MECHANICAL FIBER POLISHING. What to look for in a machine; about fiber connector standards and acceptance criteria; about polishing techniques and guidelines

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Connectors play a key role in fiber optic communications. The finish of a polished connector's endface determines the quality of its lightwave transmission. Consequently, all polished connectors used for communications are required to comply with a strict set of standards and specifications. Some people in the field think the highest levels of performance have been reached, while others believe there is room for improvement. The labor force developed for this field is made up of technicians whose tools have evolved from manual devices into precision machinery. These machines, combined with an experienced work force, are creating the path for global communication.

Initially, connector polishing was a manual task performed by a single operator. After a few years of growth the traditional production assembly line was taking hold. Large-scale cable assembly manufacturers ("Jumper Houses") had dozens of people, each polishing one connector at a time (and, to this day, manual polishing continues to be play a role). Although manual polishing may be practical for some applications, it is very impractical for high volume polishing, or for efficient and repeatable meeting of tight specifications. The alternative, mechanical polishing, is a cost effective method, which produces large volumes of connectors whose levels of performance meet or exceed the industry standards. A machine that uses a specific polishing motion and is tested for conformance to the industry standards will produce quality polished connectors with high levels of consistency from batch to batch.

THE POLISHING MACHINE

When it is time to purchase a mechanical polishing machine there are a number of questions that should be asked:

- 1. Are the operating functions simple to use?
- 2. Does the unit offer easy connector interchangeability?
- 3. Are the polishing platens easy to access?
- 4. Is there a pressure-setting feature?
- 5. Does the polishing motion attack the connectors from all sides equally?
- 6. Can the machine perform angle polishes?
- 7. Does the manufacturer have the capability to supply custom fixturing if needed?
- 8. Are the end results meeting and/or exceeding current end-face standards?

A quality production polisher will answer "yes" to all of these questions.

In detail, a fiber-polishing machine will have:

- 1. **Timer--**a settable timer allows a pre-defined timed sequence of operations techniques to be used. Timing has proven to be critical in obtaining connector performance specifications. A timer should have time settings ranging from 0 to 60 seconds.
- 2. **Pressure setting device--**a polishing machine must have adjustable pressure loading capability. Pressure combined with the hardness of the polishing surface will allow the machine to produce the connectors' required end-face geometry. This device should have a setting tool that has clearly marked divisions of measurement.

- **3.** Inter-changeability of connector holders--connector holders that can be removed quickly and easily offer increased output, less downtime and improved production. A machine that offers connector holders for all connector types adds flexibility to production.
- 4. Availability of connector holders--In evaluating the equipment, it is important to consider the available connector holders. It is important that the manufacturer has available holders for the standard connectors used around the world--SC, FC, ST--for both PC and APC configurations.

Also, the manufacturer should have the capability to provide a range of connector holders beyond the "standards" used--versatility in this area will minimize lost opportunities and maximize the ability to meet potential customer requests.

- 5. **Removable Polishing Platens--**polishing platens carry the polishing films that act upon the connector end-face. These should be easily removed and replaced. This minimizes contamination, increases connector output and maximizes polishing film life.
- 6. Polishing Motion--A key element of a high quality polishing system is the motion of the surface that performs the polishing. If the polishing action is not balanced evenly from all sides, connector performance will suffer and costs will increase because of rejected material and excessively rapid wear of the polishing films. To obtain consistent high quality results, the machine must provide an orbital polishing motion--a circular oscillation.



7. Can the Machine perform Angle Polishes--Though new polishing techniques, such as MPC (Maximum Physical Contact), allow PC finished connectors to achieve APC (Angled Physical Contact) results, the need to perform angle polishing is a must. Angle polishing (typically polished to 8°) is necessary when Backrelection readings of <-65dB are demanded.

> A polisher should offer the option to polish connectors Flat, with a PC finish, or an APC finish. Different machines should not be purchased for different types of polishes. A quality polisher will have the capability to perform all types of polishing.



8. A 'Recipe' for meeting the standards--Standards for today's connectors are stringent. It is important that the machine manufacturer provides, along with a good, preferably illustrated operation manual, specific polishing "recipes" for obtaining the connector specifications (described in the section below)--and, that you have open lines of communication with the manufacturer to keep you up to date in this developing technology.

POLISHED-END ACCEPTANCE CRITERIA FOR FIBER OPTIC CONNECTORS

Within the communications field, high standards are needed for Telephone transmission and even higher standards for CATV transmission--with the apparent movement to the higher standards being influenced by the logic of using telephone lines for CATV. Singlemode connectors are used to assure optimal results--and these optimal results are a function of the quality of the polished connector end-face surfaces--Specifically, these are the measurable performance characteristics that are controlled in connector polishing. The characteristics that a polishing machine must provide are:

- 1. Backreflection
- 2. Insertion Loss
- 3. Apex Offset
- 4. Radius of Curvature
- 5. Fiber Undercut/Protrusion
- 6. Connector End-face Inspection

1. BACKREFLECTION

Backreflection is light reflected back through the fiber toward the source, which transmits the lightwave. The light reflection occurs at the contact point of two connectors when they are mated. A high level of Backreflection will cause transmission problems for systems that depend on the speed and clarity of a fiber system, since the desired high data rates can encounter bit errors if the signal is distorted. The current industry Backreflection standard is <-55dB.



Connectors are commonly referred to as PC, SPC, UPC and APC. These are terms, which describe connector end-faces and also relate to the Backreflection designation:

- PC (Physical Contact) A description of the contacting spherical end-face Backreflection Value = -35db
- SPC (Super Physical Contact) A description of the contacting spherical end-face Backreflection Value = -45db

- UPC (Ultra Physical Contact) A description of the contacting spherical end-face Backreflection Value = <-55db
- APC (Angled Physical Contact) A description of the contacting angled spherical end-face. The angle of choice is 8°. This angle deflects Backreflection to <-65db.

A manufacturer of polished cables may see any of these values specified--including the common "in-betweener" of <-50db, but the growing requirement is UPC (<-55db), something heavily influenced by the needs of CATV transmission.

2. INSERTION LOSS

Insertion loss is the amount of optical power lost at the interface of two connectors. Poor insertion loss readings are generally a result of fiber misalignment, separation between connections (also referred to as 'air-gap') and/or the quality of the finish on the end of the connector.



Insertion loss is a function of the polishing equipment and the technique used to perform the polishing. A machine that produces poor end-face geometry will almost always generate unacceptable levels of loss. The currently stated standard for insertion loss is <0.5db, but the commonly expected level, has become <0.3db. In addition to the above performance characteristics, there is a specified product geometry--specified to assure reliability and ongoing proper connector performance under adverse conditions such as vibration and temperature cycling. These characteristics depend on the high level of control that a mechanical polisher provides.

3. APEX OFFSET

The term Apex defines the highest point on the spherical surface at the end-face of the connector. Apex Offset is the measured distance between the center of the fiber and the actual high point of a polished connector.

Although Apex Offset describes a physical condition of the polished fiber, rather than a performance parameter, it is considered an acceptance criterion in itself. An excessive Apex Offset contributes to high Insertion Loss and high Backreflection readings.



4. RADIUS OF CURVATURE

Radius of curvature is the measurement of a connector's end-face spherical condition. The radius generated on a connector end-face affects connector performance, and so is specified--the radius must be such that when mated with another connector most of the compression that occurs is applied to the material that surrounds the fiber (also referred to as ferrule absorption). In general, the ferrules used are pre-radiused. The radius is maintained during polishing by applying pressure between the connector and a resilient polishing surface, by application of a weight or by setting compression dimensionally (it is increasingly rare, but the forming of a flat

ended ferrule into a PC end is still done through the same basic technique of applying pressure against a resilient surface). The harder the resilient polishing surface the larger will be the resultant connector radius (more flat). Conversely, the softer the polishing surface the smaller the connector radius. A proper radius, in conjunction with fiber under-cut, allows for correct fiber-to-connector compression. The industry specification for radius of curvature is 10-25mm. This range allows for maximum connector performance.



5. FIBER UNDERCUT/PROTRUSION

When a fiber is recessed inside a connector ferrule the term used is "Fiber Undercut." When a fiber protrudes above the ferrule it is called "Fiber Protrusion." Measurement of this characteristic is accomplished by using an interferometer. An Interferometer displays the offset of the interference lines that pass over the fiber.

Most polishing sequences begin with aggressive materials, silicon carbide to remove epoxy and diamond lapping films for the beginning and intermediate polishing, that remove both the ferrule and fiber at the same rate. During the last polishing step, however, a less aggressive material, usually silicon dioxide, is used because it attacks only the fiber. If an aggressive film is used for the final polishing step excessive under-cut will result.

Excessive Fiber Undercut is usually specified as more than 50nm. Fiber Undercut is a condition that affects both Backreflection and Insertion Loss. When connectors are mated, the ferrule material surrounding the fiber compresses, which optimally allows fibers with an acceptable undercut/protrusion to make contact. Fibers that do not make intimate contact have an air-gap. An air-gap will produce unacceptable Backreflection & Insertion Loss measurements.



Fiber Protrusion also has a limit--50nm of protrusion being acceptable--Both Undercut and Protrusion, are a result of the polishing process. If excessive protrusion is present, fiber chipping and/or cracking may take place during the connector mating process.

6. CONNECTOR INSPECTION

For measurement of the performance criteria, Backreflection and Insertion Loss, there are meters available which are generally familiar to polishers. The geometrical criteria, Apex Offset, Radius of Curvature, and Fiber Undercut are confirmed by using an Interferometer.

Visual inspection will always play an important role in evaluating the polished surface (see diagram below), but the now increasingly used interferometer is needed to confirm geometry. Interferometers are available from a number of sources, ranging from those which provide a monitor from which the user determines product acceptability, to computer aided programs that provide a printed readout which includes all performance and geometric characteristics of the connector.



POLISHING TECHNIQUES

Critical to proper polishing is the applied process--the technique--that results in meeting the various specifications.

Early connectors were all produced with flat end-faces, which were specified to be close (the linear tolerance on the SMA, for example, being 8 microns), but too specifically avoid actual contact. As Polishing evolved the PC (Physical Contact) concept was developed--spherical end-faces, with the fibers making actual physical contact--The PC finish resulted in much improved performance because air-gap was eliminated which allowed increased lightwave transmission.

The early PC connectors, preceding development of the now common pre-radiused ferrules, required spherical forming of their flat end-faces as part of the polishing process. These traditional polishing techniques, for singlemode PC connectors, involved a four-step process: epoxy removal, ferrule forming, preliminary polish and a final polish. These steps used aggressive materials for the epoxy removal and ferrule forming steps, generally accomplished by using a diamond polishing film. Now, however, almost all connectors are "pre-radiused", and the polishing process should avoid excessive disruption of the spherical surface--the sort of thing a mechanized process can do well (and a manual process poorly). As a result reducing the cycle time and changing the film gradations to adapt to the current connector configurations has revitalized the traditional polishing techniques. Now, the traditional four-step process is much improved (epoxy removal, beginning polish, intermediate polish and final polish).

tep	Description	Film Type	Timer Setting	Lubrication
1	Epoxy Removal	15µm Silicon Carbide	10 Seconds	Dry
2	Beginning Polish	5µm Diamond	30 Seconds	D/I Water
3	Intermediate Polish	1μm Diamond	60 Seconds	D/I Water
4	Final Polish	ULTRAFILM 5	10 Seconds	D/I Water

The following is a list of polishing techniques for singlemode & multimode polishing.

MPC TECHNIQUE (new three step polishing technique for singlemode connectors)

Step	Description	Film Type	Timer Setting	Lubrication
1	Epoxy Removal	3um Silicon Carbide	5 Seconds	Dry
2	Intermediate Polish	1um Diamond	45 Seconds	D/I Water
3	Final Polish	ULTRAFILM 5	10 Seconds	D/I Water

	Description	Film Type	Timer Setting	Lubrication
	Epoxy Removal	5μm Silicon Carbide	5 Seconds	Dry
2	Final Polish	1 μm Diamond	60 Seconds	D/I Water

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ADDITIONAL POLISHING TECHNIQUE COMMENTS

More recent polishing techniques indicate that the aggressive epoxy removal and ferrule forming steps that were previously popular should be minimized during the polishing process, increasing reliance on the pre-formed radius. This can be accomplished by using finer grades of silicon carbide for the epoxy removal and by replacing or even eliminating the ferrule-forming step. The most current techniques use a three-step process; epoxy removal, ferrule polishing and fiber polishing. This technique offers higher levels of output while maintaining current performance standards, and results in lower cost per connector.

Machine polishing is the only practical means available to meet the demands for increased performance and production. To the extent that manual polishing can be effective, it demands performance by highly skilled personnel (for a repetitive and monotonous task), and, as the specifications become more difficult--SPC, UPC, APC--manual polishing becomes an unreasonable (if not impossible) task. As in other "high tech" fields, the ability of machines to perform repeatable ultra-precision tasks is the answer.

As described above, a Polishing Machine should have good instructions and a "recipe" for producing polished connectors that meet all specifications. There are a number of variables, however, which affect the process, about which the industry continues to learn and develop. It is important that the machine selected has the capability to incorporate new developments and that the manufacturer keeps you informed and is available for support and advice.

POLISHING TIPS & PROCESS CONSIDERATIONS

In some cases, the machine user will become aware of some factors that involve variables other than the polisher itself. The following are a few items that are commonly overlooked.

- 1. Polishing Films
- 2. Epoxy
- 3. Cleanliness
- 4. Lubrication
- 1. **Polishing Films--**Films are the most significant factor in your polishing operations. Quality and gradations vary from supplier to supplier. When a polishing technique is developed the film type, make and particle size must be chosen carefully. Excessively aggressive films can destroy a 125µm fiber, and the spherical radius can be disrupted beyond repair. Also, of critical importance to real cost, is the initial cost of the polishing film as it relates to the cycle life that the films provide--this can vary significantly from various manufacturers.

Tip--Clean each piece of polishing film before and after each use. Cleanliness (discussed below) will increase the film life and decrease the cost per connector.

2. **Epoxy--**different types of epoxies can be removed more easily with specific grades of silicon carbide polishing films. The films to use on this step depend on the epoxy type and the size of the epoxy bead mounted on the connector end-face. Different epoxies have varying levels of hardness--some are tacky, and some are firm--Hard epoxies are removed easily with coarser particle sized films (20 um, 30 um, etc.), while softer epoxies are better suited to smaller particle sized films, i.e. 9 um, 5 um, etc.

Tip--The epoxy bead that remains on the connector before polishing should be minimized (the size of a pinhead). This will extend the life of all the polishing films. Also, try different gradations of silicon carbide until you find the epoxy removal film that works best for your needs.

- **3. Cleanliness**--A contamination free environment is essential when an optimum connector polish is desired. Five items are needed to minimize contamination:
 - 1. Deionized/Filtered Water
 - 2. Isopropyl Alcohol
 - 3. Lint Free Tissues
 - 4. Lint Free Swabs
 - 5. Canned Air

Deionized/Filtered Water--Clean water is needed to prevent foreign particles from destroying the polish. Tap water and other water sources, contain particles (dirt) that can be as large as 15 microns. Debris of this size will destroy a polished connector. Deionized or Filtered Water will eliminate this possibility.

Isopropyl Alcohol--The alcohol should be used to clean the polishing films, connectors, and the surrounding area (inside the automatic polisher) before and after each polishing step. This will virtually eliminate any particles or debris from transferring to the next polishing step.

Lint-free Tissues--The tissues will be used to apply the alcohol to the films, connectors and machine. The tissues will also be used to dry the connector end-face before the testing and inspection stage of the polishing process.

Lint-free Swabs--Always clean the reference meters and couplers will the swabs soaked in alcohol. Measuring instruments and coupling devices are the most overlooked pieces of equipment when creating a contamination free environment. Test equipment cleaning should become a habit. Repeated use of these instruments will result in debris build-up. If maintained properly, correct results can be assured with confidence, not to mention trouble shooting poor performance will be minimized.

Canned Air--This is very useful for removing debris from connector couplers. It can also be used as a general cleaning agent to remove dust from connectors, films or the workstation.

Tip--Check the reference cable end-face periodically for end-face defects. Connecting and de-connecting will result in debris build-up over a period of time. Clean the end-face with alcohol using a lint free tissue. Also, at some point in time the reference will need to be repolished. After repeated re-polishing the reference cable will need to be replaced.

4. Lubrication--deionized water, filtered water and suspensions, when used correctly can result in enhanced connector performance. The best solutions have very small particle sizes 20-60nm. The solution particle size should be at least half the size of the final polishing film. Solutions are used to decrease Return Loss by as much as 5dB. Be careful of colloidal based solutions. They tend to dry quickly and can destroy a polish if it is not removed from the connector end-face quickly. Also, place the solution is a dry area at room temperature. Guard solutions from cold temperatures. Many solutions loose their ability to improve performance as they become more solid (dense).

Tip--Dilute the solution. Any range of 2 to 5 parts filtered/deionized water to one part solution may improve your performance.

CONCLUSION

Mechanical polishing machines provide fiber cable manufacturers and original equipment manufacturers with an economical means of meeting high production requirements while maintaining the high quality levels that are demanded. While using polishing machines has become a necessity, it is important to use judgment in machine selection. It is reasonable that manufacturers be asked for objective evidence to back up performance claims (the existence of automatic test equipment that provides a printed copy of test results makes this possible), to provide references, and samples of your components for your own inspection. Don't overlook the fact that this is still a dynamic and growing field. Connectors will change and processing techniques will improve. It is important to have equipment that can readily adapt to changes of connector configuration and polishing technique. And it is equally important that the equipment manufacturer be aware and involved in these developments, and communicates effectively with users of their equipment. High performance and economical manufacture represent a challenge to all of us in the industry, and it seems apparent that the challenge is being met effectively. It is an indication of a bright future for fiber optics communications, a future in which a company that is properly prepared can prosper.

REFERENCES

- 1. "New Techniques for Cutting & Polishing Optical Components," by J. Rubin & T. Hazeldine: *ULTRATEC Web-site.*, Surface Technology, 1998.
- 2. "Measurement of Terminated Singlemode Optical Fibres," by John M. Tait Msc: Electro Optics, December 1997
- 3. Jeff Hecht: Understanding Fiber Optics, Sams Publishing Indianapolis, IN 1995, 2nd Ed. 243-267
- 4. Interview with Richard O'Lear, Fibertron Inc., Artesia, CA, July 1998
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