GLUEX

REGINA TEAM

B-CAL PROGRESS AND CONSTRUCTION REPORT

NOTES AND PROCESS MODIFICATIONS FROM 2004 CONSTRUCTION

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B-CAL PROGRESS AND Construction Report

NOTES AND PROGRESS MODIFICATIONS FROM 2004 CONSTRUCTION

EXECUTIVE SUMMARY

During the summer of 2004 the University of Regina sent a team of undergraduates to Edmonton to build a 4m calorimeter module. This device was the last in a series of three prototypes that have been built over the last two years. Composed of 210 alternating layers of lead and scintillating fiber the module measured 4.04 m in length, .12 m in width and .24 m high. Over 70 km of fibers and 12 kg of epoxy was used in the four weeks of construction. The process itself was a learning experience, as much of the facility was custom built for the occasion. Before the full production of the remaining 48 modules begins, a number of the innovations devised during the test construction should be closely revisited.

The first stage of construction consisted of building the clean room where the module would be constructed. This clean room includes an electro-pneumatic press and storage facilities for the lead and fibers that will be used to construct the module. While the lead was stored in rolls, the fibers were stored in their packing crate and in black polyethelyne tubes. These fibers were then sorted into bundles of 95 and stored on a special table that was built. The table surface is covered with copper foil to ground static, and ha special section in the middle to allow easier clamping of the fibers.

The second stage of construction was the building of the 4 m module. A five-member crew built this module working two three-hour shifts each day. This resulted in module growth of two centimeters each day. The third and final stage of the production was the construction of a one-meter “baby” module that was only 5 cm tall. This module was subsequently cut into two segments to be used for testing various readout systems.

Over the course of the construction a number of innovative devices were built or conceived. In the future there is work to be done researching and developing tools to assist production. Also, significant thought needs to be put into the matter of number of presses and work crews. When choosing a final location and design for the clean room it will be important to remember that the construction process will last almost two years.

GLUEX NOTES

EDMONTON CLEAN ROOM AND B-CAL CONSTRUCTION NOTES

INTRODUCTION

The Sub-Atomic Physics At Regina with Research Offshore (SPARRO) group at the University of Regina has been working in collaboration with a number of other Universities across Canada and the United States. This GlueX project is one of a few research projects seeking to understand quark confinement by means of mapping the exotic hybrid spectrum. Located at Jefferson Lab's (JLab) soon to be built Hall-D the GlueX project will shed some light on the mystery of quark confinement. The role of SPARRO in this project is to build a major component of the detector, a barrel calorimeter (B-Cal). This device will be composed of 48 lead and scintillating fiber (Pb/SciFi) matrices that measure 4m long, .25m thick and .12m wide.

This document was prepared to outline the procedure used for all of the construction that took place at the University of Alberta, Edmonton, Alberta, Canada. After building a custom clean room the first 4m module was successfully completed. The month of June 2004 was used to construct the clean room where production would take place. The first module was estimated to take the month of July as well as some of August. This was the case, however, it was only due to a limitation of a crucial component. Future construction will most likely last only three weeks. Construction notes from the SPARRO crew are included in this document as well as general information regarding the module and the clean room its self.

CLEAN ROOM CONSTRUCTION

- Approximate dimensions 7m x 5m (future dimensions will be 10.6m x 5m)
- Walls are composed of 2" x 4 " studs with black poly and Tyvek sheathing
- Ceiling was sheathed in clear poly and yellow filters to protect fibers
- Air supply consisted of a filtered, variable speed fan
- Air output was four circular ducts with a total area of .22 m^2
- A standard door, with plastic guard at the bottom opens to the airlock
- A heavy curtain acts as the door between the clean room and the airlock
- Large supply door is sealed with tape during gluing (dimensions 2.1m x 1.8m)

CONSTRUCTION NOTES

Some suggestions can be made regarding this design. First would be the choice of sheathing. The black poly is quite thin and easily torn, not to mention very dark. The white Tyvek provides a good tough protective layer that is much brighter, however, it would be advantageous to replace both components with a plywood or gyproc wall. This material is much more resilient to the pressure inside the room and provides a far more durable covering while offering the same seal. In both cases it is wise to use a sealing agent (PL Acousti-Seal from LePage) at the seams of walls and the ceiling.

The ceiling was a bit tricky to install, as it must be left transparent but filtered using yellow filters to protect the fibers from UV damage. First a clear poly barrier was stapled up to the rafters. Each piece was sealed at the wall and allowed to overlap the neighboring sheet by a few inches. The overlap was then taped with a piece of plastic packing tape to complete the seal yet provide transparency. Underneath this barrier, the yellow filter was stapled to the rafters. As the filter tears rather easily, thin strips of masking tape were placed underneath the rafters and staples were driven through the tape. This provided much needed strength to the filter. It would be possible to reinforce the filter with thin strips of wood, a meter in length and no thicker then the rafters. These slats would be screwed into the rafters through the filter, locking them in place. During the modules construction, the filters seemed to be holding themselves up well enough that wooden supports were not added.

The ventilation of the room is provided by a filtered fan that has its input placed in the corner of the room, above and in line with the press. This fan has six settings though the lowest setting has provided enough air exchange for the clean room. We have found that in order to maintain pressure in the room that does not damage the poly walls or filter a total of four exhaust vents are needed. This has been done by placing a four inch circular vent at the end of the press, on the back wall. Two additional six inch circular vents were then placed at the end of the press in line with the air flow. A fourth vent, five inches in diameter was placed next to the original four inch vent. To promote proper air circulation in the room, plastic strips were placed in front of the filtered fan.

CLEAN ROOM ACCESSORIES

A fiber sorting table and two small cupboards containing the lead was placed inside the clean room. These cupboards provided the only shelf space in the room for the cheese cloth, Kim wipes, alcohol, log book and other supplies. It would be wise to provide additional shelving in the room that can adequately hold the supplies that are needed for construction. This includes a small shelf built just below the main vent of the room. This will be used to hold the water bath for the glue cups during construction.

The fiber table was specially constructed on site for the project. It is composed of a pair of identical tables that are about 1.8m long and 60cm wide. These tables were placed just over a meter apart, yielding a total length of 4.80m measured from the farthest ends. Two pieces of plywood with identical dimensions (approximately 60cm x 60cm) were then used to join the two tables. One of the pieces of plywood was fixed permanently and the other was fastened to the table using spring hinges. Closed, this gate provides a level working surface that can be dropped down to clamp the fibers at the center. The gate was latched using a turn stop made from a piece of plywood that was screwed into the fixed extension. Spring clamps were used to then keep the tabletops level during sorting.

The surface of the table was covered in Tyvek to protect the workers from splinters. This was then partially covered in copper foil that was connected to a ground at the base of the table. Ideally the entire surface would be that of a copper plate that runs the full length of the table. This would provide a better ground and would prove to be much more durable. If the table receives a deep scratch from a knife or sharp object, it can be easily burnished so that it is flat again. The foil received some cuts, and the tape that was used to patch it got in the way of working. A reference line was made on the table to align fibers to. Since the maximum length of the lead was 4.04m we decided that the minimum length of the fibers should be just above that. Two parallel lines, 4.08m apart were placed on the table surface and their center was also marked. These lines would be used to check if fibers were long enough to be used and to mark the center of the fibers.

Lastly, storage of the fibers presented a small problem. The table that was used was only wide enough to have about 15 bundles sorted and still have two bundles flattened at a time. This meant that everyday bundles needed to be prepared for the next two gluing sessions. Storage shelves or racks for the fibers would be very useful to free up table space. One design that was proposed was to use PVC tubing that had been sawed in half. These tubes would not need to run the full four meters, however, their minimum length must be long enough to be fastened to two studs. Also, the gap between two consecutive half pipes should not exceed half a meter. In addition, it may be wise to use copper tubing so that the racks can be grounded to help dissipate static. The ideal diameter of these would be no less then 1/2". Diameters larger then 2" would result in the bundles tangling with each other. These racks can be mounted on the wall directly behind or above the fiber table so that the workers can easily load and unload bundles.

PRESS CONSTRUCTION

The electro-pneumatic press that was used for the 4m module was identical in design to the press used on the two previous modules with some modifications.

- The number of pistons was increased to 20 pistons (22 for the final model)
- The number of lifting pistons was doubled to 2
- Also doubled was the number of vertical plastic guards
- 10 upright supports are used to lock the press down (12 on the final model)

PRESS NOTES

Perhaps the most complex part of the press is the electronics and pneumatics of the press. Twelve switches can be found at the front of the press. The first switch operates the tilt function and the next ten operate the piston pairs. The eleventh, which is not currently hooked up, will operate the piston pair that is not present. Each switch runs to a solenoid on the valve manifold mounted on the back of the press. The manifold, which contains eleven valve controllers, provides air to the pressure pistons. The tilting piston is separate from the manifold but operates under exactly the same principle. Running from the manifold are two _" air hoses for each pressure piston pair. These hoses are then T-ed so that they provide air for each piston in the pair.

> ***Note:*** *It is essential that the hoses are connected such that the solenoid default position corresponds to the pistons being extended. This means that in the event of a power outage the pistons will maintain pressure on the module during a gluing sequence. The setup that provides this is the compression hose that is attached to the connection opposite the solenoid. The tiny screw on the solenoid must also be in the 0 position at this time. The compression hose refers to the hose that runs to the top of the piston supplying air to extend the piston.*

The compressed air for the press was first run through a dual filter for water and particle. A pressure gauge was placed in the line before the press was attached. This gauge will be used to check the pressure of the air during a gluing sequence. It is important that each layer is glued under approximately the same pressure. It is also crucial that the gauge is placed inside the clean room, while the filter need not be. The pressure supplied on the source used is anywhere from 85 PSI to 95 PSI which is adequate for our purposes.

Also attached to the press were four vertical strips of plastic. These acted as a visual guide for laying lead onto the module. These guides should not touch the module as that would obstruct construction. However, it would be advantageous if the base layer could be positioned against these strips in order to align them. For the 4m module the strips were placed 2 – 3 mm from the edge of the module. Before placing the beam onto the press a sheet of poly needs to be placed on the press bed. This will protect the surface of the press from the epoxy that inevitably runs off of the module.

Additions to the press were made to accommodate the accessories to the gluing procedure. The first is a set of brackets that are attached to the press legs just a few inches above the base. These five brackets hold the aluminum pressure plate just above the ground and just below the electronics box. This keeps the plate clean and out of the way of the gluing procedure. The second addition is a thin cord that is attached to the bolts at the very top of the piston cylinders. This cord was placed across the entire length, but would only need to be placed across the gaps wherever there is a locking arm. The cord prevented the locking arms from falling back all the way behind the press. Secondly, when the press is tilted back, a storage shelf is created for the Teflon. During the gluing sequence the Teflon can be stored on the arms and pistons to be out of the way of the gluing crew.

On top of the press bed is a steel support for the module. This tube is 4 1/2” wide and 3” tall and runs just a few centimeters short of the 4m length. This beam will give the module its rigidity during handling and transport. On top of the steel beam lies a 1” thick aluminum backing that has the module fastened directly to its surface.

B-CAL CONSTRUCTION

B-CAL CONSTRUCTION NOTES

Most tasks in the construction process are simple tasks that are repeated each layer. However, there are a few initial steps that are done once for each module. This section briefly outlines the many steps in the building process. A more comprehensive manual is included in the appendices of this report.

MODULE PREPARATION

Before construction begins on any module a layer of plastic should be placed on the press bed. During the pressing a large quantity of glue will seep out of the module. If this epoxy is allowed to cure on the press bed it would have to be cleaned off so that it would not be in the way of future construction. The first step in module construction is to place the first base layer of lead on the aluminum backing plate. This plate is temporarily fixed to the steel beam but will it will be permanently epoxied to the Pb/SciFi matrix. It is essential that this layer is placed such that it is completely straight as all subsequent layers will take the path of this base. In order to align the lead properly a 1mm wide and .5mm deep groove is machined into the backing. A guide fiber is then fixed into this groove and the base layer is rolled onto the fiber. Once it is determined that the lead has been placed properly on the plate an outline is marked on the aluminum. Using industrial epoxy the first lead sheet is placed on the aluminum and the perimeter is given a coating of a half an inch of Vaseline. This prevents the epoxy from seeping onto the lead and curing in the fiber channels. Next a sheet of Teflon is placed on the lead and an aluminum pressure plate is centered on the module. This plate will distribute the pressure from the pistons evenly over the surface of the module. The center piston pair is then allowed to come down. After one minute the next set of pistons is brought down and this process is repeated until all pistons are compressing the module. By starting at the center the epoxy will migrate towards the ends ensuring that the entire surface is covered.

MODULE CONSTRUCTION

Construction of the module closely resembles an assembly line style process. Each of the five crew members has a small number of tasks that must be carried out in a certain sequence before the next tasks can begin. There are some tasks that can and do overlap with each other to minimize the overall construction time.

1) First the pressure plate and Teflon are removed and alcohol is used to remove all of the Vaseline from the surface. During the cleaning process the first batch of Bicron-600 (optical epoxy) is mixed in a fume hood.

2) When the lead is clean a layer of optical epoxy is placed over the entire surface. While this is happening two people are flattening a bundle of 95 fibers so that they can be loaded in the clamps.

3) While two people hold the clamps two more people place the fibers on the epoxy-painted lead. At this time the fifth person is starting to flatten another bundle of fibers or to mix optical epoxy if it is needed.

4) After the fibers are placed in the module two people check that all fibers are fully in their grooves and are long enough at each end. A third person begins to paint a thin layer of epoxy on the fibers.

5) The next layer of lead is now rolled onto the module. While one person does this, two others paint the surface with optical epoxy. The lead must be lined up to run parallel with the module and begin no longer or shorter then other layers. As the lead is rolled its surface can be painted with optical epoxy.

6) After no more then two hours the module must be pressed. Using virtually the same process that was used for the base layer the module is compressed for seven to eight hours. The only difference is that the first three piston pairs have a two minute waiting period between each compression. The next three pistons have a minute and a half between compression and then the remaining pistons, a minute. This additional time allows the epoxy to migrate farther as it will not flow as easily as the epoxy at the very ends of the module.

B-CAL CONSTRUCTION STATISTICS

As the Edmonton construction was the first 4m module that was built by the SPARRO group it was necessary to track the usage of supplies and manpower. This data was recorded both on hardcopy and in electronic form. A copy of the electronic log can be found in the appendices of this report.

CONSTRUCTION MATERIALS

Over the course of construction a large number of supplies were consumed. These supplies included the Bicron-600 epoxy, Pol.Hi.Tech scintillating fibers, lead as well as a number of other disposable products. The usage of these items was recorded to anticipate the cost per module of the many components. Table 1.1 shows the total amount of each material used in the construction of the 4m module.

Lead		**Sci/Fi**		**Glue Used**		
PB Layers	186	Sci/Fi Layers	186	Total Resin	12890	g
PB Lost	2	Sci/Fi Lost	215	Total Hardener	3631	g
Lead Lost/Layer	0.01	Fiber Lost/Layer	1.16	Kits used	4.02	Gallons

▪ *Table 1.1: Materials used to construct a 4m module.*

These data provide a good approximation for the preparation of all future module construction materials. On two rare occasions the lead sheets had to be removed from stock because of defects that rendered them unusable. The low number of lead rolls that were discarded may have been due to the fact that the lead rolls were checked during the manufacturing process. However, few were removed at that process. The majority of the lead waste comes from the stage where the small lead strips are cut from the large master roll.

During the construction process it is the Sci/Fi that have the most waste. This waste comes from three situations. First is incorrect length from the manufacturer. This is an unavoidable problem so long as the fibers come precut. Typically there are anywhere from one to four fibers in a packet that are too short to be used. In this case the fibers were cut to a meter and used in the 1m “baby” module that was constructed after the 4m module was completed. The next source of lost fibers is surface or shape defects. Many fibers have small bumps in the cladding that results in a diameter that is greater then a millimeter. As a result, most of these fibers must be removed from the module as they will not sit in the lead properly. Shape defects result in fibers that are no longer linear. These fibers may have multiple curves in their structure and almost always result in the fiber being discarded. Luckily this type of defect is rare counting for maybe 1 in 30 discarded fibers.

The last reason for discarded fibers is human error. This may be the improper treatment of fibers resulting in damage to the core or cladding. The most common source of this type of loss is when too many fibers are placed in a bundle. When the fibers are placed in the lead the excess fibers get glue on them which almost always results in them being discarded. There are two possible ways to combat this problem. First is to put excess fibers on a clean storage facility where they can be used on the next layer. It is essential that this fiber does not come into contact with any sort of dirt as everything will adhere to the fiber. The second way to help minimize loss is to place 95 fibers in each bundle instead of 96 fibers. Although there are supposed to be 96 grooves in the lead often there are in fact only 95 full channels and two half channels.

Using this data predictions have been made as to the materials that will be needed for the future production of 48 full sized 25cm thick modules. These predictions can be found in Table 1.2.

Lead		Fibers			Epoxy		
Layers / module	202	Layers / module	201		Resin / module	13905	g/layer
Min. Layers needed	9691	Min. Layers needed	9631		Hardener / module	3917	g/layer
Total Layers needed	9795	Total Fibers needed	935699		Kits / Module	5.88	gallon
		Total Length needed	3742796	m	Total Kits	282.2	gallon

▪ *Table 1.2: Projected materials required for future production.*

The number of layers that is required to achieve the desired height is based on the average thickness of the 186 layers in the 4m prototype. It is entirely reasonable to imagine that this may result in a difference of one or two layers for each module as layer thickness depends heavily on glue usage. In the cases of lead and Sci/Fi, the minimum layers needed states the ideal case where there is no waste during construction. All totals have had the appropriate allotment for the inevitable waste that will happen during construction.

CONSTRUCTION TIME

The Edmonton construction crew had a varying size of five to seven people. While a crew of four people could be used, they would not be able to work at a pace that would complete the module in a suitable time frame. It is the opinion of the SPARRO team that the difference in layers placed per session between a team of five and six is negligible. For this reason it is recommended that a team of five people be used for production. Table 1.3 below lists the details regarding construction time for the 4m module.

Employees/Time		
Crew (average)	5.4	people
Time/layer	0:14	hours
Total hours	329.08	hours
Session Length	2:15	hours
Total Sessions	29.3	

▪ *Table 1.3: Construction time of 4m prototype.*

Using the assumption that a work crew of five people will be able to consistently place eight layers on a module it is possible to make the following predictions.

Timeframe	
Session / module	26
Total Hours / module	65.2
Manhours / module	326.0059
Total Production Hours	3129.657
Production Manhours	15648.28

▪ *Table 1.4: Construction time of 4m prototype.*

This would mean that a crew of five people could complete a module in 26 sessions over a period of 13 days. If each session lasts just under two and a half hours, that would mean just over sixty five hours of construction time. That comes to just over 300 man hours for each module, or a total of almost 16 thousand man hours for the construction of 48 modules.

CONSTRUCTION SUPPLIES

Over the course of construction there are a number of disposable items that are consumed. These include the static dissipative and Nitrile gloves, Vaseline, paint brushes, plastic cups and spoons as well as cheese cloth and ethanol. All of these items, except for the static dissipative gloves are not reusable. The static gloves however, have a lifetime and it is will need to be replaced a few times over the course of future production. The table below contains the approximate amount of each item that was used as well as an approximation of what will be required for the future production.

ITEM	USED	NEEDED
Vaseline (500g jars)	4	192
Ethanol (gallon)	1	52
Gloves (standard boxes)	6	290
Paint Brushes	319	2500
Plastic Cups	63	14000
Plastic Spoons	93	3800

▪ *Table 1.5: Supplies used and required for 4m module construction.*

Looking at these figures we can see that there will be a significant amount of waste for the paint brushes and plastic ware. Unfortunately the paint brushes must be discarded after use as it is not possible to clean all of the epoxy from them. The plastic cups could be exchanged for glass ones, and plastic spoons for metal ones allowing them to be reusable. This would however create an increase in each session time by about a half an hour and a significant increase in the ethanol used per module.

CONCLUSION

It is safe to say that the research and development stage of the 4m production is virtually closed. All that is left is to streamline the process by speeding up the gluing process, reducing waste and training a full time crew. The 4m module that was constructed in Edmonton over the summer of 2004 has not yet undergone the majority of its testing, however, visual inspection of the module showed only a few instances of shifted layers. These shifts are all on the order of one or two millimeters over four meters, and they were often corrected shortly after the initial mistake was made. As light will be collected over a large area, these shifts do not pose a significant problem.

RECCOMENDATIONS

The Summer 2004 construction was the first real practice of full scale production. As a result there were as many unanticipated problems as there were useful discoveries. This section is a summary of recommendations for the production clean room and process.

Clean Room Modifications

- The length of the clean room must be doubled to place the table in line with the press or two presses in line with each other. With the table and the press in line only two people are required to move fibers to the module. However, one press will still not be inline with the table and the time lost in this process is minimal.

- Storage racks for at least 25 bundles. With two presses gluing at the same time, the number of fiber bundles a day will be very high. For this reason we need to provide the means to build up a stock of fiber bundles. After each morning gluing session the bundles for the next four sessions should be prepared.

- An Internal fume hood. The clean room would be far more productive if there was a fume hood located inside the clean room. A small enclosure that is vented directly into an air output would probably be sufficient.

- Sealed access panel in the roof. This panel allows the crane to lift the module off of the press. This panel should be centered over the press and it should be easily sealed and opened when needed. Preferably this panel would also be translucent to allow filtered light through.

PRESS MODIFICATIONS

- Cable support for locking arms. The current press has a nylon cord tied to the upper piston bolts to stop the locking arms from falling behind the press. A more permanent steel cable should be attached to these bolts to provide greater stability to the arms. This added strength is very important since the Teflon sheet is being placed on these arms during gluing.

SORTING TABLE MODIFICATIONS

- The sorting table should be resurfaced with grounded copper sheeting. A very light gauge of copper is needed to provide a tabletop that is durable enough to resist light scratches.

GLUING ACCESSORIES

- Static dissipative gloves. These gloves proved very useful in testing, however, the will begin to wear out after a while. At second package should be acquired, as it seems that the gloves have a bit of a lifetime of usefulness.

- Fiber clips. These devices would be a small _" clip that would be used to separate bundles of fibers. Currently elastics are used, however, these have a tendency to fall off. Hair clips might be used in their place as they will hold the fibers securely without damaging them.

- Envelope opener. When the plastic bundles containing fibers are opened using a knife the table surface may be damaged. An envelope opener, consisting of an protected angled razor blade can be used to open the bags. This device would not harm the fibers or the table and can increase counting time.

- Anti-static Vacuum. When the fibers are removed from the shipping packets many contain an inordinate amount of lint and dirt. These contaminants must be removed before the fibers can be glued properly. A small vacuum cleaner, exhausted to the outside, with an anti-static brush at the nozzle, could be used to clean much of the dirt off. A hand held unit should do the trick.

GLUING ACCESSORIES (ONLY IF TWO TEAMS ARE GLUING AT THE SAME TIME)

- Additional sorting table. This table should be built using the same design as the existing table.

- An additional set of clamps. These are the spring clamps that have been modified to hold fibers for gluing.

- An additional set of eight weights. Half of these weights should be eight inches long and have foam feet. Two of the clamps should be the same size but with swaged lead feet. The other two could be either foam or lead and need only be five inches long.

- An additional two fiber knives. While the Teflon coated metal knife works well, the plastic icing knife is much larger. The extra length of the plastic knife allows it to hold the fibers much more reliably.

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APPENDICES

MODULE CONSTRUCTION

There are a number of jobs that must be done during the gluing process. Some of these tasks require a good deal of specialization. This section is a detailed manual outlining the main points of each job.

GETTING STARTED

To begin module construction a one millimeter groove must be machined down the center of the 1" aluminum backing plate. In this groove, a fiber will be glued down to provide a guide for the first layer of lead. Small amounts of optical epoxy is used to fix the fiber into this groove. Excessive epoxy results in lumps on the plate that must be cleaned off so as to not damage the next layers of lead. The aluminum plate its self is treated by roughing it's surface with sandpaper. This rougher surface will bond better with the Araldite Industrial Epoxy and help prevent de-lamination.

It is possible to use a wire in place of the guide fiber. The wire would run the full length of the plate and then hang over the ends by a few centimeters. At both ends a sizable weight would be attached to the wire to keep it embedded in the groove. This wire would have to be made out of a soft metal such as aluminum or copper. Harder metals would damage the machining disc.

Next, the base layer of lead is rolled onto the fiber and its outline traced to provide a visual guide for positioning. The lead was seated such that it had a 3mm gap next to the vertical plastic guides. After rolling up the base layer industrial epoxy is applied to the aluminum. This is done using a plastic putty knife to ensure that the epoxy is spread evenly. The epoxy must be kept very thin a few centimeters around the fiber. This is done to ensure that the lead can still be rolled onto the fiber in a reliable fashion. It was observed that if the epoxy built up on the fiber it becomes quite difficult to feel where the fiber is. After the lead layer is seated, Vaseline is applied to the perimeter of the top surface of the lead. This Vaseline acts like a gasket with the Teflon and prevents epoxy from seeping into the grooves of the lead.

Unfortunately the lead has a tendency to drift while pressure is being applied, this is the reason for using a guide fiber. Once the industrial epoxy has cured the drift of the base layer needs to be checked. If it is a reasonable amount then the rest of the construction can continue.

GLUING PROCEDURE

CLEANING THE MODULE

Gluing begins each day by removing the pressure from the module. The pressure plate is removed and stored at the foot of the press in its brackets. The Teflon is placed above the press with the white surface up so that it may be cleaned. This is done using a piece of clean dry cloth or Kim wipe. The same treatment is given to the module to remove all the excess Vaseline. Next, ethanol is used to remove every last trace of Vaseline. Even a small residue of Vaseline on the module will prevent the epoxy from adhering correctly. For this reason the surface is wiped many times with ethanol and then allowed a few minutes to dry before any epoxy is put down. While this is happening, the first batch of glue can be mixed in the fume hood.

MIXING THE EPOXY

> ***Note:*** *At all times, proper gloves must be worn while handling the epoxy resin, hardener and mixed epoxy. Mixing ratio for Bicron 600 is 100g Resin : 28g Hardener*

The first step to mixing the epoxy is to cover the measuring scale with a clean sheet of saran wrap. The saran wrap protects the scale from the epoxy. While resin simply makes a mess when it is spilled, the hardener is actually quite destructive to plastics and will eat through the saran wrap if left on for too long. First a small plastic cup is placed on the scale, which is then zeroed. Resin is now added by means of a large metal spoon. Because the resin has the fluidity of honey, the spoon should be scraped clean using a stir stick. This excess can be put into a cup to be used or back into the resin tin. When not in use, the spoon can be rested on the upside-down lid of the resin tin so that the runoff is recovered. When the desired mass of resin is in the cup (typically 100g) the hardener can be added.

Hardener is added first by pouring a small amount of the liquid into a plastic cup. The plastic cups pour much smoother then the brown glass bottle that it originally comes in. Slowly the hardener is added to the resin tin until an additional 28g registers on the scale. The leftover hardener can be replaced into the bottle and very little of it will be wasted.

Next the mixture must be thoroughly mixed. This is done using a spoon, most usefully a clear spoon. At first the mixture will be quite cloudy, however, after a minute of stirring the epoxy will become quite clear and the spoon, if translucent, will become almost invisible. When it is properly mixed, the viscosity of the epoxy will be consistent throughout the entire cup. This is best accomplished by stirring the mixture vertically as the resin tends to sit at the bottom of the cup. When the mixed stage is reached, the epoxy is split into three cups. The first cup gets just enough epoxy to cover the bottom of the cup with a few millimeters of epoxy. Over the next two hours this glue will be tested to see if it is curing. After two hours the module should be pressed, however, if that cup begins to set then gluing needs to stop regardless of the elapsed time. The next two cups receive equal proportions of epoxy to ensure that their volume is low enough that they will not overheat and cure prematurely. This process is then repeated to make a batch of glue consisting of 200g of resin and 56g of hardener.

> *Batch = 200g resin : 56g hardener*

SPREADING THE GLUE

First glue is spread onto the module using a 2” bristle brush. These brushes are cheap disposable brushes, so the glue spreaders must be mindful that a bristle or two may fall out while they are spreading the glue. These loose bristles, lint and dirt must be removed for the scintillating fibers and lead to sit correctly with each other. This is done with a toothpick or a gloved finger.

When glue is spread onto the module it is important that the entire surface of the lead is covered with a only a light layer of epoxy. This layer should not have puddles, though it is acceptable for the center to have a bit of excess epoxy as this will be spread over the length during the pressing. It may take a few sessions to get a sense of how much glue is too much or too little, but two batches of epoxy should just adequately cover six layers of lead and fibers. By experimentation this has been established as the minimum amount of glue that should be used. Remember, too little glue may result in de-lamination of the layers. For this reason it is better to err on the side of too much epoxy, just don't get carried away. Also, when applying glue to the fibers, make sure that the fibers receive full coverage. That being said, remember that less glue is needed, as there is already a significant amount of epoxy below the fibers.

While the glue is being spread onto the dry lead, the fiber sorters should already have one bundle loaded into the clamps. Typically at this point there is a second bundle on the table that is mostly spread out. This means that when the two sorters are done holding the clamps at the lead, the next bundle is almost ready to go into the clamps right away.

FIBER SORTING

Fiber sorting has the potential to be the most time consuming task in the gluing process. Due to some innovative techniques this is no longer the case. The most important factor to increasing efficiency is to improve manual dexterity, reduce the effect of static and gain experience working with the fiber tools to sort the fibers. Next is to ensure that a large enough supply of bundles is prepared for the gluing session. Each afternoon between gluing, the stockpile of 16 bundles should be topped up.

First, a packet of fibers if placed on the fiber table from the supply crate located at the foot of the table. This packet is then opened with a knife, being careful not to cut the table surface. A small envelope opener, kept very sharp, would be very useful for this operation. The fibers are then removed from the plastic sleeve so as not to increase the fibers static charge. At any point in the counting or sorting process short fibers should be removed and marked in the log book on that day's lost fibers tally. Using a small Teflon knife the fibers are flattened at the center and separated into bundles of 95 fibers. Typically the lead contains 96 grooves, however, often one of these grooves is not complete and a fiber is wasted. Since it is easier to add a fiber during gluing, bundles are made to be one fiber short and a draw pile of fibers is left on the table. This bundle is then wrapped with an elastic band at the center and the ends are then pulled free of the original bundle. At this point the fibers could be vacuumed clean using the anti-static brush attachment to the vacuum. Then the bundle is fastened with rubber bands a few inches from each end and added to the stockpile located at the back of the table.

The first step to sorting fibers is to flatten a bundle out at the center and weight it down with two or three foam weights. This prevents the fibers from sliding too much or rolling over each other. Now, with two people working on either side the fibers are detangled from the center to the end. The first step is to pick all the fibers up on a fiber knife and begin to bounce the fibers gently out towards the ends while gently unbraiding them with a free hand. To prevent the fibers from falling off the table it is useful to place the excess weights at the edge of the table while bouncing the fibers. The bouncing allows the fibers to gain full freedom from each other and they actually begin to sort themselves out.

Return to the center of the fibers and again pick them up with the fiber knife. The sorter must then use the hand that is closest to center to separate the fibers into equal bundles between each finger. While bouncing the ends of the fibers, the sorter moves both hands at a moderate pace towards the end of the fibers. With practice the fibers will begin to detangle on the knife and then they will be channeled into smaller, less tangled bundles by the sorter's fingers. After they pass through the fingers they will sit on the table behind the sorter almost completely free of tangles. When the end is reached, it is usually required that they are sorted by hand. Again, return to the center and pick up the fibers on the knife, making sure to keep them sorted. This time, take a swaged-toothed weight and place it on the flat center of the fibers. Now, use it to comb the fibers flat behind the oscillating knife. When the knife gets to the last foot of fibers, remove the knife and just fan/tap the fibers gently with the flat of the hand while combing them with the weight. Remember to place additional weights on the fibers as you flatten to ensure that they do not simply tangle back up.

The bundle should now be quite flat, however, the ends need to be squared up to the reference line to check if the fibers are long enough. After the fibers are roughly square to one end, the center of the first three fibers is marked using a black marker. This line is used to align the fibers in the module. Now the center gate can be lowered and the fibers are loaded into the clamps marked ‘slider’. These clamps have a tiny bump at the front and back of the lead jaw to prevent fibers from sliding out when pressure is reduced on them. The clamps should be placed at a foot or two from the center and clamped firmly. The next set of clamps is then placed no more then a foot from the end of the bundle, but within arm span of the other clamp. As soon as the one bundle is clamped it can be placed towards the far edge of the table and the next group of fibers can be sorted.

When the call comes for the fibers to be glued the two clamp holders go to the ends of the table and pick up the outside clamps. A third person lifts the inside clamps so the first two people can walk around to the table to get the inside clamps. The third person then gets out of the way and the fibers are walked over to the press. This process would be much less complicated if the table and press were in line with each other as the clamps could be lifted off the table with only two people.

GLUING FIBERS

Spreading fibers into the module takes a bit of practice. First, the center of the fibers must be aligned with the mark located at the center of the module. Then, the fibers are placed into the grooves of the lead in the least tangled fashion. Using one hand to hold the fibers from underneath, the second hand is placed on top of the fibers to keep them flat. The fibers are then pressed into the module in this fashion. Next, one hand is used to press the fibers in the module, while the other hand aligns each fiber with a groove. This is done by fanning the fibers with the edge of a thumb to push individual fibers into position. Once the fibers have some glue on them they begin to slide over each other better and they also stay in the grooves quite well.

The inner clamps can be loosened but not removed so that the fibers don’t spread apart too much. These clamps should be held low to the module and about a foot and a half from the fiber spreaders outer hand. This prevents the fibers from getting tangled, while providing enough slack that they don’t tangle up before they go into the module. The outer clamp must be held so that the fibers do not touch the glue before the inner clamp passes over it. Any glue on the clamps must be cleaned with alcohol immediately after the fibers are in the module. When removing the inner clamps from the fibers, slide them to the end and pull them off near to the outer clamp.

When all the fibers are in the module the ends must be checked to see if any of the fibers are too short. Short fibers are gently pulled at their short end to hang over the end of the lead. This process requires at least two people so that both ends can be checked at the same time. Any fiber that is too short to overhang the lead, or at least be as long as the lead, must be removed and placed on the storage nails on the back wall. Next the surface of the module is examined to see if any fibers are not seated properly in their channel. This is caused by dirt in the groove or a defect in the lead or fiber. Dirt is cleaned with a fingertip or toothpick, same as lead defects.

However, the fiber lumps may result in a fiber being discarded as sometimes the fibers have large lumps or waves in its structure. Small deviations are not overly significant as the lead has some give in it. Generally this cleaning is done starting at one end and working towards the other end. That way the glue spreader can paint epoxy directly behind the cleaner and the lead roller can begin the next layer of lead behind them.

ROLLING LEAD

Rolling the lead properly is crucial to building a working module. To avoid problems that arise from systematic variations in the lead each sheet must be alternated when it is placed on the module. To keep track of the alternation the lead was marked with a picture at one end. When the lead was placed on the small PVC rolls the picture was either placed at the outside of the roll or the inside of the roll. To identify which side of lead is required the surface of the module must be examined for a picture at one end. If there is a picture visible, the next layer of lead must have a picture visible on the roll. After it is rolled out there will be no visible picture on the module and the next roll of lead must be free of a picture as well. The two types of lead are sorted into separate cupboards within the clean room to reduce confusion.

The lead roll is placed on the module such that its edges are parallel with that of the module with no more then one grove being consistently over or in. Then the end of the lead is gently pulled to be square with the end of the module. Ideally there would be a vertical guide that would let the roller know where true ninety is. This square could be mounted to the base plate during gluing and removed before machining. If the lead has already been rolled out and it is too short then this must be rectified in one of two ways. If there are only a couple of layers beneath the short layer then the lead can be pushed from the top with the flat of your hand. While doing this the end must be watched from the side to see if the other layers are also shifting. If this is happening the lead must be partially rolled and the process repeated until the lower layers no longer move under the sheer.

The lead is then slowly rolled towards the other end using one hand while the other hand presses the lead into the module. Both sides of the lead should be felt for deviations in the direction of the lead. If the lead skips off of the fibers it must be pulled back on and pressed down. Vertical strips of plastic provide a visual guide to check the positioning of the lead. There is generally a 2mm gap between the lead and these guides so the difference of 1mm should be apparent.

While the lead is being rolled out to the end it should be pressed flat into the module. At this point the next layer of glue can be placed on its surface, though one shouldn't hurry. When the lead reaches the end the length is checked. If it is the shortest layer on the module, a mark is made on the base plate at that point. This mark will give the machinists an idea as to where the module can begin and end such that all layers are complete.

PRESSING

It was found that with practice the team of five was able to complete eight layers in just under a two-hour period. During this time the glue cup was tested a number of times by stirring it a bit. It was found that after the two-hour mark the epoxy began to cure in an accelerated fashion. The team decided that at the two-hour mark, unless the epoxy set sooner for whatever reason, the module must be pressed.

The pressing sequence begins with a dry sheet of lead on top. Vaseline is then applied to the outer edge of the upper sheet. Without the Vaseline, epoxy would seep up and under the Teflon into the swaging on the lead at the top. This will then cure and ruin the top layer of the module. The Vaseline creates a gasket that prevents this because it is more viscous then the epoxy.

Additionally, it coats the lead so that any epoxy that might get it will not set onto the lead but on a layer of oil. At the ends the Vaseline must extend about 1" - 2" into the module. At the side, no more then four channels need to be filled with Vaseline. The Vaseline is applied by hand as this is the quickest and most controlled fashion. It is best to apply a thin layer of Vaseline to the surface of your fingers and use the module to scrape it off. By changing the angle of you hand with respect to the module you can control just how many grooves are filled and how much Vaseline goes onto each spot.

When the Vaseline has been applied in a continuous ring, the Teflon can be placed on top of the module. The Teflon must be placed directly against the plastic stops so that the entire module is covered. Next the aluminum plate is placed on the Teflon and again they are both pushed to the stops. The press is then tilted up and the locking arms are fastened down. An aluminum shim is placed beneath the number 1 pistons and they are allowed to come down. This shim may be neglected when there is no longer room for it between the module and the piston rams. After two minutes the second switch is toggled, and this is continued for the next three piston pairs. Piston pairs five through seven are then given one and a half minutes and the remaining pistons have a one minute pause between their compression. The time interval allows the epoxy to migrate through the module so that the entire surface of each layer is covered with epoxy. It appears that the epoxy migrates much easier towards the ends and this is the reason for the decrease in migration time as the outer pistons are reached. After seven or eight hours the pressure can be released, and the next session can begin as all the epoxy is rigid enough. After each session the electronic log is updated to keep track of the glue that is being used, fibers and lead that are lost and all other important details. These are used to generate the statistics that are used to anticipate supply usage.