Automated Fusion Splicing of Circular and D-shaped Fiber with Elliptical Core

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A new method for splicing D-shaped and circular shaped PM fiber with elliptical core using an automated fusion splicer is described. A Fujikura FSM-45PM splicer is used with new alignment techniques developed for achieving consistent splice loss less than 0.5 dB and Polarization Extinction Ratio greater than 25 dB. This process has been implemented into a commercial product and sold in the fiber market.

1. Introduction

Polarization maintaining optical fiber was developed over two decades ago [1)], and recently has been gaining wider and wider applications in many different areas. A small branch of PM fiber with elliptical core is often referred as E-core fiber. Some of E-core fiber does not have circular cladding shape. Instead, a D-shaped cladding shape was developed [2)3)] as shown in Fig. 1. Although E-Core and D-fibers are not as widely used as PANDA fiber [4)5)], they are still used in specific applications [6)]. PANDA fiber provides a history of excellent performance and can be spliced easily with low splice loss and highly accurate automatic polarization alignment. E-Core and D-fibers are challenging to splice compared to PANDA and have limitations due to their h-value polarization characteristics.

As a splicing technology development team, we need to develop a consistent and time efficient D-fiber splicing process for the production lines of fiber positioning devices, fiber amplifiers, etc to meet our customer's requirement. Two primary challenges in low loss fusion splicing of E-core and D-fiber are polarization and fiber core alignment. Many methods and approaches were developed and tested for splicing different polarization fiber types [7)8)] and rare earth doped active fibers [9)]. Only a very limited number of publications discussed E-core fiber and D-shape fiber splicing. One recently published paper reported D-fiber splicing using manual control [10)]. In this paper, D-fiber has been spliced to Panda fiber using E-core fiber in a bridge splice. First, a Panda fiber is spliced to E-core fiber, and then the E-core fiber is spliced to the D-fiber. E-core fiber is chosen as the bridge fiber because its circular cladding matches with Panda fiber, and its elliptical core matches with D-fiber. The E-fiber core is expanded to match the mode of the Panda fiber, and the D-fiber is connected to the E-core fiber using a low temperature splice. Using this previous method, the polarization alignment was performed manually resulting in time consuming extinction ratio measurements. This process can be done in a laboratory setting, but it would be costly in both equipment and labor time for production which is not yet a refined process ready for use in a production environment.

In addition to the rotational alignment and exact discharge timing for core expansion control, we have to deal with one more major issue for D-shaped fiber splicing [11)]. When observing a length of D-fiber it is seen to be slightly bowed (curled) when suspended from one end. The effect is caused by the mismatch in thermal expansion between the silica body and the doped guiding region. This characteristic of D-fiber presents challenges in cleave end face quality, splicer rotational alignment, and low splice loss.

In this article, new methods using automatic splicer rotation and power meter feedback are described. Average alignment and splicing time of 2 minutes, less than 0.5 dB average splice loss and higher than 25 dB

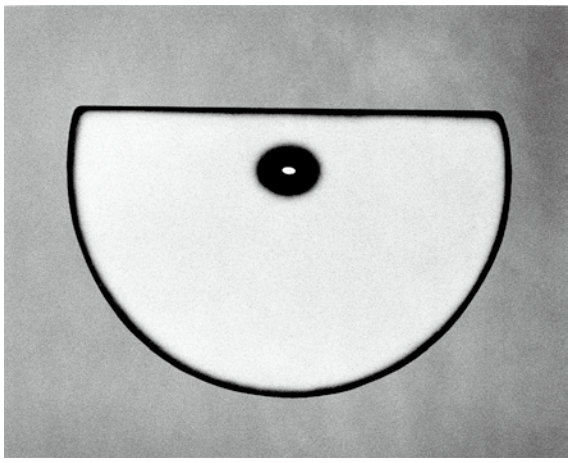

Fig. 1. Cross section of a typical D-shape fiber with an elliptical core.

1 AFL Telecommunications

Panel 1. Abbreviations, Acronyms, and Terms.

PM—Polarization Maintaining
E-core—Elliptical core
PANDA—Polarization Maintaining and Absorption Reducing
ER—Extinction Ratio
PER—Polarization Extinction Ratio
PAS—Profile Alignment System
LED—Light-Emitting Diodes
dB—decibel

polarization extinction ratio were achieved consistently for both D-fiber and E-core fiber.

2. Fiber preparation

To reduce the size of optical modules, 80 micron diameter fibers are normally used. It is a great challenge to achieve reasonably good fiber end cleaving angle due to the special shape of 80 μm D-fiber. With a Fujikura CT-38 cleaver D-fiber is cleaved using a specific method. The D-fiber is aligned in the fiber holder visually so the flat surface of the D-shape is facing upward by observing maximum brightness reflecting off the surface. This ensures that the cleaving blade contacts the circular portion of the stripped fiber resulting in the best cleave quality. This technique produces adequate facet smoothness and cleave-angles less than 2 degrees.

However, in order to load the fiber in a correct position into fiber holder, operator needs to rotate the fiber in the fiber holder a few times. When the fiber is fully clamped by lid of the fiber holder, the fiber cannot be rotated anymore. If the lid is open, the curled D-fiber will be released and hard to control by hand. So, a special fiber holder is modified with split lid (see Fig. 3). The small lid will only hold the D-fiber in its position and not prevent from rotating of fiber. When the D-fiber is rotated to a desired position, the main part of lid will be closed, which in turn locks the small

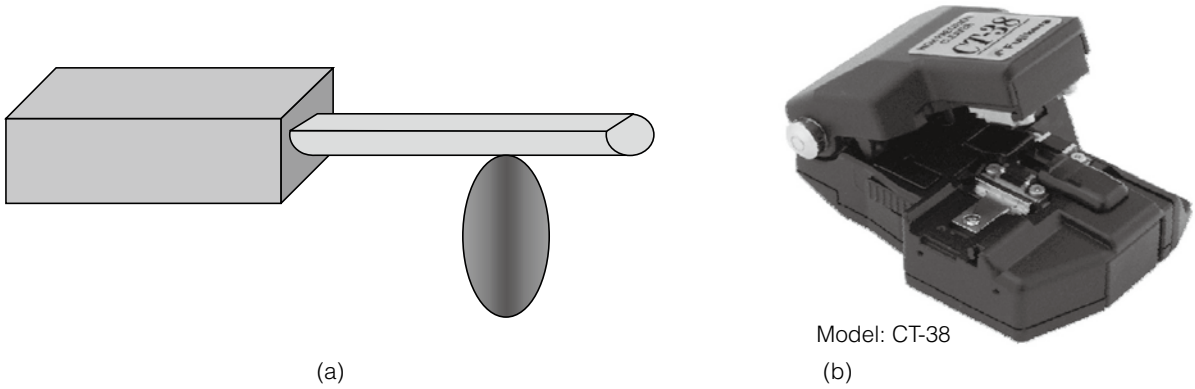

Fig. 2. D- fiber is clamped with flat surface upward (a) in a custom designed cleaver for 80 μm fiber (b).

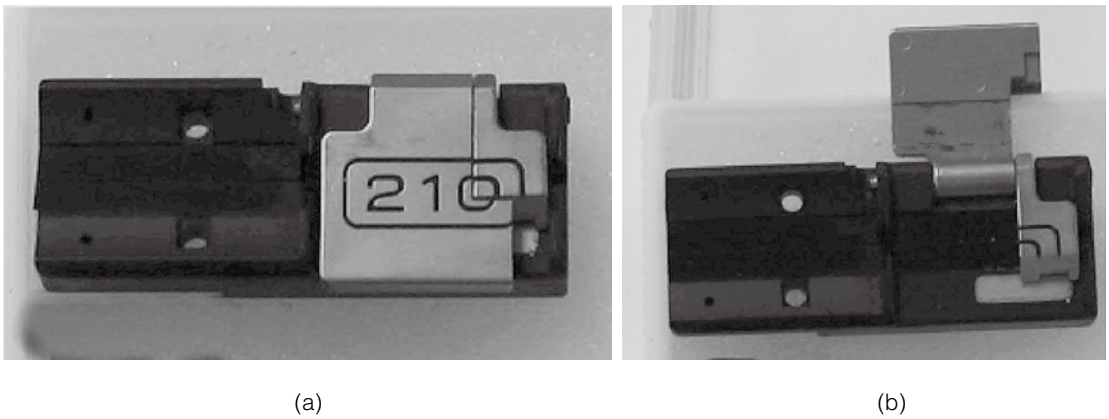

Fig. 3. Modified fiber holder with split lid. (a) Both lids closed and locked. (b) Small lid closed for adjusting fiber position.

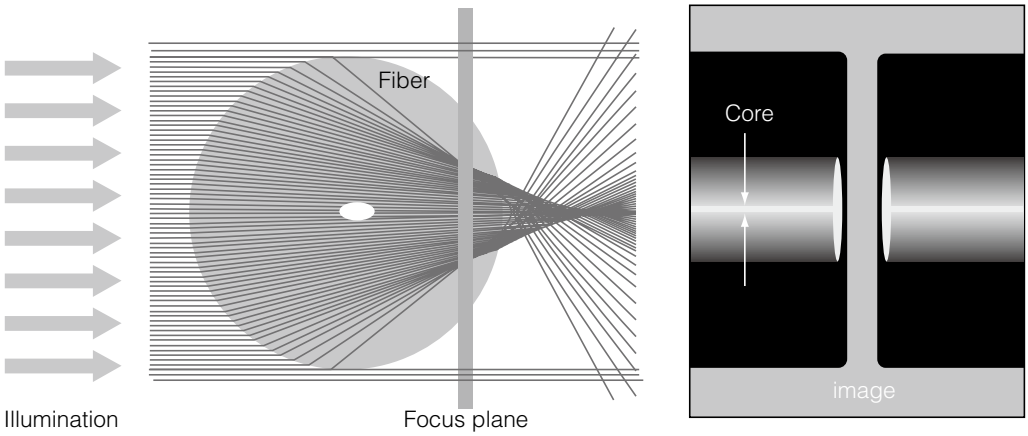

Fig. 4. Ray tracing of profile alignment system (PAS) for E-fiber alignment.

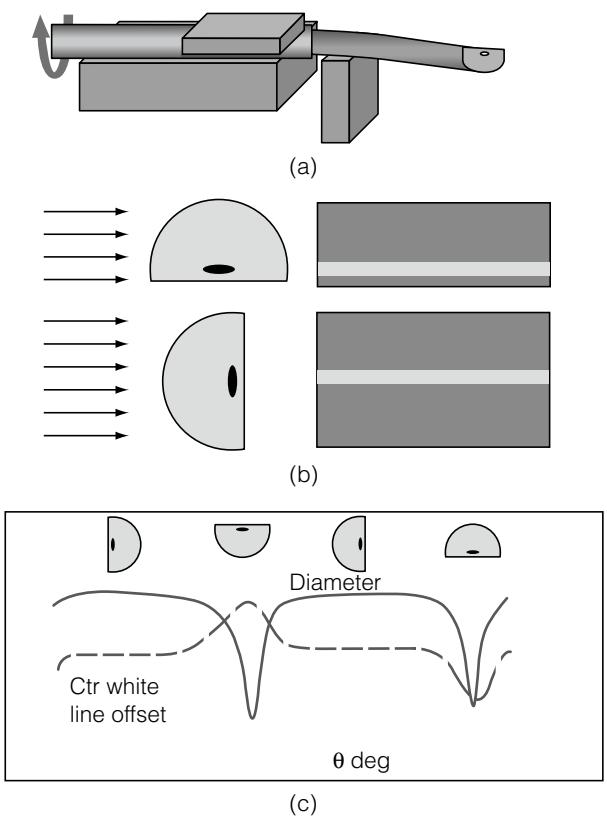

Fig. 5. D-fiber is automatically rotated with fiber holder (a) and alignment with image processing techniques (b) and (c).

lid and the fiber for cleaving and splicing.

3. Fiber alignment and splicing

The PM fiber alignment consists of two major goals: polarization axis alignment and core alignment. The polarization alignment addresses the highest possible extinction ratio (ER) between the two perpendicular polarization modes. The core alignment reduces the splice loss due to core offset and deformation. These two alignments are critical, and it is a time consuming and labor intensive process if performed manually. With software modification to a commercially available splicer, we have demonstrated polarization and core alignment can be successfully automated.

3.1. Polarization alignment

For optical fibers with circular cross section, the polarization axis can be aligned with a special technique using the light intensity profile when the fiber is illuminated from one side (see Fig. 4). With a camera imaging system, the image can be analyzed and the width of the core can be calculated. When the E-core fiber is rotated, the width of the elliptical core can be measured from image by profile alignment system (PAS) in the splicer. Depending on the customer requirement, the fiber rotational position with maximum or minimum core width will reflect the position of polarization axis.

However, the polarization axis cannot be aligned using this technique for D-shape fiber, since its core is not visible for most fiber orientation angles. A new process is developed to align D-fiber. First, the D-fiber is rotated 0° - 200° and using the image profile of the cladding diameter, the fibers are aligned to the minimum diameter. Since there are two minimum points within the 360° rotation, the central white line of the fiber image is used to identify the desired point. The fiber acts as a cylindrical lens under the side illumination and a central white line appears as shown in Fig.5 (b). In this image the central white line does not represent the fiber core as the focus plane has been adjusted to the profile of the D-fiber. By iteratively releasing the clamps and adjusting v-groove height with software control, it is possible to rotate the D-fiber in v-groove within the field of view and record image profile. Once this step is complete, an automatic power meter feedback method is implemented for optimal core alignment. This method is tolerant to eccentricity and slight inconsistencies of the D-fiber.

3.2. Core alignment and splicing

Most polarization maintaining fibers have stress

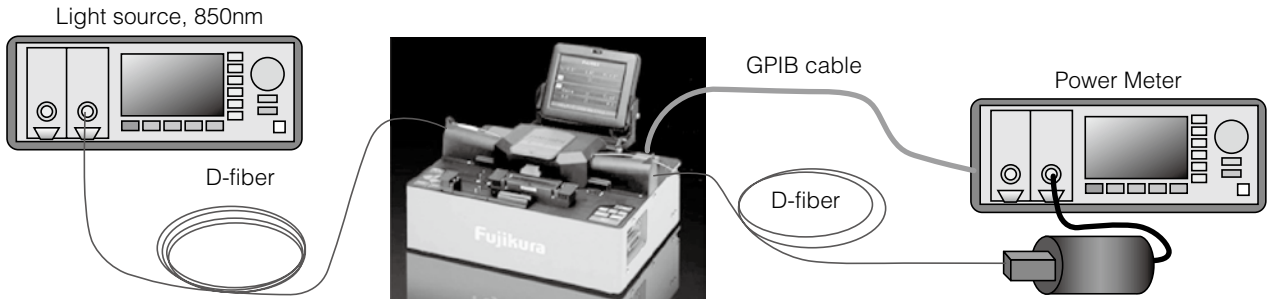

Fig. 6. Setup for D-fiber core alignment and splice loss measurement.

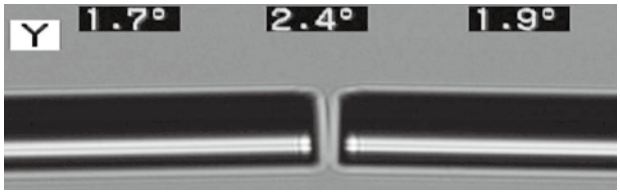

Fig. 7. Large view angle (2.4 deg) due to fiber curl.

Fig. 8. After splicing, D-shape preserved.

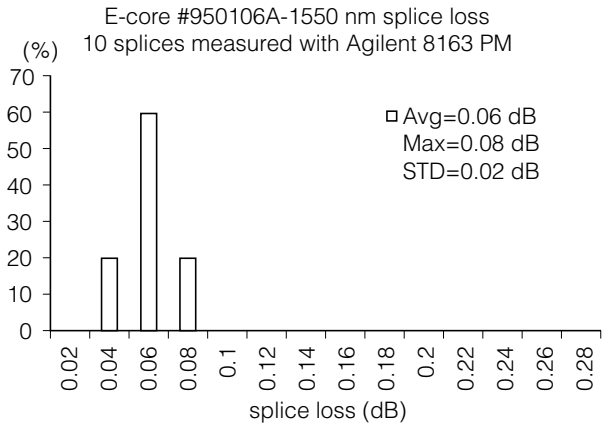

Fig. 9. Splice loss distribution of 85 μm E-core to E-core fiber splicing.

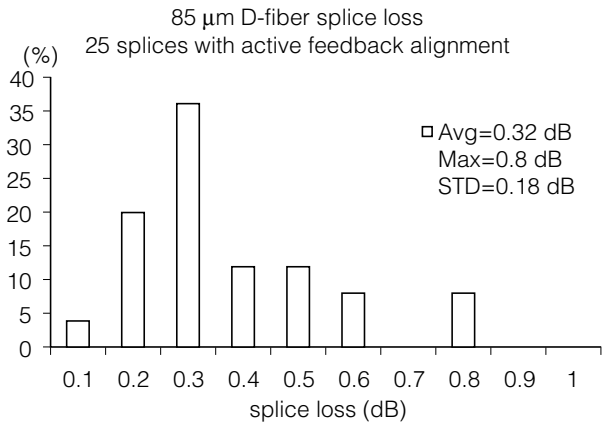

Fig. 10. Splice loss distribution of 85 μm D to D fiber splicing.

rods or elliptical jacket in the structure of cladding. These structures in the cladding make the fiber core invisible during angular rotation and thus core alignment is impossible. However, elliptical core fiber is the only PM fiber in which the fiber core can be observed in any direction. So, the standard core alignment process of PAS method would work reasonably well. The splice loss of E-fiber can be very well controlled.

For D-fiber splicing it is completely different. Its core is invisible and the PAS core alignment method does not work. We measured more than 1.3 micron core to cladding concentricity error in the end-view of D-fiber. Thus, cladding alignment will not work either. So, we have to modify the software to do active power meter feed back for the core alignment. The equipment setup for this feedback alignment and loss measurement is shown in Fig. 6. In addition, D-fiber is very sensitive to arc power and duration. In order to preserve the D-shape, prevent excessive rounding and core deformation at the splice region, several parameters are adjusted. Short cleaning arc (80 ms at 0 bit), Pre- fusion is turned OFF, and Short Arc 1 Time (250 ms at 0 bit).

It was observed that fibers move or 'jump' slightly at the start of arc ignition. This is likely a result of the asymmetric shape of the D-fiber cladding interacting with some arc ignition 'force'. To reduce this effect we use a small gap (typical 6 μm) to reduce heating time before fibers touch during splicing.

4. Measurement Results

Splice loss results were measured with an 850nm LED light source used in conjunction with an Agilent 8163A power meter. The average splice loss is 0.06 dB for E-fiber and 0.32 dB for D-fiber, which is below the specified limit of 0.5 dB. The standard deviation for E-fiber and D-fiber is 0.02 and 0.18 dB, respectively, which is likely a result of a number of factors such as fiber curl, fiber movement, and cleave quality.

Polarization extinction ratio was measured with the Adaptif A1200 measurement system. A length of PM fiber was heated in a thermal cycling unit before and after the splice region. The PER is determined by cre-

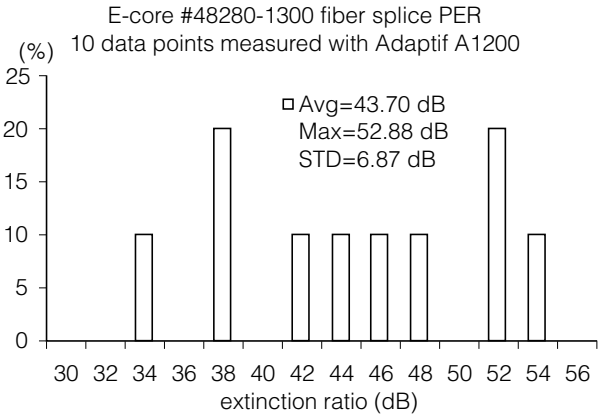

Fig. 11. Splice extinction ratio distribution of 85 μm E-core to E-core fiber splicing. Where the absolute extinction ratio is defined as PER = -20log[tan(ϕ)], ϕ is angle offset.

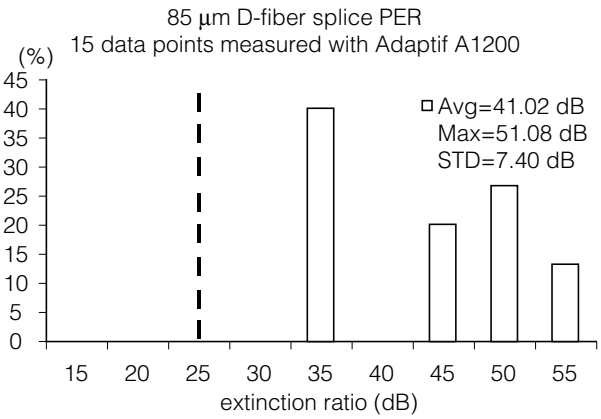

Fig. 12. Splice extinction ratio distribution of 85 μm D to D fiber splicing. Typical customer requirement is 25 dB and higher.

ating circle trajectories on the Poincaré sphere. The measurement was performed after splicing and releasing the E-fiber or D-fiber from the fiber holder. The stress induced by the fiber holder lid typically introduces a 1-2 degree polarization angle offset. Since the splicer aligns the fiber using image processing any polarization degradation due to the fiber clamp pressure that would be measured with an active polarimetric method is avoided. The average PER measured for E-fiber was 43 dB and for D-fiber was 41.02 dB.

5. Conclusion

A new method has been developed for splicing KVH Industries E-core fiber and D-fiber using automatic polarization and fiber core alignment. Through extensive testing and software development, repeatable and acceptable results have been obtained.

Although D-fiber presents difficulty in fiber splicing due to its unique shape, inherent fiber curl, and small variability from different lot productions, this method developed has proven to be effective. The automatic rotational alignment is a vastly improved technique for optimal Polarization Extinction Ratio which is critical for fiber module performance. A new PER specification towards 30 dB is proposed due to the success of this new splicing technique.

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