CHANGES IN CONSTRUCTION PROCEDURES
Version 2

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The experience gained and problems encountered during the building of the Construction Prototype have led us to modify our procedures in this regard. Minor modifications have also been implemented in the fibre QA.

Construction

Difficulties were encountered during the build up process for the Construction Prototype, resulting from inadequate crew training that led to errors in the handling and swaging of the lead sheets. This Construction Prototype followed the ‘Mayan Pyramid’ design of the second full-scale prototype (Prototype 2), although with four steps instead of the previous seven.

Unfortunately, our standard swaging and building procedures were not followed throughout the building of the Construction Prototype, resulting in three errors:

1. The Left-Up-Right and Right-Down-Left method of avoiding stacked tolerances was not strictly adhered to, resulting in the majority of layers between the 80^{th} and 140^{th} being of the Left-Up-Right type. This was a result of crew renewal in September and a failure to transmit this information to the new crew. Deliberate stacking in the other direction was done for layers 140-180 to partially rectify this error. It was one of the main contributors to the so-called front/back height asymmetry.
2. At least one, and possibly several, layers resulted in having ‘jumped track’ fibres. Although these jumps do not affect the final performance of the matrix, they can contribute to serious misalignments affecting all the building of all subsequent layers. A full inspection of the machined module will be carried out when it is returned to the UofR from RMS.
3. Using a lead sheet that escaped the aforementioned quality checks caused the most serious error. Around layer 120, a sheet was used that had at least a three-groove shift. Whereas the sheet itself was rectangular, the grooves did not run parallel to the long edges, resulting in three grooves disappearing on one side and reappearing on the other. The sheet was then incorrectly laid and glued into place. This misalignment was not noticed until several layers later, following a pressing. Layers following these were then deliberately offset in an attempt to correct a curved shape of the module about 100cm from one end, termed the ‘serpentine’ effect. The attempts were not successful and

only promoted the curvature to higher layers. Finally, it was decided to build a perfectly straight standalone patch and apply it to the top. This succeeded and the remaining 40 layers were perfectly straight. This method is now available to us as a proven technique in the (unlikely) event that such a misalignment reoccurs.

The above swaging and build-misalignment errors were perhaps compounded by a machining and assembly error in Press 1 and resulted in the produced matrix having regions of non-uniformity to the extent that building was suspended at the 140^{th} layer and the module was removed from the press table. Immediately, the press errors were rectified and the press was surveyed and leveled to 0.004" across its surface.

Following this, many short lengths of lead sheets were passed through the swager and accurate readings of the swaged thickness were taken using 10 1-mm steel rods placed in fibre grooves and, of course, subtracting their thickness. This showed a 0.05mm thickness difference between the edge near the table's guide and the one away from it and closer to the operators. During the swaging for Prototypes 1 and 2, the fibre sheets were tagged using a marker, and were handled to avoid stacking tolerances, as mentioned above. This required a thorough cleaning of each sheet to remove the marker's ink just before laying the sheet on a layer of fibres. It also made sheet laying a pneumonic exercise once the markings were removed.

Now, just before using a sheet in the build it is unrolled and rechecked for straightness and then re-rolled alternatively in a right-to-left and left-to right manner. The latter rolls are then rotated along a vertical axis by 180 degrees. Both types of sheets are dispensed always from the same end of the build, thus ensuring a close alignment on one side with a slightly varying alignment on the other due to small variations in the sheet length following swaging.

Another important change during swaging is that enormous emphasis has been placed on the straightness of the sheets before and after swaging. Literally, the 'riot act' has been read repeatedly to the students and we continue to do so daily! These students have first hand experience in the problems that a single mistake in one lead sheet can cause. Every sheet is carefully swaged and a toothpick is run along its edges to determine by how many grooves the sheet is off from being parallel. Sheets that are perfect or one groove-off are acceptable for the build; otherwise the sheets are marked (two or three grooves) and segregated. The perfect sheets are used in the first few layers of each Mayan step where alignment is more critical. One-groove-off sheets are used above this to the top of each Mayan step, and so on. All other sheets are set aside as scrap to be used for small-scale prototyping. See the 'Lead Handling Procedures' document for more details.

Returning to the Construction Prototype build, a standalone three-layer 'patch' was the built on the table using a top (inner) 8mm plate as its underlay. Care was taken to build this patch precisely square and parallel to within one groove. Subsequently it was removed from the table, the matrix was repositioned and aligned and the patch was affixed directly on the topmost lead using industrial epoxy. No fibres were placed in between, in other words a fibre layer was skipped. The application of the patch immediately rectified the straightness of the matrix. Thus, we have developed a successful correction technique in the unlikely occurrence of that type of misalignment in the future.

As a result of these problems, the construction procedures quality control in all construction steps were completely overhauled. The new procedures were applied to the last 40 layers of this prototype producing a uniform matrix. Furthermore, even greater emphasis and care was placed in assuring that RMS provides us with base (outer) plates as square and parallel as possible. The plates and their guide groove are surveyed in situ (on the press table) before a build commences.

In addition to updated and newly developed procedures, an instructional video is available to further assist in the training of the students. Student labour for the first year of construction has been secured, in a manner allowing continuity with 5-6 students staying on for this period, and only 1-2 new ones added to the crew.

Fibre QA

Kuraray shipped nearly 1/4 of all production fibres (200,000 canes) to Regina in the first five shipments (May to October 2009), due to their own preference and agreed to by JLab and Regina. As it turned out, the handling and testing of so many fibres proved onerous and logistically challenging, at the time that protocols and procedures for handling, measuring, analyzing and interpreting the results were being developed. On the positive side, this great 'push' resulted in final protocols by early October.

Several modifications to the fibre QA have been successfully implemented from the initial methods that were used to test the 'First Article' fibres. These were implemented in the testing of production shipments 1-3 and a further change was implemented on shipments 4-5 and beyond. Detailes are listed below.

1. Our initial plans were to extract and evaluate the number of photoelectrons (Npe) – yielded by the fibres following stimulation by a ^{90}Sr radioactive source – using a 3x3mm^2 SiPM as the readout sensor. The

method was proven successful on a single fibre but we abandoned it when the SiPM electronics board failed and we could not procure replacement parts or boards from the vendor. This was unfortunate because the great resolution of the SiPM allowed for individual photoelectron peak identification and counting, this being a great cross check of the results from sophisticated fitting and analysis procedures.

2. From then on, we relied on a calibrated PMT for the extraction of Npe. The initial evaluation of the method was compared to the results with the SiPM on the same scintillating fibre and yielded consistent and reliable results. The method was significantly refined over the summer and is now completely stable and has been applied to all five shipments so far.
3. Minor refinements have taken place in the handling of the fibres and placement in dedicated testing trough belonging to the photoelectron test station. It is now easy to place and remove fibres from the setup and an online analysis script provides immediate feedback on data quality such that imperfect coupling of a fibre to the PMT becomes immediately apparent and the students re-couple and re-test said fibre.
4. The far end (away from the photosensor) of each fibre was polished and dipped in black enamel (model) paint for all tested fibres from the 'First Article' and first three production shipments. We changed the method for Shipments 4 and 5, and now do not polish the far ends but still blacken them, following tests which demonstrated that the extra polishing affects the extracted results by only a few percent. This resulted in simplification in the tests that allows more fibres to be tested and will prolong the lifetime of the fibre polisher and render part replacement less frequent. The near end that coupled to the sensor was always polished and we wil continue to do so as it results in up to 10% higher light yield.
5. The collaboration goal was to test approximately 1% of fibres from each shipment. In practice over the summer, the number tested was in the 0.5-1% range. Nevertheless, even 0.5% has proven to provide adequate statistics for these tests, since it results in a minimum of 100 fibres tested (smallest shipment) to 250 fibres (largest shipment), allowing batch-to-batch and shipment-to-shipment performance variation to be tracked.
6. Over the summer we finalized our fibre handling procedures that now result in extremely few broken fibres. These include physically moving each tested shipment from the test lab to the construction lab following QA approval before receiving a new shipment in the test lab. This precludes any mix up in fibre processing. Tested fibres are stored in the test lab for the duration of the project.

In conclusion, we have final QA protocols and fibre handling and storage procedures that will be implemented to the testing of all fibre shipments.