Fermi National Accelerator Laboratory

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An Overview of Plastic Optical Fiber End Finishers at Fermilab

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AN OVERVIEW OF PLASTIC OPTICAL FIBER

END FINISHERS AT FERMILAB

1) INTRODUCTION

Several years ago the need for equipment to precisely finish the ends of plastic optical fibers was recognized. Many high energy physics experiments use thousands of these fibers which must be polished on one or both ends. A fast, easy-to-operate machine yielding repeatable finishes was needed. Three types of machines were designed and constructed that are in daily use at Fermilab, all finish the fiber ends by flycutting with a diamond tool. Although diamond flycutting of plastic is not new, the size and fragility of plastic optical fibers present several challenges.

2) PLASTIC OPTICAL FIBER AND THE REQUIREMENT

The plastic fibers commonly used for high energy physics experiments are mostly 1 mm or smaller in diameter, either scintillation fiber, waveshifter fiber, or clear fiber. There is a core usually made of polystyrene and one or two layers of thin cladding over the core. Single layer cladding is PMMA and the double layer cladding is a lamination of fluorinated polymer over an inner cladding of PMMA. This is the case at least for three major works going on at Fermilab, KTeV, D0, and CDF.

The cladding thickness is typically 3% each of the outer diameter. The configuration is about the same for commercial fibers with PMMA core and fluorinated polymer as the cladding.

The finish on the end of the fiber needs to be smooth and perpendicular to the fiber axis irrespective of whether the fibers are terminated individually or bundled in a connector, which is also made of plastic.

In the case of the CDF upgrade as a typical example, there are three different treatments of the ends of the fibers. One is the end of the waveshifter fiber embedded individually in plastic scintillator "tiles". The end needs to be mirrored by aluminum sputtering. This presents the most stringent requirements. If the surface is not smooth or not perpendicular to the fiber axis, or both, there will be a significant light loss.

The second is the splicing of two fibers, waveshifter fiber on one side and a clear fiber on other, by fusing the junction. The requirement is less stringent but it was evidenced as discussed in later chapters that a crude hand cutting by a sharp razor blade is not enough.

The ends of clear fibers are collected into a plastic connector. In order to have a good transmission, the surface of the end of the fibers each facing with the correspondent fiber on the other side of the connectors has to be smooth and perpendicular to the fiber axis.

Though the requirement for such application is far from true "optical" finish because of the limitation of practicality and a few percent level light loss is only one of the components of the light loss in the path, it is desirable to keep it to a minimum. Also the reproducibility has to be kept to a few percent level so that it is comparable to other sources of irregularity.

There have been many techniques tried to fulfill such a requirement and found to be not easy. As evidenced in the later discussion, the customary way of slicing the fibers with a sharp razor blade, cold or heated, either by hand operation or by using some mechanism, is far too crude to be applicable.

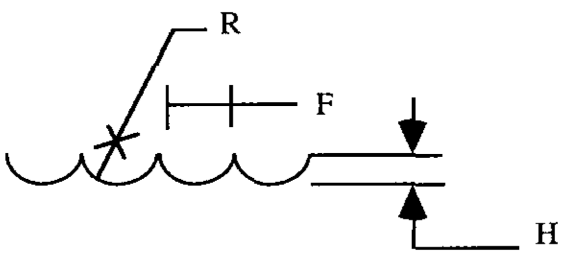
A laser beam was also tried to cut the fibers. Although the result was encouraging and there was much room to optimize, we stopped the investigation because it was felt that it is not easy nor economical to find an optimum type of laser nor to find optimum conditions.

The only practical way so far is to use a diamond flycutter for every case described above. It is a fast and simple operation, and quite reproducible. The finish satisfies our requirement well. After developing three types of machines, they have been heavily used for the three major operations at Fermilab in addition to small scale R&D works as mentioned above. The reproducibility has been monitored by visual inspection, by microscopes and also by other tests and it has been quite satisfactory.

3) DIAMOND MACHINE BASICS

The surface finish obtained by flycutting is a function of the radius of the tip of the diamond bit and the feed advance per cut. These parameters will determine the best finish obtainable. However, vibration caused by bearing irregularities and the lack of straightness in the feed motion all degrade the finish. The best finish will be obtained if the spindle and feed mechanism are supported by fluid bearings or typically air bearings so that the vibration is minimal and feed rate is controlled to be uniform. This ideal situation is often compromised due to the constraints on cost, size and finish quality required. Tool tip velocity can be high, limited by motor capabilities, balance, and centrifugal force considerations. An increase in RPM allows a corresponding increase in feed rate for a given surface finish contour. The theoretical finish is a series of shallow grooves. The contour is described by:

$$H = R\left[1 - \sqrt{1 - \frac{F^2}{4R^2}}\,\right] \quad \text{or} \quad H \approx \frac{F^2}{8R}$$



Where:

F = Feed per revolution.
R = cutter tip radius.
H = peak to valley distance of finish.

The diamond bit is a single crystal, natural or synthetic. The cutting edge is extremely sharp with no visible defects at a magnification of 300 minimum. On the machines to be described, two diamonds are mounted on a single cutter head wheel. A "pre-cutter" is mounted approximately 10 μm recessed and at a slightly different radius than the "finishing" cutter. This has the effect of making two cuts on the fiber with only one pass across the tool and also the finishing cutter removes a controlled amount of material so that the finish is more reproducible.

Three types of machines have been designed and constructed. The first two are for single fiber finishing and the third machine is to finish a connector surface in which some number of fibers are embedded.

4) PRODUCTION SINGLE FIBER FINISHER "F-4"

This machine has been designed for machining a large number of fibers and has been in daily use for a few years. It is self contained, needing only an air supply and electric power. The machine has a slowly rotating disc with 36 fiber slots/chucks which feeds fibers past a saw and a diamond flycutter and ejects the finished fibers. For work requiring an absolutely chip free cladding a sacrificial sleeve is used. (See Section 6.)

4.1 Work Holder

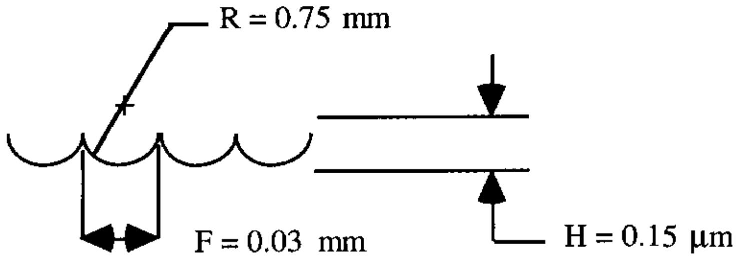
An air bearing supported disc driven by an anti-backlash worm gear slowly rotates 36 fiber chucks past the operators loading zone. In the loading area the fiber chucks gently hold the fiber to permit easy insertion. The fiber is inserted against a fixed stop which determines the amount of material to be removed. This allows rough cut chipped fibers to be machined. Following the loading area, the fiber chuck tightens to firmly hold the fiber during machining. After machining, the fiber chuck opens completely, allowing the finished fiber to drop out. The chucks then close as they enter the loading zone once again. The rate of rotation is variable. It is usually set to machine one fiber every 2 seconds for ease of operator fiber handling.

4.2 Saw

The fiber, tightly clamped on the work holder disc first encounters a small saw blade which trims approximately 1.5 mm off the end of the fiber to eliminate any chipped cladding and to present an exact amount of material to the diamond flycutter in the next operation. The saw blade is 3" diameter with 200 teeth. The teeth are beveled at 45° to minimize the force applied to the fiber on the work holder side. The blade cuts the fiber approximately 0.2 mm from the work hold disc face. Turning at 5,100 RPM, the saw produces 17,000 cuts per second.

4.3 Diamond Flycutter

The fiber is next presented to a diamond flycutter with two bits. The first bit removes 125 μm and the finishing bit removes an additional 25 μm. The final cut occurs 50 μm from the fiber chuck offering rigid support for the fiber. The high frequency, water cooled, air bearing spindle rotates at approximately 20,000 RPM yielding a tip speed of 5,235 ft per min. The tool bits have a radius of 0.75 mm yielding a theoretical finish of:



Both cutter velocity and feed are variable over a wide range, offering control over the peak to valley height.

5) SINGLE FIBER FINISHING "OPTIFINISHER"

A series of small non air bearing machines have been built to satisfy the need to cut a small quantity of fibers for testing, development work and detector construction. The machine requires a connection to a vacuum for chip collection and electric power. This machine is easily portable and is used on a bench top.

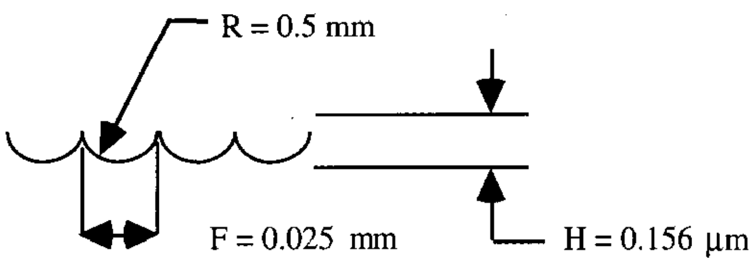
5.1 Fiber Holder

A variety of holders can be furnished to fit various fiber diameters. They can be interchanged in seconds. Two styles are made. A simple clamp for less critical work and for use with a sacrificial sleeve (see Section 6) and a foil type that surrounds the fiber to reduce chipping.

5.2 Cutting Cycle

The automatic cutting cycle is shown in Fig. 1. A full cycle requires approximately 4 seconds.

The diamond flycutter rotates at 15,000 RPM and the diamond has a tip radius of 0.6 mm. Note that the diamonds cut from inside the cutter to the outside. This provides adequate clearance for the cutting edge. The theoretical finish provided by the machine is:



5.3 This machine now commercially available from:

AVTECH DESIGN, INC.
625 Schneider Drive
South Elgin, IL 60177
Tele.: (708) 741-4121

6) SACRIFICIAL SLEEVES

Even with the final cut a few thousands of an inch away from the fiber holder, some chipping of the cladding occurs with some fibers. This has proven detrimental when thermally fusing as well as in some other applications. A solution to this problem was found in the use of a close fitting plastic sleeve that is cut with the fiber, supporting the cladding at the cutting line. Many plastic optical fibers have a cladding only .025 mm thick which is not firmly in contact with the core and is easily chipped. The first sleeves used were 2 mm diameter fiber drilled on axis to accept a smaller fiber. These sleeves are now extruded from polystyrene.

7) FUTURE PLANS

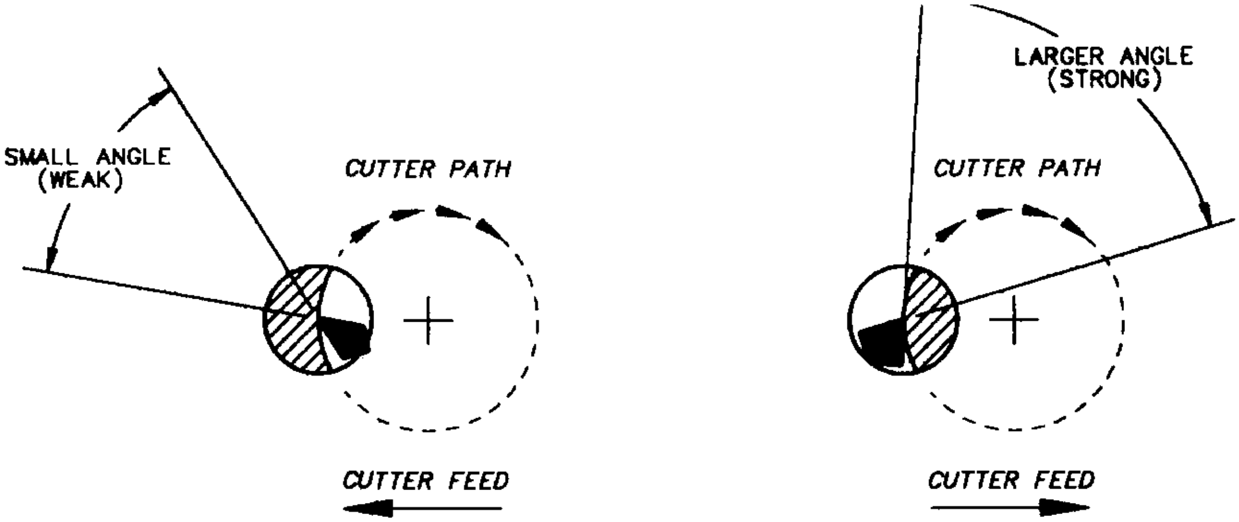
Several new machines are under study to further improve the efficiency and lower the cost of preparing fibers.

7.1 A re-designed single fiber finisher with a better motor and lower cost is under consideration.

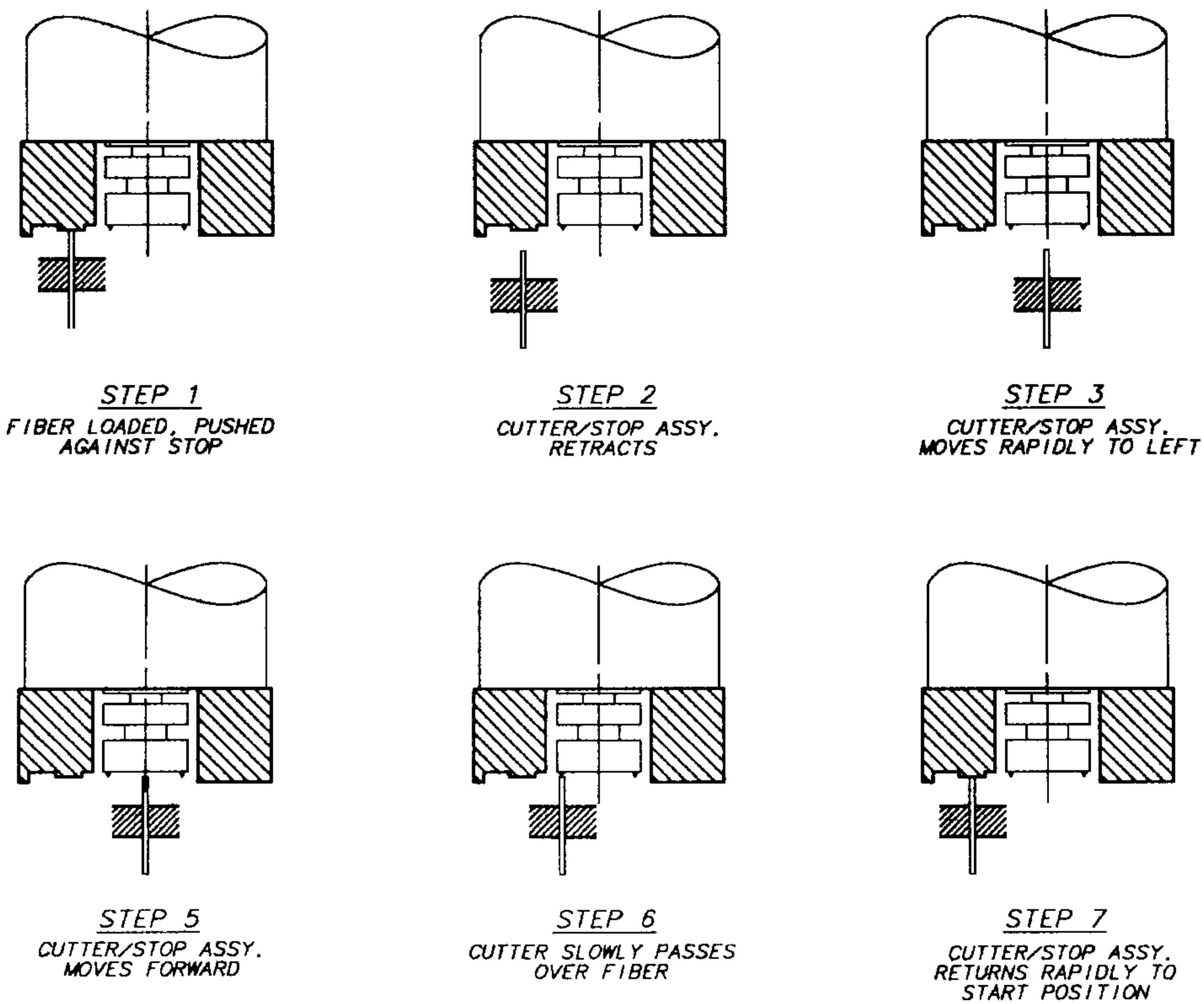
7.2 A "circumcision" device for preparing fiber ends for welding using orbiting blades cutting radially inward and sever the fiber without chipping the cladding. A prototype is under construction.

7.3 Improved tool tip geometry using an essentially flat tool face to minimize the peak to valley height of the finish. This scheme may succeed because of the very small size of a fiber relative to the flycutter diameter. The small scale of the cutter head precludes cutter adjustment but the spindle axis may be moved to provide a correction over a limited area.

7.4 A new machine for connector finishing is now under construction. The machine has an air bearing spindle and an air bearing slide. This machine is expected to produce a superior finish on parts larger than an individual fiber.



CUTTER GEOMETRY



CUTTING CYCLE

FIGURE 1