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Polishing Optical Fibers for the D0 ICD in Run II

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Polishing Optical Fibers for the DØ ICD in Run II

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The active element in the Run II DØ Inter Cryostat Detector (ICD) is an array of scintillator tiles. Charged and neutral particles produce light in the tiles which is transported to the photodetection system along optical fiber pathways. In general, building a tile/fiber detector requires very conscientious technical support and a high degree of quality control. Polishing fibers is one of the most delicate of tasks involved.

This note describes methods used by the ICD group to polish the ends of fibers. These methods may be used in the ICD production as well as in prototype development.

Contents

1 Introduction

The Inter Cryostat Detector (ICD) is a scintillating tile based detector array which augments the DØ liquid argon calorimetry in the region between the central and end cryostats. The ICD improves both missing transverse energy and jet energy resolution.

The Run I configuration of the ICD will not operate in the Run II environment because the phototubes cannot be fully shielded from the expected magnetic field of over a kiloGauss. In the Run II ICD, the photodetection and preamplification components of this detector are moved to a region of lower field. The motivation and design of the Run II ICD is fully described in the ICD Technical Design Report [1]. The purpose of this note is document the fiber polishing techniques not included in the TDR.

The most significant physical changes to the system are the relocation of photodetection electronics and the increased number of optical fiber pathways which bring light signals from the tiles to the phototubes. The fiber subsystems of the ICD are shown schematically in Figure 1.

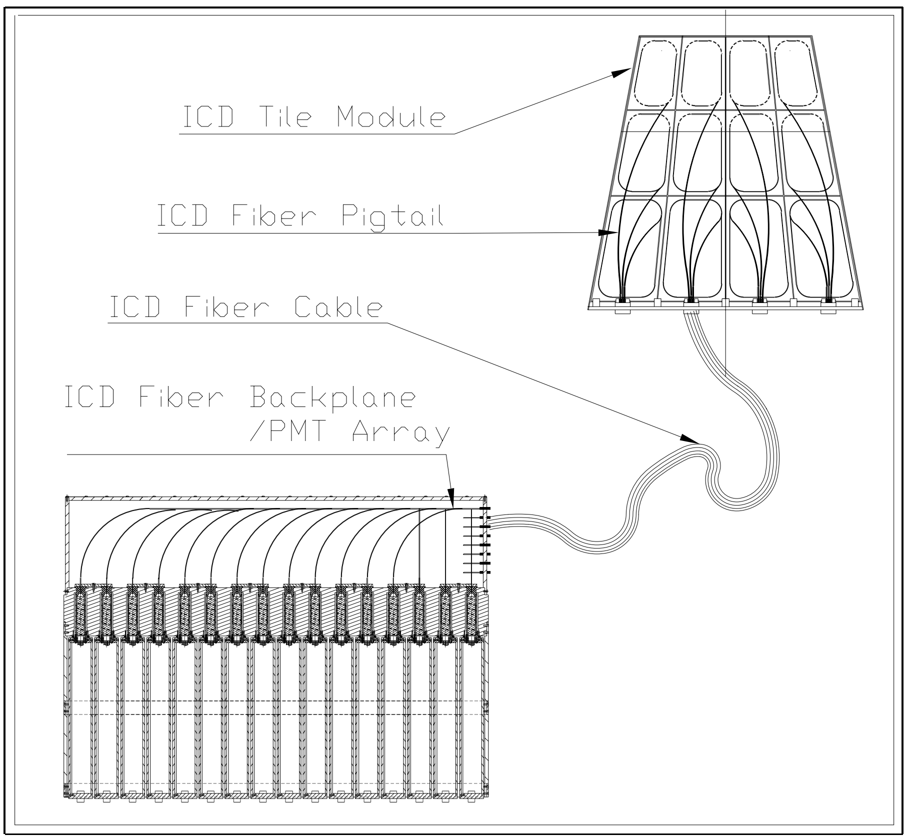

Figure 1: Schematic of the 3 optical fiber subparts of the ICD for DØ's Run II detector: a) WLS fiber pigtail within the tile modules, b) clear fiber cable, and c) fiber backplane, in which signal as well as calibration fibers are routed to the individual PMTs.

In order to minimize light loss along these pathways, it is crucial to have fiber polishing techniques which produce uniformly smooth polishes across the face of each fiber perpendicular to the fiber length.

2 Types of Fiber Interfaces in the ICD

In the Run II ICD, the light signal must pass through 3 fiber subsystems to arrive at the phototubes (as enumerated below and shown in Figure 1). At each interface between fiber pathways, fiber ends must be polished to maximize transmission (minimize light loss) so as not to degrade the signal seen by the PMT's. The subsystems are listed below, highlighting the types of fiber ends to be polished.

1. WLS (wavelength shifting) fibers laid in grooves in the scintillator tiles bring the light signal to a connector at the edge of each tile module. The WLS fibers and the connector as a unit are called a *pigtail.* The maximum individual channel WLS path length is less than 0.5 meters. The current design includes two WLS fibers per fiber groove.

   - The fiber ends within the tile grooves must be polished and mirrored (mirroring, or aluminum sputtering, will be performed in Lab 7 at Fermilab - see Figure 8). **Individual fiber ends are polished before mirroring.**
   - The other end of these WLS fibers are potted into connectors using optical epoxy. **These connector ends must be polished.**

2. Clear fiber cables, with fiber connectors at both ends, bring the light signal from the tile modules to the PMT crate, a path length of about 14 feet. The cable manufacturer (Mitsubishi Optical) will wrap clear fibers in bundles protected by a black dielectric covering. Fiber ends will be epoxied into connectors supplied by the ICD group (purchased from DDK Electronics).
   Both connector ends will be polished by Mitsubishi.

3. Light signals are sorted and distributed to PMT (photomultiplier tubes) in the rear section of the PMT crate (called the fiber backplane).

   - Fibers will be potted into connectors at the input end of the fiber backplane using optical epoxy. **These connector ends must be polished.**
   - The other end of these fibers will be potted into cookies which bring the light signal to individual PMTs.
     - If the cookie is flat at the end, the fibers can be polished by facing off the end of the cookie. **These cookie ends must be polished.**
     - If the cookie end is the inverse conical design (which allows a finite fixed distance air gap between the cookie and the PMT), these fibers need to be individually polished. **Individual fiber ends need to be polished before they are epoxied into cookies.**
   - LED calibration signals will be fanned out to the PMTs in the fiber backplane (epoxied into the same cookies as the signal fibers).
     - **Both ends of the calibration fibers need to be polished, either individually or in the PMT cookie (as above).**

3 FNAL and UTA Diamond Polishing Machines

The Fermilab Lab 5 polisher was built by FNAL mechanical support staff and has been operated by the CDF/CMS Rochester group to produce the Run II CDF end plug calorimeters. This machine has a rotating wheel with progressively finer cutting bits at decreasing radii: There are 2 course cutting carbide blades at outer radial points a course diamond bit at an intermediate point and a fine cutting diamond bit beyond that. In a single pass, the object/connector to be polished should move at a constant speed along a linear path intercepting the bits on the spinning wheel along an inward radial path. By pushing a single (START) button, the machine is automated to start the rotating wheel, move the connector assembly smoothly with precise positioning into the cutting bits and return the piece to the starting position.

The integrity of the diamond bits can be preserved by using them to 'cut' as little as possible in any single pass. John Korienek, who built and maintains the FNAL polishers, recommends the following:

- Relative spacing:
  1. between the carbide bits and the roughing diamond is 5/1000 (5 mils) and
  2. between the roughing diamond and the finishing diamond is 1/1000 (1 mil).
- Bits will be ruined quickly if this spacing is larger.
- It is possible to take off $\frac{1}{8}''$ of a plastic material in one pass, but less for a harder material since taking off more would draw the piece into the machine (it is very important to hold the piece securely).
- If you want a smooth polish, it is better to use smaller increments.

Daniel Ruggiero, who used the Lab 7 FNAL polisher to polish a large number of DDK connectors, said that one diamond bit was good for about 70 CDF hadron end plug connectors when it is CAREFULLY used. The ICD group will use these same connectors. Connector polishing is described in a later section. When polishes do not pass inspection, the diamonds should be turned over to a machine shop for off-site repolishing.

The UTA polisher is described in the ICD TDR and is shown in Figure 2. The UTA polisher and the Fermilab Lab 5 polisher are very similar - their design, construction, and components are in many ways identical. Since the UTA polisher was not operational at the time, the Lab 5 polisher was used to polish ICD prototype connectors. The procedure for operation of the Lab 5 machine is given in the next subsection: Operation of both machines is very similar. The UTA polisher is now being used for prototype fiber cable production and will soon be used to polish all fiber connectors on tile modules and on the backplane.

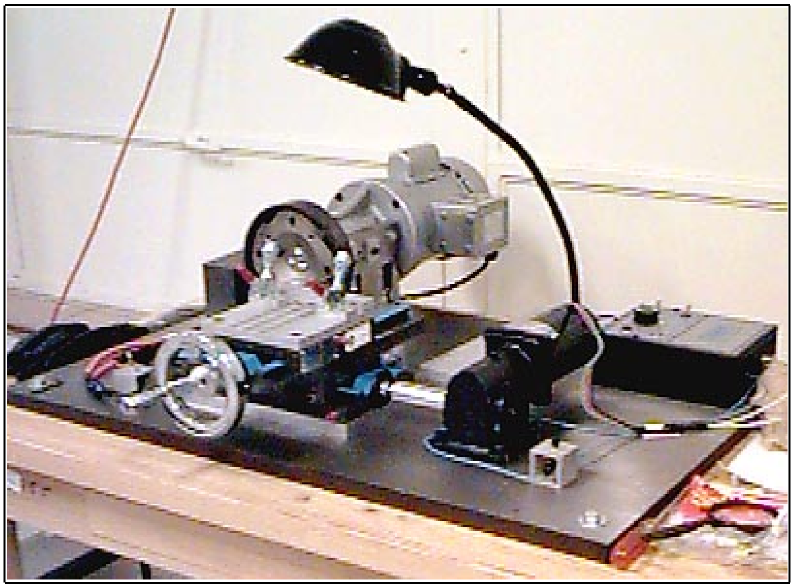

Figure 2: The UTA diamond polisher.

3.1 Polishing Fibers in DDK Connectors

Connectorized fibers at the tile module edge and at the fiber backplane will be polished by facing off the connector end with multiple passes with the UTA diamond polishing machine. In addition, the DØ ICD group is using the same fiber connectors as the Rochester group used for the Run II CDF End Plug Hadronic Calorimeter.

The precision injection molded connectors are distributed by DDK Electronics, Inc. They are modular and are available for ICD fiber diameters 0.9 and 1.0 mm (contrary to the ICD TDR, 1.1 mm fibers will not be used in the fiber backplane because connectors are not available from DDK for this fiber size). Since they are only available only in 10-channel models, all channels may not be utilized. A drawing of a connector assembly is shown in Figure 3.

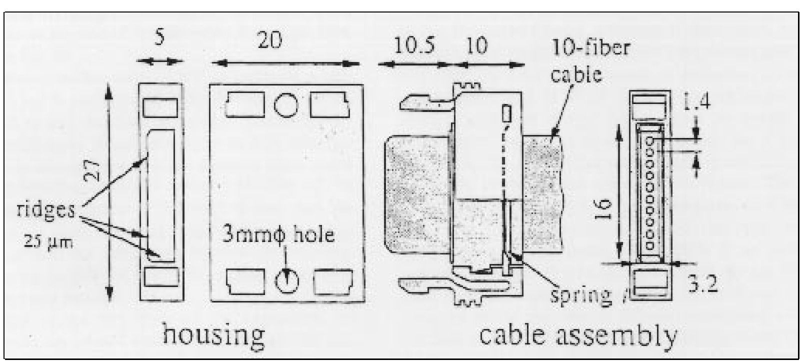

Figure 3: Fiber ribbon cable connector.

This procedure for polishing fibers epoxied into these connectors was developed with the assistance of the Rochester group using the Lab 5 polisher. Operation of the UTA polisher should be very similar. Supplies needed are indicated in **boldface type.**

- **Fibers** are potted into the **connectors** with 24 hour **Bicron 600** optical epoxy as detailed generically in Appendix A or in D0 note 3433, which describes the epoxying of the WLS pigtails.

- With a **sharp razor blade** or scissors, cut off excess fiber length off the connector face to within about 1/8 inch.

- Initially, the connector end tab containing the fibers measures about 436 mils with a **vernier caliper.**

- Slide the connector end into the **custom-made vise** (for DDK connectors) on the **connector polisher** until the tab edge hits the tab stop. Screw down the vise so that the connector is held firmly.

- These connectors contain fiberglass, so a **vacuum** should be attached to the polisher to collect debris. Turn on the vacuum.

- Ultimately, about 22 mils should be removed from the connector face to optimize transmission for connector interfaces.

  - On the FNAL machine, the first setting is at the 35 mark. Push the START button. The cutting wheel ramps up to speed, then the table motor moves the piece transversely into the cutting bits. This removes the fiber ends hanging off the connector face. After cutting, the connector returns to the initial position.
  - Now turn the dial to the 25 mark. Push the START button. Machine will take off 10 mils more than the previous cut. Machine cycles and returns to initial position.
  - Turn the dial to the 20 mark. Push START. Machine will take off 5 more mils. Push the STOP button, which cuts power to the cutting wheel for safety.
  - Remove the fiber connector from the vise. Measure the tab length (T). The next 2 passes should remove enough material to bring the tab length to between 415 and 414 mils, but *no less than* 413 *mils*. Length to remove $L = T - 414$.
  - Slide the connector end back into the vise until the tab edge hits the tab stop. Set dial to cut off another L/2 mils. Press START.
  - Again, set dial to cut off another L/2 mils. Press START. After the machine cycles, press STOP.

- Measure the connector tab length. If it is more than 415 mils, then re-polish accordingly.

- Blow cutting debris away with **compressed air** or wipe clean the connector face with a solution of 50/50 (50% **isopropyl alcohol** and 50% **water**) using a **cotton swab (q-tip).**

- Inspect the connector face in the **microscope**. Fiber faces should be smooth with slightly visible cutting lines all parallel to the cutting direction. Fiber cladding in all areas must be intact.

- Cover the end of the connector face with a protective cap or kapton tape to protect it from damage and soil.

4 Single Fiber Polishing

There are a number of techniques which may be used to polish fiber ends which are not connectorized or otherwise epoxied into a larger piece which can be faced off with a diamond polisher. The inherent difficulty in polishing single fibers is

- holding the end of the fiber firmly with uniform radial force
- with the fiber axis perpendicular to the cutting direction,
- while preventing longitudinal slippage,
- such that the fiber core and cladding are evenly polished
- without the cladding peeling or coming away from the core.

The following three subsections describe techniques for polishing single fibers. The first 2 subsections describe the procedure for using **a single fiber polishing machine and** the technique for polishing single fibers in a **drilled teflon (or plastic) block**. These **techniques are useful to polish a small number of fibers** and were employed for prototyping components of the Run II ICD.

For a larger number of fibers (many hundred at a time), an **ice polishing technique** has been conceived and developed over the last few years. When executed correctly, the product of the ice polishing technique **far exceeds previous methods in both quality and efficiency.** Ice polishing is described at the end of this section and is expected to be employed for the bulk of fiber polishing in the production of ICD fiber components for Run II.

4.1 Inspection Procedure

In every case, **inspection of the product is essential at regular intervals** when more than a few individual/batches of fibers are being polished to insure quality control through the production process. Inspect the fiber end in the microscope, holding the fiber in a vise which insures the fiber axis is parallel to the viewing direction:

- Clean the fiber end by blowing bits off with compressed air or wiping with a q-tip and 50/50 (water and isopropyl alcohol).
- The entire fiber end should be in focus across the face (insuring end is squared off).
- Fiber cladding in all areas must be intact and in contact with the core (a half moon shadow in the interface indicates cladding has come away from the core).

On a high power microscope, cutting lines will be slightly visible across the face, parallel to the cutting direction.

4.2 The Fermilab Lab 7 Single Fiber Polishing Machine

Machines which polish single fibers have been designed by Fermilab engineers. Such machines, made both at Fermilab and in industry, are available at Fermilab. While these machines are useful for polishing a small number of fibers, they are expensive, require maintenance, and are labor intensive. In building the CDF end plug calorimeter, approximately 200 to 400 fibers could be polished in one day by an experienced technician. The polishing success rate varies widely. According to an expert technician [2], the CDF fiber polishing rate varied most due to nonuniformity in size of the plastic tubing used to support the fiber during polishing. This experience was affirmed in producing components for the ICD full prototype where a new user managed to polish 31 fiber ends in an entire day, the major difficulty being finding a plastic sleeve that 'works'. Other groups corroborate this experience [3].

UTA does not have a single fiber polishing machine, but a small number of fibers used for prototype development were polished using a single fiber polishing machine located at Fermilab in Lab 7. The technique for using this machine is described here with equipment needed as indicated in boldface type.

- Turn on the **polishing machine** and the **vacuum** connected to it.
- Find a piece of **plastic tubing** at least 1.5″ long in which the fiber end fits snugly (to protect the cladding).
- With a **sharp razor blade**, cut one end of the tubing perpendicular to the tubing axis.
- Polish the empty tubing using the polishing cycle described in subsection 4.2.1.
- With the razor blade, cut the other end of the tubing at an angle (this makes inserting the fiber into the tubing easier).
- Skim off any damage on fiber ends using a sharp razor blade: Insert the fiber in a **copper block** (at least 1″ thick) with drilled holes the same diameter as the fiber.
- Insert the skimmed fiber into the angled end of the tubing. Push the fiber all the way or slightly beyond the polished end of the tubing.
- Put a piece of kapton tape at the angled end of the tubing to keep the fiber from slipping longitudinally.
- Polish the fiber/tubing assembly using the polishing cycle described in subsection 4.2.1.

4.2.1 The Polishing Cycle:

1. Back off the dial on the polisher to the highest number position (maximum).

2. Depress the lever and put the piece to be polished into the vise as far in as possible (up to the stop).

3. Press the CYCLE START button: Machine will automatically cycle, moving the diamond cutter across the face of the piece.

4. Turn the dial down to the 12 mark, for example. Press the CYCLE START button: Machine will automatically cycle again. Continue stepping down through to the lowest setting: to 8, 4 and 2, for example.

5. Optimize the number of passes and settings by inspecting polished fibers in a microscope as described in subsection 4.1.

4.3 Drilled Teflon Block

Another way to polish fibers is to insert them in holes drilled in a thick teflon block and shear off the face with the diamond polisher. The advantages of this technique are that it is an inexpensive and a straight forward procedure to implement (with some adaptation of the diamond polisher). Like the previous technique, this method can be used to polish fibers individually when a small quantity of fibers needs to be polished.

1. Using a high speed steel drill, drill out holes in a teflon block about 2 inches thick.
    - The drill bit should have a diameter the same or slightly larger than the fiber you want to polish.
    - Holes should be tapped gradually, with each tap progressively deeper into the block. Keep the block clear of teflon debris.
    - The number and pattern of holes should allow for the distance over which the polishing bit can travel and make it easy to hold fibers from slipping longitudinally during polishing (using kapton tape).
    - Make the holes penetrate as straight as possible. The teflon is soft so the drill may tend to wander. Holes must be perpendicular to the polishing face so that polishes are perpendicular to the fiber axis.
    - On the final tap, do not push the drill bit past the edge of the block. The hole diameter will be tapered - larger at the end where the bit penetrated the teflon.
2. Inspect each fiber. Cut off any cladding or core damaged ends: put the fiber through a drilled hole in a copper block and cut perpendicular to the fiber length using a razor blade.
3. Insert fibers into holes in the block from the side where the bit penetrated the teflon.
    - The fiber tips should extend no more than 0.5 mm from the block.
    - Fibers should fit snugly in the holes so that the cladding is protected during polishing.
    - If possible, tape the back end of the teflon to secure the fibers in the holes (hold fibers from slipping longitudinally).
4. Place the block on a secured vise and polish.
    - Use at least 3 passes (cuts) at the face of the teflon block - 10 mils, then 5 mils, then 2 mils, for example.
    - While polishing, use an air source to blow teflon debris away to prevent teflon residue from smearing on the fiber.
    - Keep the polishing head cool.

Dmitri Denisov reports that the DØ muon group polished fibers for the Run II muon scintillator system using a teflon polishing jig. They polished 5000 fibers at both ends, at a rate of about 500 per day and a failure rate of $10 - 20\%$.

4.4 Ice Polishing of Fibers

4.4.1 Introduction

It takes a long time to polish fibers individually. This makes the construction of a detector needing hundreds or thousands of individual polished fibers prohibitory in both time, effort, and quality control if one of the previously described techniques is used. The ice polishing technique has proven to provide the best quality polishes at a much faster rate than any other known technique. The caveat is: success of the technique depends on the fine tuning of many variables including the type of fiber to be polished. Any group/individual interested in ice polishing should consult with those who have successfully used the technique, modifying it wherever necessary for their specific application.

4.4.2 Proviso

The information included here is by its nature biased by the author's reference frame. The history of ice polishing development, names and experiment numbers are included in the next section as a point of contact for others pursuing the technique, NOT as the infallible historic record. We apologize if important contributions to the development of the technique and the individuals involved are unknown to us at this time.

4.4.3 History

The ice polishing technique was conceived and initially tested by Ron Richards at Michigan State University early in 1995. His proof-of-principle crude test included a 1 inch diameter polyurethane tube to hold the fiber ends in a foam insulated chamber cooled with dry ice. The end of the unit was polished with an 8 inch diameter wheel holding two (one medium and one fine) diamond grit wheels. In inspecting the polished fibers, Ron found that the wheel did not tear up the cladding and figured the diamond fly cutters would work even better.

Ron communicated his results to Roberto Mussa who coordinated with Carl Lindenmeyer to modify/build diamond polishing machines and develop the technique to make it work for a specific application. They were the first to use it on fibers in an operating detector (Fermilab experiment E835). Simultaneously, the DØ technical support group (lead by David Butler under Delmar Miller's DØ technical support group) developed the technique for production processing of fibers for the DØ CPS (Central PreShower) detector which will operate in Tevatron Run II. After tuning the process to their application (many months of R&D), they were able to polish 10,000 DØ CPS fibers in a few days, orders of of magnitude less time than the time required to polish an equivalent number of single fibers using the best single fiber polisher (such as the one in Lab 5 at Fermilab). CPS spokesman [4] claim that about 5% of the fiber polished ends might not pass the quality control inspection, but the other 95% look great. In 1996, Casey Durandet also did R&D to use the technique to polish larger 2 mm diameter fibers for experiment E871.

Refinements of the ice polishing technique at Lab 7 (under Fermilab Technical Centers) have improved polishing quality and efficiency such that Lab 7 has become the ice polishing center of expertise at Fermilab. They played a major role in the quality control for fiber polishing for the DØ CPS and have polished more than 18,000 fibers for the

DØ FPS (Forward PreShower). Currently, they are working to polish fibers for other DØ subsystems:

- 100,000 fibers for the VLPC's,
- 100,000 fibers for the scintillating fibers of the CFT (Central Fiber Tracking) detector,
- a few 1000 fibers for the ICD,
- and both round (0.4 mm diameter) and square (0.8 mm sided) fibers for the FPD (Forward Proton Detector).

Improvements in the technique now include the use of a urethane mold with a hexagonal rather than circular inner surface, the cast of which was designed by Carl Lindenmeyer. The current set-up in Lab 7 includes a clean room with special lighting to eliminate UV damage to CFT scintillating fibers. This room contains space and equipment for efficient fiber handling, a modified freezer which can freeze the longer fiber assemblies, and the P3 diamond flywheel polisher with custom vices to hold the frozen fixtures during polishing.

The ICD group specifically worked with Glenda Adkins, Eileen Hahn and Jack Upton of Technical Centers in Lab 7 at Fermilab. Specific details for the polishing of ICD fibers is described within the following section along with pictures of the ICD polishing fixture.

4.4.4 The Ice Polishing Technique

The general technique is outlined below and should work for any diameter fiber. The supplies needed are highlighted in **boldface type.**

1. A **bulk fiber holding fixture** must be constructed to hold the fibers during the entire freezing/polishing cycle. Fibers packed into the fixture must run parallel without twisting and be held firmly without stress along the entire length of the fibers. Successfully used fixtures earlier in the development of ice polishing were based entirely on PVC (Poly Vinyl Chloride) tubing, found in hardware and plumbing supply stores. Improvements in the technique now add a urethane mold with a custom inner and outer surface, such as the one shown in Figure 4. The mold is clamped into an aluminum/G10 structure, shown in Figure 5. which also attaches to PVC pipe to support the full length of the fibers. The full unit is shown in Figure 6.

   In general, the fixture to hold the fibers should have the following:

   - The inner surface is octagonal or hexagonal in cross section (as shown in Figure 7, which helps to keep the fibers parallel: Fibers coming from a spool are especially susceptible to twisting or sitting in the tubing at an angle with the tube axis - the straight edges help to align them. Any angle of the fibers with the tube axis will cause a skewed polishing angle (this was more of a problem when using only round PVC tubing).
   - The fixture inner diameter depends on the number of fibers to be polished. Generally, hundreds of fibers are polished at one time.

- The DØ CPS group used a $1 - 1\frac{1}{4}''$ diameter PVC pipe to polish $0.83''$ diameter fibers.
- Casey Durandet (HyperCP E871) used a 1.9 cm diameter PVC tube to polish about 75 2 mm diameter fibers at a time.
- For the DØ ICD, a urethane mold measuring $3/4''$ across the inner facing hexagonal flat surfaces was used to polish the 0.9 mm diameter fibers.

The $3/4''$ hex mold like the one pictured in Figure 4 is being used for all DØ subdetector fiber polishing done in Lab 7.
Attempts to polish a much smaller number of fibers at one time have not been successful.
If using only a PVC tube as the polishing fixture, drill a small hole about 3 inches from the bottom of the tube to insert water after fibers are packed inside.

2. Clean the fibers and PVC tube. The tube should be long enough to support the fibers all along the length but a few inches of fiber should stick out of both ends. An **anti-static gun** is suggested to reduce static.

3. Gather the bundle of fibers to be polished, holding them as parallel as possible while packing them into the PVC pipe.

4. Tap all fibers down into the end of the pipe.

5. Place the urethane mold into the aluminum/G10 frame and clamp the end of the PVC onto the frame.

6. Slide the packed fibers into the urethane fixture. The assembly should look something like that pictured in Figure 6.

7. The packing fraction (fraction of space in the tube occupied by fibers) should be as high as possible without causing mechanical stress during fiber insertion. Insert additional dummy fibers at the end to make the fit snug, but not tight.

8. Tap down the fiber ends to be flush with the bottom of the fixture. The the polisher will be set to take $1/8''$ off the end.

9. Tape up the end of the fixture with **kapton tape**. The taped end must be water tight.

10. Holding the tube bottom side down, fill the bottom taped end of the fixture with **deionized water**. For a PVC tubing fixture, insert water using a syringe or eyedropper through the small hole 3 inches from the bottom of the tube. For the urethane mold, water can be dropped over the top edge of the mold. The tube bottom is filled when water flows back out of the hole/top.

11. Put the upright tube in a **freezer** overnight.

12. The end of the fixture (including the G10/aluminum/urethane_mold/fiber_ends) must be very gradually immersed in a nitrogen bath. If the temperature drops too rapidly, the piece will crack. All groups agree that it is critical not to rush the cooling process or the fibers will be irreparably stressed. Both of the following techniques have been employed successfully, but the second is more reliable and systematic in a production mode:

    (a) Put the bottom of the fixture into an empty **dewar**, then slowly pour **liquid nitrogen** into the bottom of the dewar, bringing the temperature of the fixture down very gradually.

    (b) Slowly lower the fixture into a **nitrogen bath**, or use a **motor** to raise the bath onto the fixture.
    Attempts to eliminate the freezer overnight, compensating by slower immersion in the bath, yielded inconsistent results but they did not have time to pursue it further.

13. Allow the end of the assembly to reach liquid nitrogen temperature. The recommended length of time in the bath varies from 15 to 30 minutes depending on the fiber and tube size etc. The time used for ICD fibers was 30 minutes, using the 3/4″ mold. Lab 7 polishing experts have found this time to be optimal for this size mold regardless of fiber type and size.

14. Take the fixture out of the dewar and remove the tape. Clamp the frozen fixture end into the **customized vice** on the **diamond polishing machine**. The vice must hold and insulate the frozen unit during polishing.
    The P3 polisher in Lab 7 has a custom vice for holding the end of the fixture shown in Figure 7.

15. Use multiple passes (cuts) at the face of the fixture/tubing, starting with one or two rough cuts, followed by one or two passes with the diamond bit.

    - The number of passes depends on the polishing machine.
    - The cutting must be done fairly quickly before too much heat is transferred to the ice.
    - If the ice melts, you're in trouble so if there is any delay, put the tube back in the freezer overnight.
    - While polishing, use a cold air source to blow debris away and keep the polishing head cool.

Inspect individual polished fibers (as in subsection 4.1) and use those which pass the polishing criteria.

Note that the assembly must be polished immediately after removal from the dewar (within minutes). Re-immersion of the assembly back into the dewar can shock the fibers resulting in irreparable cladding damage. Should a delay occur which allows any significant defrosting, it is best to return the assembly to the freezer (overnight) and try again the next day. Repeated freezing and thawing of the assembly is also prohibited, even over a longer time scale since this has also shown to be detrimental to the fiber integrity.

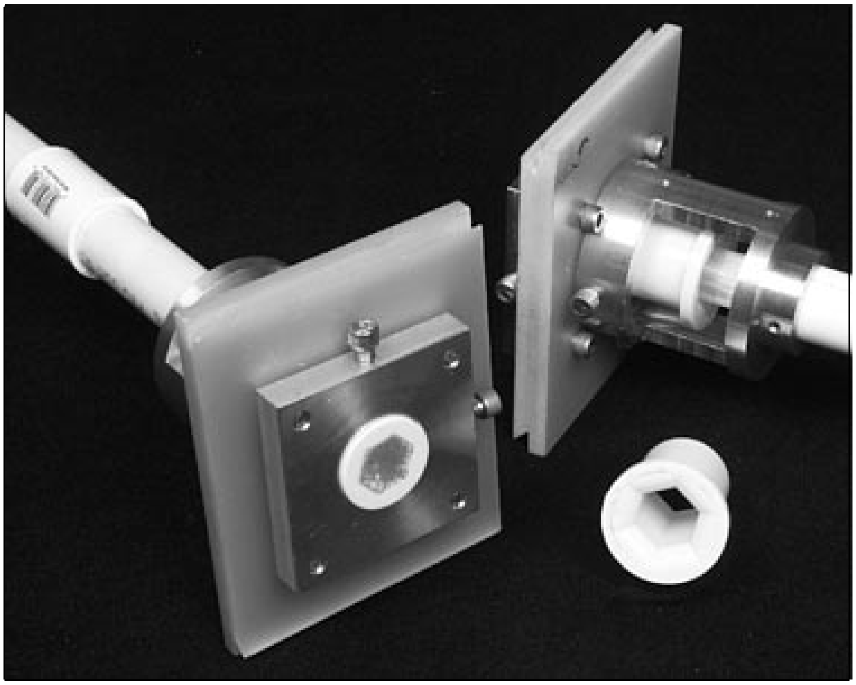

Figure 4: Detail front and side view of the end of the ice polishing fixture: fibers are packed into the urethane mold held in the G10/aluminum frame. A separate urethane mold is also shown (Photo by Visual Media Services, Fermilab).

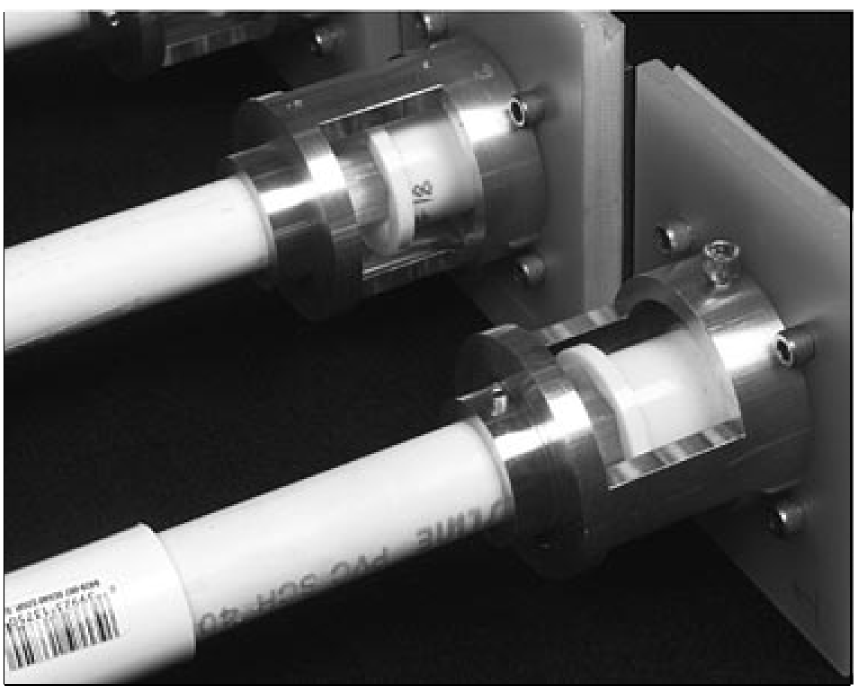

Figure 5: Side close up view of the end of 2 ice polishing assemblies. Fibers to be polished are supported along their length with PVC tubing and held on the polishing end by the the urethane mold in the G10/aluminum frame (Photo by Visual Media Services, Fermilab).

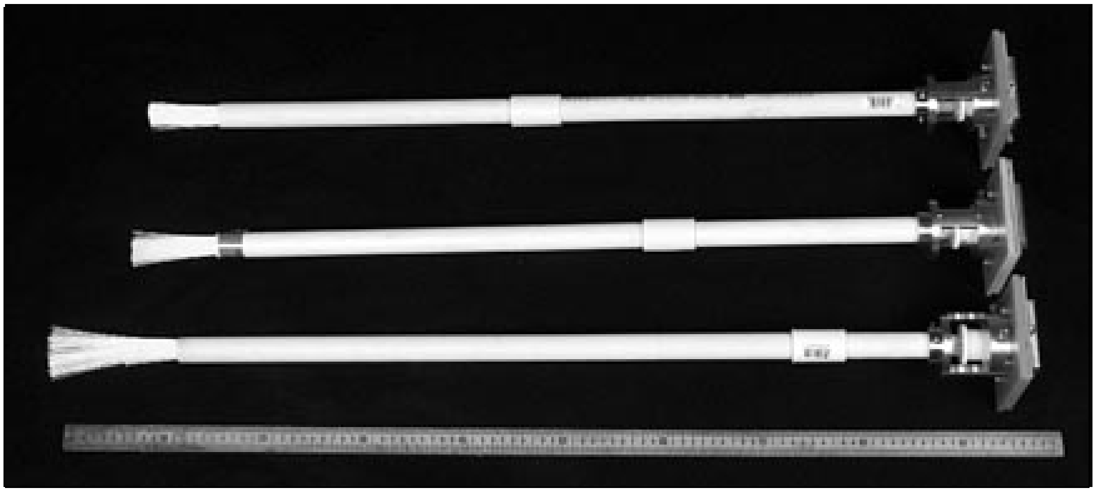

Figure 6: Full view of 3 ice polishing assemblies each consisting of fibers to be polished which are supported along their length with PVC tubing and held on the polishing end by the the urethane mold in the G10/aluminum frame (Photo by Visual Media Services, Fermilab).

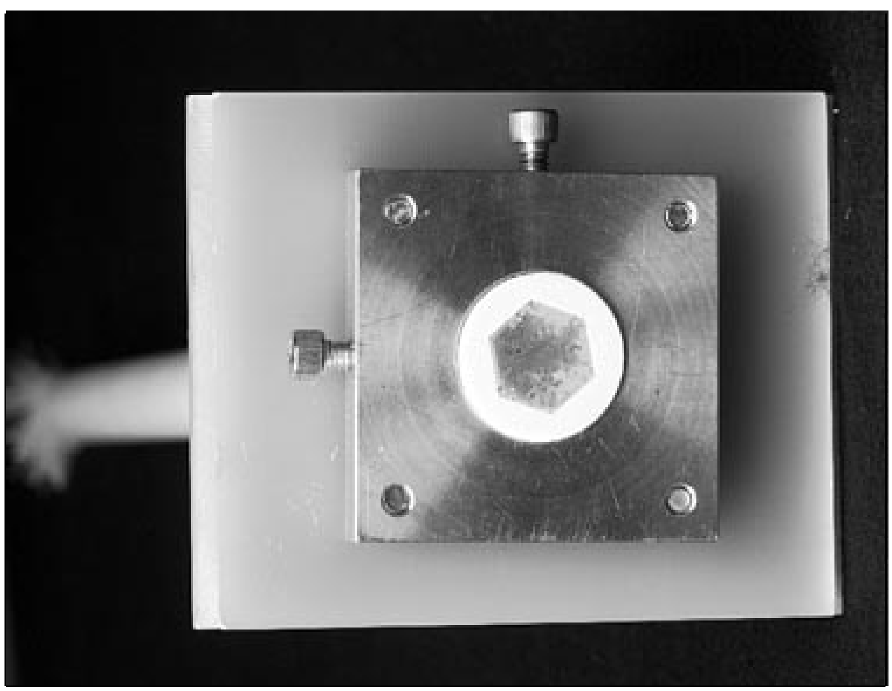

Figure 7: Front view of the ice polishing fixture, showing the hexagonal shape of the mold inner surface. The parallel flat surfaces of the hex are 3/4″ apart (Photo by Visual Media Services, Fermilab).

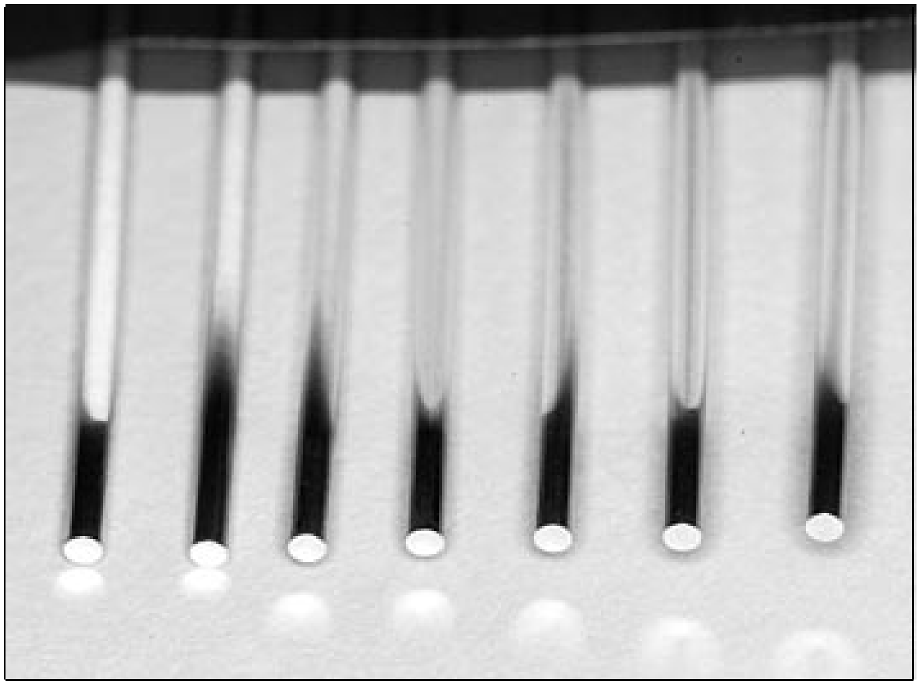

Figure 8: Close up view of ice polished and mirrored fiber tips (Photo by Visual Media Services, Fermilab).

5 New Polishing Machines !

In the time lag between the author's evaluation of polishing machines and the final date of this note, there has been considerable improvements in the design/availability of polishing machines. There is a new single fiber polishing machine available commercially from PM Manufacturing, two of which are currently operating in Lab 6 at Fermilab. This new machine requires no sleeves and polishes fibers in a single pass with a 2 to 3 second cycle time.

PM Manufacturing also offers a polishing machine like the P3 in Lab 7, which could be used for the ice polishing or connector polishing, for example. This machine operates in a fixed position and depth (like the P3) with a $5\frac{5}{8}''$ opening.

Further information about either of these machines may be obtained directly from the manufacturer. Additionally, we strongly encourage questions regarding this and the latest polishing technology to be directed to Carl Lindenmeyer or John Korienek of Fermilab.

6 Acknowledgements

There are a quite a few groups who are building or have built detectors which required the polishing of plastic fibers. The techniques and procedures documented here are a collection of those used and shared by many groups. We apologize if someone's original ideas or techniques have not been appropriately acknowledged and hope that gross errors and omissions will be brought to the attention of the authors.

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History of the development ice polishing technique was included in an earlier section. The authors again thank those individuals involved. In addition, we thank Reidar Hahn and Fermilab Visual Media Services for the digital photographs of the ice polishing fixtures.

A Appendix: Epoxying Fibers into Connectors

Supplies needed for this process are:

- Clamp assembly for holding connectors upright and DDK connectors: the ten hole piece and the spring assembly
- Bicron 600 24-hour optical epoxy, scale, calculator, mixing tool (ie tongue depressors), plastic cups, syringe for epoxy application with needle dispensing tip
- Fibers to be connectorized, some spare pieces of fiber, black tubing with a slightly larger fiber diameter and a new sharp razor blade or scissors

This is the procedure for epoxying fibers into connectors to be polished by a diamond polisher adapted for connector polishing.

1. Place a connector piece in a vice with the 10 holes pointing downward. Beware: dripping epoxy may drip onto the area below.
2. If the other end is finished, cut fibers to approximate length plus an inch or so. [1]
3. With a NEW SHARP razor blade, cut 1 to 3 inch lengths of black plastic sleeve, one for each transmitting fiber to be epoxied into the connector. Place a sleeve over each fiber end and slide it temporarily up the fiber at least 5 inches from the fiber end.
4. If the other ends of the fibers are already epoxied, slide the spring assembly over all fibers to be epoxied in the same order as they should ultimately be in the connector with the fins pointing DOWN.
5. Stick the fiber ends into the appropriate connector holes. Fibers should extend at least 1/2 inch below the connector bottom (an inch or so).
6. There are 10 holes in the DDK connectors. In the current scheme, only 6 of the 10 holes in the connector will be filled, leaving 4 empty slots. Signal fibers should occupy holes 2,3,5,6,8 and 9, leaving holes 1, 4, 7, and 10 for dummy fibers (one on each end and one between each pair).
7. Put dummy 3 inch length fibers into vacant connector holes (in the current scheme, only 6 of the 10 fiber holes in the connector will be filled leaving 4 empty slots. These dummy fibers prevent epoxy from flowing directly through the connector and dripping excessively out the bottom.
8. Mix Bicron epoxy according to manufacturer directions in a plastic cup. Mix thoroughly. Pour into a syringe and attach a dispensing tip. Fill the connector end with epoxy. If the epoxy is viscous, slight back and forth vertical movements of the fibers in the connector will deliver epoxy more uniformly down to the connector face. Epoxy should be pooled up at the connector open end (top).

[1] This process will remove a fiber length equal to what is hanging off the bottom (that inch or so).

9. Slide the black plastic sleeves down the transmitting fibers into the pool of epoxy on the connectors as far as they will go. These sleeves prevent cross talk within the connector and provide strain relief.
10. Apply more epoxy after 20 minutes if the level is reduced below the top of the connector.
11. Wait at least 24 hours for the epoxy to cure.
12. Remove connector from the vice.

References

[1] H.Lee Sawyer, *et al.*, "Technical Design Report for the Upgrade of the ICD for DØ Run II", DØ Internal Note 2686, June, 1997.

[2] Ewa Skup, expert technician. Private communication.

[3] Dmitri Denisov, DØ muon system. Private communication.

[4] Don Lincoln, physicist at large. Private communication.