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Application Note

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Polishing Best Practices

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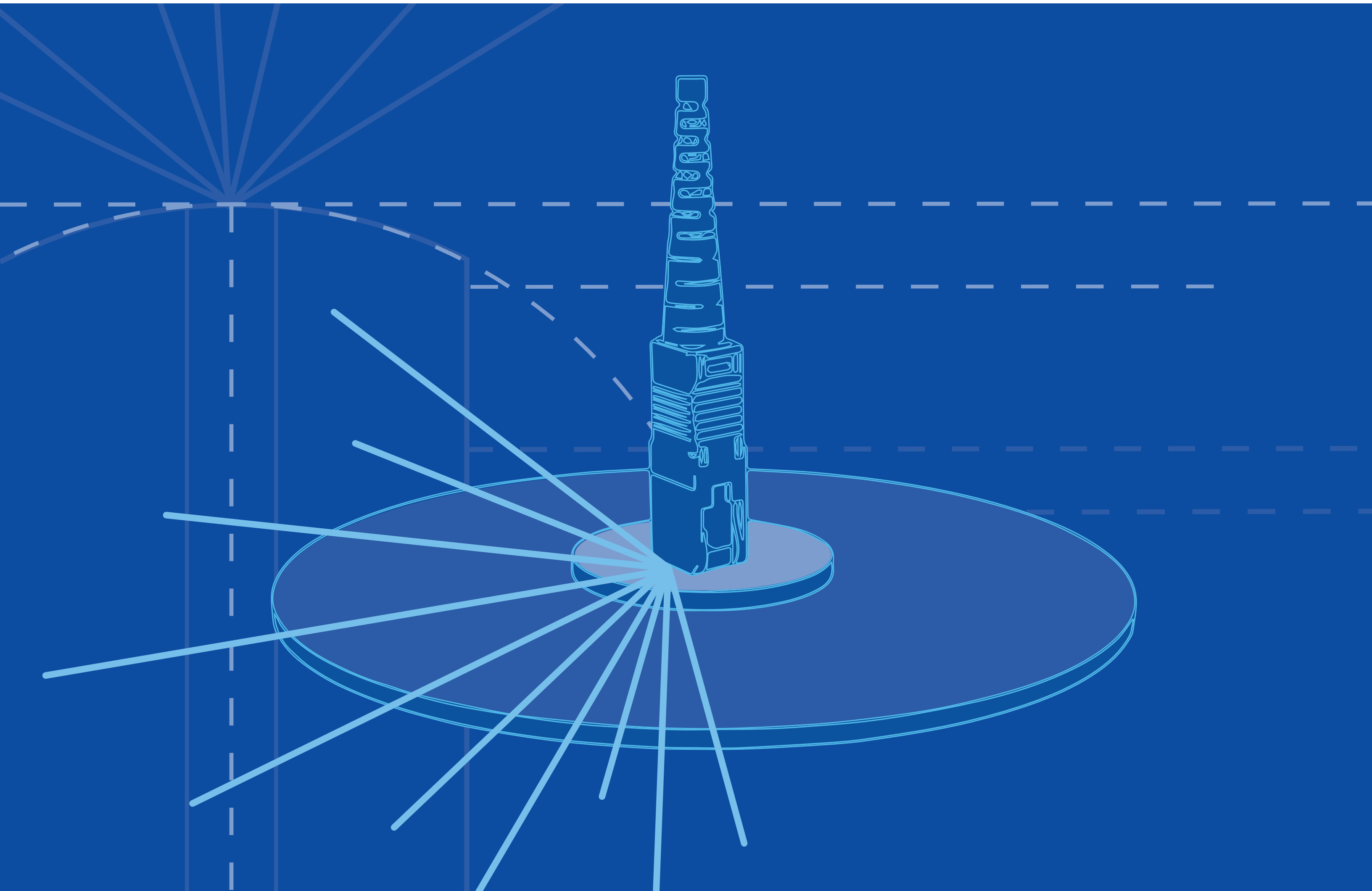

Polishing Best Practices

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Introduction

The purpose of this document is to highlight the science behind the polishing process and discuss various polishing techniques for a variety of fiber optic connectors. The paper also discusses troubleshooting methods when re-polishing is required due to the various post polishing failures. The document is intended to inform and educate about polishing processes and commercial automated polishing equipment with various fixturing in order to achieve a stable low insertion loss, targeted return loss, acceptable 3D endface geometry, and defect free visual fiber appearance according to the latest standards. The end-face geometry compliance is critical for fiber optic interconnect solutions to perform reliably for extended periods of time while enduring common mechanical and environmental stresses.

What is fiber optic connector polishing? Fiber optic connector polishing is a very critical step after connectorization that utilizes an epoxy termination technique. Polishing finalizes the connector endface and cleans the surface, which has a direct impact on optical performance parameters such as insertion loss, return loss, and ultimately bit-error-rate for overall network performance. Reliable polishing processes rely on proper training and a well-equipped termination facility.

Several polishing options are available in the market, ranging from hand polishing fixtures that work on one connector at a time to automated polishing machines that can process multiple dozen connectors simultaneously. The effectiveness of each method depends on factors such as the connector termination process, the consumables employed, the polishing process itself, and the technical expertise. However, automated polishing consistently outperforms manual hand polishing due to the challenge of maintaining uniform pressure, speed, and timing—essential factors for achieving acceptable 3D end-face connector geometry.

Figure 1 *Manual vs automated polishing.*

The acceptable 3D end-face geometry for ceramic ferrules is defined by GR-326-CORE, *"Generic Requirements for Single-mode Optical Connectors and Jumper Assemblies,"* in North America, and by IEC 61300-3-47, *"Examinations and Measurements – End face geometry of PC/APC spherically polished ferrules using interferometry,"*. IEC 61755 series has standards covering: angle polishing, ferrule geometry, materials, and other connector parts. This geometry plays a critical role in achieving a dependable optical connection through Physical Contact (PC) between interconnected products. Connector interferometry equipment employs cameras, mirrors, phased light, and intricate analysis to provide a comprehensive 3D assessment of a ferrule's end-face. This geometry determines the degree of physical contact when two connectors are mated. The geometry measurement of end-face parameters includes radius of curvature, apex offset, and fiber height. These parameters serve as tools for both quality control and quality assurance.

Controlling the end face geometry of a fiber optic termination provides the following benefits:

1. Helps ensure proper optical performance
2. Minimizes Insertion Loss (IL) and Return Loss (RL)
3. Confirms consistency of polishing process
4. Provides assurance for the long-term reliability of the connector when exposed to environmental and mechanical stresses.

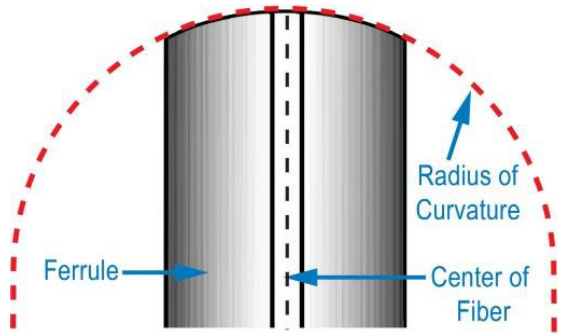
GR 326 STANDARDS

IEC 61300-3-47

The key measurement parameters are:
Radius of Curvature (RoC), **Apex Offset (AO**) and **Fiber Height (FH)** also known as **Undercut (U)**.

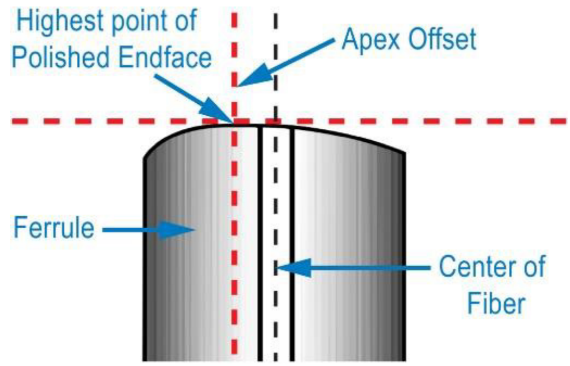
Radius of Curvature

The radius of curvature is defined as the 3D radius of the best fitting sphere over the defined fitting area.



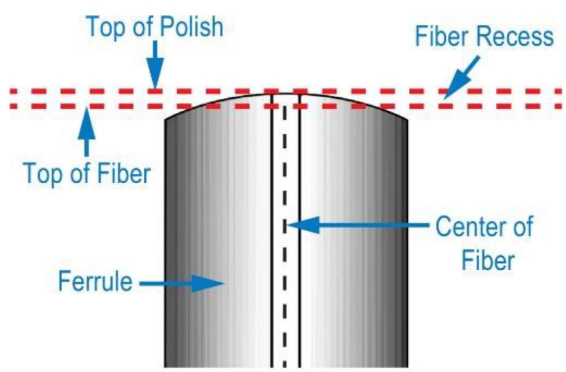
Apex Offset

Measuring the apex offset requires defining the high point or apex of the polished ferrule surface. Since the fiber itself could be recessed or protruded, the sphericity of apex. The apex offset is defined as the distance from the highest point of the ferrule sphere to the center of the fiber core.



Fiber Height

There are two possible ways to define fiber height, spherical height and planar height.



1 **Spherical Height** is when the ideal connector end face (ferrule and fiber) is considered to be a continuous sphere. It is defined as the difference in height between the center of the fiber and the theoretical height in the center sphere based on the ferrule radius.

2 **Planar Height** is when the ideal connector end face is considered to be a flat fiber in the middle of a spherical ferrule. It is defined as the difference in height between the center of the fiber and the height in the center of the theoretical plane formed by connecting the points on the ferrule. The planar height is more commonly used to assess the fiber's position after polishing.

As mentioned earlier, there exist both the GR-326 standard and the IEC 61755-3-1(2) international standard, which quantify the geometrical parameters of polished ceramic ferrules. The standards are largely similar, with minor exceptions, and they are summarized in the table below. For instance, GR-326 is more stringent in terms of the ROC range, upper Apex offset limit, and Fiber Height range when compared to IEC 61755-3-1, and it employs a formula to calculate the Undercut based on the ferrule radius. In theory, a smaller radius allows for a deeper fiber recess or undercut because a smaller ferrule radius will have more compression when connected with physical contact. Consequently, this heightened compression pushes the fiber closer to the planar height of the endface in comparison to ferrules with larger radii.

Table 1 Ceramic ferrules geometry summary

	PC GR-326 Core Issue 4	**PC** IEC 61755-3-1	**APC** GR and IEC
Radius (ROC)	7-25 mm	10-25 mm	5-12 mm
Apex Offset (O)	<50 µm	<70 µm	<70 µm
Protrusion (FH)	50 nm	100 nm	100 nm
Undercut (U)	U = -.02R3 + 1.3R2 -31R +325	U = -.02R3 + 1.3R2 -31R +325	-100nm

In the current market, two primary types of connectors are predominantly used: pre-terminated connectors (also known as field-installable connectors), which come pre-polished; and factory-terminated connectors which require epoxy application, polishing, and testing during the manufacturing process. Pre-terminated connector assemblies eliminate the time-consuming factory termination involving epoxies, polishing processes, and inspections, providing a convenient connection option; however, they also come with limitations. Pre-polished field-installable connectors tend to be more expensive and are not as reliable for long-term performance when compared to factory-terminated ones. This discrepancy is due to the mechanically spliced connection relying on index-matching gel between fibers within the connector, which cannot withstand severe environmental and mechanical stresses.

On the other hand, epoxy/polish connectors involve permanently gluing the fiber in the ferrule using heat cured epoxy, followed by automated polishing. This approach offers a more dependable connection over time, resulting in losses of less than 0.5 dB per mated pair. SENKO premium ceramic connectors conform to the highest performance grade available, which presently is Grade B. This pertains to the optical performance criteria outlined for single-mode connectors as specified in IEC 61753-1, concerning Random Mating IL performance grades. It's noteworthy that grade A has not yet been defined in this context. SENKO's typical insertion loss (IL) is significantly lower than 0.5dB, a benchmark that could be regarded as an industry average. Specifically, SENKO Mean IL is ≤ 0.12 dB, and SENKO Maximum IL is ≤ 0.25 dB, applicable to over 97% of randomly mated samples.

This paper focuses on the polishing processes applied to factory-terminated connectors that feature zirconia ceramic ferrules.

Main Polishing Steps

The polishing process for fiber optic connectors can be broken into four main steps: air polish, epoxy removal, surface geometry formation, and a final buff. This applies to a manual or an automated process. This paper focuses on the process of automated polishing, utilizing commercial polishers capable of achieving high-volume polishing with consistency.

Main polishing steps are:

1. **Air polish** – typically 15 µm, sometimes 30 µm, Silicone Carbide polishing film that removes sharp fiber edges protruding over epoxy bead
2. **Epoxy Removal** – typically Silicone Carbide 3 µm or 5 µm polishing film
3. **Geometry Formation** – typically 1 µm and/or 3 µm Diamond polishing film
4. **Final Step** – finishing the optical surface – typically chemical glass etching with the process called chemical-mechanical polishing (CMP) or also known as "planarization"

The following four sections are the science behind each step of the process.

Air Polish

After cleaving the air polish is required to remove sharp fiber stubs, otherwise the stubs can snap and break under the polishing pressure which could result in the fiber being broken below the ferrule surface.

The sharp fiber end left after cleaving can potentially tear the polishing paper and cause damage to the underlying supporting rubber pad. Air polishing can be carried out either individually or collectively for all the ferrules simultaneously when loaded into the polishing fixture, also referred to as a polishing puck or plate. Typically, a 15 µm or 30 µm Silicon Carbide (SiC) film is placed on the rubber pad. The process is depicted in the figure 3 on the next page and is detailed as follows: with the connector ferrule pointing upward, manually apply gentle hand pressure while using light circular motion to polish the cleaved fiber down to the same level as the epoxy bead. This approach helps minimize the risk of fiber breakage during the initial polishing phase. Alternatively, this step can also be conducted using the same polishing film within the machine, without the application of manual pressure.

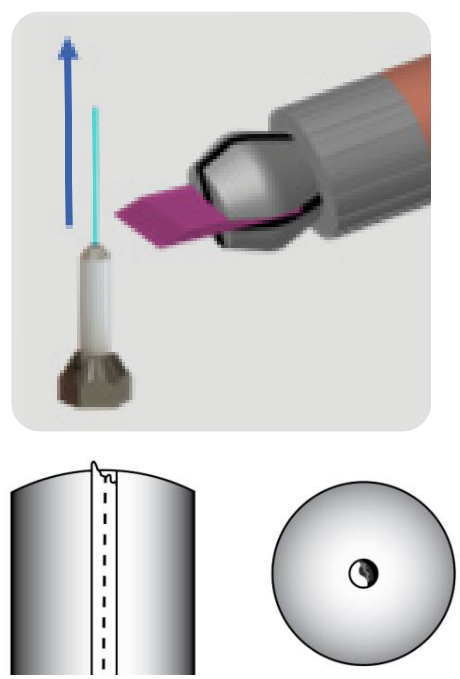


Figure 2 *Improper cleaving can lead to cracked fiber after polishing*

Figure 3 *SENKO SC/APC Air polish of fiber stub after cleaving.*

Care should be taken not to over-polish or alter the chamfer shape of the ceramic ferrule. The air polishing process will ensure more consistent fiber protrusion across all the ferrules, resulting in improved polishing outcomes.

Before the epoxy removal step, it is suggested to inspect the ceramic ferrule visually to ensure that no epoxy is still present on the ferrule outer surface as shown in figure below. Epoxy on the outer surface could prevent the ferrule from loading in the precision fixture properly. It is also very important to inspect the chamfered sides. It is possible to use a razor blade to remove residual epoxy if present on the ferrule as seen in the Figure 4.

Figure 4 *Excess epoxy from the sides can be removed by blade.*

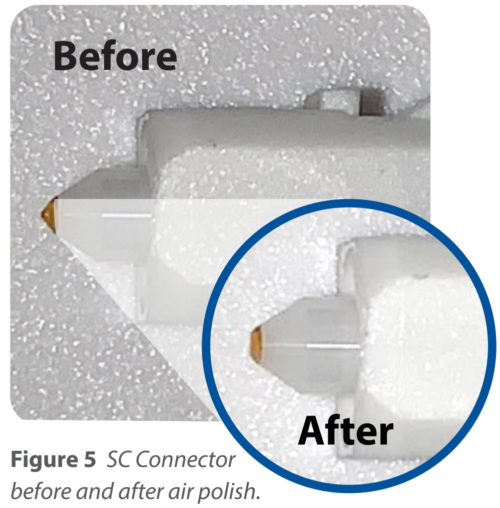


Figure 5 *SC Connector before and after air polish.*

Epoxy Removal

At this stage all the ferrules are loaded in the polishing fixture and either 3µm or 5µm Silicone Carbide lapping film will be used to remove all the remaining epoxy from the endface. Silicone Carbide film is relatively inexpensive and does not change the ferrule surface geometry much. The film is used to remove the cured epoxy quickly and efficiently. Before using more expensive Diamond films, you want to make sure that the epoxy is fully removed as it can clog and contaminate the Diamond film, making the

Figure 6 *Domaille CS® polishing fixture needs to be cleaned in an Ultrasonic bath.*

polishing surface ineffective. There should be no epoxy present on the ferrule prior to continuing with the next polishing steps. It is considered good practice to double check the end-face of the ferrules after the epoxy removal step to ensure complete elimination of all epoxy residues.

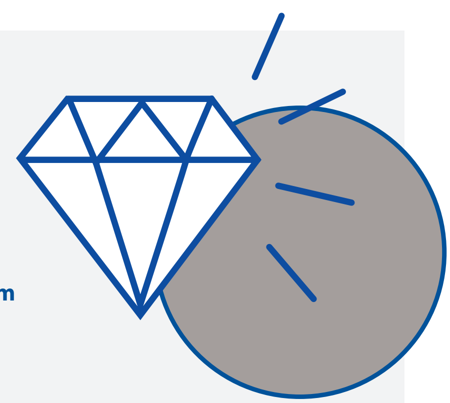
Special attention is warranted when dealing with polishing fixtures equipped with independent pressure control (IPC) which rely on spring force of the connectors and the plate simultaneously. Each ferrule should move effortlessly with its own spring force when carefully pressed from the bottom of the plate. Confirm if the ferrules recede back into their original positions while maintaining consistent protrusion across the polishing plate. If a ferrule becomes stuck when compressed, it is likely that epoxy or other polishing debris has accumulated in the holes of the polishing fixture. The most effective method for cleaning a polishing fixture involves utilizing an ultrasonic bath and a nylon brush. A comprehensive discussion regarding the ultrasonic cleaning technique and corresponding recommendations is provided later in this document in Section 8. Figure 6 depicts a polishing fixture in ultrasonic equipment.

Geometry Formation

Following epoxy removal, the subsequent phase involves geometry formation using Diamond films. This geometry formation can be carried out through two steps: 3µm followed by 1µm, or it can be accomplished in a single step with a 1µm Diamond film.

Methods for geometry formation using Diamond Film :

3 µm Diamond film Step 1 → **1 µm** Diamond film Step 2 **or** **1 µm** Diamond film Step 1



Each approach has its advantages and drawbacks. Opting for the two Diamond film method will extend the time required and introduce additional costs for consumables, but it will result in a higher first-pass yield. Conversely, choosing to employ only a 1µm Diamond film may entail more frequent rework of the ferrules, as it might not provide sufficient time to properly shape fiber geometry or eliminate deeper scratches from the previous Silicone Carbide films. The utilization of a Diamond film, in conjunction with a meticulously selected durometer of the rubber pad, is the key factor responsible for ensuring compliance with the Radius of Curvature and Apex Offset requirements stipulated in GR-326.

While performing Diamond film polishing, it is important to place the film onto the rubber pad in a manner that avoids any entrapment of air bubbles. In instances where air bubbles do occur, they must be promptly eliminated. This is because, during the polishing procedure, an air cushion has the potential to alter the ferrule's geometry or even cause scratches. To prevent air bubbles, ensuring the surfaces are clean, utilizing a hand roller, and applying a light mist of water to the polishing pad can be effective measures.

As illustrated on the next page in Figure 7, the example showcases trapped air bubbles beneath the film on the left, contrasting with the correct film placement in Figure 8, devoid of any bubbles.

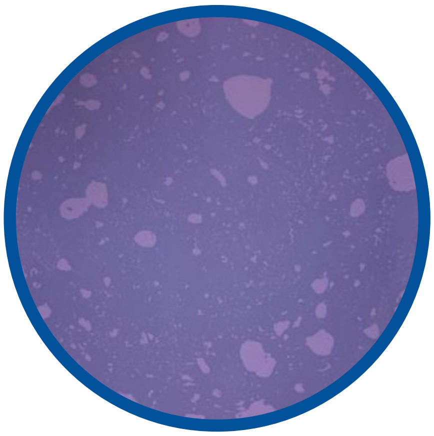


Figure 7 *Trapped bubbles may negatively affect 3D ferrule endface geometry.*

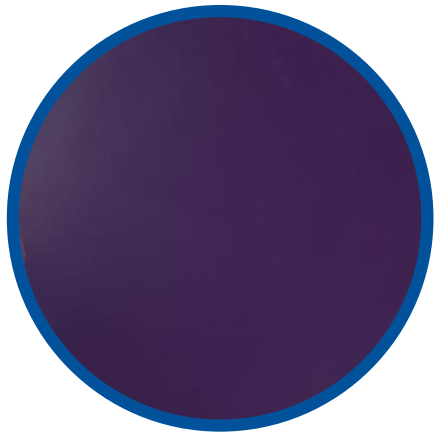


Figure 8 *Film devoid of air bubbles.*

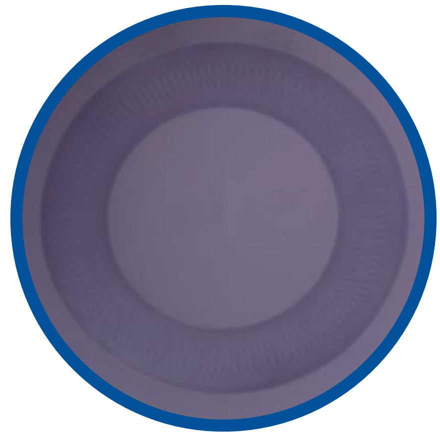


Figure 9 *Overused 1µm diamond polishing film.*

Diamond films represent the highest cost consumable within the polishing process. Consequently, when choosing a supplier, it is imperative to assess the longevity of the film. Various Diamond films are available, with usage spans ranging from 5 to 15 times, and even up to 25 times or more, contingent upon their quality. SENKO advises opting for Diamond films that are rated to endure at least 5 uses. This recommendation arises from the fact that the cost-effectiveness of longer-lasting films is comparable, and monitoring the usage of such films can pose challenges. Prolonging the lifespan of the product is achievable by cleaning Diamond films with an alcohol-dampened lint-free wipe after each utilization.

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USES

Final Step

The final step determines both the fiber height and the visual end-face appearance.

To achieve the required fiber height, it is crucial to select the correct final lapping film. The fibers should either protrude or remain slightly below the ferrule surface as per the required standards. This ensures optimal physical contact between fibers in a connector. In fiber optic interconnects, establishing physical contact between mating pairs is essential, as an air gap between them would result in high back reflection. Physical contact occurs when there is fiber protrusion. Taking into account the compression force applied by the connector spring, there is a degree of compression between the fiber and the ferrule. Conversely, if the fiber is undercut—positioned beneath the surface—the ceramic ferrule's compression under spring load will push the fiber forward, eliminating the air gap and establishing physical contact. This contact is crucial for minimizing return loss. A study conducted by SENKO concluded that slight undercut is preferable to a protrusion. This preference arises from extensive temperature cycling tests, revealing that after the cycle, the fiber might slightly push up the ferrule increasing overall fiber height. Initially, a compliant fiber height, in line with GR-326 standards, might change following environmental tests. This change could lead to non-compliance with the latest GR-326 revision 4, which mandates that fiber geometry must be remeasured and remain compliant even after exposure to environmental stresses.

The final film typically comprises a dry slurry that becomes activated upon the addition of water. This slurry facilitates a chemical-mechanical polishing process (CMP), during which the actual ceramic portion of the ferrule no longer undergoes polishing. Only the fiber, composed of silica glass, undergoes a process known as "etching," which involves continuous polishing through the chemical reaction of the slurry solution's alkaline pH. The presence of diamond particles in the slurry, which generates heat, causes a slight alteration in the refractive index of the fiber from its original value, which is not desirable. To achieve a low Return Loss, a layer of the fiber, about 20-30µm in thickness, with an altered refractive index, needs to be removed through slurry etching. Thus, the secondary objective of the CMP process is to eliminate the silica glass layer with a modified refractive index. This is accomplished by employing a tribochemical process after the erosion of the silica glass layer caused by the diamond films.

A high pH and slurry particles work together to carry out the etching process, responsible for achieving the final smoothness of the glass surface. The presence of scratches and pits poses a challenge for fiber optic assemblers. If such imperfections arise, the connectors will necessitate re-polishing, leading to additional time and material consumption. Aside from the chemical-mechanical benefits of the slurry, the concluding step demands thorough flushing and cleaning to prevent contamination from previous stages. Utilizing distilled water in a jet spray form is recommended for eliminating debris in and around the ferrule, as well as at the base of the polishing fixture. Following this, gently wipe the polishing fixture's base using lint free cleaning wipes, moving from the center of the jig to the outer edges. Once again, a liberal use of water with a jet-style nozzle is advised.

It's important to note that using alcohol after slurry applications is not recommended. Alcohol has a tendency to rapidly dry the slurry, resulting in spots on the end-face that become challenging to remove once they set. Achieving the final level of visual cleanliness can also be influenced by adjusting the settings of the polishing machine, such as RPM, time, and pressure.

Rubber Pad Role

During the polishing process, the polishing papers are placed onto rubber pads which typically have a certain hardness. The hardness of the rubber pads are measured on a scale using units called Shore durometers ranging from 50 to 95 in increments of 5. Maintaining consistent geometry can pose a challenge because rubber pads tend to increase in hardness over time as the rubber material dries out. In general, a softer rubber pad has a greater impact on reducing the Radius of Curvature (RoC) compared to a harder pad. Additionally, a smaller RoC contributes to improved symmetry and, consequently, a better Apex Offset (AO). Using a harder pad yields a more uniform radius, but this often results in a slightly elevated Apex Offset on average and proves to be more challenging to control. Based on SENKO's experience, it is preferable to apply higher pressure when using a harder pad, as opposed to applying less pressure when using a softer pad to achieve good results. Since rubber pads tend to lose moisture and become harder over time SENKO recommends periodically checking the durometer of the pads to ensure that the value falls within the required parameters.

The figure below displays the data that illustrates the relationship between AO and RoC for LC ferrules. There is no linear dependency of the AO as a function of the RoC due to variables in the polishing process. Generally, the smaller the radius, the better the offset, and vice versa.

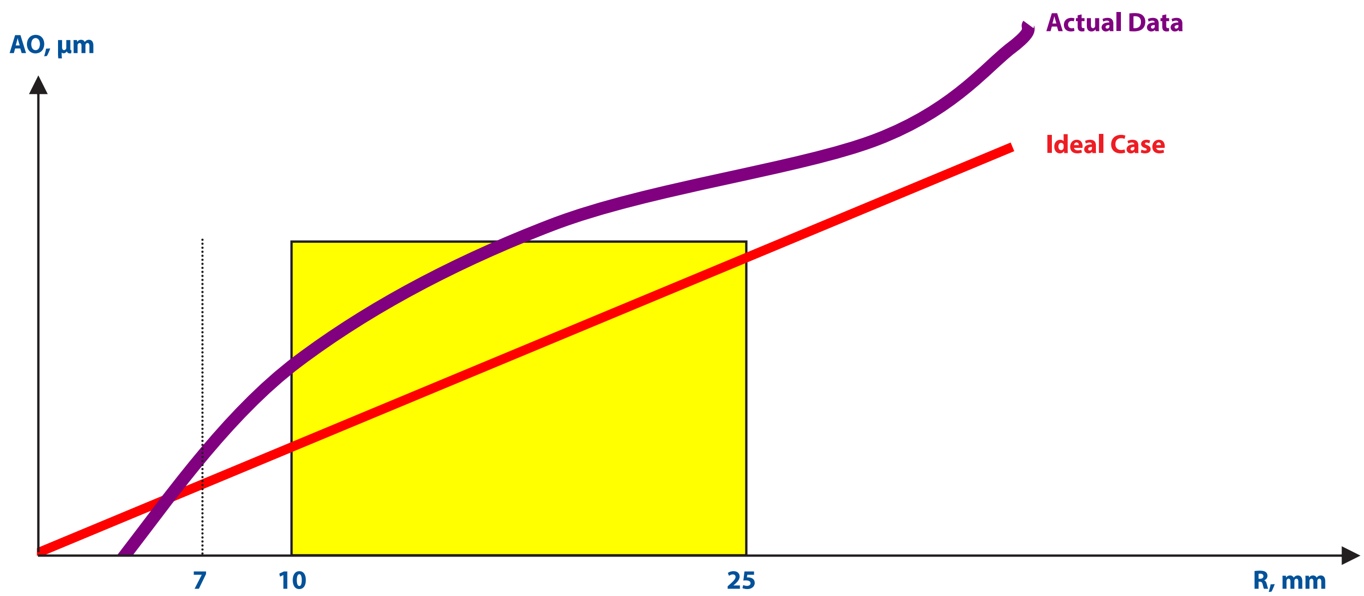


Figure 10 *Graphical representation of relationship between Apex Offset and Radius of Curvature.*

The yellow block represents the area where AO and RoC are compliant to GR-326 requirement. Typically, you would rarely see large RoC, such as 20-2 5mm with Offset being close to zero.

GR 326 COMPLIANT

The Importance of Cleaning Between the Polishing Steps

Before starting the polishing process, it is essential to clean the rubber pads and polishing fixtures using isopropyl alcohol with a purity of at least 99%, along with lint-free wipes, distilled water, and clean, dry compressed air. Cleaning between polishing steps holds utmost significance in achieving successful outcomes. Following each polishing step or cycle, it is advisable to generously spray the entire bottom surface of the polishing fixture, allowing all the polished material to flow into a drip tray or bucket. Subsequently, apply water directly onto the end-faces of each connector. This practice aids in minimizing cross-contamination between steps. Once the plate and ferrules have been thoroughly sprayed with distilled water, utilize clean, lint-free wipes. Afterward, employ filtered, high-pressure air to effectively remove the remaining water from the plate. Focusing the air directly onto the connector end -faces is recommended. Employ a lint-free tissue soaked in water to meticulously wipe the bottom of the connector fixture, including its outer perimeter. Subsequently, employ high-pressure air once more for thorough drying. It is advisable to repeat this process a second time. Furthermore, conducting a visual inspection immediately after polishing is strongly recommended. This time frame offers the optimal opportunity to identify and eliminate any residual polishing contaminants. Remember, if residual slurry dries out, it becomes significantly more challenging to clean, or even impossible without rework.

While polishing, it is advisable to clean the Diamond lapping films that are intended for reuse. Begin by flushing them out with distilled water, followed by an alcohol-soaked (99% isopropyl) lint-free wipe to clean the film. Wipe from the center to the outer edge. A prudent approach is to allocate a dedicated rubber pad for each Diamond film used in the process, instead of sharing the same rubber pad with other lapping films used in the process. This practice prevents contamination and eliminates the need for additional time spent on changing films.

When utilizing distilled water as a polishing fluid, ensure that a fine mist or spray is evenly distributed across the film, including the flocked slurry films. Be cautious, as excessive water can cause the lapping film to slide off the rubber pad. Alternatively, it's possible to employ a mixture of distilled water and 90% isopropyl alcohol as a lubricant. Nevertheless, it's crucial to bear in mind that alcohol might react unfavorably with certain slurries. The combination of alcohol and certain slurries could lead to the formation of hard crystals, which could potentially cause scratches on the endface.

Polishing Angled Connectors *(FC/APC, SC/APC, etc.)*

Up to this point, the discussion has revolved around general polishing practices. This section will delve into a more detailed exploration of Angled Physical Contact (APC) Connectors. What if an APC polish is mandated? An APC connector represents a type of fiber connector designed to minimize reflections by incorporating an 8° angle-polish on the end-face. This angle ensures that reflected light does not remain confined within the fiber core, but rather reflects into the cladding and is absorbed.

When initiating the angling process with a flat ferrule, it is advisable to employ a grinding metal disk as the initial step for forming the angle. This specialized coated metal plate can be procured from SENKO (Part Number: PLA-518-MD-15). Following the angle formation through the grinding stage, the subsequent procedure becomes straightforward and parallels the process employed for UPC connectors. If the ferrules are already pre-angled, the polishing closely aligns with the UPC process, eliminating the need for the angle grinding step.

It is important to note that the ferrules that are made to be angled typically have two variations in design:

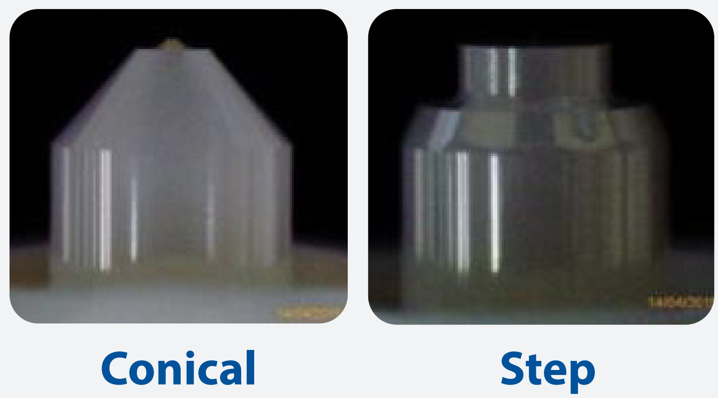


Figure 11 *Conical (left) and Step (right) ferrule.*

Typically, manufacturing a step ferrule requires more time compared to the conical one due to the additional ceramic grinding involved. Consequently, the initial cost of a step ferrule is slightly higher than that of a conical ferrule. However, the step ferrule design proves to be the most convenient for polishing and achieving the necessary geometries outlined in Table 1: *Ceramic Ferrules Geometry Summary* in the APC column. This design emerges as a superior choice because it leads to higher polishing yield s for users. The most common challenges encountered by termination houses during APC polishing usually revolve around the Apex Offset and the Actual Angle of the ferrule during interferometric geometry measurements.

As we already mentioned in the *Introduction*, Apex Offset is the distance from the high point on the polished surface to the center of the fiber.

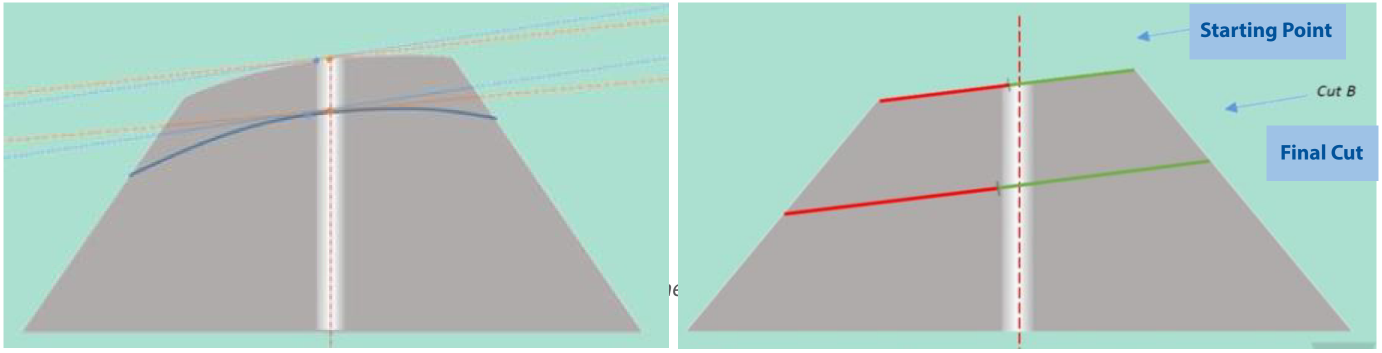


Figure 12 *Evolution of Conical Ferrule Polishing: The deeper it's polished, the greater the offset.*

If the ferrule is not perpendicular to the polishing surface, the Apex Offset of the curved end -face will not be centered on the ferrule, as seen in the case of the conical shape in the figure above. The more the conical ferrule is polished down, the farther the Apex Offset will be from the center of the ferrule, resulting in a larger offset value. The Apex Offset is directly proportional to the amount of material removed from the cone. The deeper it is polished, the greater the offset becomes. However, this is not the case for a step ferrule design. When the initial surface is flat, the offset value remains consistent regardless of the polished depth.

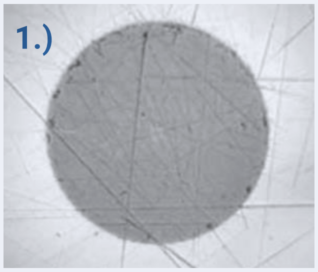
This is why there are variations in polishing fixtures for APC, which are offered by polishing equipment manufacturers. To counteract the increasing offset dynamics, conical APC ferrules must be polished in fixture that has an angle greater than 8.0-degrees (typically around 8.25 degrees). In contrast, polishing fixtures for step APC ferrules require precisely 8.0-degree angles. Nevertheless, even when utilizing specialized conical fixtures, the more material that is polished away, the larger the apex offset becomes.

Troubleshooting Visual End-face Cleanliness: *Scratches and Pits*

In general, when scratches appear after polishing, they usually trace back to earlier operational steps. It is also crucial to identify and rectify any problematic issues during the assembly process. However, troubleshooting commences with a thorough review of the final images.

See the next page for the most common visual defects.

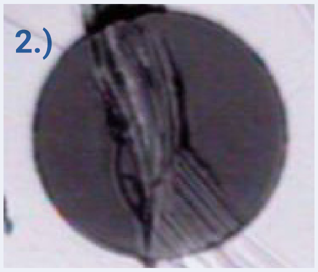
1.)



A few, thick scratches in random directions *(in the photo)*

These are most likely caused by cross-contamination when debris from the rough lapping film isn't thoroughly removed before transitioning to a finer grit polishing film. Once it's confirmed that the lapping film process is stable, the next step is to assess the roughness and consistency of the scratches after using the 1µm Diamond film. Visual inspection should reveal uniform roughness at the typical 0.5µm to 1.0 µm level. If the surface roughness isn't consistent, cross-contamination is I1nce a uniform batch of connectors or fibers is achieved, the transition to the final film can proceed.

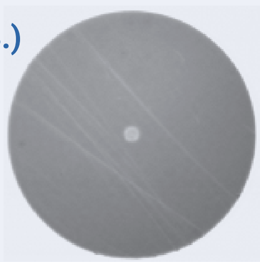
2.)



Thick,wavy scratches in a single direction *(in the photo)*

These are most likely scratches that resulted from cleaning after polishing. This could happen when wiping the end-face against a cleaning substance containing contaminants or if the wiping was performed on a hard surface.

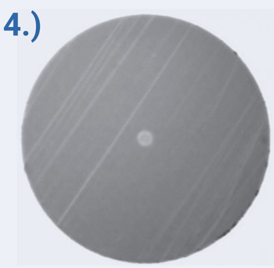
3.)



Clean fiber edge with small scratches around the core *(in the photo)*

These are most likely a result of insufficient pressure during the final step. Additionally, this issue could be attributed to a rare occurrence of a defected manufacturing lot for the final polishing film.

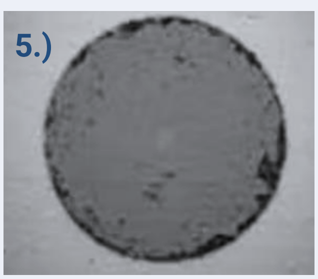
4.)



Tiny scratches all over *(in the photo)*

This is likely due to insufficient time and/or pressure applied on the final film. Additionally, it could be attributed to non-uniform heights of adjacent ferrules, causing connectors that are more recessed to not establish solid contact with the polishing pad.

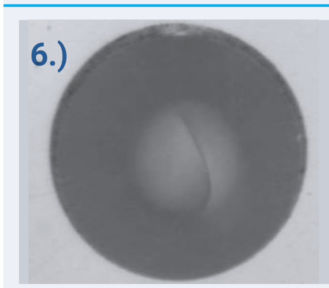
5.)



Fiber edges chipped *(in the photo)*

This issue is connected to problems in earlier steps of the assembly process. For instance, it could be linked to epoxy application, epoxy mixing and/or outgassing, epoxy curing schedule, or poor fiber cleaving technique. The fiber edges can be chipped if the epoxy fails to adequately secure the fiber due to improper mixing and/or curing.

6.)



Core crack

It typically occurs in MM fibers with a larger core. The additional Germanium doping material in the glass structure makes the core softer and more susceptible to cracking due to temperature stress. To prevent this, SENKO recommends using smaller epoxy beads during termination and curing, as well as employing either lower curing temperatures or a step-curing process, beginning with lower temperatures and gradually increasing them.

Troubleshooting End-face Geometry Failures: *Fiber Height, Apex Offset and Radius of Curvature*

Ensuring proper end-face geometry compliance with GR-326 requirements guarantees stable optical performance for fiber optic interconnect solutions. Monitoring the end-face geometry of polished ferrules begins with the quality of your polishing fixture and how it has been cleaned and maintained. Any significant deficiencies in the fixture will manifest in the end-face geometry of the ferrules.

1 **Fiber height**, also referred to as undercut or protrusion, is distinct from parameters such as Apex Offset and ROC, which are influenced by polishing fixture design and tolerances. The ultimate fiber height, however, is determined by factors including the chemical composition of the slurries, particle sizes, and the pH level of the final lapping film. As previously mentioned, the CMP process selectively etches the fiber glass while preserving the surrounding ceramic. Achieving the desired fiber height entails adjusting polishing time and pressure. Generally, to attain a lower fiber position, greater time and pressure are applied, and conversely for the opposite effect.

2 **Apex Offset** issues primarily stem from factors like the precision of the polishing fixture ferrule hole, perpendicularity, wear, or contamination of the polishing fixture. The data in Figure 6 demonstrates a correlation between a smaller radius and a reduced apex offset. Ultimately the Fixture needs to be within tolerance limits first then the process can be optimized to achieve the best results.

3 **Variations in the Radius of Curvature** can signal potential issues with connector latching or a worn clamping mechanism in the fixture. If this occurs, and no changes have been made to the polishing process, it could be advisable to consider replacing either the latch or the polishing fixture entirely. Moreover, as time passes, the rubber pads lose elasticity and harden. As the pad hardness increases, the Radius of Curvature also tends to increase, and vice versa. It is recommended by SENKO to periodically assess the polishing pads with a durometer device to verify that the durometer value remains within the specified range.

How Many Times can Connectors be Re-polished?

This question lacks a definitive answer due to the varying designs of ferrules, which encompass cone shapes defined by chamfer angles and pedestal (ferrule top circle) diameters, as depicted in Figure 9. In a typical production setting, connectors can generally undergo re-polishing around two to three times on average. Drawing from SENKO's experience and data, a complete polishing cycle typically removes 0.05 mm of the ferrule length for a 1.25 mm diameter ferrule. For ceramic ferrules with a 2.5 mm diameter, the available material for polishing is doubled, thereby enabling the possibility of re-polishing these ferrules four to five times. Notably, Diamond films contribute to the removal of around 80% of the material in a UPC polish. Importantly, the ferrule's pedestal diameter must not exceed 0.1 mm from its initial value. This is why re-polishing depends on the ferrule design and time they are polished on a Diamond film.

Table 2 *Production data for LC ferrule pedestal diameter change*

LC Connector No	Pedestal Diameter		
	Before Polishing	After Polishing	Increase
1	0.932	0.992	0.060
2	0.924	0.968	0.044
3	0.930	0.988	0.058
4	0.924	0.962	0.038
5	0.934	0.942	0.008
6	0.930	0.990	0.060
7	0.932	0.974	0.042
8	0.928	0.972	0.044
9	0.924	0.974	0.050
10	0.932	0.968	0.036
11	0.928	0.964	0.036
12	0.930	0.988	0.058
13	0.934 0	0.972	.038
14	0.934	0.976	0.042
15	0.922	0.972	0.050
16	0.936	0.976	0.040
17	0.924	0.972	0.048
18	0.932	0.974	0.042
19	0.928	0.980	0.052
20	0.940	0.990	0.050
Average	**0.930**	**0.975**	**0.045**

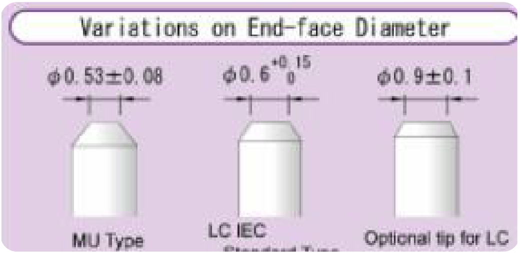


Figure 13 *Examples of pedestal design variations in 1.25 mm ferrules.*

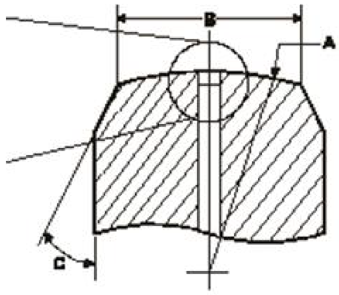


Figure 14 *Example of 1.25 mm ferrule requirement.*

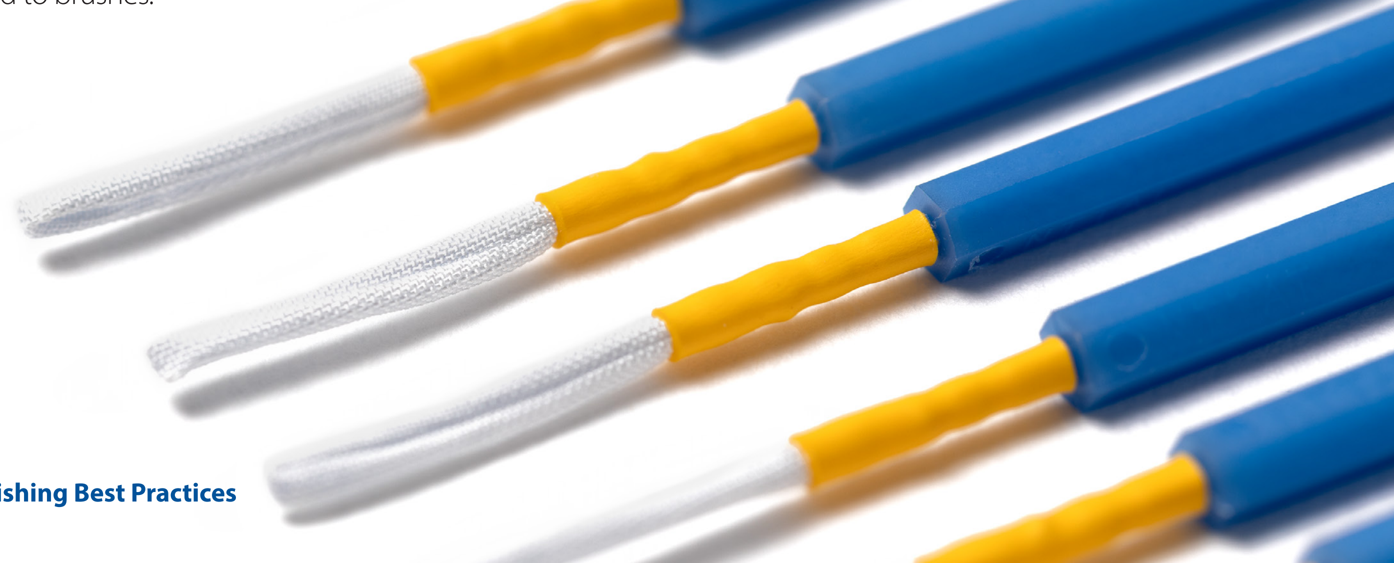
Table 2 *Recommended 1.25mm ferrule geometry for 0.9mm pedestal diameter design*

Parameter	Reference in Fig. 8	Minimum Value	Nominal Value	Maximum Value
Radius	A	7 mm	12 mm	25 mm
Pedestal	B	0.8 mm	0.9 mm	1.0 mm
Chamfer	C	25º	30º	30º

Recommendations for Cleaning Polishing Fixtures

Many of the defects arising from the polishing process can be pre-emptively avoided by investing time in maintaining the polishing fixture. It is advisable to engage in daily cleaning, as opposed to a weekly or monthly frequency. When cleaning, use distilled water due to its absence of salt ions and other abrasive minerals. It's imperative to refrain from using tap water, which might contain mineral-based deposits. The use of tap water could result in fixture corrosion and dimensional tolerance changes, consequently impacting future polishing performance negatively.

For the cleaning of ferrule holes, SENKO advocates the utilization of 1.25 mm and 2.50 mm nylon brushes or NEOCLEAN sticks (CSK-01 for 1.25 mm with yellow and CSK-02 for 2.5 mm with blue) designed for cleansing fiber optic adapters. The robust fabric of these sticks surpasses the strength of traditional brush bristles, implying that the sticks offer an extended lifespan compared to brushes.



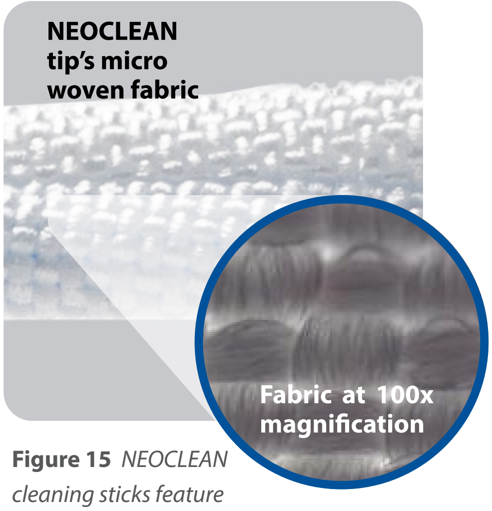


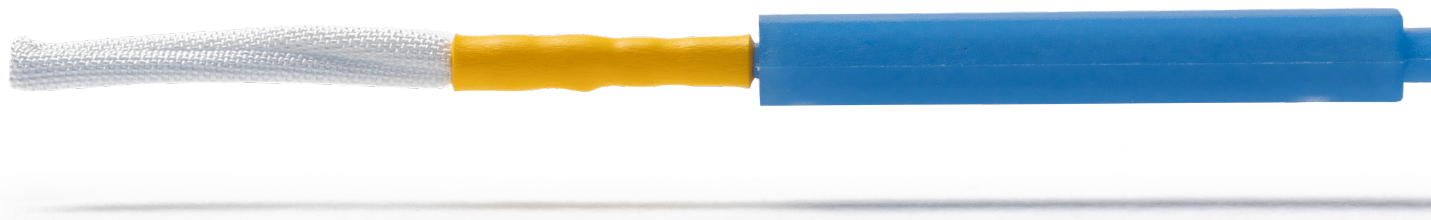
Figure 15 *NEOCLEAN cleaning sticks feature strong micro woven fabric.*

The best is to clean the fixture while it's still wet from the polishing process. To clean areas that are difficult to access with a brush, SENKO recommends an ultrasonic bath. Remember to change the bath solution daily. We use Branson Ultrasonic with the recommended Branson solution (1:10 - Solution: Distilled water).

If the ultrasonic bath is utilized once per shift, the requirement for extensive brushing to clean the fixture holes is minimized. Certain companies opt for an ultrasonic bath cleaning method employing only distilled water, without the addition of detergents. In an ultrasonic cleaner, the walls vibrate at a high frequency, transmitting pressure waves into the water. These waves induce a pushing-and-pulling motion in water molecules, generating cavitation—a phenomenon where short-lived vacuum bubble bursts form within the water. This process is similar to the action of a pressure washer, effectively dislodging contaminants from surfaces through the energy of these miniature explosions, primarily near the submerged surfaces.

Crucially, cavitation solely occurs within the water medium, necessitating complete submersion of the entire polishing fixture. As long as the surfaces requiring cleaning are in contact with the water and not with the ultrasonic walls, the cleaning process takes effect. It's worth noting that most ultrasonic cleaners are calibrated to attain peak wave power at the center of the bath. Therefore, objects to be cleaned are suspended within the bath water, ensuring they do not touch the bottom or interior walls of the ultrasonic cleaner. A basket is often used to suspend the objects in the bath. Objects that touch the cleaner's bottom or sidewalls experience reduced movement, resulting in diminished cleaning efficacy. After cleaning the fixture, it is important to dry it thoroughly to avoid corrosive effects.

Figure 16 *Branson cleaning solution for ultrasonic bath.*



Summary of Tips and Recommendations

1.) Always perform an air polish prior to running a loaded polishing fixture on the machine

Air polishing removes the sharp edges from the fiber to get the fiber flush with the epoxy bead. Ten to fifteen small circles with 15 to 30µm silicon carbide is typically sufficient.

2.) Clean pads and plates

Clean pads and plates with pure isopropyl alcohol, lint free wipes, distilled water and filtered, dry air. Lint-free wipes ensure contamination free polishing.

3.) Use minimal distilled water

Use a minimal amount of distilled water to adhere non-PSA lapping films to the polishing surface of a rubber pad. Ensure that no debris and air bubbles are trapped between the film and polishing surface. The use of an acrylic roller helps with proper film adhering. Note, that the rubber polishing pad has two surfaces that can be used: a highly polished shiny side and a dull, unpolished side where durometer value is typically stamped. We recommend placing the lapping film on the polished side of the rubber pad with a slightly moist surface. In some cases, it is also possible to use small double-sided tape in the middle to hold the film from slipping.

4.) Apply distilled water uniformly

When using de-ionized or distilled water as a polishing lubricant, make sure it is applied uniformly across the film and flocked papers.

5.) Flush components between each polishing step

Between each polishing step, flush out connector end-faces, work-holder surfaces, and underside of polishing pads with a distilled water jet or pressurized spray, and then clean with lint-free wipes and blast with filtered high-pressure air. Also, clean the lapping film that will be reused by flushing it with distilled water, and then (omit for slurry final films) use an IPA dampened lint-free wipe to wipe the film from the center to the outer edge. Proper cleaning will help to ensure an end-face free of scratches, pits and defects, and it will extend the life of the film.

6.) Use polishing recipes and consumables specified by SENKO

Use polishing recipes and consumables specified by SENKO. Please note that these are generally starting points and adjustments may need to be made based on various factors like connector style, manufacturer, number of connectors per fixture, materials used, and required performance.

Keep in mind that fiber optic polishing is a blend of science and art. The scientific aspect hinges on the quality of meticulously maintained automated equipment, whereas the artistry lies within the procedures and the ongoing endeavor for enhancement by each individual user. Alongside the polishing machine, the significance of procedures, knowledge, and training cannot be overstated. SENKO possesses a technical team equipped to guide you in crafting a personalized process that aligns with your objectives and facilitates the attainment of your desired outcomes.

Biography

Andrei Vankov, is an Application Engineer at SENKO Advanced Components. He received his BS from Thomas Edison State College and his MSEE from Pennsylvania State University. He began his career in 1993 at Sumitomo Electric Lightwave Corp as a Fiber Optic Manufacturing Engineer where he worked on active and passive components using Kaizen methods in Yokohama, Japan. As a Senior Optical Design Engineer in Franklin, MA (founded as Advanced Interconnect) Andrei Vankov developed various passive optical components and packaging integration to meet Telcordia industry standards. He designed optical interconnects, including optical backplanes (MTP, HBMT, PHD, OGI), and a fiber optic SMPTE compatible Broadcast Connector for HD applications. In 2013-2020 Andrei worked at Nokia division Radio Frequency Systems (RFS) where he provided leadership for an LTE RAN launch project team. Andrei holds several US and European Patents in fiber optics interconnect technology.

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