

SmartPhantom Prototyping Summary

Hin Tung Lau
Imperial College London
Supervisor: Prof. Kenneth Long

18th September 2019

1 Summary

1.1 Assembly

- There is a maximum deviation in straightness of 0.1 mm across the length of the winding jig.
- When winding, the second groove should be used when starting.
- How to secure wires?

1.2 Initial Winding

- Outer frames when in parallel to each other results in the winding jig being a bit misaligned.
- Easy to spot if a wire is knocked out of a groove.
- Wires secured with a screw.
- Tensioning done with washers.
- Winding is easier/faster with more winds.
- Idea to use a small clamp for snapped fibres.

1.3 First Prototype

- Prototype wound with two layers (not fully due to incomplete amount of fishing wire)
- Second layer is potentially easier to wind than the first layer.
- Average rate was that two layers took about 5-6 hours.
- Acetone used to clean the carbon fibre before gluing.
- Superglue was used to glue the wires to the frames due to a shorter curing time.
- Grooves cut into the frame could help with spreading the glue.
- Gluing double layers can be tricky.
- The tension caused the frames to warp.
- However, the preserved edge kept the doublet pattern.

1.4 Second Prototype

- For second prototype only one layer would be wound with less tension.
- Gluing was easier with just a single layer.
- However, gluing had a tendency to shift the wires.
- When wires cut, there is still a bend but smaller than in the previous prototype.
- However, the alignment is not ideal as due to the gluing some wires clump together.
- Two frames attached together, though there is still a perceivable bend.
- Clear that there is a conflicting issue of Tension vs Alignment.

2 Assembly and Metrology Results - 20/08/2019

2.1 Summary

The parts needed for assembly of the winding jig arrived at Rutherford Appleton Laboratories (RAL) on 15/08/2019. The winding jig was assembled on 20/08/2019 as specified in the schematics. Fishing wire was wound across a couple of grooves in order to check the straightness along the two lobes. This can be seen in Fig. 1. This was brought to the Metrology department to check using the SmartScope, where the straightness of the fishing wire was compared against a reference edge. The results from Metrology show that over 330 mm, there would be a maximum deviation from being parallel to the reference edge of 0.1 mm. The position of this maximum deviation is not known, but since two frames would be wound across one side of the winding jig, this is an acceptable result.

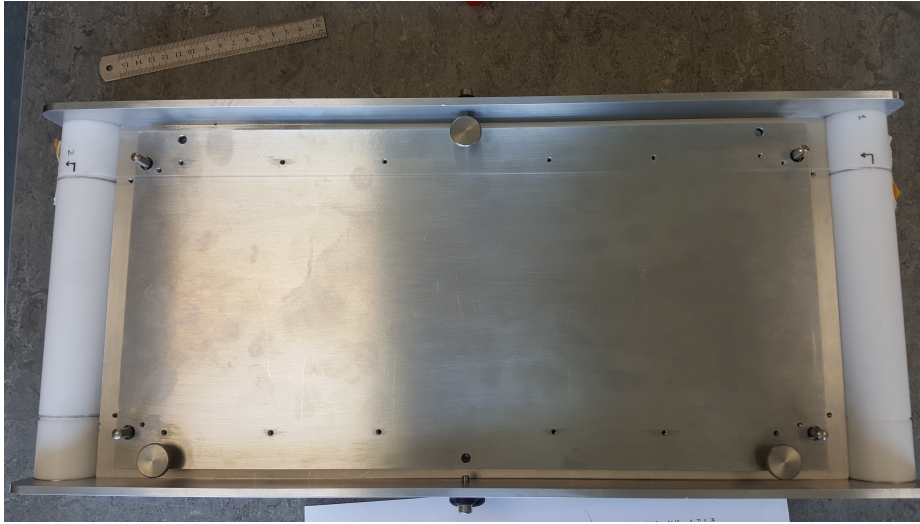


Figure 1: Assembled winding jig with two winds of fishing wire across the two lobes.

2.2 Inspection

The straightness of the position of the lobe grooves was compared against a reference edge. However, this inspection needed to be non-contact due to the wires. But with the wires being cylindrical, it was difficult for the SmartScope software to identify an edge on the wire to compare against the reference edge.

Initially it was planned to compare several different points between the wire and the reference edge, however, the results were inconclusive. It was decided that measuring over 330 mm (this being the extent of the SmartScope bed travel) would provide the best results.

Straightness of Reference Edge	26 μm
Straightness of Fishing Wire	36.5 μm
Average Distance from Edge to Wire	37.94 mm
Maximum Deviation of Wire Straightness to Edge (over 330 mm)	0.1 mm

Table 1: Results from Metrology regarding the straightness of the winding jig.

The maximum deviation of the wire being parallel to the reference edge was found by averaging a straight line from the reference edge to a straight line along the wire. Due to limitations of the software, the actual position of this deviation is not known, such that this maximum deviation may not be on the second lobe, but some point in the middle. The results from Metrology can be seen in Table. 1.

To fix this one could rotate one of the lobes due to the grooves being a screw thread. However, this would only resolve the situation if the maximum deviation was on the opposite edge. Since it is not known where this deviation is, it may not actually resolve the deviation issue. In addition, since two frames would be wound at once on one side, this actual deviation would likely be much less, so this deviation can be accepted.

2.3 Assembly/Procedural Issues

For the alignment jig, it was found that the guide rod from the manufacturer was not the correct size. However, a rod which did fit the schematic was found and was substituted instead.

It was also found that the spring beneath the platen was a bit too large such that the platen was raised too high. A bit of the springs will be cut in order to resolve this issue.

It was noted that the platen across the winding jig was slightly bowed. The plate was positioned such that the convex section was upwards, so the fibres being wound would rest against the protruding edge.

Another point that was noted was difficulty in placing the fishing wire on the very first groove. The issue was that the first groove was on the edge of the screw thread, hence, making it difficult for the fishing wire to stay in place. To get around this issue, the second groove was used instead for both lobes. Since there are extra grooves, this should not present an issue.

An issue was with how the fishing wires could be secured. Initially an idea was to use double sided sticky tape along the lobe. However, since the lobes were made of PTFE, this had some issues. The part of the lobe without the grooves was quite good in keeping the tape adhering to the surface, however, the tape did not adhere well to the part with the grooves. For the purposes of the metrology tests, the tape was placed on the back of the plate, but a solution for the actual winding needs to be found.

Another issue was that it was relatively easy to accidentally nudge the wire such that it would slip out of the grooves. This could be an issue related to how to secure the fishing wires. However, it is expected that this is a main issue when beginning to do the winding. When more wires are wound, the next line of wire being wound could be pushed against the previous line of wire and would drop into the groove, which would make nudging the wires less likely to result in it being knocked out of a groove.

3 Prototyping with Fishing Wire – 29/08/2019 to ???

3.1 Initial Winding

29/08/2019

Carbon fibre frames enough for two frames and steel outer frame were brought to RAL to be used to create a prototype of the SmartPhantom planes for the Resin lab to use as a reference.

It appears that the clear fibre connector plate holes were a bit too small, and would need to be enlarged. The frames fit quite well, though don't quite sit flat with the winding jig.

The outer frame were modified from the initial design, with holes to suit the table at Imperial. Since the fishing wire prototypes were in RAL, initially clamps were attempted to secure the outer frames. However, there were only two clamps available, which were not sufficient. In addition, not enough space was available even if more clamps were found. Instead, a wood plank was found and a screw and washer was used to fix the outer frame onto the plank. It was found that placing the two outer frames parallel to each other would result in the winding jig to be a bit misaligned. There wasn't much that could be done, but a compromise was eventually found to better align the two outer frames.

Some winding with the fishing wire was attempted with a spool of fishing wire. One end of the fishing wire was tied around the lobe. With the fishing wire and outer frame it was a rather quick process after the first couple of grooves, with it being relatively easy to spot if the wire was knocked out of a groove. However, an issue that became apparent was that some kind of tensioning solution would be required.

30/08/2019

A tensioning solution was found for the winding fibres, though with the clear and scintillating fibres, it may just be a simple matter of a screw and washer pressed against the spool. Images of the setup at RAL can be seen in Fig. 2.

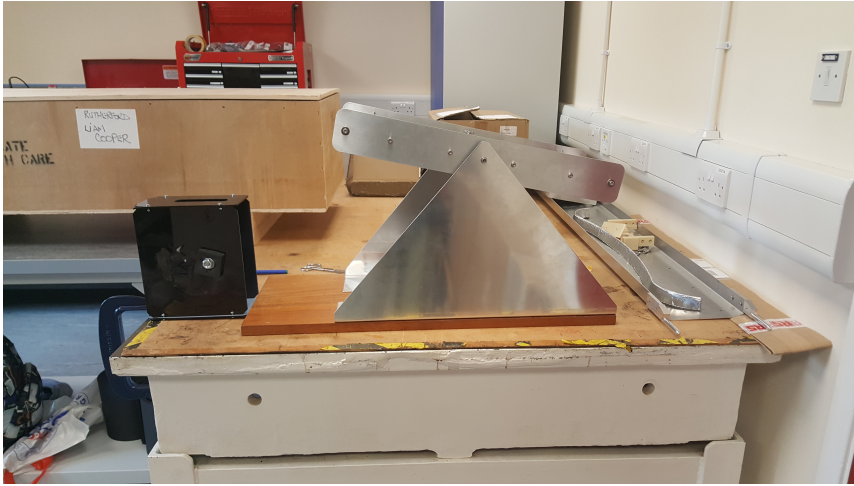


Figure 2: The setup for the winding jig at RAL. On the left one can see the winding jig affixed to the outer frame atop a wooden plank. On the right one can see the tensioning solution, which consists of washers pushing against the spool of fishing wire.

From various testing the hardest part is the starting groove and the other wires would just need to be pushed against the previous wire and it would naturally fall into the grooves. In addition, when making the rotation it is helpful to keep one hand on one of the lobes while the other hand pushes the second lobe against the previous one. The result of the test winding can be seen in Fig. 3.

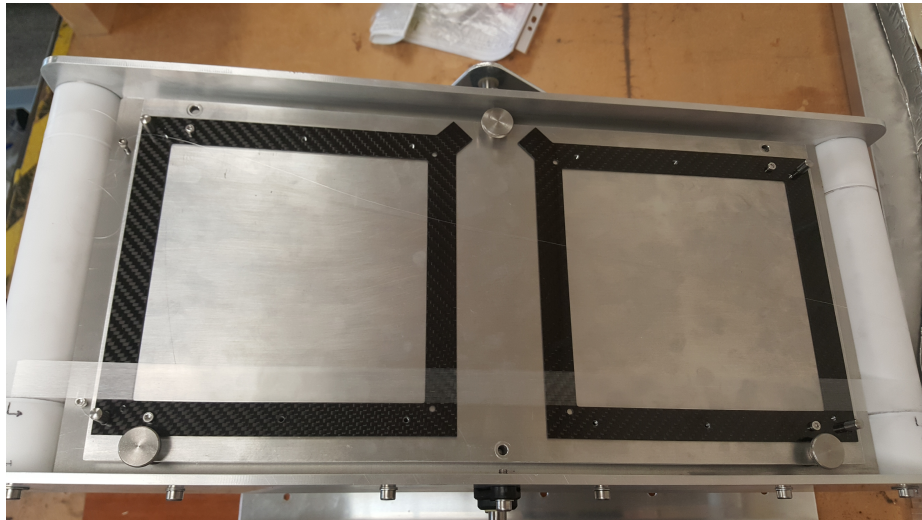


Figure 3: The result after using the fishing wire which was available. One can see the two carbon fibre frames being wound at the same time. Note that the orientations of the two frames was incorrect, and one should have been rotated by 90 degrees.

Some consideration was also given to how to connect two fibres in the case of i.e. the fibre snapping. with the fishing wire, one could tie two different spools of wire, but this would not be an option for the scintillating/clear fibre. A proposed idea is to use some sort of small clamp on the lobes.

3.2 First Prototype

03/09/2019

The previous observations were noticed where the greatest difficulty was with the starting groove. The efficiency of winding increased as more winds were made. Some of the winding was done with gloves to test the subdued tactile feedback and it proved to not be a major issue. Due to the limited amount of fishing wire in a given spool, the wires were tied together, this can be seen in Fig. 4.

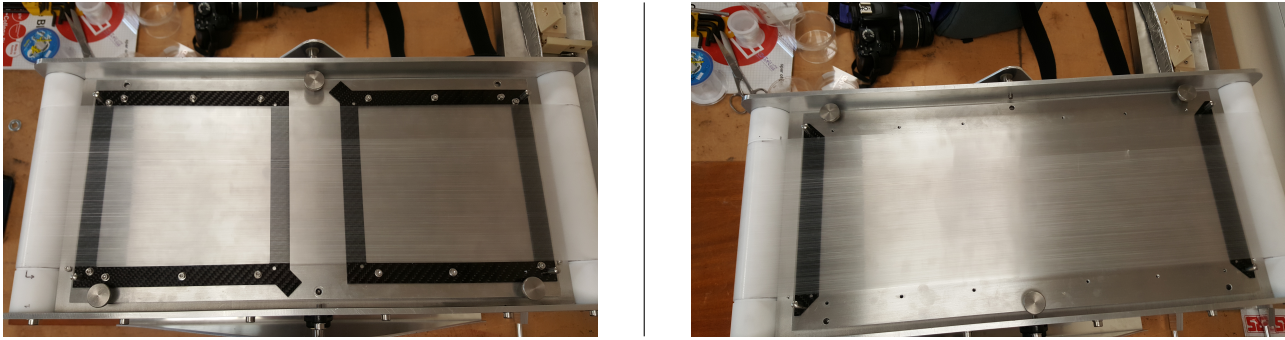


Figure 4: Images of the result after winding one layer of wire across the winding jig. On the left is one side of the winding jig with the frames in the correct orientation with respect to each other. On the right is the other side of the winding jig with the connector plates. Note the knot in from connecting two separate spools of fishing wire.

One observation made was that as the fibres for the first layer were wound to the end there was a perceived unequal number of grooves between the two lobes. This may be explained by the lobe missing a groove to only have half a groove compared to the full groove present in the other lobe. The wires were wound to the very end to ensure there would be an equal number of fibres for the clear and scintillating fibres. However, it may not be a major issue if there was a different number as long as the scintillating fibres receiving beam would be connected to the clear fibres.

04/09/2019

When doing the second layer the approach pursued was to wind back in the previous direction (i.e. using the same continuous spool without tying it off after the first layer). Again the greatest difficulty is with the first couple of grooves (empty gaps from the first layer). As long as the wire was taut this was potentially easier than the first layer as it is just a matter of pushing back against the previous wire. This is also made easier if the spool is coming from behind such that the wire naturally pushes back.

The rest of the fishing wire was used to try to complete as much of the second layer as was possible. No additional observations were noted. At the very end, to keep the fishing line taut, the fishing wire was wound around a screw. For scintillating fibres it may be possible to keep it on the spool, as it should still retain the tension. Then for the next set of rotations, the scintillating/clear fibre would just need to be held in place with a large headed screw and screwed down to keep in place. The final result of winding for the first prototype can be seen in Fig. 5.

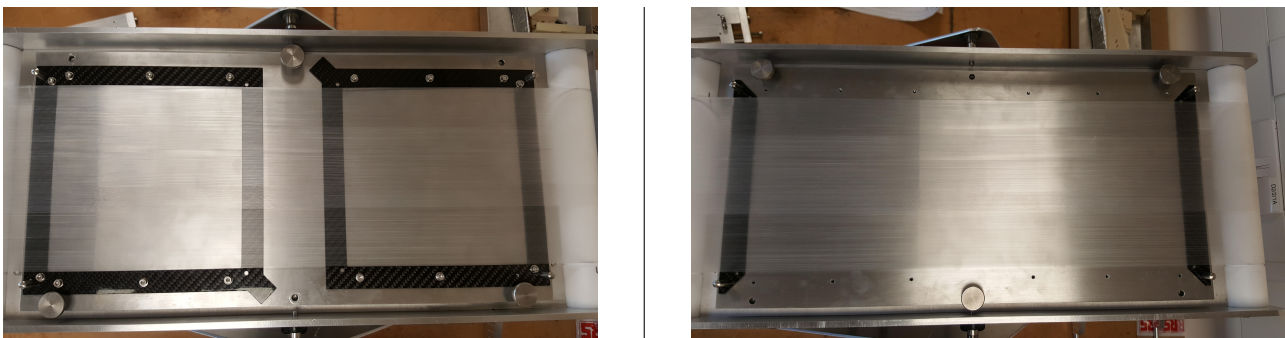


Figure 5: Images of the result after winding two layer of wire across the winding jig, though not enough fishing wire was available so the second layer remains incomplete. On the left is one side of the winding jig with the frames. On the right is the other side of the winding jig with the connector plates.

An estimation of the time it took to ‘complete’ the prototype was about 5 to 6 hours. With the real fibres, in the darkened room, perhaps it may take a bit longer, perhaps 8 hours. Considering that one set of winding with the jig can do four scintillating fibre screens at a time or one clear fibre connection plate, getting 5 stations would take roughly 104 hours in total without consideration for time for gluing fibres to frame. Though it is reasonable that the efficiency would increase for subsequent windings.

The result was shown to the Resin Lab group at RAL, where an initial consideration was made between standard resin or G/flex for viscosity, but it was decided that the standard resin used would be sufficient. However, later on it was decided superglue would be sufficient with a shorter curing time. However, since the carbon fibre frame was not cleaned beforehand, some acetone was considered to be used. In addition, the application of the epoxy can only be done on one side at a time, with it likely being required to cure overnight.

Prior to gluing some potential issue were raised:

- A potential issue that crops up is how the polishing for the ends of the fibre for the connection would be done with the real fibres. For the fishing wire, the plan is to simply cut with an exacto knife.
- With the clear fibre, should a snap occur, then likely it would have to be redone, hence, extra care needs to be taken.
- Some investigation of the clamp concept to connect snapped scintillating fibre needs to be done.
- It was pointed out that in order to glue the fibres to the frame, the carbon fibre needs to be cleaned before hand.
- Some sort of material or foil must be placed under the carbon fibre to prevent overspill of the epoxy.
- For gluing the fibres to the carbon fibre frame, a question is if a glue layer should be placed before winding. As there is a limit to the amount the platform can be lowered, making application on the bottom of the fibres potentially tricky.

Some observations that resulted from gluing with superglue with the result seen in Fig. 6:

- To clean the carbon fibre frame, acetone was used.
- Grooves cut into the carbon fibre would be useful in spreading the glue on the frames.
- When applying the superglue there was a slight spreading of glue to fibres near the edges.
- Placing paper or some material beneath the frames would be helpful in ensuring the glue spread to the edge where the connection of scintillating fibres and clear fibres would be made.
- There can be issues in ensuring the glue spreads to the lower layer.
- If the frames are not raised sufficiently, then the glue only glues the two layers of wires together, but not to the frame.

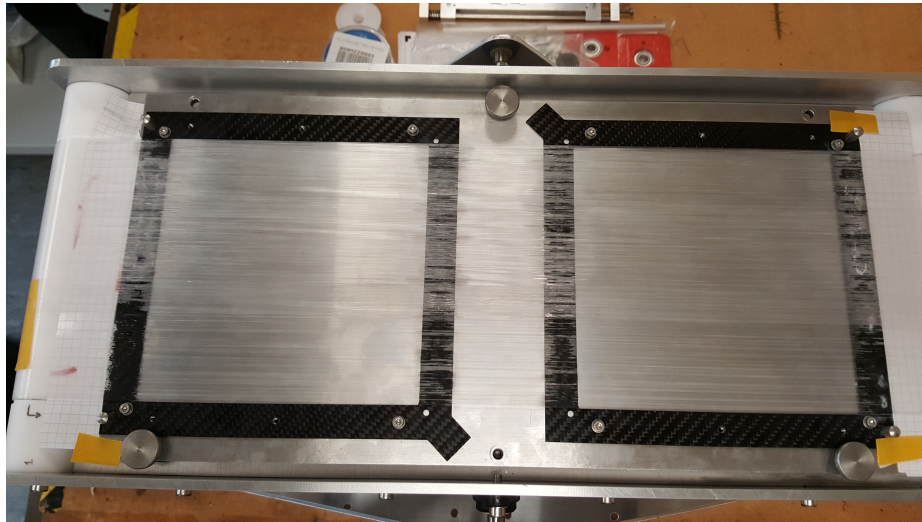


Figure 6: The frames after superglue was applied. Note the presence of the glue may make it seem like the wires are criss-crossing, but the wires are straight. In addition, the sections with the double layers were harder to glue and is quite evident as with the single layer one can see the frame, which is not as clear with the double layers.

From the conclusions of the tests with gluing to the frame, some recommendations for gluing to the frame are:

- Add grooves to the carbon fibre frame.
- Place paper beneath the frames before winding for the purposes of collecting any excess glue on the edges.
- When gluing, lower the platform (lowering the frame relative to wires) and with a sufficient nozzle have a layer of glue on the frame.
- Then raise the platform up and apply another layer of glue on top.

It remains to be seen whether or not the edges affixed to the frame are sufficient, if the wires are still taut, and if the edges get frayed when cut. Then the connection between scintillating fibre frames and clear fibre frames can be tested.

05/09/2019

After letting the glue cure overnight, it was found that when the wires were cut, the resulting tension of the wires caused the frames to warp upwards as seen in Fig. 7. This may be an issue due to the fishing wire which is 'stretchy' and hence leads to the warping of the frame. It is unknown whether or not under the same conditions what would happen with the scintillating fibres. Most likely it would lead to the fibres snapping.



Figure 7: The result after the wires were cut where the tension in the wires caused both frames to bend.

However, it should be noted that for the edge not damaged by the bending of the frames, one can see that the double layer of wires is quite nicely preserved in Fig. 8.



Figure 8: In the areas not affected by the warping we see that the double layer pattern is quite nicely preserved.

3.3 Second Prototype

09/09/2019

More wire was ordered to be used for a second prototype where a tensioner would not be used for the winding. In addition, only one layer would be used this time. The rationale is that if there is still warping with one layer, then likely it would mean that two layers of scintillating fibres would also be an issue.

If one layer still prove to be an issue, then either a thicker frame would need to be used, or an additional frame would need to be placed on top of the wires to keep the frames from warping to the tension or some other solution would need to be used with the result of winding seen in Fig. 9.

The method found for the winding was:

1. Place frames into place with the correct orientation.
2. Place some paper underneath for the gluing portion later on.
3. Place end of wire under a screw and screw down to keep in place.
 - It may be useful to rotate such that the wire is aligned with the starting groove.
4. Fix the wire to the second groove and rotate keeping one hand pressed on the wire to keep it in place and the other on the other end of the wire near the spool to keep some tension.
5. Now on the underside fix the wire to the other lobe's second groove.
6. Rotate again, keeping one hand on keeping the wire in place and the other on the wire.
7. Check to make sure there is not too much tension.
8. Repeat for the next grooves until finished.
 - Easier with more turns of the wire as it is more a case of pushing against the previous turn.
 - The wire can sometimes pop out, but is a relatively easy task to knock it back into place.
 - Sometimes it may appear that there is a groove missed when there isn't, this could be an issue with the wires touching the frame or manufacturing defects. Best to look and run fingers along the lobes to ensure a groove was not missed.
 - If spool runs out, one can tie a new spool to the previous with a knot.

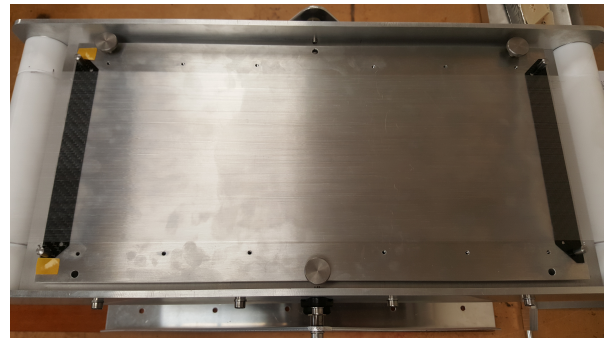
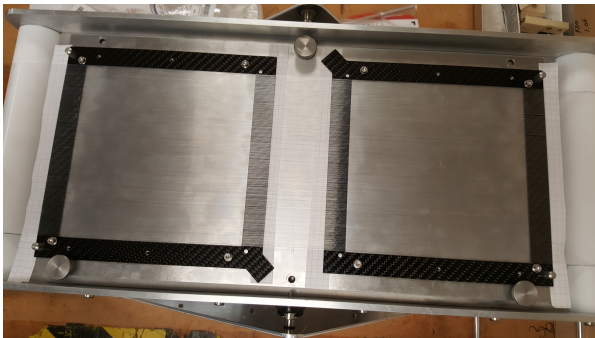


Figure 9: Second prototype with one layer of wire wound. On the left is the side with the frames, note the paper placed underneath the frames beforehand for the gluing. On the right is the connector plates, in this case the paper is missing as it was found the connector plates were loose and the paper would be placed afterwards before the gluing.

10/09/2019

The previous observations about lowering the platform and applying glue to the bottom would not be as effective as was thought due to the fact it would be an unequal layer of glue. This might be mitigated if there were grooves which would allow the glue to spread out somewhat to equalize. The approach used was to bring the platform up as before but just enough that the wires just about touch the frame without adding additional tension. The result of the gluing can be seen in Fig. 10.

Since only one layer of superglue was used it was found that once superglue was applied, the wires for the most part locked into place. Hence an issue is that if the wires are knocked out of frame during the gluing process, it will stay knocked out.

A useful technique was found where when gluing it was useful to drop and drag the superglue along without actually physically touching the wire and letting the meniscus eventually break to spread the glue. Also, it was useful to apply an ample amount of superglue first and then dab excess off. There was some movement with the wires when doing so. An idea was tried where release film was used to hold the wires in place during the gluing, but it did not seem to make a noticeable difference.



Figure 10: Images of the second prototype after gluing. On the left we see the frames, where with a single layer it is more visually obvious of the wires being glued to the frames. On the right is the connector plates where one side has release film intended to hold the fibres in place while the other side doesn't. It did not appear to help much however.

While waiting for the gluing some brainstorming was done should the tension still prove to be an issue. One method is to do the potting on the jig itself. Where a PTFE square could be placed underneath the square frames with some frames on the sides and superglue as before. But by doing so, the tension would be held by the epoxy which may resolve the issue. But this might be hard to realize without an extensive modification to the winding jig.

Another possible solution is to make the window smaller to give the edges a bit more length to spread out the tension a bit more to prevent the bending seen previously.

Also one could just use one layer which simulations show does not show a massive difference to the doublet layer. This might work because the scintillating fibre would not be as 'stretchy' as the fishing wire/bead wire used for the prototypes so should not have an issue of the frames warping. Instead, it is likely that the fibres would snap.

11/09/2019

After letting the superglue cure overnight, the wires were cut, and unfortunately the tension caused the frames to bend and can be seen in Fig. 11. Though to a lesser degree compared to before due to only using a single layer. It seems apparent that there is a lower limit during the winding of the amount of tension that can be used as if it is too low then the fibres would simply pop out of the grooves.



Figure 11: The result of the frame bending after the wires were cut for the second prototype.

Due to the wires shifting while gluing took place, the alignment was also an issue where the clear fibres would not line up to the scintillating fibres and can be seen in Fig. 12.

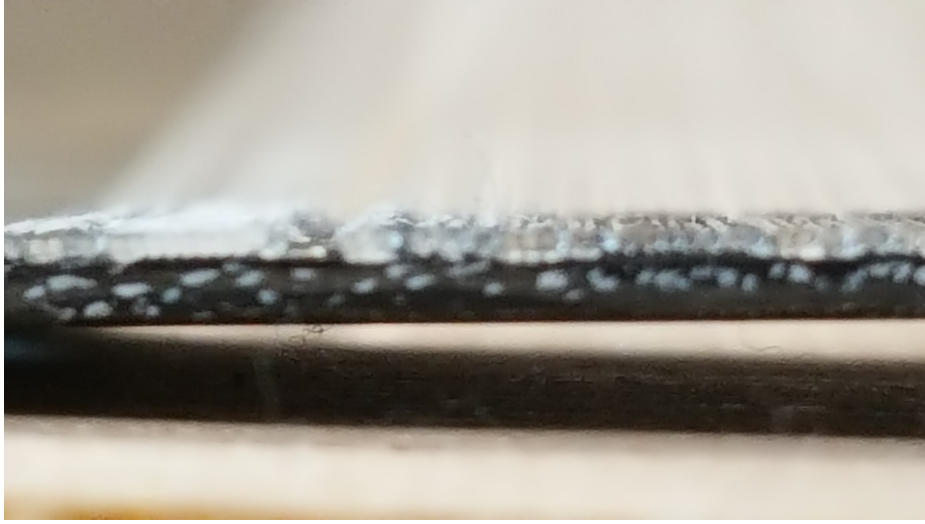


Figure 12: An image of one of the ends used for alignment. There are some noticeable gaps where during the gluing process some of the fibres have shifted to group and stick together.

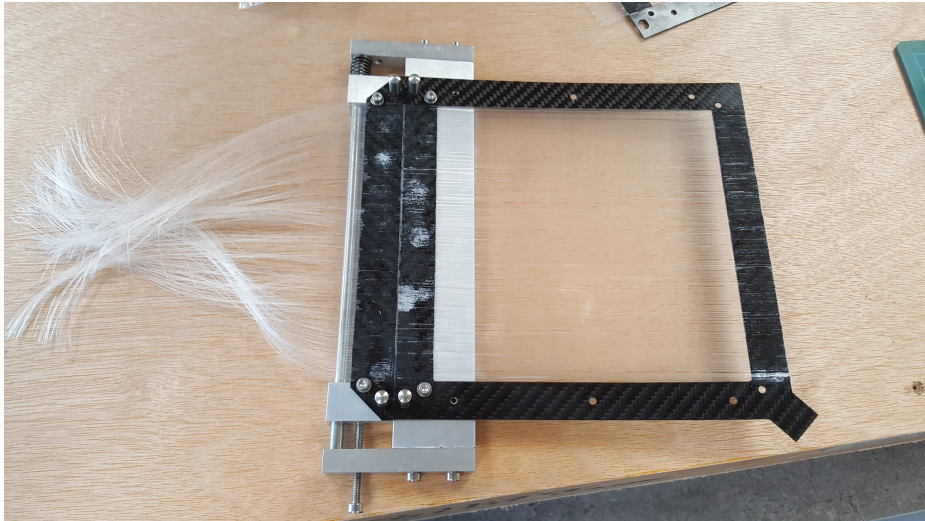


Figure 13: The alignment concept of aligning the connector plate wires with the frame wires. The connector tab position can be moved with respect to the frame through the screw rod on the bottom.

With the prototype, when attempting to do the alignment it appeared a small gap was visible between the connector plate wires and the frame wires which can be observed in Fig. 14. This may be an issue to do with the edges of the wires not being polished. Although the edges were attempted to be cut to be flush to the edge as much as possible, the small gap is still visible.



Figure 14: A close up of the connection being made between the frames and connector tab. In the case of the prototype it appears there is a gap which may be an issue of the fishing wire not being polished on the edges.

Furthermore, when the frames were put together to form one station, the bend is still present. It may be possible that having multiple stations in succession could help mitigate this. The final second prototype can be seen in Fig. 15.

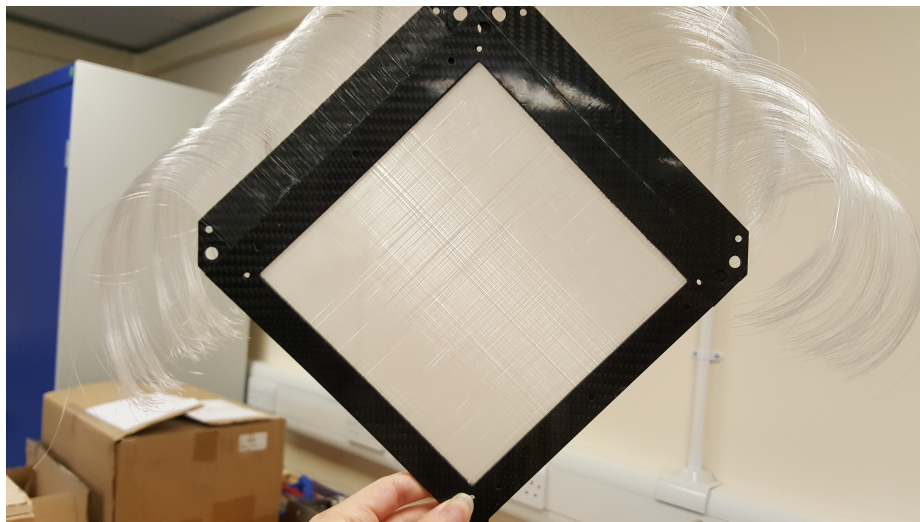


Figure 15: A second prototype station with the two frames glued together with the wires oriented 90 degrees with respect to each other, and each frame is aligned to a connector tab.

Essentially there are two issues which conflict with each other:

1. Tension
2. Alignment

Tension would cause the frame to bend/fibres to snap, but lowering the tension would result in problems with the alignment.

Tension

There were some brainstormed solutions to the issue with tension:

- Use a single layer
 - This was attempted with the second prototype which still had the bending issue. But if it is to be believed that the scintillating/clear fibres will not stretch, then it may not be an issue but may instead result in the fibres snapping. Furthermore, gluing a single layer was much easier to ensure the wires stuck to the frame.
- Changing frame aperture
 - The window aperture is currently a square, but if it is changed into a circle, it may help to spread the tension in the wires. Though this may come at the cost of losing some information on stray particles from the beam.
- Changing the frame thickness
 - Changing the thickness would prevent excessive bending. However, the issue with a thicker frame is that there is very little space for the lower energies. Increasing the thickness would mean being significantly less effective in taking measurements for those lower energies.
- Winding with Less Tension
 - If the wires were wound such that they simply lay on the frames then tension would not be an issue. But there is a lower limit to the tension as if the wires are not very taut then they would simply fall out of the grooves. In addition, this leads to the second problem to do with the alignment.

Alignment

Aligning clear fibres to scintillating fibres is difficult as during the process of gluing, some fibres shift in position. The concept behind the alignment method was relying upon the wire positions to be exact.

Some brainstormed solutions are:

- Use more tension during Winding
 - If the wires were wound with a lot of tension then wires do not move during gluing, but this leads to problems with the tension.
 - Or in the case of real fibres, may lead to fibres snapping.
- Move lobes closer to the frames
 - If the frames were adjacent to the lobes, then when gluing there should be very little movement on the alignment edge.

The method to be pursued to rectify these issues is being considered. But at the moment the way forward would be:

- Changing the frames to have a circular aperture
- Moving the lobes closer to the frames