Fiber Optic Splice Optimization

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Abstract

Optical fibers transmit data when light waves are propagated through them. Optical fibers have many applications at LLE, such as the fiber-optic switch module in the ROSS streak camera.[1] It is often necessary to splice two fibers together by a process called fiber-optic fusion splicing. There are two significant sources of optical power loss in a fiber: unoptimized splices and losses contributed by the connectorization of the fiber ends. In order to ensure that a splice is optimized it is necessary to have an apparatus that will measure just the loss of optical power caused by the splice, account for power fluctuations of the laser used to test the fiber, and do so accurately enough to measure low loss. A ratiometer was constructed that measures only the power loss induced from the splice and can measure losses as low as 0.5%. The ratiometer splits the beam into two paths. One path serves as the reference (reference fiber), and the other path contains the fiber being tested (fiber under test). Each fiber has a connector on both ends. Samples of power measurements are made before and after a fusion splice. This sampling process allows the energy loss contribution of the connectors to be eliminated. Using the ratiometer, an amended fusion-splicing program has been shown to reduce the loss in a splice from between 1.0 dB (20%) and 2.6 dB (45%) to 0.1 dB (~2%).

I. Introduction

Fiber splicing is a process by which the cut ends of two optical fibers can be attached together, resulting in one physical piece of fiber optic cable. Fusion splicing[2] involves aligning the fiber cores, heating the two ends, and pushing them together. There are some alternatives to fusion splicing. Mechanical splicing can be used; however, there is an alignment loss involved with the mechanical splice process. Fusion splicing, when optimized, is the best way of connecting two fibers because it minimizes optical power loss. The theoretical limit for an optimized fusion splice is a power loss of less than 0.01 dB (0.23%).

Some of the most common factors that contribute to a high-loss fusion splice are low arc power, excessive arc power, incorrect arc duration, uneven heating, and incorrect hot-push delay. Low arc power or incorrect arc duration will cause insufficient heating of the fiber. This causes a visible seam in the final splice. This seam acts as a reflective and refractive surface which in turn creates a high-loss splice. Excessive arc power will cause deformation in the core of the fibers. Deformation of the core changes the refractive index at the splice, which can also cause a high-loss splice. Uneven heating occurs when one fiber is heated and the other is not. This will cause the fiber to fail during the tension test, i.e. a brittle splice joint. Incorrect hot-push delay settings can cause the fibers to continue being heated when they are pushed together. This will cause the fiber to deform at the splice joint. The diameter of the fiber at the splice often changes under this condition, again leading to a high-loss splice.

The current fusion-splice program used at LLE for multimode fibers was designed for single-mode fibers of smaller core diameters. When applied to multimode fibers, where the core diameter is larger, the splice process caused a visible and often warped seam. The appearance of this seam indicated low arc power, incorrect hot push settings, or possibly both. In order to optimize the fusion splicing process, the program must be modified, and a ratiometer is needed to test the results. This project involved the construction of a ratiometer to measure the optical power loss from fusion splices and its preliminary use to test an improved fusion-splice program.

II. Procedure

A Fitel[3] S183PM fusion splicer was used for the fiber-optic fusion splicing. The splice process starts with precision alignment of the cores of the fibers. The S183PM does this by passing light orthogonally through the fiber core and recording the output with a CCD camera installed on the fusion splice machine. Light that passes through the center of the core will be un-refracted and the resultant output light intensity will have a Gaussian type distribution with the peak of the distribution curve corresponding to the center of the fiber core. The core location is then calculated and aligned appropriately. The aligned fiber ends are then heated by an electrode arc shot across the ends of the fibers. The hot push brings the fibers together while the fiber ends are in the molten state. Improperly heated fibers will not bond well during the hot push. An optimized splice will have no visible seam through the core; i.e., the splice joint will look homogeneous.

The ratiometer illustrated in the block diagram of Fig. 1 was developed in order to test the loss from the splice and not from the connectors or any other source of potential error. The apparatus starts with a green laser (532 nm) as the light source, followed by a lens used as a fiber launcher to fill the fiber with higher order modes. Filling the fiber with higher order modes replicates how the fiber would be used in a typical application at LLE. The splitter is used to split the beam into two paths. Both sides are followed by a photodiode, so that the light is turned into measurable voltage. The ratiometer measures the ratio between a reference fiber, which is not moved or spliced for the duration of the experiment, and the fiber being tested. The other side of the ratiometer holds the test fiber. The light transmitted across the fiber is sampled twenty times. The fiber is then cut and spliced and sampled again another twenty times. By using sample statistics, the mean loss due to connector misalignment can be calculated. Subtracting this loss from the overall power loss of the spliced fiber will yield the loss component due to the splice.

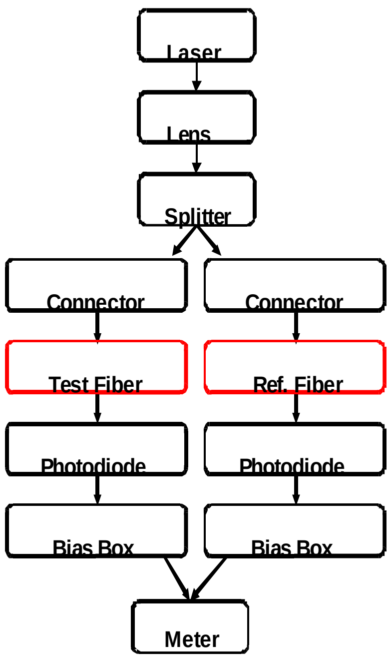

Fig. 1. Block diagram of the ratiometer used to test fiber splices.

III. Results

Results from twenty samples of an un-spliced fiber using FC connectors are shown in Fig. 2. An oscilloscope and meter were both used for simultaneous data collection. Statistics of the 20 samples from the scope and meter should yield similar results, i.e. they should track each other. This eliminates the possibility of one measuring device being “bad”. Data from the reference fiber was also collected and used for the final data comparison. The reference data were recorded every time that sample data were taken. Statistics were also applied to the reference samples in order to calculate mean laser power. The distribution of the reference samples was very narrow and 20 samples resulted in a mean calculation that was equal to the true laser power to a high accuracy. The very small variations in the signal obtained using the meter and scope show that the transmission through the fiber can be measured to an accuracy of better than 0.5%. This allows the loss due to the splice to be measured to an accuracy of 0.5%.

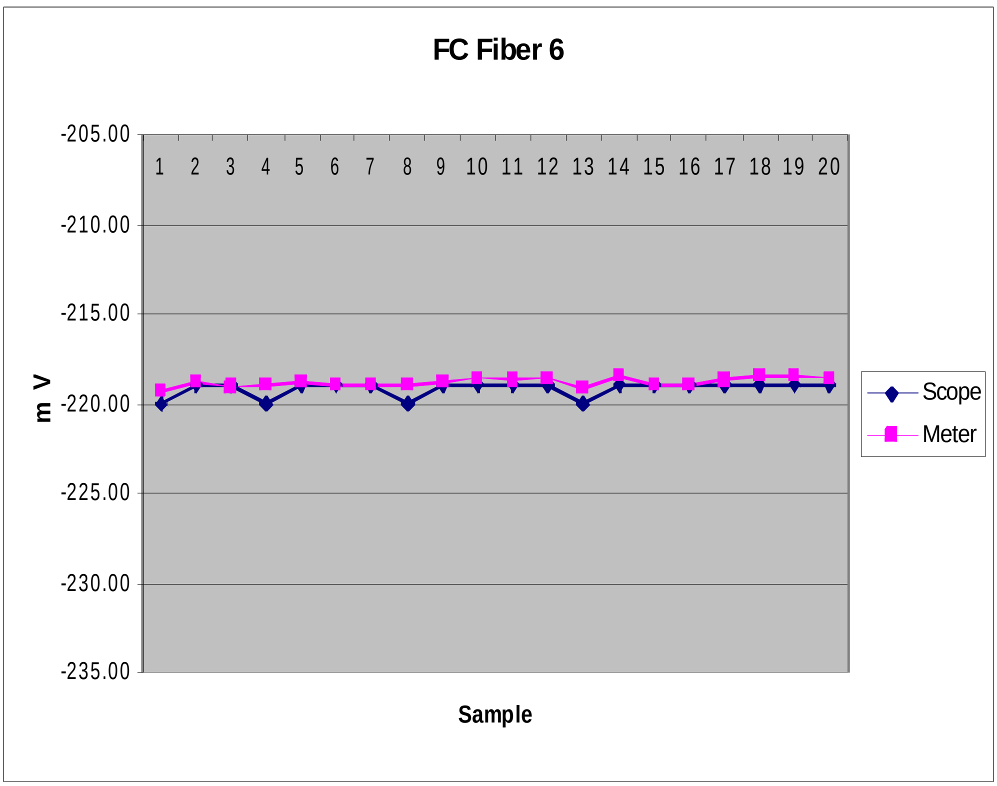

Fig. 2. Signal representing the light transmitted through an optical fiber measured on 20 consecutive samples. The fiber was disconnected and reconnected between samples. The fiber used FC connectors. The consistency of the meter reading allows the fiber transmission to be measured with a 0.5% accuracy.

In contrast, results for an un-spliced fiber using SMA connectors are shown in Fig. 3. Here the large variations between samples (up to 10%) demonstrate that the transmission through fibers with these connectors cannot be measured with the desired accuracy.

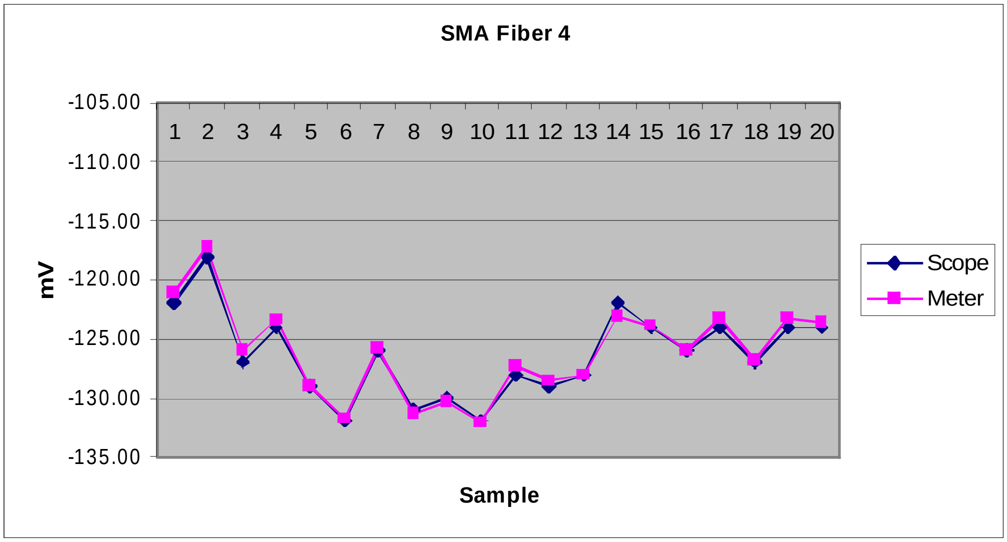

Fig. 3. As Fig. 2, but for a fiber using SMA connectors for accurate measurements of fiber transmission.

The FC connectors are keyed, meaning that they align to approximately the same position every time they are connected, unlike the SMA connectors. The FC connectors were therefore used in subsequent experiments to optimize the fusion splicer program.

The program was modified by increasing the end power setting of the arc from 100 to 175. The arc duration was also increased from 3000 ms to 3200 ms. Overall, the average normalized arc power was raised from 300 to 440. Results for a test fiber are shown in Fig. 4. The navy blue and yellow plots are for the reference fiber, pre and post splice respectively. The pink and light blue plots are for the test fiber, pre and post splice respectively. The overall loss of this optimized splice was measured to be 0.117 dB. Since the previous fusion splicer program resulted in a loss of 20% – 45%, the modifications to the program resulted in a decrease in loss from the splice by about a factor of 10, a large improvement.

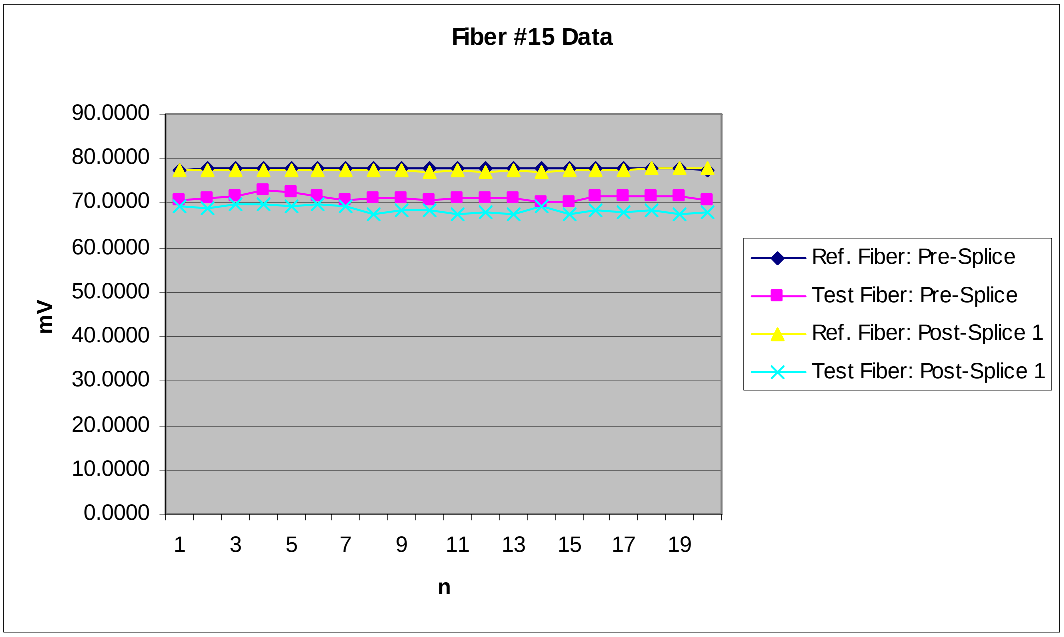

Fig. 4. – Data plots of reference and test fiber pre and post splice. N = 20 sample points. The overall optimized splice loss is calculated as 0.117 dB.

IV. Conclusions

A ratiometer was constructed to accurately measure the transmission loss in a fiber due to a fusion splice. Initial tests found that it was impossible to obtain consistent results from fibers using SMA connectors, so FC connectors were used instead. It was found that the transmission through a fiber with FC connectors could be measured to an accuracy of 0.5%.

The ratiometer was then used to evaluate changes to the fusion splice program by measuring the transmission before and after the splice. The modified program showed significant improvement, reducing the loss due to the splice by a factor of 10. The process is still not fully optimized and more improvements need to be made for the splices to have the minimum loss possible.

IV. References

1. P.A. Jaanimagi, R.Boni, D. Butler, S. Ghosh, W.R. Donaldson, and R.L. Keck, "The Streak Camera Development Program at LLE," in 26*th* *International Congress on High-Speed Photography and Photonics,* edited by D.L. Paisley, S. Kleinfelder, D.R. Snyder, and B.J. Thompson (SPIE, Bellingham, WA, 2005), Vol. 5580, p. 408.

2. A.D. Yablon, "Optical Fiber Fusion Splicing", Springer 2005

3. Fitel Inc., 200 Westpark Drive, Suite 190 Peachtree City, GA, 30269 USA