TITLE: BCAL WEDGE FABRICATION PROCEDURE	DATE: 8/27/2010
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Original Application:

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BARREL CALORIMETER CONSTRUCTION MANUAL

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1 INTRODUCTION

The GlueX Barrel Calorimeter (BCAL) is being constructed at the University of Regina, between 2009-2012. The BCAL is a sampling calorimeter based on scintillating fibres and will be deployed inside the GlueX detector's super-conducting solenoid.

Specifically, the BCAL will be comprised of a lead and scintillating fibre matrix, consisting of 185 layers of corrugated lead sheets, each of 0.5~mm thickness, sandwiching 184 layers of 1-mm-diameter, multi-clad, Kuraray SCSF-78MJ scintillating fibres (SciFi), bonded in place of the lead grooves using BC-600 optical epoxy. This geometry results in approximately 15500 fibres per module. The detector will consist of 48 modules, each having a trapezoidal cross section (8.5-12.5~cm taper), and will form a 390~cm long cylindrical shell with inner and outer radii of 65~cm and 90~cm, respectively. Each module's construction will be organized nominally into four steps of progressively decreasing width: 20 layers at 13 cm, 60 layers at 12 cm, 60 layers at 11 cm and 40 layers at 10 cm – from the builds of the first 10 modules, the actual layer count is 20/63/63/39 (see table in Section 10). A schematic is shown in Figure 1.1. This shape lends the nickname to the construction process: 'Mayan Pyramid' builds.

The pyramid-style design was introduced to reduce wasted fibers when modules are machined. The first three prototype modules (1-m, 2-m and 4-m long (Prototype 1), respectively) were built with a straight design where all lead sheets were the same width, and each layer contained the same number of scintillating fibers. The fourth (Prototype 2) and fifth (Construction Prototype) were built employing seven and four pyramid steps, respectively. All production modules are being built following the four-step design, as shown in Figure 1.1.

2 CONSTRUCTION LAB

Construction of the 48 production modules is occuring in LB113, at the University of Regina. Lead swaging takes place in the LB113.3 alcove and lead is stored in LB113.1, LB113.2, UofR Cold Storage and Ross Machine Shop. The Construction Manager's office is in LB113.4.

- Approximate lab dimensions for the main lab are $1000 ft^2$.
- The main instrumentation includes: two electro-pneumatic presses, one swager with its table, one lead cutting and fibre sorting table, one A-frame hoist, one 'cherry picker' crane, and several dollies for the movement of all heavy objects.
- Air supply: standard overhead ventilation and filtration system.

- The room has a standard fume hood for epoxy mixing.
- Personnel wear lab coats and latex or cotton gloves, depending on the task, as well as protective footwear.
- All overhead fluorescent lights are covered with yellow UV-blocking filters to protect the fibres from UV exposure.
- MSDS sheets, construction manuals and instructions are at hand and/or posted.
- The lab is regularly cleaned and mopped. All shelving and drawers are clearly labeled based on their contents.

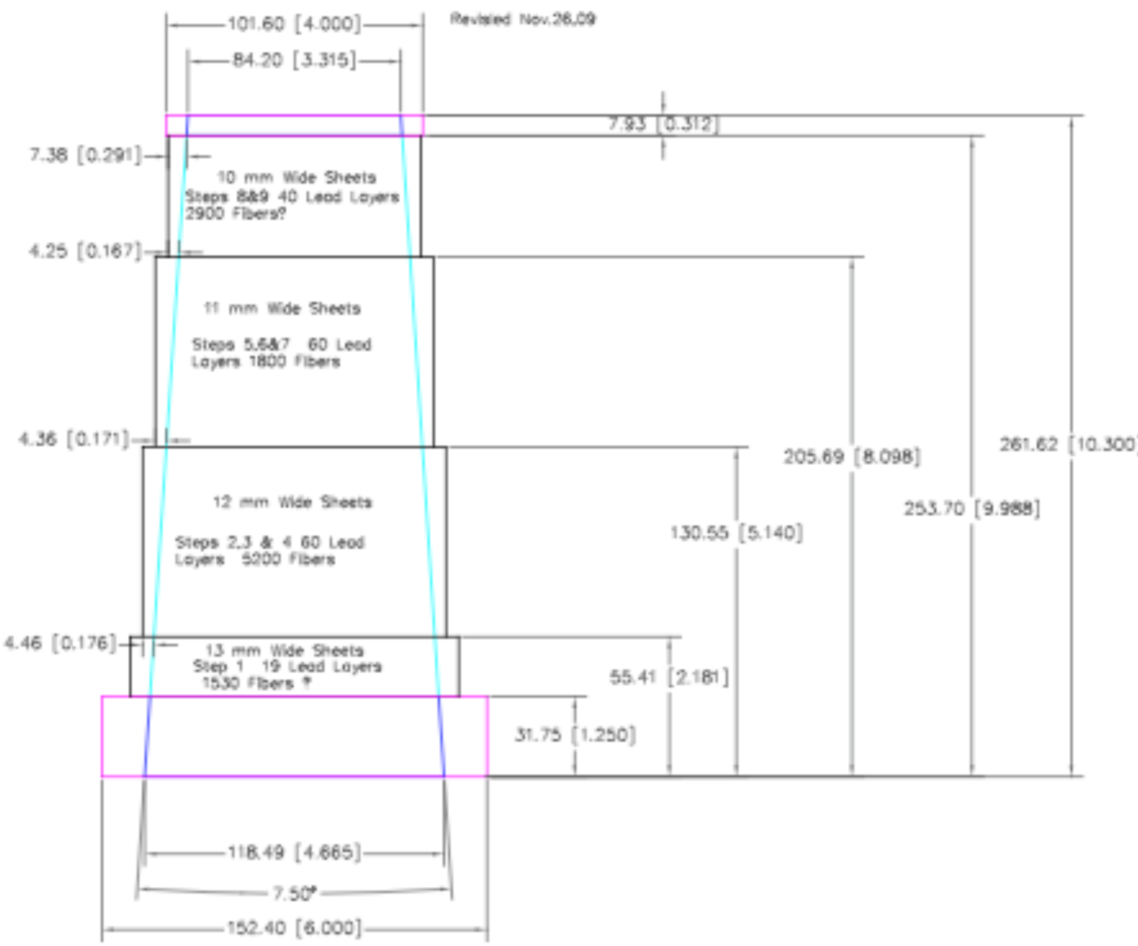

Figure 1.1. Design cross-section of Mayan pyramid-style module showing the 20/60/60/40 split of layers for the 13-cm to 10-cm widths, respectively; the actual build process has resulted in average stacking of 20/63/63/39. There is always one more layer of lead than fibres.

3 FIBER TESTING PROCEDURES

3.1 Attenuation Length Station

General Remarks

The Fibres from Kuraray come in wooden crates, each containing a number of cardboard boxes. Each box contains two (large) pouches/bags and each of those contains 8-12 sub pouches (or small bags). Each of the sub pouches contains approximately 100 fibres.

1. Two people are always used to transport fibres.
2. Kuraray cardboard boxes in which naked fibres are placed are cleaned with ethanol.
3. The puck board groove and work area at the attenuation length station are cleaned with ethanol and Kim wipes.
4. Ensure that the fibres are only exposed to UV filtered light (yellow film). This means that all measurements are taken with the overhead room lights OFF (even though they are covered with yellow filters), and that only one small desk lamp is on and it is covered with a UV filter. The overhead lights are ON for brief periods, only while moving/gathering fibres.

NOTE: All fibre handling is done while wearing cotton gloves, with the exception of the hand that is used to clean and/or grease the fibre's end.

Specific Procedures

1. Receive fibre crate at the RIC loading dock and move to LB127.
2. Document external condition of crate. Take photos if necessary.
3. Open the crate. Note internal condition and document observations. (Example: Shipment 5 had water droplets inside, although the plastic sheet protected the cardboard boxes from moisture.). Include in the documentation whether the fibre lots (cardboard boxes) were packaged sequentially and incrementally from top to bottom.
4. Open a cardboard box, starting with the ones at the top of the crate and working down into the crate. Document if any box is overstuffed with fibres.
5. Withdraw fibre pouches carefully from the box until they protrude by about 30cm.
6. Carefully cut the protruding end off each pouch to reveal 8-12 sub pouches.
7. Carefully cut the protruding end off all enclosed sub pouches.
8. Carefully remove a fibre from each sub pouch applying a radius of curvature of NOT

LESS than 0.5m (typically in the vertical direction) and place it in a cleaned wooden plastic-lined box.

9. Tag each removed fibre with a pre-made paper. The tag includes the fibre code consisting of the pouch, the sub pouch, and the fibre number, which is threaded onto the fibre through two holes in the tag.
10. Blacken the far end of each fibre by dipping them in black enamel (model) paint. The blackened ends of the fibres need to dry by hanging them over the edge of the bench. Inspect and ensure that the far end is thoroughly coated by the paint.
11. Polish ONLY the near end of all fibres using the FibreFin polisher.
12. Slide the LED housing to the very far end of the puck board.
13. Place each fibre to be tested in turn onto the puck board, after removing its paper tag.
14. Thread the near end of the fibre through the opened Ocean Optics bit chuck leaving about 2.5cm visible on the other end.
15. Dab the near end of the fibre in a small amount of optical grease and thread it through the brass guide towards the photodiode.
16. Push the photodiode onto the fibre until contact is made with the window of the photodiode.
17. Push back the fibre by a few millimeters using the entire photodiode platform until the end of the clamp and the photodiode touch, in order to guarantee that the fibre is in direct contact with the photodiode.
18. Smooth (gently press down) the fibre into the puck board's groove with care and without tugging on the fibre, while wearing cotton gloves.
19. Slide the LED housing all the way across the puck board to the 18 cm mark on the ruler.
20. Turn on the LED and let it warm up for 10 minutes.
21. Record the current reading from the Keithley 6485 pico-ammeter directly into an Excel spreadsheet taken every 20cm along the fibre's length, for a total of 20 data points per fibre. As a guide, the nearest distance should result in a current around 110-120 nA.
22. Do not touch the fibre or LED housing while a measurement is being recorded. There is only one exception to this rule: when the fibre has a permanent curvature (as a result of overstuffing in the pouches) and will not stay down in the groove, hold it down at both sides of the LED housing, with fingers pressing gently.
23. Observe the exponential decrease in the measurements and repeat any measurements that appear out of the ordinary. This may occur due to the fibre "jumping" out of the groove or failure to sit in the full depth of the groove.
24. Slide the LED housing to the far end of the puck board, after the fibre has been tested.
25. Pull the fibre gently out of the opened chuck.
26. Wipe off the optical grease with a Kim wipe.
27. Re-thread the paper label onto the fibre.
28. Move the fibre into the `test completed' fibre box.
29. Repeat procedure (steps 13-28) for 0.5-1% of fibres in each shipment, corresponding to approximately one fibre per sub pouch.
30. At the end of each shift a 'shift summary' is entered into the Elog.
31. Store the 'test completed' fibre box (when full) on one of the lower shelves against the wall above the attenuation length station. Label the box with the shipment date

and number. These fibres will be set aside as reference standard for (nearly) the duration of the build and perhaps used only in the last few modules.

32. Disassemble the photodiode and chuck set up and thoroughly clean the photodiode's window with Kim wipes and ethyl alcohol once a week. Reassemble for reuse.
33. Insert all tested sub pouches into their corresponding cardboard box, being careful not to jam them. If there are too many sub pouches to do this safely, leave out a few.
34. Place tested cardboard box aside and continue the procedure (steps 4-28) for the next box until the shipment is fully tested.
35. Return tested cardboard boxes to their crate; seal and move it from LB127 to LB113.

3.2 Number of Photo Electrons (Npe)

Overview

1. Confirm that the power is OFF on the LeCroy high voltage supply.
2. Open the 'coffin' and remove the centre-beam brace.
3. Insert a cardboard box with the fibres to be tested in the coffin, as well as a second empty cardboard box (two persons).
4. Replace the centre-beam brace beam.
5. Power ON the LeCroy unit and carryout measurements.
6. Power OFF, remove centre-beam brace and tested fibers, and repeat.

NOTE: All fibre handling is done while wearing cotton gloves, with the exception of the hand that is used to clean and/or grease the fibre's end.

Handling Instructions

1. Move the 4-m-long cardboard box containing the fibres tested at the attenuation length station and place inside the 'coffin' (two persons).
2. Lay a second, empty 4-m-long box next to the fibre box. (Move fibres from the first box to the test station trough and after testing place into the second box.)
3. Oriented facing the computer, Person 1 sits on the right of the signal cables and is responsible for the computer and inserting the fibre into PMT.
4. Person 2 sits on the left of the signal cables and is responsible for recording information in the logbook and placing the source on the trigger.
5. Person 1 chooses a fibre from the untested fibre box and holds it so that Person 2 can reach it. Then both place the fibre carefully in the testing trough.
6. Person 1 greases the polished end of the fibre with a small amount of optical grease, enough to just cover the tip.
7. Person 1 positions the fibre against the Hamamatsu PMT by threading the greased fibre through the Plexiglas guide's tapered hole and feeling for buckling and helical twisting of the fibre upon contacting the PMT's photocathode.
8. Person 1 holds the fibre down in this position and communicates to Person 2 to gently press the fibre down at a location near the trigger PMT with one hand, while with the other hand to place the collimator and source on top of the fibre (and trigger

scintillator). The groove at the bottom of the collimator must mate to the fibre so as to prevent the fibre from being tugged out of the PMT. The fibre is kept as straight as possible while in the testing trough.

9. Upon a signal from Person 1, Person 2 places the source on the fibre. Person 1 then checks again to make sure that the fibre is still in contact with the PMT.
10. Rotate the collimator slightly to see if the fibre moves in sync with it, in order to test if the source was placed on correctly. Avoid affecting the fibre's contact to the PMT.
11. Upon signal from Person 2 that the source has been correctly laid, Person 1 lets go of the fibre and both lids of the coffin are closed and the test commences. Weights are placed on the coffin lid to ensure good optical sealing.
12. Monitor the data using an online PAW script, which indicates graphically the acceptable data limits.
13. If the test was successful, Person 2 removes the source while Person 1 pulls the fibre off the PMT and out the Plexiglas guide and wipes off the optical grease using a Kim wipe.
14. Similarly, if the test was unsuccessful, Person 2 removes the source and the fibre is wiped, re-greased, re-inserted. Retesting is done until data fall within the acceptable limits or up to a maximum of three times before abandoning further testing for this fibre.
15. After the successful test of a fibre (see below), remove the fibre from the trough and carefully move it to the 'tested fibres' box (two persons).
16. Once all fibres are tested, remove the 'tested fibres' box from the coffin, label it and transfer it to shelf.
17. Record run numbers and relevant information in the dedicated logbook.
18. Enter a 'shift summary' into the Elog at the end of each shift.
19. Disassemble the setup every week: thoroughly clean the tapered hole of the Plexiglas rod and PMT window.

Apparatus Signal Cables/ High Voltage Power Supply Channels}

1. NEVER step on a signal cable.
2. Connect the signal cable labeled 'Calibrated PMT' on the coffin to the top red delay line labeled 'in'.
3. Connect the signal cable labeled 'Photodiode' on the coffin (this is for the trigger counter and not a photodiode) to the splitter panel labelled '10'.
4. Set the Calibrated PMT to 2200V on the LeCroy HV supply (Channel 3).
5. Set the trigger counter ('photodiode' label) to 1700V on the LeCroy HV supply (Channel 2).
6. Check the LeCroy high voltage power system for the correct voltage by holding down the 'Channel' button and pressing the up or down arrow.
7. If Channel 2 and/or Channel 3 are not at the correct voltage, change the voltage by holding down the 'Voltage' button and depressing the up or down arrow.
8. Pressing the 'On' button on the mid left of the LeCroy HV crate turns on the voltage. Pressing the 'Off' button immediately beside the 'On' button turns off the voltage.

ATTENTION: The HV must be OFF if the coffin is open and/or the room lights are on.

The Data Acquisition System

Computer name: sklavos
User: midas
Password: ********

1. Turn on the central white switch on the black Kinetic Systems Model 1502 CAMAC Crate located second from the bottom.
2. Turn on the small black switch on the top brown right faceplate labeled "bin'".
3. In the first workspace, open two terminals and in both change to the directory */localhome/midas/test.oldcode*
4. In one of the terminals, type *dio ./fal* and always choose option '4'.
5. In the other terminal, type *odb* and again choose option '4'.
6. After confirming that the fibre is correctly positioned close the coffin lids and turn the room lights off.
7. Person 2 turns ON the High Voltage.
8. To be ready to run a test, type 'start' in the odb terminal. Enter the following information at the prompt:
   a. Comment: Sr90 at 205cm; trig at 1700V/40mV/100ns; R329-02 at 2200V; fiber [fibre code]
   b. Run number: [run number]
   c. Are the above parameters correct? ([y]/n/q): [enter]
   d. Starting run # [run number]
9. Person 2 enters in the logbook the end time, test verdict, and diameter of the last tested fibre and then the fibre count, fibre code, run number, and start time of the current test.
10. After the data event count has met or exceeded 100000 events, Person 1 types 'stop' in the odb terminal. Then in the other terminal, '[shift] !' is pressed and 'reset' is typed. The letters will not appear as this is being typed.
11. While waiting for the terminal to reset, turn off the High Voltage.

Data Evaluation Script

1. After the terminal has been reset, type *./ana [run number]* and choose option '4'.
2. Move over to the other workspace on the computer and view the raw data by typing *exe phetest [run number]*.
3. The peak on the distribution must be over (to the right of) bin 50 or the red line. If the mean is between the red and the green line, REPOSITION the fibre correctly and run the test again on the next run number but with same name and count number all documented in the logbook. If the peak of the distribution is past the green line, the test was successful.

4. If after three attempts at testing the fibre the above criteria are not met, mark the fibre as failed.
5. If the test was successful, then Person 2 checks again for the High Voltage to be OFF and signals for the coffin to be open. Person 2 then removes the source to be placed on the floor of the coffin while Person 1 pulls out the fibre and wipes off optical grease with the Kim Wipe, which is available.

3.3 Fibre Diameter Measurement

At any time measure the diameter of 30 fibres from each shipment using a micrometer caliper, at three positions along the fibre: 50, 200 and 350 cm. Use the micrometer sideways with the fibre oriented as to face the same direction of that of dial and take multiple readings recording the average.

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4 LEAD HANDLING

4.1 Introduction

The lead for the construction of the BCAL production modules was received from Vulcan Resources in four main shipments, each comprising approximately 25% of the total order. A fifth small shipment contained enough lead to account for the rejection rates, and a sixth, even smaller order was comprised exclusively of 13-cm wide sheets to be used for the top sheet in each 12-cm build, in order to suppress epoxy migration to the top surface.

The lead came in coils (rolls), each packaged in a clear plastic bag inside a cardboard box. Coils were cut to width by the vendor: 10-cm, 11-cm, 12-cm and 13-cm wide, and weigh 50-70 lbs each. Each shipment was inspected upon arrival. Some coils (still in their cardboard box) were extracted from the crates and arranged on shelving in LB113.1 and LB113.2. The remainder was left in Cold Storage until needed.

Each coil yields on average ten 398-cm-long cuts. As swaging progresses, the cuts are processed, inspected for acceptance and returned to dedicated shelving in LB113 (main) to be used towards construction.

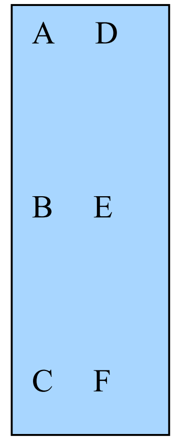
NOTE: At least two persons are needed to flip over a lead sheet.

4.2 Preparing and Cutting

1. Remove lead coil from packaging. Record Lot # from sticker on coil.

2. Insert an aluminum rode through the coil's core and balance the rods ends on lead blocks at the far right (in-feed) edge of the swager table, thus creating a dispenser. Dispense lead from the bottom onto the swager table.

3. Pull lead gently to uncoil.
4. Cut a 30 cm test piece and mark the coil code and width on it using a marker.
   a. Mark 3 points along each end (A, B, C, etc, as shown in adjacent figure), for a total of 6 points.
   b. Swag the cut.
   c. Measure the swaged cut's thickness at each point using the standard brass gauge and micrometer. Measure its length. Record the measurements.



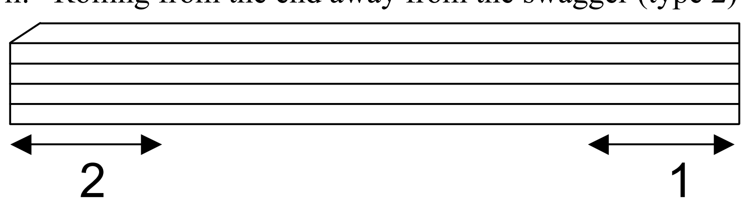
5. Cut ten 398 cm pieces from coil, in the following manner.
   a. Unroll the lead from its dispenser along the swager in-feed table.
   b. Inspect the lead, smoothing out any wrinkles or blemishes on its surface and noting any irregularities. If there are irregularities notify the Construction Manager.
   c. Use a measuring tape to mark the 398-cm mark, and cut the sheet slowly and carefully using scissors.
6. Clean the top surface of the lead using ethanol and wipe-all lint free cloths. Ensure that each piece is clean and free of excess oxidization (yellow-white dust). If there is excessive oxidation, use a Brillo pad and ethanol, and flip the lead over and clean the other side.

4.3 Swaging

1. One person mans the in-feed station of the swager and one mans the out-feed side.
2. Prior to swaging each sheet, make sure that it is PERFECTLY straight and flat. Push the sheet gently up along the polyethylene guide wall along its entire length on the in-feed side, working out ("massaging") any banana-type curvatures or ripples. Flip the sheet over and repeat massaging when needed. If the sheet does not align with the guide or there are defects (e.g. folds, creases) that could affect swaging or the build, contact the Construction Manager.
3. The out-feed person turns the swager on in the forward direction (controlled by a switch which should be in the up position), with the speed set to 1 on the dial.
4. Douse the end of the sheet closest to the machine with ethanol on both sides to prevent it sticking to the swager rollers.
5. The in-feed person gently feeds the sheet into the swager being sure to keep it firmly against the guide using only a sideways force, while avoiding the creation of folds or wrinkles. Do not press down on the sheet.
6. The out-feed person is ready to peel the sheet off the rollers if it becomes stuck and/or to ensure that it comes off the rollers and onto the out-feed table surface. Slow speed (dial at 1 or 2) on the motor and attention are the keys to this crucial

step. If the sheet is stuck too firmly onto the top roller or catches the edge of the out-feed table and thus rips or bends, the swager needs to be turned off (by moving the switch to the middle position) and the sheet is peeled off and any damage done should be assessed and repaired accordingly.

7. When the sheet is lying flat on the out-feed table the swager should be turned back on (if it had been turned off before) and the sheet is fed through continuously with the speed dial at position 2 or 3, or at a speed that is easy for the out-feed person to handle.
8. The out-feed person should gently keep the sheet flat on the out-feed table (it tends to 'hill up' as it comes out of the swager) and be ready to stop the motor if any irregularity occurs.
9. Ensure that the sheet is completely out of the swager.
10. Clip the corner of the sheet at a 45-degree angle on the end that started in the swager and is against the metal edging/guide. This is done to identify which edge came out of the guide side, as the swager tends to produce swaged sheets that are slightly thinner on the that side.
11. Ensure that the long side of the lead is parallel and square to the guide. Work out banana curvatures; if not possible mark the sheet with a tag inside the PVC tubing and store for recycling.
12. Run a toothpick along the two outermost grooves. If none or one groove is lost from one edge and appears on the opposite edge, the sheet is acceptable for building. If off by two grooves or more mark and store the sheet for recycling. Never use sheets that are off by two or more grooves in a build.
13. Measure and record the swaged length of the sheet. Acceptable length is between 404 cm to 407 cm; if longer, cut to 406 cm; if shorter, discard.
14. Roll/wrap the sheet around a pre-cut section of 3" PVC tubing (shell) after the ethanol has evaporated completely. Roll the sheet ensuring that the groves lock into place and that it forms a tight, compact roll, and that the edges remain lined up. Roll it in one of two orientations:
    i. Rolling from the end closer to the swagger (type 1)
    ii. Rolling from the end away from the swagger (type 2)



15. Label the inside of the PVC tube with the following information: coil code (ie AA); sheet number (1-10); width; length; type (ie. 11 cm, AA-2, type 1, 406 cm).
16. Measure and record the length of the remaining piece of lead on the original coil. Label this lead with the coil code, width, and length. (ie AA 11 cm, 189 cm left) Leftovers are stored for recycling.
17. Record the following information in the log book:
    i. Date, workers' initials,
    ii. Lot #, width,
    iii. Coil code,

iv. Length of each piece before and after swaging,
v. Thickness of test piece.

18. Record information on all swaged sheets in the Elog at the end of the shift.
19. Store coiled lead sheet together with like-length coils, until it is time to use it in a build.

4.4 Prior to Build

- All quality control checks on the lead sheets occurs during the swaging process.
- The PVC-rolled sheets are dispensed on the build always left to right, so that precise alignment of the left edges can be accomplished and the differences in sheet length are manifested on the right side. This allows accurate tracking of the length so that after machining the final, cleaned-up length of 390 cm can be achieved. It also avoids tolerance stacking, since the thin side is alternatively positioned at the front/back of the module, owing to the manner in which each sheets is rolled on the PVT tubing (see Swaging point 14 above).

5 MODULE CONSTRUCTION PROCEDURES

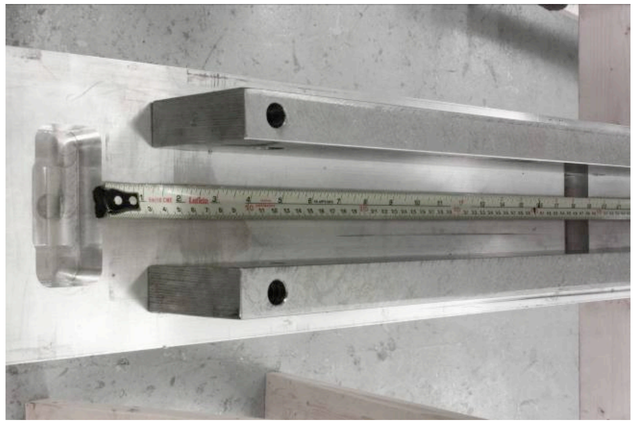
Proper safety procedures, clothing, equipment, and materials must be used during the entire construction and all measuring equipment must be properly calibrated before use.

5.1 Preparing Base Plate

1. Clean the bottom of base plate with a water soluble degreaser followed by ethanol.

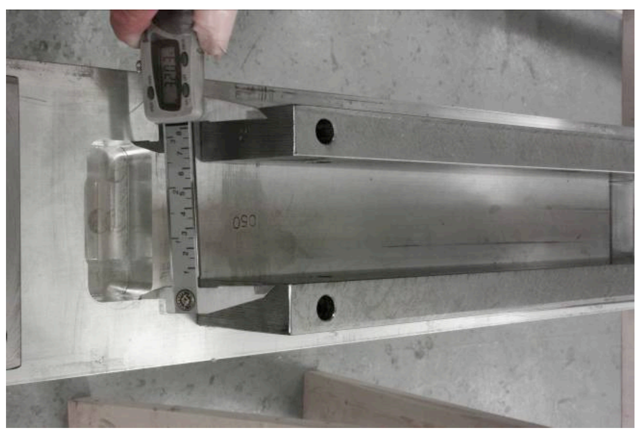
2. Check that the inserts (two sets of four) have been properly installed. Position is checked at Ross Machine Shop using the gauges that the UofR has provided.

3. Using a calibrated tape measure check the <u>position</u> of the bolt hole pockets, and report only out of specification measurements on the traveller for that specific base plate.



4. Measure the <u>width</u> of each bolt hole pocket with calibrated digital callipers at the top of the draft, and report only out of specification measurements on the traveller for that specific base plate.

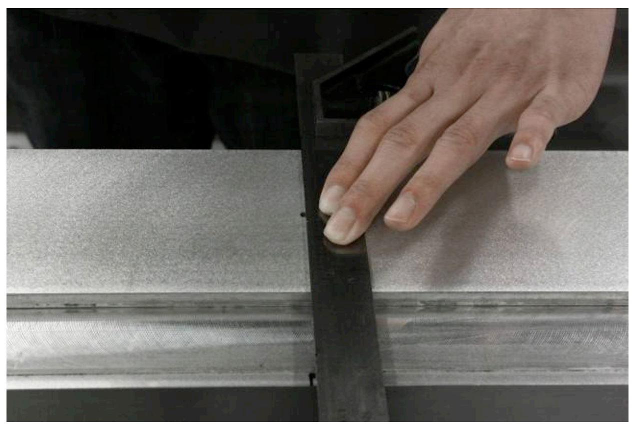
5. Measure the <u>length</u> of each bolt hole pocket with calibrated digital callipers at the top of the draft, and report only out of specification measurements on the traveller for that specific base plate.



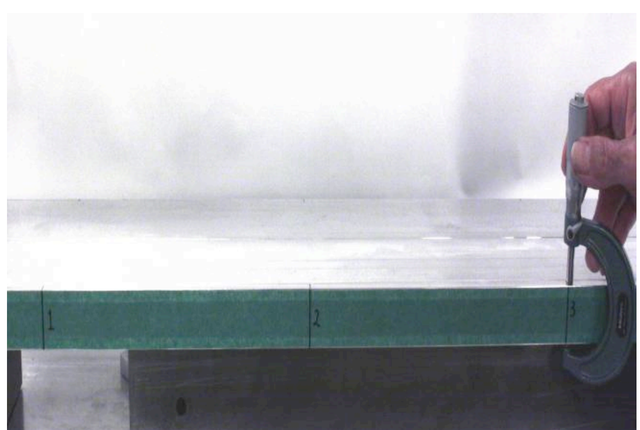
6. Measure the depth of each bolt hole pocket with calibrated digital depth gauge, and report only out of specification measurements on the traveller for that specific base plate.

7. Turn plate up-side-down and clean the top and side of plate.

8. Label 16 points on the side of the plate:
   Facing the machine side (front side), point 1 is on the left; stamp is near point 16. Either use the drill holes on a top plate as a guide, transferring them to the base plate as shown here or measure the position using tape measure. Center to center spacing is 10 inches. Point 8 and point 9 are centered on the length of the plate.

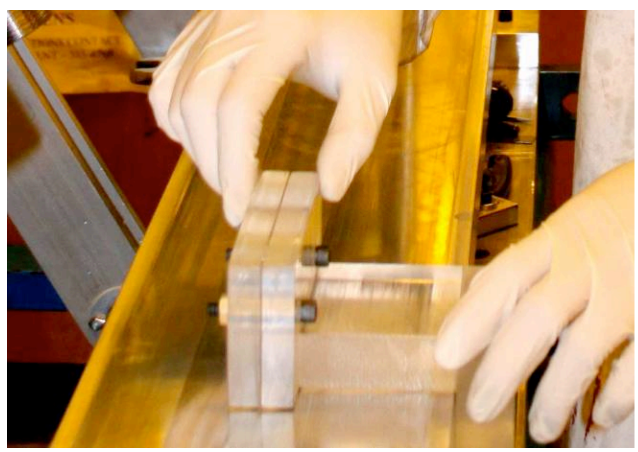


9. Measure and log the thickness of the plate at each of the 16 points. Two measurements on each side (front and back) are needed – from the bottom to the top of plate, and from the bottom of the plate to the top of recess. Enter all measurements into a digital spread sheet.



10. Using an orbital sander, abrade the top of the plate using 80 grit sand paper to improve epoxy bonding characteristics.

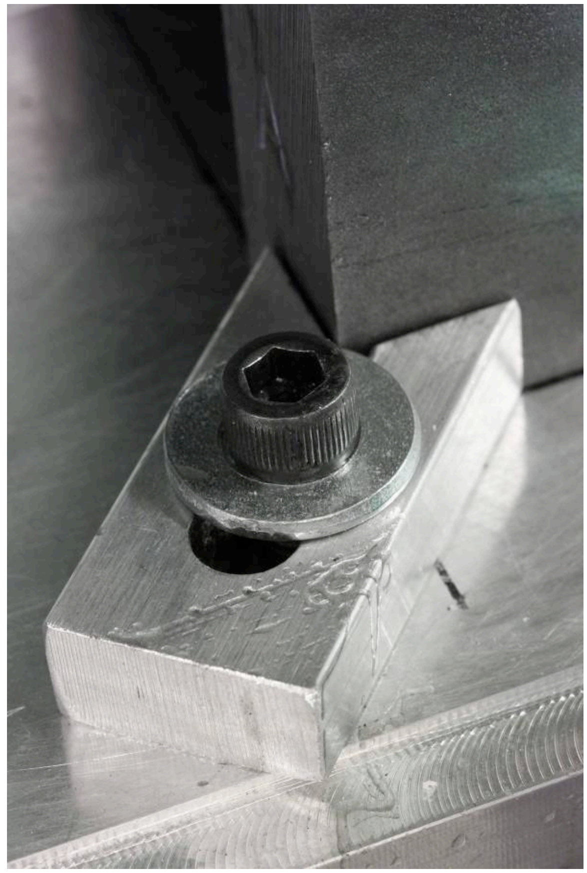
11. Using the groove cutting and cleaning tool rework the alignment groove if necessary to ensure the minimum depth is 0.024 inches. Ethanol may be used as a lublricant.



12. Set up alignment posts and wire, and set guides 0.5 mm above the top of the plate.

13. Move the base plate with rails attached on to the press, level, shim if necessary, center and align the groove parallel to the wire.

14. Fix base plate into place using four corner brackets pressed tight against the rails.



15. Clean the plate using appropriate solvents. Mask the side, ends and top recess of the plate using green masking tape. Transfer numbers onto tape.

5.2 First Build

- Layer 0 is glued to the base plate using industry epoxy, layers 1 and 2 using BC-600 optical epoxy.
- Two more layers are built on top of Layer 0 so that there is enough height for the epoxy to flow down. This minimizes the amount of epoxy that goes on top of the lead sheet.

1. Measure and dispense only in separate cups, Araldite 2011 industry 100 g epoxy resin and 80 g hardener and cover cups with plastic wrap. Do Not Mix.
2. Measure and dispense only in separate cups, 150 g Bicron BC-600 Optical Epoxy Resin and 42g hardener, only in separate cups, cover cups with plastic wrap. Do Not Mix.
3. Sort two bundles of 95 fibres each.
4. Take off the guide wire. Place a fibre to act as a guide, in the groove of the abraded and pre-cleaned base plate.

5. Note the length of a clean rolled up 13cm sheet of swaged lead. Set its end where the unrolled length will be centered on the length of the base plate. Align and place, setting the center most groove of the lead sheet onto the fibre in the base plate. Slowly unroll the lead carefully following the fibre under it, making sure the fibre remains in the groove.

6. Set up the guide wire. Use the polyethylene runner to check that the lead sheet is straight. If necessary, "massage" the lead sheet back and forth gently to straighten, align and ensure it is parallel with the guide wire and guide fibre. Feel the top of the lead sheet to confirm that the fibre is still in the base plate groove. If not, roll up the lead and repeat step 5.
7. Roll up about ¾ of the lead sheet from one end on a core. The other ¼ of the lead sheet should remain on the base plate to ensure the position and alignment remains unchanged.
8. Mix the industry epoxy resin and hardener together.
9. Mix the optical epoxy resin and hardener together.
10. Using a 18 pitch hacksaw blade as a notched trowel, spread the industry epoxy evenly on the base plate keeping the epoxy a minimum of 3 mm away from the fibre to avoid forming a high spot in the center, caused by epoxy getting squeezed and trapped under the guide fibre.
11. Unroll the lead sheet onto the epoxy again using the fibre as a guide.
12. From the opposite end roll up about ¼ of the lead sheet until the epoxy is exposed making sure that the epoxy doesn't contact the top of the rolled up lead.
13. Use the saw blade to spread the industry epoxy evenly on the remaining surface of the base plate.
14. Unroll the remaining lead sheet following the guide fibre.
15. Set up the guide wire to check that the lead sheet is straight and parallel to it.
16. Inspect the top of the lead using your fingers to ensure the guide fibre is set in the base plate groove.

NOTE: If conditions in steps 15 or 16 can not be satisfied, DO NOT CONTINUE to step 17; the lead must be repositioned or removed and the process started over.

17. Build two layers of 13-cm lead sheets and optical fibres in all grooves using optical epoxy, inspect each for alignment and press.

5.3 Preparing Fibres

1. Make sure the copper-covered fibre table is grounded.
2. Take a box of fibres from the crate onto the fibre table.
3. Open the box at one end. There are two large bags of fibres in each box. One person holds the bags and keeps the fibres on the table, while another person pulls the box out.
4. Cut the end of the large bags. There are 12 small bags of fibres in each large bag. One person holds the small bags, while another person pulls the large bag out.
5. Cut one end of the small bag. Be careful not to damage the fibres. Also cut a small portion of the side of the bag. This will allow a person to hold on to the fibres. Another person will pull the bag out.

6. Separate the fibres into bundles. The number of fibres in each bundle will depends on the width of the lead sheet to be used in the construction:
   13cm – 96-97 fibres
   12cm – 88 -89 fibres
   11cm – 80-81 fibres
   10cm – 73-74 fibres
7. Line up all the fibres in the same bundle.

5.4 Preparing Epoxy

1. Check and recalibrate the weighing scale if necessary using a 100g weight.
2. Cover the scale with plastic wrap.
3. Put a plastic cup on the scale. Zero (tare) the scale.
4. Measure the resin and hardener separately in clean new 10 ml. plastic cups.
5. The ratios are as follows:

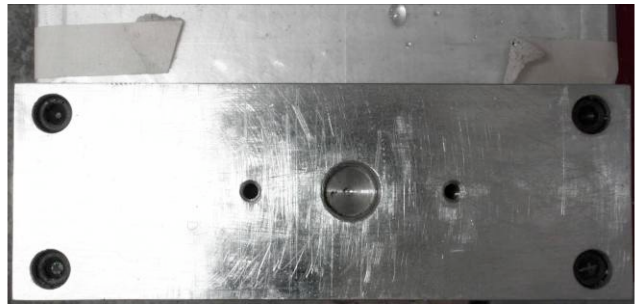
Bicron Optical Epoxy:	100.0g resin 28.0g hardener
Arldtite 2011 Industry Epoxy:	100.0g resin 80.0g hardener

6. **Do not mix** the epoxy until it is ready to be used. Cover the resin and hardener with plastic wrap until such time.
7. When the epoxy is ready to be used, add the hardener to the resin. Stir and fold with a mixing stick for one minute in the original cup and then transfer mixed

contents to the center of a clean new cup and continuing mixing for a total minimum time of 4 minutes.

5.5 Setting up the post and guide wire

1. Ensure that the aluminum plates that the posts sit on are clean and flat. If you are unsure contact the Construction Manager before proceeding.



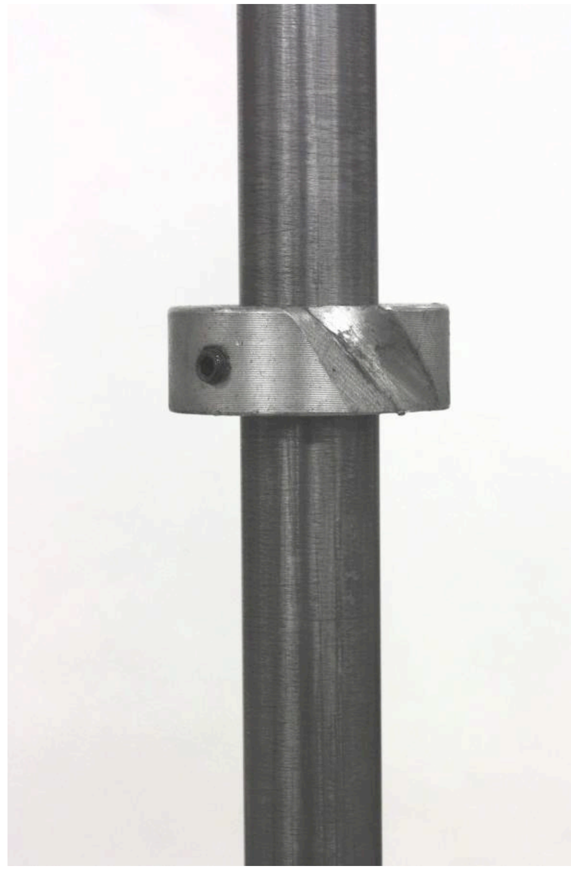
2. Using the Lufkin #59 level placed on the above plates check that both ends of the press are level within three divisions of level, if more than three divisions contact the Construction Manager to re-level the press before proceeding.

3. Brush off any particles and any high points underneath the post. Repeat Step #1.

4. Install the posts at each end of the press. There is a number stamped on each post on the blue press (Press 1) and letters on the red press (Press 2). Make sure that the stamp on

each post matches the one on the press. Tighten the screws evenly with an Allen wrench.

5. Put the aluminum alignment wire guide on Post # 1 (or Post D for Press 2). Adjust the height so that the top of the guide is about 1mm above the module. Tighten the setscrew lightly to lock the position.

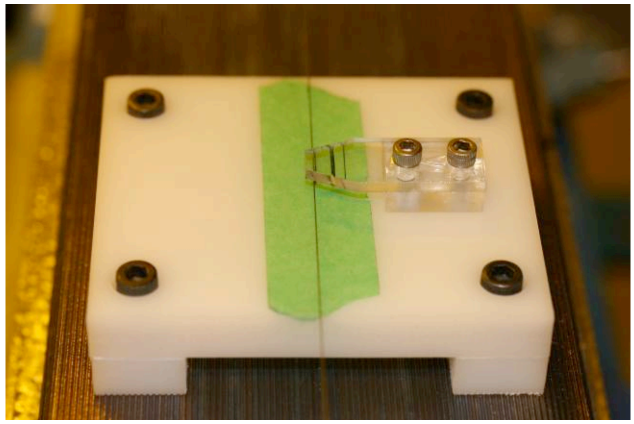


6. When not in use put the wire on the plastic drums at the top of the press.

7. Wrap the wire around the pole so that the wire is on the side along the center line.

8. Put the other end of the wire on top of the aluminum guide and wrap around the post. Attach a weight to pull the wire taunt and straight.

9. The alignment of the grooved lead sheets can be checked by setting the alignment wire height 1 mm above the cart and then running the polyethylene runner along the grooves on top of the module from one end to the other while viewing directly from above. The mark on the cart stays aligned with the wire if the module is straight.



5.6 Construction

Preparation

While two crew members are preparing for the constructions with the following steps, the other two should prepare fibres and optical epoxy.

1. Open the press and clean up the top of the BCAL module. Using custom built re-grooving and groove grooming tools remove any epoxy that might have migrated into the grooves on the sides and ends of the module.
2. Remove the tape on the top sides of the base plate recess. Measure and log the height of the module at each of both the front and back positions of the 16 labelled points. These points correspond to the 16 #8-32 holes spaced at 10.0 in. centers on the top aluminum plate.
3. Enter the data into an electronic spreadsheet.
4. Tape the top sides of the recesses of the base plate to prevent epoxy running onto it.
5. From the schematics and the height data, determine the appropriate width of lead sheet to be used.
6. Set up the posts and wire. The wire represents the center of the module. Use either a calliper or gauge plates with appropriate width to outline where the lead should be positioned.

Build Process

Once the preparation is done, mix the optical epoxy. Write the time when the epoxy is first mixed in the log book. Pour a small sample of the mixed epoxy into a clean up as a reference for epoxy viscosity. Within two hours after the epoxy is first mixed, build up alternate layers of optical fibres and lead on the BCAL module. The procedures for building one layer are as follows.

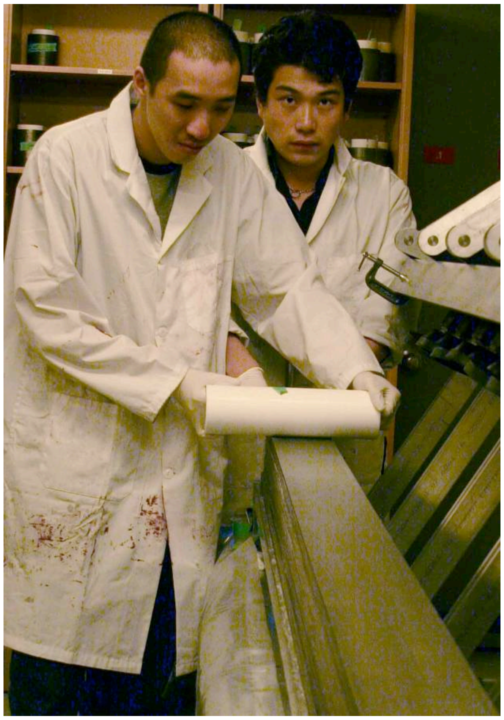
1. Two people paint optical epoxy evenly on the top lead layer of the module.
2. One person with clean gloves (no epoxy) should lift one end of a bundle of fibres from the grounded copper covered fibre sorting table so that another person can hold the fibres from that end. Repeat this at the middle of the bundle and at the other end. Three people carry the fibres to the module.
3. Line up the fibres on the top lead sheet so that they extend evenly past both ends.
4. Placing the fibres into the grooves: One person rolls and massages the fibres into the grooves at the middle of the lead sheet while two people using their fingers comb, untangle and slide the fibres into the proper grooves along the rest of the length of the lead sheet to the ends. At this point all fibres should be seated in their grooves and be parallel to each other.

5. If additional fibres are needed, the person with clean gloves will count and lift them for the other three people. If there are too many fibres in the bundle which has been in contact with the epoxy, place the extra fibres on a piece of clean poly and use them for next layers. Once all fibres are seated and the quantity is known, record the batch number of the fibres and number of fibres used for that layer in the log book.
6. Slide fingers gently over the top of the fibres to feel for irregularities in fibre height. Irregularities may be caused by particles underneath the fibres, or there may be irregularity on the lead sheet. Use a toothpick to remove any particles underneath the fibres. If the grooves of the lead sheet are deformed or if you are

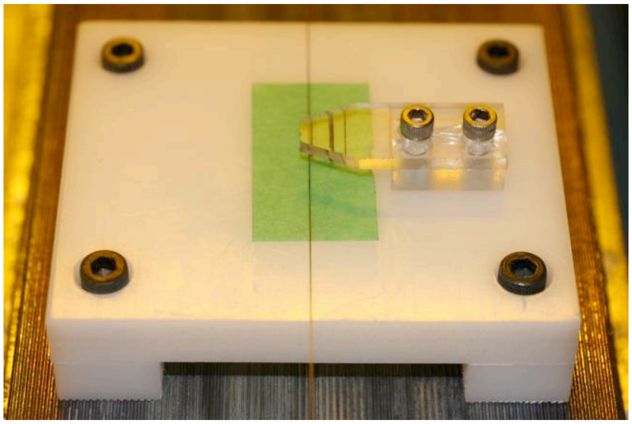
unable to seat the fibres properly in the grooves, inform the Construction Manager before proceeding.

7. Two people paint a thin coat optical epoxy evenly on the fibres, cross checking each other's work.
8. One person centers, on the fibres, and unrolls a lead sheet of appropriate width on the module slowly. (Alternating Type 1 and Type 2.) Another person "massages" the lead back and forth gently to ensure the grooves lock onto the fibres.

9. With one person holding the lead sheet from moving another rolls the lead sheet flat using a Teflon roller, first cleaned using ethanol.



Alignment



To ensure that the placement of the lead sheet is correct install the wire on the posts and guides and use a weight at one end to pull the wire taught. Using the polyethylene runner, check that the lead sheet is straight and aligned with the wire. If not, roll up the lead sheet on a core (spool) and reseat the fibres, if it is on the last layer of the day and has epoxy on the top side of the lead sheet, discard it and re-apply a coat of epoxy and use a clean lead sheet. All discarded lead sheets must be documented in the logbook. When checking for straightness of the build put the brass wire guide on the appropriate post, Post 2 for Press 1 (Post C for Press 2). Adjust the height so that it is about 1mm above the runner. Lightly tighten the set screw to lock the position. Position the aluminum guide at the same level on the opposite side.

Note: the guide wire is made using 11gr musical wire fastened to this guide with a loop tied at the other end for weighting purposes. If substantial kinks develop in the wire it be must be changed.

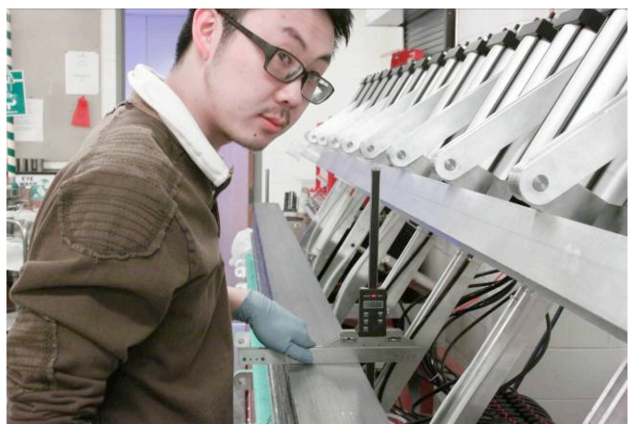
5.7 Last Layer of the Day

- Change to clean gloves with no epoxy on them. Clean the Teflon roller and traveling cart using ethanol.
- Use a lead sheet that is 1cm wider and approximately 6 cm. longer than other layers you built that day. (If you are building 13cm, use 13cm for the last layer since there is no 14cm lead.)
- Lift the PVC core slightly while unrolling the lead sheet. If there is any fibre not in the groove, the person "massaging" the lead sheet will feel it more easily.

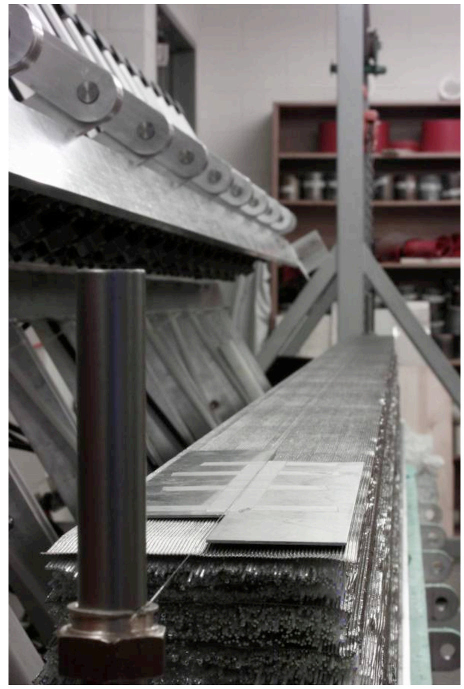
5.8 Last Build of Each Step

1. Reference drawing Fig. 1.1 (posted on the bulletin board) to determine the minimum height needed to complete the step.

2. Using a digital depth gauge measure the height of the build from the top of lead sheet to the top of base plate step at positions 1-16, both at the front and back edge. Enter the data into a spread sheet which will automatically add the thickness of the base plate that was measured at each of the 32 points. The sum of the two will equate to the distance from top of the lead to the bottom of base plate.



3. Use the point where the smallest total distance was measured to determine the number of layers needed at that point to finish to the minimum required height for each step.



4. After a build is pressed and cured, use the guide wire and alignment templates to center the next build.

5. The total fibre/ lead height should be as close as possible to 253.7 mm, but should never exceed 254.0mm measured from bottom base plate to top of lead sheet.

6. If the lead sheet is above 253.7 mm it must be shaved off using a custom made guide and joiner plane with a sharp blade set to the correct depth.

5.9 Top Aluminum Plate Installation

Preparing the Module and Plate

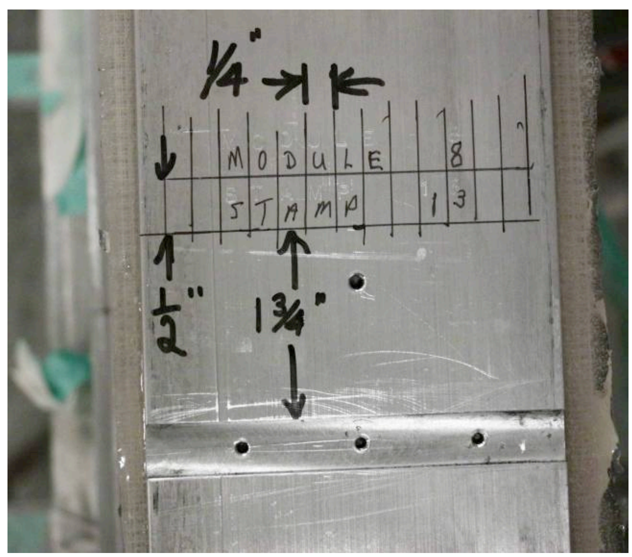
1. Trim off both ends of the cured module using a pull saw.

2. Clean all surfaces of the top aluminum plate using water based industrial cleaner followed with ethanol.

3. Abrade the inside surface of the top plate using an orbital sander with 80 grit sandpaper as done with the base plate.

4. Clean abraded surface with ethanol.

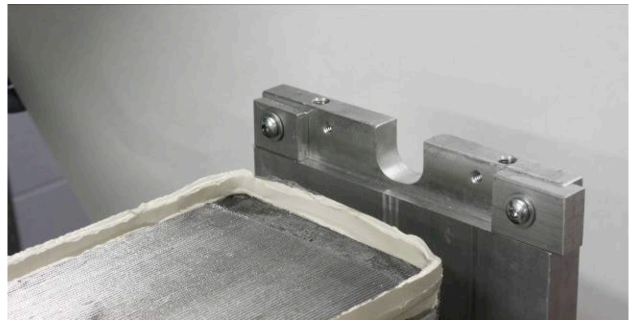
5. With the machined front sides facing you stamp the top right hand side of the plate.



Setting the Top Plate into Position

1. Measure only and place 300g of industrial epoxy resin and 240g of hardener in separate cups. Measure and place two of each, 100g of industrial epoxy resin and 80g of hardener in separate cups. Do Not Mix.

2. Wrap 1 layer yellow sealant tape around the top of the top of the module. It is important that the top edge is slightly below the top of the lead layer even when it is compressed from the side.

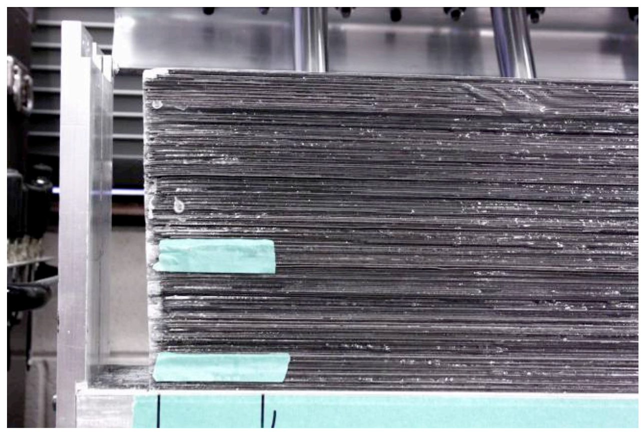


3. Remove the paper from the previous tape and wrap another layer of tape on top of it leaving the top edge forming a dam 2 mm above anticipated glue height.

4. Wrap two layers of packing around the sealant tape to support it.

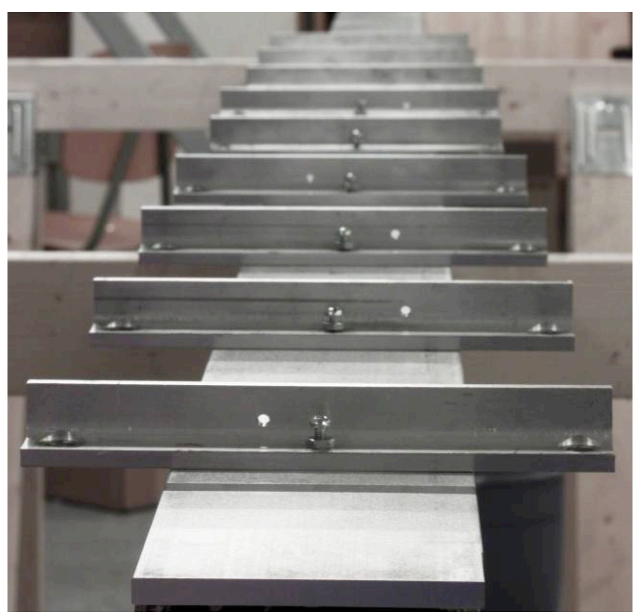
5. Cut the corners of the tape to allow the top plate to fit inside.

6. Bolt the alignment/height plates at both ends of the base plate using two - 5/16 socket head cap screws and washers with the fixed top plate stop facing the front of the module. The front edge should be flush with the front edge of the base plate and the bottom step should be pulled down tight to the top of the base plate, using the three bottom screws on the bottom clamp.



7. Set up the 16 stand-offs along the back side of the base plate.

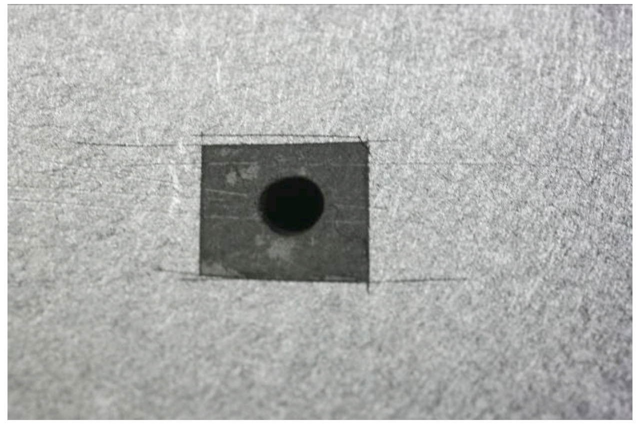
8. Screw the 16 angle brackets facing up, on top plate using #8-32 screws.



9. Move the top plate with brackets attached to the solvent room, abraded side up, don appropriate safety clothing and equipment and degrease abraded surface with degreasing solvents. Leave the

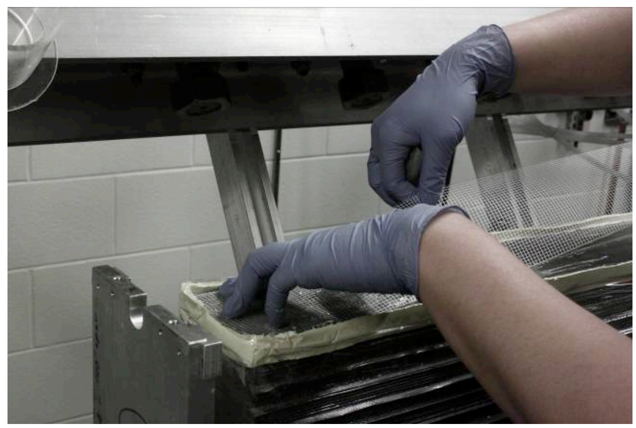
plate in the room for minimum 5 minutes.

10. Tape all holes on the abraded side of the plate using 2 layers of transparent tape approx. 8mm sq. being careful not to touch the cleaned surface any more than necessary.



11. Mix up the 300g batch of industrial epoxy and coat the top surface of the module.

12. Referencing the last build total measurement chart lay in 4" wide (or 2" if necessary) fibreglass tape to bring up to a level 0.5 mm under 253.7 mm.



13. Fill the dam level to about 254.7with mixed epoxy, more of the measured epoxy may be needed, but mix only as needed.

14. Set up the 16 stand-offs at the front of the base plate.

15. Install the cleaned and degreased top plate with angle brackets installed making sure that the top plate doesn't contact the sealant tape.

16. Press the adjustable top edge clamps forcing the top plate machined front edge against the fixed stops at both ends and fix in place by tightening screws. Fixed stop is on the left side.
    i. Note: In this and the following

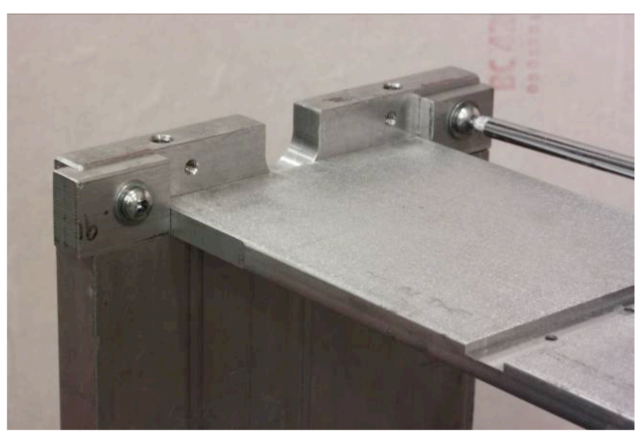
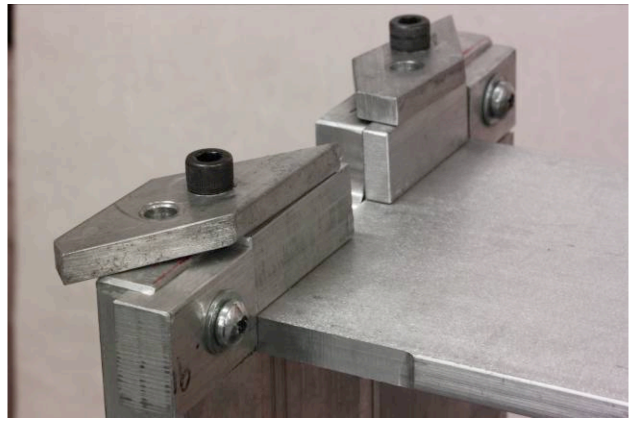


diagram the module is removed for clarity.

17. Clamp both ends of the top plate down to the alignment plate using spacer blocks. Excess epoxy should squeeze out.



18. Attach the 16 brackets to the stand-offs using 3/8” socket head machine screws.
19. Adjust all screws and nuts to fix the top plate at the proper height. Excess epoxy should squeeze out.
20. Continue to adjust all screws and nuts as epoxy squeezes out.
21. As the epoxy squeezes out pressure is released so check and readjust all screws at least four times before leaving.
22. Let epoxy cure overnight.
23. Remove brackets, stand-offs and alignment plates.
24. Remove sealant tape and excess cured epoxy.
25. Scrape top and sand using orbital sander.
26. De-bur all holes.
27. Trim off ends of top plate and paint module ends with two coats of black chalkboard paint.
28. Undo clamps, hoist module into crate using the A-frame hoist, and fasten into place.
29. Place cover on crate and screw down with four wood screws, mark the position of the screws with a felt pen, label crate cover indicating both module and stamp number and prepare crate for shipping to Ross Machine Shop.

6 PROCEDURE CHANGES FROM PAST TECHNIQUES

Aside from the obvious distinction between the construction of the first 4 m prototype module in 2004 and the hybrid module in 2006 (module design), there are also several important differences in production technique. With these modifications, it was found that a crew of three workers could complete a module in less time than a crew of five workers had previously. This translates into total manhours for the B-Cal production being reduced by over 40 per cent.

Our experience during the building of the first eight production modules has led us to modify our procedures in this regard, as compared to those in place after the BCAL Readiness Review (Version 2, November 27, 2009).

<u>Several issues remained.</u>

1. Minor difficulties continued in build-height asymmetry between the front and back edge of each module, as being erected up on the press tables.
2. Local height bulges or dips appeared at different positions along the length of each module and at different spots on each press. These features did not seem to be correlated with the order of ram lowering.
3. At the conclusion of each build, a pair of cooked fettuccini noodles would straddle the width of the module at each end. Then, in sequence, a .006 in. thick polyethylene sheet, first a ¼ in.-thick later replaced by a .1/16 in.-thick soft rubber sheet, a .1/8 in.-thick Teflon sheet, a 1-1/4 in. thick, and a ¾ in. thick aluminum press plates would be placed on top of the topmost lead layer, before pressing over night. This covering process was quite time consuming, and on one occasion – during the build of Module 05 – the rubber slipped causing damage, and five layers of fibres and lead had to be discarded.

We believe that the local high/low spots and the front/back height asymmetry were due primarily to the rubber, which either retained memory of its shape from previous pressings, and/or accentuated any inherent press asymmetries.

<u>Procedures were modified.</u>

1. We first degrease and then abrade (using a orbital sander with a 80 grit emery cloth disk) the surfaces on both (top and base) aluminum plates that are bonded to the matrix, in order to provide a better bonding surface. We then degrease them again after abrading.
2. We decided to simplify the end-of-build layering, and kept only a .006 inch thick polyethylene sheet and use a 1-1/4 and ¾ in. thick, 6"-wide aluminum press plates.
3. We stopped using the 'lunar lander' feet on the press rams.
4. We implemented the use of wider lead sheets for the top three Mayan steps (12cm, 11cm, and 10cm) from widths of their preceding steps (13cm, 12cm, and 11cm), and of slightly longer length, in order to overhang the top lead layer on all four sides, and completely prevent epoxy migration from the layers below during the pressing. The only exception was the top builds of the 13cm step, as no wider sheets than those exist. Those layers (two builds only) continue to be constructed in a similar manner and any epoxy migration is physically removed.
5. We stopped using the fettuccini noodles except for the very first lead sheet (on top of the aluminum base plate) and in one other case where an overhang lead sheet was defective.

6. We now bring the press rams down sequentially from the center out, but without any time delay in between. After all the rams have seated, all but the middle two

are released and the process is repeated three times. The two center rams take the slack out of the press and hold the build in position. The pressing and releasing of the other rams aid in the epoxy flow. This helps eliminate the possibility of excess epoxy being trapped in areas between where the rams are pressing. Many other sequences were tried and this method produces the best results. This also simplifies operations, as previously at least one person had to bring the rams down manually at 2-3 minute intervals, leading to a 20-30 minute period.

7. We trim the protruding fibre ends off the module before setting up the top plate fastening apparatus. We then apply a flat (chalkboard) paint to protect the ends from light during shipping and machining.

The preparations to press became considerably easier and quicker; and epoxy migration no longer seems to be a major issue. Productivity has increased by 10-20%.

7 SUMMARY

The construction of the BCAL modules is now proceeding smoothly. At this date, the 16th module is near completion and 12 modules have been delivered to Jefferson Lab.

The construction and testing procedures have been officially signed off and are uploaded to the Jefferson Lab document handling system. This means that any changes from here on need to be officially agreed upon by both Jefferson Lab and the UofR.

8 BCAL CONSTRUCTION HAZARD CONTROL AND RISK ASSESSMENT

8.1 BCAL Construction University of Regina, Lab Bldg. 113

- All workers have taken and passed the WHMIS training program.
- MSDS on all hazardous materials used in the lab are posted and readily available.
- Emergency contacts off and on campus are posted and readily available.
- A first aid kit is installed in the lab.
- Eyewash and safety shower stations are installed.
- A Fume Hood is installed.

All workers are issued and will wear PPE (personal protective equipment) such as lab coats, safety glasses and protected toe foot ware.

8.2 Controlled Products Needed

1. **Epoxy Resin**: Likelihood of harm (**very unlikely**) - Measuring and mixing to be done in a fume hood. Empty containers of both resin and hardener will be rinsed three times with wash acetone in a fume hood and dumped in a waste disposal drum in Science Stores.

2. **Epoxy Hardener**: Likelihood of harm (**very unlikely**) - Measuring and mixing is to be done in a fume hood.

3. **Ethanol**: Likelihood of harm (**very unlikely**) - Small quantities used over long intervals with adequate ventilation.

4. **Dichloromethane**: Likelihood of harm (**unlikely**) - Very small quantities used for a final wipe of all plates will be done outdoors.

5. **Acetone (wash):** Likelihood of harm (**unlikely**) - For rinsing epoxy containers in a fume hood.

8.2 Risks

- **Inhalation of lead oxide from old lead** (**very low risk**): No old oxide lead will be used; if oxide is present it will be vacuumed up using an asbestos-certified cleaner.

- **Lead Contamination (very low risk)**: Protective gloves (vinyl or latex) will be worn when handling lead. No food will be allowed in the lab. All workers will be instructed to remove their gloves and wash their hands thoroughly before touching their eyes, nose or mouth. Contaminated gloves are to be disposed of and not re-worn.

- **Epoxy Contamination** (**risk very low**): All workers are to wear proper personal protection equipment and are rotated frequently so no one person is constantly in contact with the material and adequate ventilation is provided.

- **Back Injuries** (**low risk**): All workers are instructed in the proper methods and limits of lifting.

- **Toe Injuries** (**low risk**): All workers will wear PPE and are instructed on procedures to prevent injuries.

- **Other Injuries** (**low risk**): The swaging machine (swager) has a set of slowly rotating rollers with good shielding and speed control. Fingers cannot reach the rollers by a physical barrier. Lab is well organized with proper storage; workers' jobs are rotated often.

- **Fire (low risk)** Lab has passed inspection by Mr. Murray Fisher (University fire safety consultant) and Mr. Mark Briggs (University building inspector).

- **Injuries to the fingers and hands during the pressing stage (very low risk):** The rams of the press move very slowly and are controlled by remotely via electric switches. Workers need not be near the press once switches have been turned on.

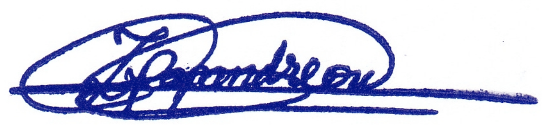
9 SIGNATURES

The procedures and methods outlined herein have been optimized at this stage, and signed off below. Any changes from here on need to be officially agreed upon and approved by the following individuals.

Mr. Timothy Whitlach
Hall D Chief Engineer

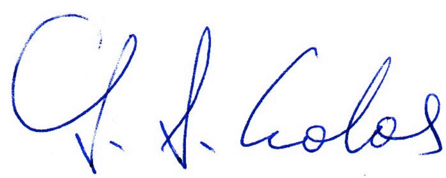
Mr. Dan Kolybaba
BCAL Construction Manager

Dr. Elton Smith
Hall D Project Manager



Dr. Zisis Papandreou
BCAL Construction Liaison

Dr. Eugene Chudakov
Hall D Manager



Dr. George Lolos
SPARRO Group Leader