locational tolerance limits, the fabrication procedure will be modified. Instead of bonding a G-10 face sheet with etched copper to the core, the two face sheets will be left unetched for the bonding operation. Once the panel has been fabricated, it will be left to acclimate to the temperature and humidity of the photo-etching facility and then post-etched. It is assumed that the photo-etching facility would have to be modified to accommodate the 20 millimeter thick panels. Concerns regarding this technique include warping of the panel due to temperature gradients developed during the cooling down phase, and the effect of removing (post-etching) portions of the copper material possibly resulting in reduced strength of the face sheet and panel warpage.

LLNL will also investigate techniques in the preparation of the panel face sheets. The current "baseline" face sheet is a 4-ply glass fiber cloth and copper sheet (17 micron thick; 1/2 ounce) laminate. Approximately 10,000 of these face sheets must have precision cathode circuits (strips) photo-etched onto them. An alternative process in which an ink is printed onto copper coated thin mylar or kapton film, much as ink and paper are used in the newspaper industry, could greatly reduce the time spent preparing the precision cathode. In this process, ink is printed only in the areas where copper is to remain. The exposed copper areas are then etched away, leaving a copper strip pattern. The thin film printed circuit would then be bonded to the G-10 face sheet. Preliminary work with this technique using small panels and a RT bonding process shows that the copper strips coated on thin mylar can maintain their precision after bonding to the G-10 face sheet. This work will continue with the construction of larger panels.² The use of HT processes to complete this step will also be investigated.

Also included in this portion of the R&D plan is an effort to evaluate panel core and edge materials for the required strength characteristics. Panels fabricated in the large and small panel development efforts will be used for destructive testing to obtain material and composite structure properties needed to verify design analyses. The conclusions drawn from

this testing will be applied towards the development of materials to be used in the fabrication of the chamber perimeter components (gap frame, wire fixation and sealing bar) and their configuration - the "baseline" chamber perimeter design.

Process Model

An important component of the R&D plan is the development of a process model that can be used to estimate finished panel unit costs. This model will be used to evaluate competing materials and fabrication process combinations, culminating in a final "baseline" process for GEM Detector Muon Chamber panels.

Schedule

The schedule for the Panel R&D Plan is shown in Figure 2. It is predicated on having seven chambers ready for the Fermilab Beam Test in the summer of 1995.

FIGURE 2. - PANEL R&D PLAN

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