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Application Note

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The Importance of Proper Cleaving for Fiber Optic Connectors

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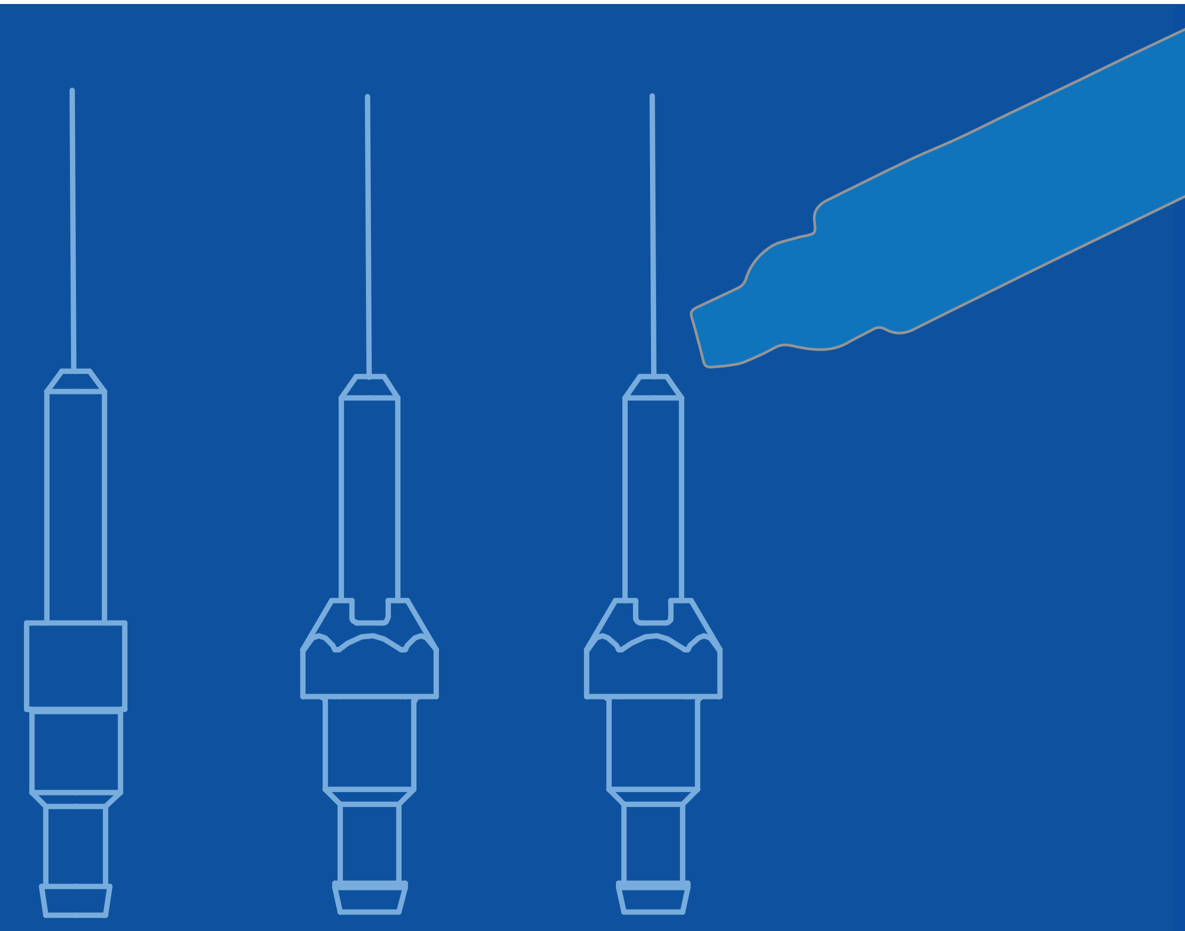

1.0 Introduction

Cleaving is part of the fiber optic connector termination process that follows the epoxy heat cure of the connector (or ferrules) and precedes the polishing process. After injecting the epoxy and inserting the fiber into the connector's ferrule, the epoxy will permanently cure with approximately 5 - 10 mm of fiber protruding out of the epoxy bead that has formed on the ferrule's surface. This surface is commonly referred to as the end-face. Since the exposed fiber is not encapsulated by the epoxy, it is prone to uncontrolled breakage that can propagate down below the ferrule end-face. When mating ferrules, the applied force between fibers can reach 45,000 psi. Thus, it is imperative that fibers are cleaved and polished flush with the ceramic ferrule end-face to ensure proper physical contact, without damaging the polished interfaces.

Cleaving is a controlled cut of the optical fiber that protrudes through the epoxy bead on the ferrule end-face. The process begins by scoring or scratching the side of the fiber with a sharp blade made of diamond, tungsten carbide, or sapphire. Tensile force is then applied to the fiber with the operators' fingers, which induces a controlled break that propagates rapidly from the fracture point across the entire fiber cross section. Executed properly, cleaving will yield a relatively flat surface perpendicular to the length of the fiber and only a miniscule protrusion of glass remaining.

Fibers are cleaved and end-faces are air polished to equalize epoxy beads that are uniform in size and consistency. These steps are necessary to produce connectors with satisfactory visual and geometrical end-face parameters.

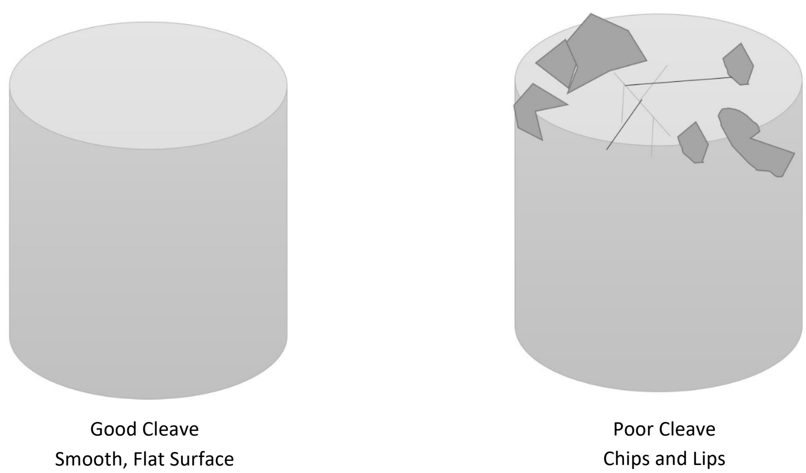

Figure 1: Example of a good cleave (left) vs a poor cleave (right)

2.0 Overview

Tools for fiber cleaving are typically called fiber cleavers or scribes. There are a variety of cleaving hand tool designs available, but they all rely on the same basic principles to cleanly cut fibers just above the epoxy bead. Simple and inexpensive cleavers typically look like pen-shaped scribes (Figure 2) and are sufficient for achieving the desired result with proper training. These are typically equipped with sapphire or tungsten carbide blades. Tungsten is used because it is one of the strongest materials with an 8.5 to 9 rating on the hardness scale. For comparison, the hardness rating for titanium is only 6.

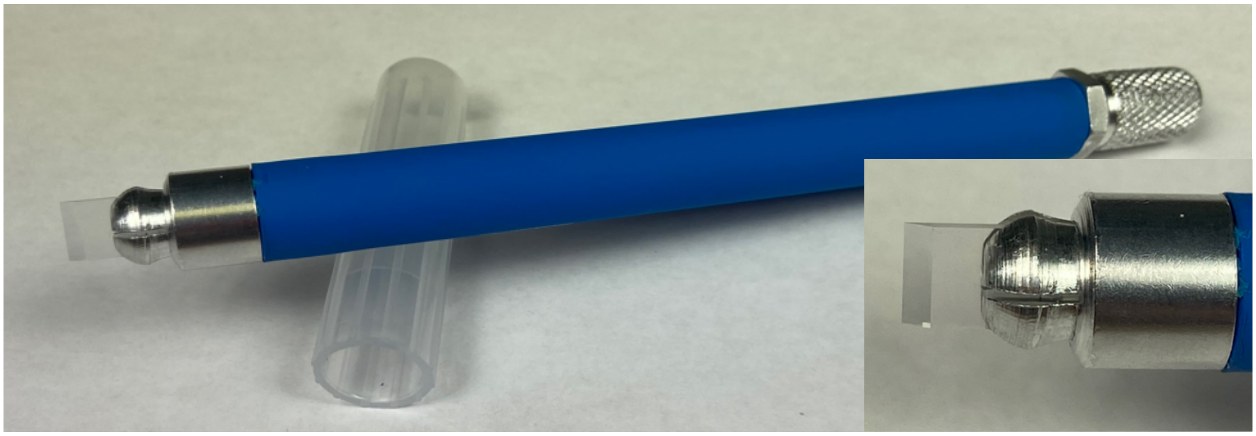

Figure 2: Manual fiber optic cleaving tool, SENKO PN AFT-T-CT

Manual cleaving (or scribing) relies on a trained operator scoring the fiber with a scribe and then breaking the fiber away from the ferrule with tension. SENKO's recommendation for a manual cleave is the following process, which can also be found in relevant SENKO Engineering Termination Procedures (ETPs):

After epoxy curing, the end-face needs to be cleaved and air polished. Cleaving and polishing are necessary to satisfy the required specifications for optical connectors. Incorrectly following these steps may cause a yield problem and/or contribute to problems further along in the termination process. When cleaving is done improperly and the fiber breaks, the resulting crack often causes the terminated assembly to fail. After cleaving, a manual air polish process is recommended to trim the fiber stub down to the epoxy level – this helps avoid fiber cracking during the epoxy removal step on the polisher.

Caution: Please handle the exposed fiber carefully to avoid breakage.

1. *After the ferrules have cooled to room temperature, remove the excess fiber protruding from the tip using a suitable cleaving tool (recommendation: SENKO P/N AFT-T-CT).*
2. *Hold the ferrule with the fiber pointing upwards.*
3. *Set the blade of the cleaving tool against the fiber just above the epoxy bead on the surface of the ferrule.*

4. *Gently run the full length of the blade along one side of the fiber. Be careful not to break the fiber with the cleaving tool.*
5. *Lift the fiber up with your fingertips.*
6. *Properly dispose of the cleaved fiber into a scrap bin.*
7. *When all the fiber has been removed, check the sides of the ferrule for excess epoxy that may have cured. Use a scalpel or Stanley blade to remove any excess.*

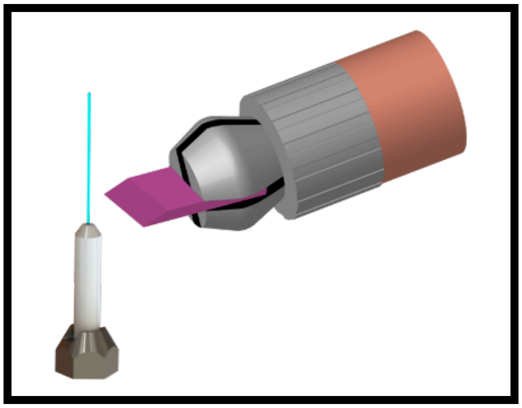

Figure 2: *Scribing*

The manual aspect of fiber cleaving exposes the process to human variability and error. The best way to eliminate this is to use automated cleavers (please contact your SENKO Account Representative for more details). Automated cleavers are marketed as long-term cost-saving solutions, with benefits that include:

- Consistency and precision, with a significant reduction in process variation stemming from fiber damage
- Critical time savings for the overall manufacturing process
- Uniform starting point requiring less polishing time/consumables
- Consistent epoxy removal
- Improved geometry
- Improved safety by minimizing the handling of scrap fiber

There are two main variations of automated cleavers, laser-based and mechanical. Both are capable of cutting the fiber through the epoxy bead, thus cleaving closer to the ferrule surface and reducing the amount of epoxy that needs to be removed during the polishing process. In a CO_2 laser-based cutting system, a CO_2 laser (typically 9.3 – 10.6 μm) cleaves fibers at specified angles. The mechanism by which the cut is performed is absorptive, with strong thermal heating. The laser beam emitted by the automated cleaver is reflected by metal mirrors before being focused on the target area. Average laser power is below 50 watts with high output stability (< 5%). The less expensive automated alternative, the mechanical cleaver, uses two controlled precision tungsten carbide blades to cut the fiber from both sides.

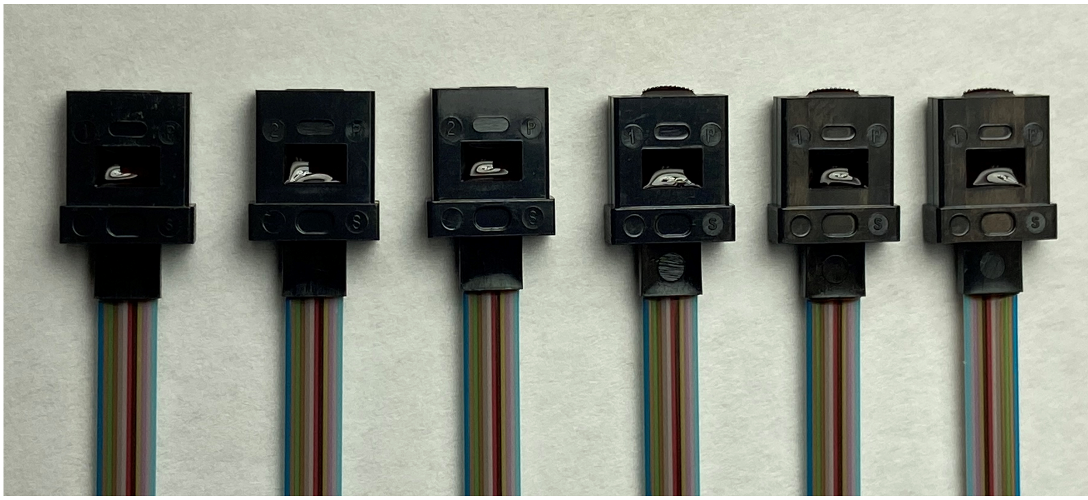

Figure 3: Mechanical blade cleave (left) vs manual cleave (right)

3.0 Manual vs. Automated Cleaving

Automated cleaving has a much higher upfront tooling cost, which is justified when production volumes are consistently high based on Return on Investment (ROI) calculations. The investment for an automated cleaving system is significant, but the financial calculations need to consider the increased processing speed and overall improvements in quality. An automated cleave can save up to 30 seconds per connector versus the manual alternative. Unlike the automated process, the ferrule is not ready for fiber polishing after manual scribing. The manual cleave removes protruding fibers from the tip of the epoxy bead, resulting in a stub that requires removal with additional air polishing (refer to SENKO Application Note "Polishing Fiber Optic Connectors with Ceramic Ferrules" for more information on air polishing and the polishing process). In short, additional manufacturing time is required to manually remove the fiber stub before the epoxy can be polished off using an automated polishing machine. Therefore, automated cleaving leads to increased performance and production yields.

The latest generation of automated single fiber cleavers use a bi-directional laser beam, which allows for ultra-low profile cleaves at 30 – 35 µm above the ferrule tip, reshaping the fiber and removing most of the epoxy. Equipment manufacturers claim that cleaved ceramic connectors (from single fiber pre-domed connectors) can be forwarded straight to a 1 µm diamond polishing step when using a high quality polisher. This reduces the polishing process from 4 - 5 steps, down to just 2. However, from SENKO trials and experiments, this statement was found to be mostly true for multimode connectors because the final end-face allows for more imperfections when compared to a single-mode finish; per IEC document 61300-3-35 "Visual Inspection of Fiber Optic Connectors". The requirements for IEC 61300-3-35 are very detailed, with specific acceptance criteria for single-mode and multimode connectors in both single fiber (i.e. LC, SC, FC, etc.) and multi-fiber (i.e. MPO) connectors. The criteria are based on several factors, including size, count, and location of the defects/scratches.

Automated cleavers are particularly advantageous when cleaving mechanical transfer (MT) ferrules by achieving a uniform fiber height across all fibers (Figure 4). After the epoxy has cured in an MT ferrule, the protruding fibers at the edges (typically fibers 1 - 2 and 11 - 12) are encapsulated by less epoxy and are thus considered unsupported at the sides. These fibers are prone to uncontrolled breakage if mishandled. A typical manual operation entails a curved scribing just above the epoxy bead. A careful, manual, and time consuming cleave followed by a flattening of the curve of individual fibers. This is all required before polishing to avoid fiber breakage below the ferrule surface. In contrast, the laser from an automated cleaver cuts wider and results in a flat surface with a more uniform fiber protrusion. Alternatively, automated mechanical cleavers are equipped with precision adapters to ensure accurate and reproducible positioning of the ferrules during cleaving, resulting in very consistent fiber heights. The lack of fiber nubs and a flat planar surface reduces the potential for fiber breakage and its accompanying rework.

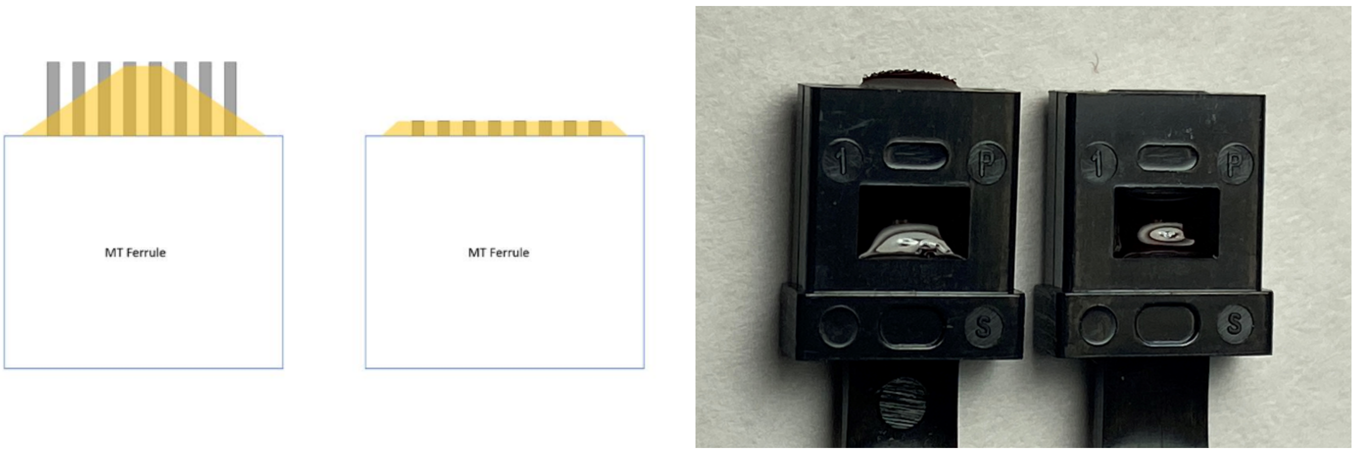

Figure 4: *Automated cleaves (flat) provide a consistent final fiber cut height in MT ferrules. Compared is the manual alternative (concave).*

Table 1. Comparison between manual and automated (mechanical and laser-based) cleavers.

Main Points	Cleaver Type		
	Manual	Mechanical	Laser
Operation	Operator dependent	Automated	Automated
Equipment Cost	$	$$	$$$$$
High Volume Production Cost	$$$$	$$	$$
Ease of Use	Skilled labor/training required	Single button operation	Requires software knowledge
Maintenance	None	Minimal	Extensive
Precision	Low	High	High
Consumables	Requires air polish	Optional	Optional
Portability	Pocket size	Small box	Large station
Reproducibility	Low	High	High
Life Span (# of cleaves)	Up to 1000	~ 750000	~ 1000000
Software	None	None	Yes
Set Up Time	None	Short	Long
Safety	Requires careful manual shards disposal	Shards collected automatically in a bin	Shards vacuumed automatically into the disposal compartment

Table Summary:

Operation
Manual cleaving relies on a trained operator scoring the fiber with a scribe and then breaking the fiber away from the ferrule in hopes of achieving the proper scribe/break combination. Automated cleaving is very consistent and precise from ferrule to ferrule, with no human variable present to affect the scribe/break combination.

Equipment Cost
Manual Scribe $15 - $50; Automated Mechanical Cleaver $10K - $15K; Automated Laser Cleaver $40K - $70K.

High Volume Production Cost
Manual cleaving leaves fiber stubs protruding over variously sized epoxy beads. It is imperative to manually air polish the individual ferrules to bring the epoxy beads to the same level before using a mass polisher. Both automated cleaving solutions cleave fibers in a highly reproducible manner with a very low profile cut. After automated cleaving, the fibers remain sufficiently protected for the initial polishing stage, making an additional air polish optional, or even unnecessary.

Ease of Use
Manual cleaving requires training and experience. Mechanical cleavers are the easiest to use with a simple setup and single button operation. Laser cleavers often require an operator that is proficient in the software for proper operation.

Maintenance
Manual cleaving requires an operator's judgment to determine whether a blade is dull and needs a replacement. Disposable cleavers are discarded. Some cleavers come with replaceable blades that are changed in a manner similar to that of a utility knife. Mechanical cleavers require less frequent blade changes and cleaning as the blades are large in size. Laser cleavers require more extensive maintenance, as depicted in the following maintenance schedule (Table 2).

Table 2. Example of a maintenance schedule for an automated laser cleaver.

Description	Frequency	Operator Task	Replacement Frequency
Adapter and hard stop	Daily	Clean	As necessary
Vacuum drawer	Daily	Empty	
Vacuum filter	Weekly	Clean	As necessary
Lens	Weekly	Clean	
Annual Service	Yearly	Check	Request manufacturer to perform

Precision and Reproducibility
Manual cleaving relies on manual labor, resulting in poor consistency. Automated versions cleave in a highly reproducible manner. When the ferrules are subsequently mounted on a polishing fixture, all automatically cleaved epoxy beads will protrude by the same amount, leading to a much more consistent polish.

Consumables
After manual cleaving, additional polishing material is required to air polish inconsistent fiber ends and epoxy beads.

Portability
The Manual Cleaver is the size of a pocket-sized pen. The Mechanical Cleaver is half the size of a shoe box. The Laser Cleaver is a small operating unit the size of a work bench that should be placed in a fixed location. It is considered to be an advantage of mechanical cleavers that they are portable, sometimes battery operated, and easily carried from station to station. In contrast, a laser cleaver is typically quite large and requires a new setup when transporting.

Life Span
Manual cleavers typically last for up to 1000 cleaves, while automated units are rated for up to a million cleaves.

Software

Laser cleavers are driven by software that requires knowledge/training and could have upgrades, glitches, etc. Mechanical cleavers typically only have two buttons for power and blade operation.

Set Up Time

Laser cleavers typically require engineering support to set up and calibrate between fixture changes, but are easy to operate via a pedal or a button once installed. Mechanical cleavers have their cut length limited by their blade size, while lasers can cleave across wider surfaces. However, mechanical cleavers can easily accommodate different connector types with a quick adapter change and calibration. In comparison, an adapter change on a laser cleaver requires fine tuning with a few terminated connectors that represent an actual product to ensure proper fiber cleaving height. Too high of a cleave leaves too much fiber nub, while too low of a cleave burns the ferrule material by singeing it with the heat of the laser, leaving it discolored and unusable.

Safety

Production safety levels are easier to manage with automation. Manual scribing results in operators handling the tiny fiber shards themselves. It is very easy for an operator to accidentally break a fiber tip off during scribing, and that broken tip can end up anywhere in the production area and/or on the operator's skin. Automated cleavers have removable trays that allow for the periodic disposal of all fiber shards in a safe and controlled manner. Laser cleavers vacuum the fiber shards into a disposal container automatically.

4.0 Conclusion

Cleaving is an important part of the termination production process, which can improve quality, yields, and efficiency. Improper cleaving could lead to process rework and costly delays. Even a seemingly straightforward step such as cleaving requires good manufacturing support, procedures, proper tools, and well trained operators. While the manual process can produce similar results, it takes extra effort to ensure that an operator has the right skills, good eyesight, and dexterity. Considerations must also be made for proper fiber scrap management, and the additional time and technique required to air polish the epoxy beads down to the same level before using a mass polisher. Both automated cleaving solutions, whether mechanical or laser based, cleave in a highly reproducible manner with a very low profile cut. After cleaving, the fibers remain encapsulated in a greatly reduced, consistent, and supportive epoxy bead and are sufficiently protected for the initial polishing stage; making an additional air polish optional, or even unnecessary. This results in increased process speed and higher output. Automation should be considered whenever production volumes justify hefty upfront investments through ROI calculations. Nevertheless, with proper training and experience, a $20 manual cleaver can do just as good a job as a laser cleaving station for $40K.

Please contact a SENKO representative if you have any additional questions.

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