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Advanced Components

Application Note

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The Relationship between Insertion Loss and Premium Ferrules

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1.0 Purpose

Senko offers connectors for various fiber optic applications and scenarios. Using high quality components, SENKO connectors can meet IEC, TIA/EIA and the requirements of GR-326 standards. What is the merit of a fiber optic connector? Fiber optic connectors main function is designed to terminate the ends of fiber optic cables so they can be interconnected. Every fiber connection has two most important values after termination and interconnection - Insertion Loss (IL) and Reflection or Return Loss (RL). A higher quality connector will lose less light due to misalignment of the connected fibers. A fiber optic connector which has lower loss, lower cost, and is easier to terminate is always in demand. Thus, dozens of fiber optic connectors have been introduced to the market with different standards and applications, but only a few of them represent the majority of the market and even fewer stand out in terms quality. One example of such connectors is a SENKO LC Unibody Premium connector, which is designed with super low loss ferrule that made to meet low loss requirements that can be found in the IEC 61753-1 standard which will be described later in this document. We will explain what makes SENKO Premium connectors different from the rest.

2.0 Overview

There are two critical parameters in a fiber optic connection. They are the Insertion Loss, which is defined as the ratio of the optical output power over the optical input power and is measured in dB. Additionally, Return Loss, which is defined as the ratio of light reflected back from a connector, to the light launched into the cable within the same connection also measured in dB.

In the past, ferrule and fiber tolerances were not as tight as they are today to meet the demand for low insertion losses. To minimize the optical loss a technique called *Tuning* was commonly used. Low insertion losses would be obtained by orienting the fiber core to a certain position, typically it was aligned with the key direction of the connector. By orienting the fiber core offset (also known as concentricity error) of each ferrule in the same direction, the total lateral offset between the joining fiber cores can be reduced if compared with random orientation, thereby reducing the optical loss. This technique is only effective when the tuned connector is mated with a tuned connector when the fiber cores are rotated and placed in the same orientation. Therefore, mating a tuned connector with a standard one loses all of its advantages of low loss which is common in the field.

What are the most critical aspects of achieving low insertion loss measurements? Of course, making the assumption that the connectors are clean, free and clear of foreign particles and defects.

The most critical aspects are:

- **Ferrule hole diameter** – The ferrule is the most important component in a fiber optic connector that ultimately bears responsibility for optical loss values. For a minimum Insertion Loss, you should use the tightest-tolerance ferrule hole diameter available. For example, if the typical values for a single-mode fiber glass Outer Diameter (OD) are 124.5um to 124.9um the desirable ferrule Inner Diameter (ID) should be 125um to 125.5um.

- **Ferrule hole eccentricity** – Eccentricity is the linear distance between two similar parallel shapes. In this case it's a displacement of true ferrule hole center from its ideal position. The hole in the ferrule must be perfectly centered. If not, the fiber cannot be properly aligned.

- **Ferrule hole concentricity** – The shape of the bore hole must be round and in the center of the ferrule. If it has any ovality you deal with another variable called ferrule hole concentricity: an oval shape instead of perfectly round one, which will not hold an optical fiber in perfect alignment.

Therefore, it's important to use ferrules considering the above tolerances for optimum performance.

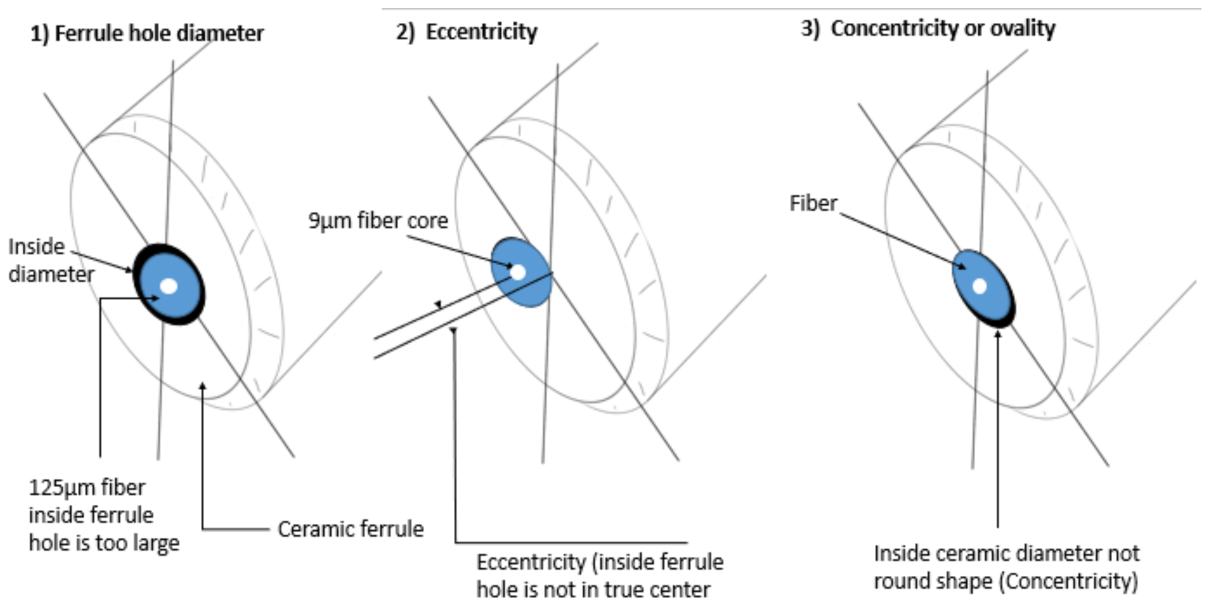

Figure 1: Examples of defects in ceramic ferrules that result in lateral misalignments.
Note, the images are exaggerated for demonstrative purposes

In fiber optics, to simplify the classical geometry definitions outlined in Figure 1, all three factors that contribute to a misalignment of the true positioning of the ferrule hole centered with respect to the outside diameter of the ferrule, referred to a *Concentricity Error.*

In simple terms the concentricity is the degree of deviation of the inner diameter of the ferrule hole from the center of the entire circle. The ideal state is zero, that is, no lateral offset. But in reality, there is an offset where generally single-mode ferrule concentricity is maintained below 1.0um. The single-mode ferrule requires its insertion loss ≤0.4 dB per GR-326 when lining up two terminated ferrules, the optical fibers must line up in order for light to be transmitted from one to another. Any amount of lateral misalignment (where one core is not concentric to another) will contribute to additional optical loss.

In SENKO a ferrule hole concentricity is measured as the difference of inside diameter center to outside diameter center (ID to OD). In this case the *Premium Low Loss* value considered to be ≤0.4 um, the *Premium Loss* value considered to be ≤0.6 um, and the *Standard Loss* value considered to be ≤1.0 um.

In addition, one needs to be aware about Random Mating. It is known that when you mate the connector and check the optical insertion loss in random mating scenario, the IL will be higher compared to measuring against a master jumper. A product such as a master jumper (or reference jumper) and a master adapter should be a jumper and an adapter that has absolute lowest possible manufacturable tolerances that typically achieved by hand selecting components. It is used as a base to measure and define the insertion loss of the tested product per testing procedures outlined in FOTP-171 and IEC 61300-3-4. It is commonly misunderstood that the IL tested with a master jumper is what you should be getting in the connection mating it inside the racks or any other field installations. When you use a master jumper and master adapter you are measuring your connection against a nearly perfect ferrule in a nearly perfect adapter. In a real-world environment, it’s very likely that you are not mating against a master jumper nor in a master adapter, but mating to a standard jumper and standard adapter often manufactured with varying quality and less strict specifications. It is known that a connector that has a guaranteed IL of 0.5dB against a master jumper can increase IL to as high as 1.00dB or higher in random mating (or roughly double) from the factory testing. To see the clear difference between a good connector and a bad connector, the Random mating method that is defined by IEC should be used.

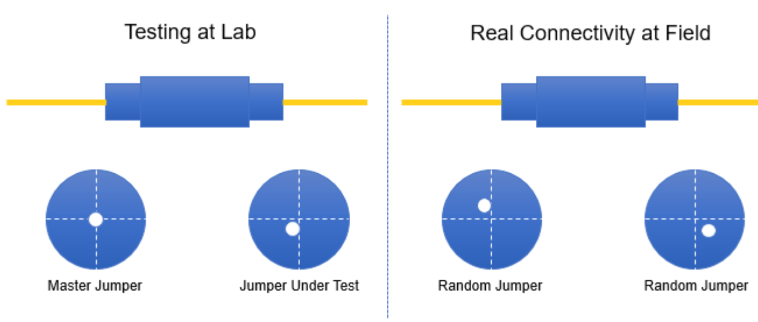

Figure 2 Testing against Master Jumper yields always lower IL due to minimized lateral misalignment between the cores. Note, the images are exaggerated for demonstrative purposes.

Insertion Loss criteria based on Random mating in the document IEC 61753-1 titled *Attenuation of Random Mated Connectors* which defines a certain minimum IL value of randomly mated connectors in a field setting and categorizes them into four different grades. It is important to note that the IEC 61753-1 defines connection performance grades for single-mode and multimode jumpers in a controlled environment. The standard gives four grades for IL from A (best) to D (worst) and RL, with grades from 1 (best) to 4 (worst). Grade "A" is not officially ratified by the IEC document, but most likely it will have similar optical performance reflected in *Table 1* below.

Attenuation Grade	Attenuation random mated IEC 61300-3-34	
Grade A*	≤ 0.07 dB mean	≤ 0.15 dB max. for >97% of samples
Grade B	≤ 0.12 dB mean	≤ 0.25 dB max. for >97% of samples
Grade C	≤ 0.25 dB mean	≤ 0.50 dB max. for >97% of samples
Grade D	≤ 0.50 dB mean	≤ 1.00 dB max. for >97% of samples
Return Loss Grade	**Return Loss Random mated IEC 61300-3-6**	
Grade 1	≥ 60 dB (mated) and ≥ 55 dB (unmated)	
Grade 2	≥ 45 dB	
Grade 3	≥ 35 dB	
Grade 4	≥ 26 dB	

Specification	Each-to-each values	Budget for 10 connections
0.1 dB connector	approx. 0.2 dB (possibly higher if different manufacturers are combined or unadjusted connectors are used)	approx. 2 dB, unclear range of tolerance
Grade C	Mean ≤0.25 dB, Max ≤0.50 dB	≤2.5 dB
Grade B	Mean ≤0.12 dB, Max ≤0.25 dB	≤1.2 dB
Grade A*	Mean ≤0.07 dB, Max ≤0.12 dB	≤0.70 dB

Table 1: IEC 61753-1 Proposed Attenuation Grade Jumpers

* Note, Grade A is not specified at time of writing, but assumed to be as shown

At SENKO, we are continuously pushing the limits with our ferrule technology to achieve lower losses. When defining your network budget needs, it is important to know what optical losses are required. While using the top-of-the-line premium ferrules will help achieve the lowest loss, it may not always be needed. For example, using a *Standard* ferrule from the table below you will achieve a Random Mating mean loss of ≤0.50dB which may be acceptable for your application.

CONNECTOR TYPE	IL AGAINST MASTER	IL RANDOM MATING	IL RANDOM TUNED
Unibody Premium Low Loss	≤ 0.05dB Mean/≤0.15dB Max	≤ 0.12dB Mean/≤0.25dB Max	≤ 0.02dB Mean/≤0.14dB Max
Unibody Premium	≤ 0.08dB Mean/≤0.20dB Max	≤ 0.15dB Mean/≤0.30dB Max	≤ 0.04dB Mean/≤0.17dB Max
Standard UPC	≤ 0.12dB Mean/≤0.30dB Max	≤ 0.25dB Mean/≤0.50dB Max	N/A

Table 2: SENKO Ferrule Loss Specifications

In order to establish specification base for high performance grade connectors, SENKO performed a study per an IEC61300-3-34 standard Examinations and measurements – Attenuation of random mated connectors:

Scenario 1 - Testing Jumpers with premium ferrules against Master Jumpers.

Scenario 2 - Testing Jumpers with premium ferrules against Jumpers with premium ferrules.

This would in turn represent a random mating scenario. A quantitative analysis using theory of probability was employed. First estimating expected losses based on the required mechanical tolerances for ferrule fiber hole diameter and concentricity error. The results were compared and determined at what ferrule tolerance threshold the loss differences are minimized between the two scenarios.

For theoretical values the following calculations were considered when estimating IL due to lateral misalignments.

The equation used:

$$\text{IL (dB)} = -10 \log e^{-U^2}, \text{ where } U = \frac{\chi}{\omega o}$$

χ = core misalignment;

$$\omega_o = \alpha(0.65 + \frac{1.619}{V^{1.5}} + \frac{2.879}{V^6})$$

ωₒ –single mode fiber (SM) spot size determined empirically with α as a fiber core radius and V as a normalized frequency – dimensional number used to describe the characteristics of SM fibers, depending of refractive indexes of fiber core/cladding.

Theoretical calculations were analyzed and correlated to an actual data set in order to develop ferrule required dimensional tolerances that satisfy the Grade B condition in Table 1. Below in Figure 3 is empirical data that shows the optical losses for the premium LC/APC ferrules that make Scenario 1 and Scenario 2 relatively close.

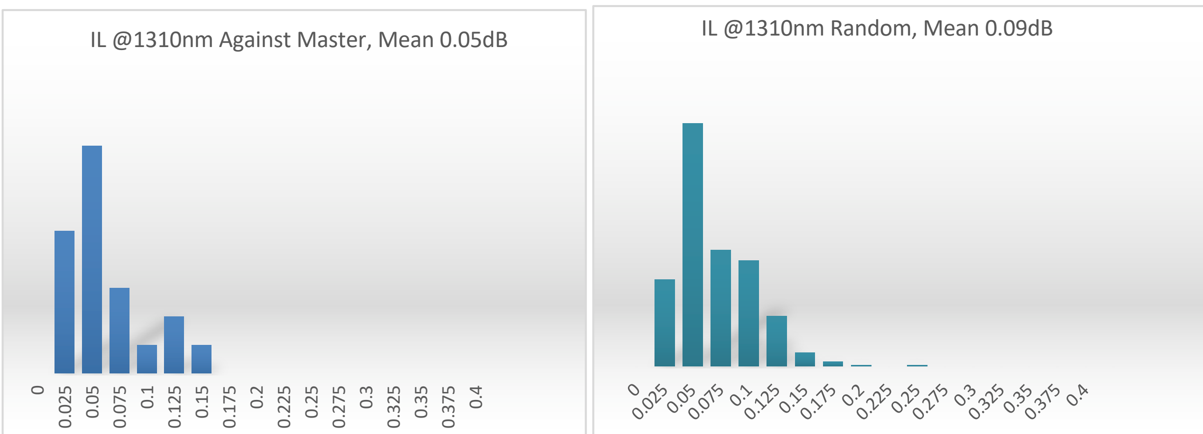

Figure 3: Test data of Premium 1.25mm LC/APC connectors against Master (Mean 0.05dB) and Random mating against each other (Mean 0.09dB).

During the study, it was determined that the fiber, and especially, the ferrule dimensional consistency was the key element in achieving low IL results. As seen in Table 2, the ferrule ID tightness and the concentricity value play an important role in achieving low losses. Through a series of experiments, SENKO has developed optimum specifications for the ferrules that exhibit premium optical losses in random mating scenarios, and yet can be relatively cost effective. SENKO emphasizes that in order to achieve this result manufacturing processes of jumper assemblies must be also under strict control and compliant to GR-326-CORE requirements in order to consistently produce the polished ferrule geometry and desired IL results that are required in today's high-end fiber optic cabling market.

Total		Pass (IL<=0.25dB)		Pass Rate >97%		Average<0.12dB	
1310nm	1550nm	1310nm	1550nm	1310nm	1550nm	1310nm	1550nm
360	360	360	360	100.00%	100.00%	0.06	0.05

Table 3: LC in Random mating with ferrule ID 125.0-125.8um and concentricity ≤0.3um

The ferrules with the *Premium Loss* will have slightly higher concentricity (0.5um vs 0.3um) and thus are expected to have a slightly higher IL averages without tuning. With Senko Premium connectors by adding the ferrule tuning technique it is possible to exceed the Grade B Loss requirements.

3.0 Conclusion

SENKO offers a range of specifications including Premium Low Loss, Premium, and Standard connectors that offer varying loss specifications. At SENKO we encourage our customers to purchase quality connectors that offer the tightest tolerances for ferrule hole diameter, ferrule hole concentricity, and ferrule hole eccentricity, but also what meets your optical budget needs.

To achieve the best results, it is important to note that the fiber itself should have core/cladding concentricity close to zero and factory termination processes must be GR-326-CORE compliant. When your manufacturing processes use connectors that meet stringent tolerance requirements, you are positioned to build world-class fiber optic cable assemblies that deliver performance and long-term reliability. We suggest you contacting SENKO representative if you have any additional questions.

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