Splice Loss Estimation with the Fujikura 41S Fusion Splicer

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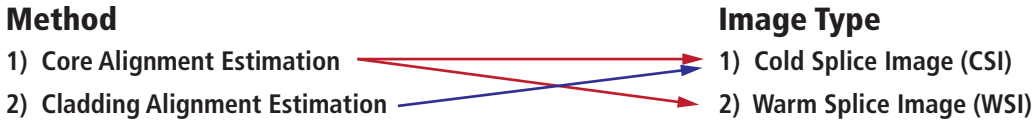
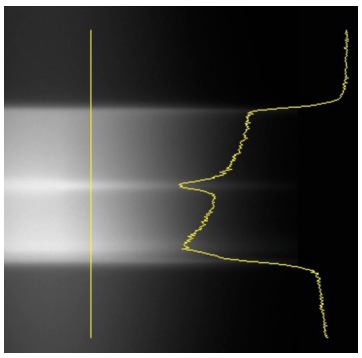
Splice Loss Estimation is an attempt by the splicer to gauge the amount of optical power dissipated at the splice joint by analyzing the profile image of the newly-fused fiber. This is common knowledge for fiber optic technicians in today's industry. However, knowledge is lacking in regard to differing splice loss estimation methods. Not all splicers use the same estimation technique, nor do they possess the same level of accuracy or precision. This white paper will not deliberate on details for all loss estimation techniques and their applications, but introduce the larger categories at an introductory level to better explain the context of how Fujikura's 41S splicer estimation technique falls within the spectrum.

The two high-level methods below are achieved by using one of two different image types. The diagram below shows the possible combinations.



Brief definitions for these methods and image types are as follows:

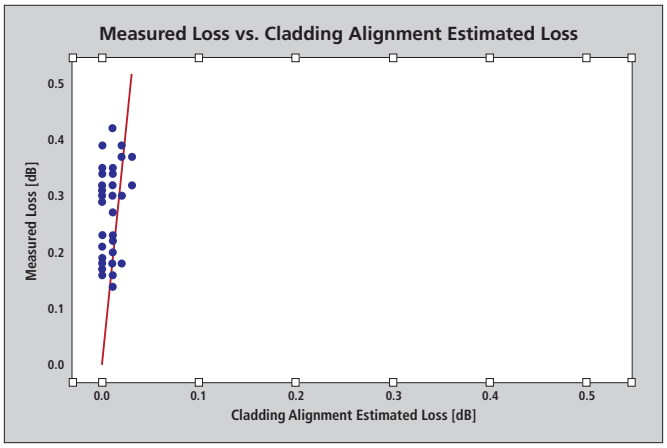
1) **Core Alignment Estimation:** The splicer has the ability to properly locate a fiber core's center, therefore detect how well the newly fused fiber's previous two cores are aligned as one. Then provide an estimate on light lost due to imperfections in the core at or near the splice joint.
2) **Cladding Alignment Estimation:** The splicer does not have the ability to accurately detect the location of a fiber core's center, therefore provides a loss estimation based on the alignment of the outer diameter of the fiber cladding.
3) **Cold Splice Image:** Image of a fiber with a Profile Alignment System (PAS) at room temperature. This is the fiber image you see on the splicer screen before and after a splice.
4) **Warm Splice Image:** Image of a fiber with a Profile Alignment System (PAS) as the fibers are fusing together.

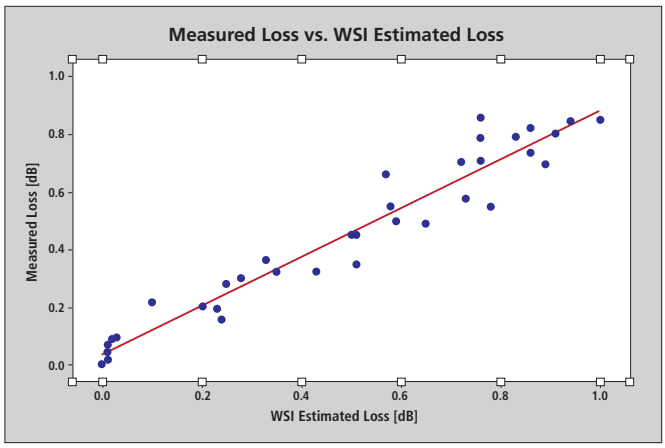


Traditionally, field splicers have only utilized CSIs for loss estimation; and as a result, splice loss estimation application was much simpler – core alignment estimation or cladding alignment estimation. Previously, WSIs have only been applied with factory splicers to aid in viewing fiber cores with unique constructions. WSIs take advantage of the fact that fiber cores contain thermoluminescent materials, which is the technical term for explaining that a fiber core which contains dopant materials glows brighter than the fiber cladding while exposed to heat. The difference in brightness causes the fiber core to be distinguishable from the cladding. The WSI at right helps explain this phenomenon.

Fujikura, once again, is leading the charge in innovation by introducing WSIs with an active cladding alignment splicer in the 41S model. The reason for this introduction is that the success of the loss estimation technique used in a given splicer is critically dependent on the quality of the optical system within the splicer. For instance, a true "core alignment" splicer, from one of the major Japanese brands, features the highest grade of optical systems and ergo will give you the most accurate loss estimation. With only a CSI, they are able to accurately detect alignment of the newly fused fiber core. Cladding alignment splicers, both active and fixed V-groove, have much lower grade optical systems and are not able to identify the fiber core center with a CSI. With the help of a WSI, the active cladding alignment 41S with a lower grade optical system is able to sense the core's location, essentially providing a low quality core alignment estimation.

The splice loss data below was gathered during a general study to asses, at a high level, the performance improvement of the 41S loss estimation with WSIs compared to standard cladding alignment estimations. These two splice loss data sets were acquired with the 41S splicer for SMF-to-SMF splices containing various loss attributing factors.

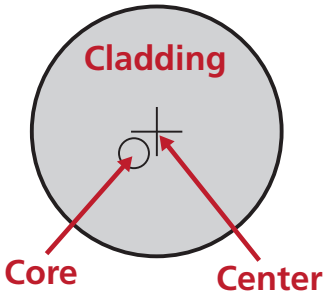




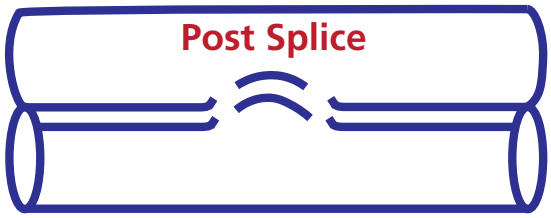
For this type of graph, if the estimated loss was exactly the same as the measured loss for every splice, you would see all points fall on a linear 1:1 line. With this in mind, you can see the measured vs. cladding estimations are nowhere near this ideal plotting. The cladding estimations are highly skewed toward zero (0) even though the measured loss values vary. The measured vs. WSI estimations, while containing marginal error, trend in this ideal direction for a wide range of loss values. The accuracy appears to stray further from the regression line as you increase beyond 0.5 dB, but still follows the desired linear trend.

A further study was also performed to analyze the average percent error from WSI estimations under the two most common loss contributing factors in the field; core/clad concentricity and core curve. These two loss inducers were tested with G.652.D to G.652.D (SMF-to-SMF) and G.652.D to G.657.A1 (SMF to Bend-Insensitive Fiber) fiber combinations.

1) **Core/Clad Concentricity:** This is a fiber geometry error where the fiber core center is not in the exact center of the fiber cladding.



2) **Core Curve:** This refers to a core that has curvature as opposed to a line, but is still connected.



Core/Clad Concentricity is a result of imperfect fiber manufacturing processes and is present in all fibers. For example, the Telcordia GR-20 specification for optical fiber references a maximum Core/Clad concentricity error of 0.5 µm. This means that the center of the fiber core is 0.5 µm or less away from the fiber cladding center in any radial direction. When two fibers that have this intrinsic error are spliced together, the total core offset between the two can be either additive or subtractive, e.g. a total offset of 0 µm or 1.0 µm if both have exactly 0.5 µm of error. Core Curve is the result of bad fiber end-faces from either poor cleave angles or cleave defects. This causes the core to bend in a given direction as the fibers are fused together. Both loss conditions were tested at the higher end of possibility for both GR-20 and the splicer's internal cleave error alarms to assess the WSI estimation quality when it's needed most. These two loss inducers were tested with G.652.D to G.652.D (SMF-to-SMF) and G.652.D to G.657.A1 (SMF to Bend-Insensitive Fiber) fiber combinations.

G.652.D - G.652.D			
	High Offset Only	**High Offset and Cleave Angle**	
Average Percent Error	20.2%	18.9%	**WSI**
Standard Deviation	15.8%	12.1%	
Average Percent Error	97.8%	96.3%	**Clad**
Standard Deviation	2.8%	3.7%	

G.652.D - G.657.A1			
	High Offset Only	**High Offset and Cleave Angle**	
Average Percent Error	22.0%	37.0%	**WSI**
Standard Deviation	16.9%	28.2%	
Average Percent Error	96.5%	98.4%	**Clad**
Standard Deviation	3.7%	1.7%	

These results tell us a few things, first and most importantly that using a WSI to sense the core's location in a low grade optical system is a far more accurate estimation method than cladding alignment estimations alone with a CSI. Secondly, 41S WSI estimations seems to track more accurately for standard SMF as opposed to Bend-Insensitive Fiber, especially when core curvature is introduced. The current theory behind this indication is due to the different dopant concentrations that exist between G.652.D and G.657.A1, causing the G.657.A1 to glow more brightly than G.652.D and possibly obscuring the splicer's view of the core. Lastly, the standard deviations indicate that 41S WSI estimations follow a wider distribution as opposed to being skewed in a single direction as is the case for cladding alignment loss estimations. This tells us that as measured losses continue to rise, cladding alignment loss estimations will not rise proportionally, so it is very possible to have estimates of 0.02 dB with measured losses ≥0.4 dB, while the 41S WSI loss estimations guarantee much more accurate trending as actual loss values increase. As a caveat, while results for this testing are positive, this is only a portion of possible fiber combinations and loss generating conditions, which means this study does not guarantee the same performance for all possible field conditions.

In conclusion, the relevance and benefit of splice loss estimation in active cladding alignment splicers is changing with Fujikura's implementation of WSI loss estimation in the 41S. This increased estimation accuracy gives operators a better tool to gauge the quality of their splice before wasting time testing and performing splicing rework. Whereas before it was a mystery as to what your actual splice loss would be with an active cladding alignment splicer, you now have confidence that an estimated low loss splice is in fact a low loss splice.

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