Automated Alignment and Splicing for Multicore Fibers

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Abstract

A novel method for aligning multi-core fibers (MCF) provides a systematic approach for MCF splicing in the lab, in cable factories, and in the field. This method also provides possibility of loss estimation for side-cores using IPA method and central core with WSI images.

OCIS codes: (060.2330) Fiber optics communications; (060.2270) Fiber characterization

1. Introduction

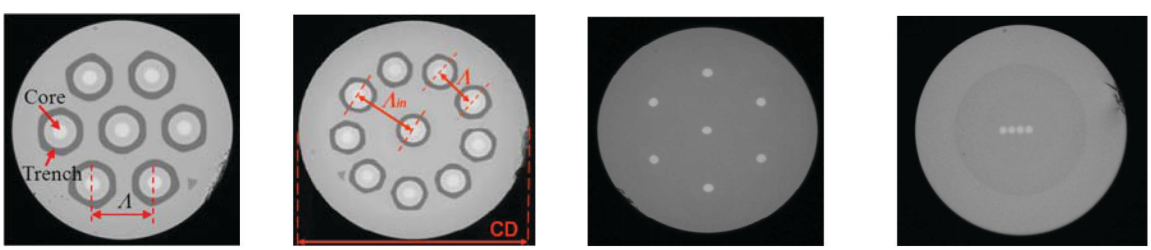
The increasing demands of Internet services require larger and larger transmission capacity. Since the multiplexing technologies in time and wavelength division are becoming more mature, attention has recently been turning towards space division multiplexing (SDM) technology with multicore fibers (MCF) [1 - 3].

Currently, there is no international standard on MCF design. MCF designers are exploring different numbers of cores (4, 7, 10, 19, etc), different core designs (SM, LEA, etc.), different core to core pitch distances, different cladding diameters, and different index trench surrounding the cores. To be able to integrate an MFC into an existing fiber optical system to test or to build up an entire MCF system, designers must find an easy and reliable way of fusion splicing MCF to MCF and MCF to SMF (traditional single core single-mode fiber).

Some previous studies of MCF splicing were published mainly related to sensor and FTTH applications [4 - 5]. No systematic method currently exists to splice SMF to side-cores of MCFs automatically with reasonably low loss. In this article, we present our recent study on MCF automated alignment and splicing using recently released ArcMaster® fusion splicers.

2. MCF Side-cores to SMF Splicing

For most of MCF applications, a tapered fiber bundle fan-out coupler is necessary for connecting all MCF cores to multiple single core fibers [6]. The coupling loss of each core was between 0.45 dB to 2.77 dB. This type of coupler may also introduce crosstalk between cores depending on the quality of the tapering process. Many situations require an easy way to test MCF, such as measuring attenuation, cutoff, crosstalk, splice loss, etc. This often requires connecting a single side-core in MCF to a traditional SMF. Thus, our first task is to develop a process for aligning and splicing such fiber combination with a commercially available fusion splicer.



(a) Trench-assisted low nonlinearity 7-core MCF

(b) Trench-assisted 10-core MCF

(c) Quasi-homogeneous low crosstalk 7-core MCF

(d) Homogeneous coupled 4-core MCF

Fig. 1: Typical examples of multi-core fibers (see [1] and [3] for detailed fiber structures).

A few of typical MCF are shown in Fig. 1. The detailed fiber design and structure can be found in [1] and [3]. A few important fiber design parameters for splicing are denoted in the images. They are cladding diameter (CD), distance between side-core center to fiber center (Λin), center distance between side-core to side core (Λ). Given a rotation alignment error θ, when an MCF is spliced to SMF, the corresponding splice loss can be computed by (derived from Eq. 4 in [7]):

$$\Gamma = C\frac{(d-\Lambda_{in})^2+(\theta\Lambda_{in})^2}{\omega^2}(dB) \qquad (1)$$

Where Γ is the estimated splice loss, *C* is a constant (*C* = 4.34 for SMF), ω is the mode field radius (half of MFD), and *d* is cladding offset between MCF and SMF. Assuming that the transverse alignment is perfect ($d = \Lambda$in) since Λin is a predefined parameter by fiber design, and that mode field diameters are matched between MCF and SMF (ω = 5 µm), and Λin = 60 µm, then one degree of rotation alignment error will cause 0.19 dB loss. Due to the parabolic relation between loss and angle offset θ, a two-degree rotation misalignment will yield 0.76 dB splice loss. To achieve the lowest possible splice loss, we need perform the following steps to align and splice MCFs to SMF:

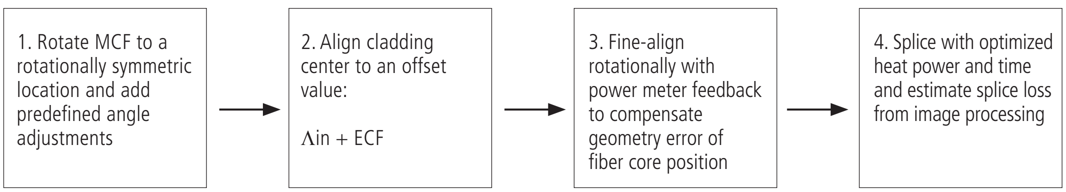


Fig. 2: Diagram of process steps for MCF to SMF splicing.

In above diagram, Step 1 is critical if the PC is not connected for feedback alignment in Step 3. If the feedback method is available, the final alignment accuracy is not strongly depending on the starting point in Step 1. For Step 2 in the diagram, Λin can be accurately measured with a fiber end-view image. The measured Λin can be input to the splicer as the target value for an offset alignment. The final transverse alignment error is contributed by inconsistent Λin of different side-cores and splicer alignment accuracy. As in the above example, 1 µm transverse offset will contribute 0.17 dB splice loss, 2 µm will be 0.69 dB. Since the surface tension of the glass will reduce the cladding offset during the fusion splicing, an ECF (eccentricity correction factor) has to be applied in the transverse alignment process (see [7] for details).

Step 3 may or may not be necessary depending on the requirement of splice loss and the fiber geometry error. In general, the power-meter feedback method will substantially reduce the splice loss distribution especially when the fiber geometry is not perfectly rotation symmetric and core to center distances are not very consistent. After the rotational and transverse alignment in Steps 1 and 2, the measured loss normally reaches 0.5 dB to 1.5 dB before splicing. These two steps can provide a good initial condition for the feedback alignment. Without Steps 1 and 2, this initial loss could be 30 to 50 dB for the low crosstalk MCF.

The splicing parameters for Step 4 have to be optimized due to the huge cladding offset in splicing. The fiber should be firmly spliced, but should not induce too much surface tension to lose the desired cladding offset. We selected the FSM-100P splicer in the ArcMaster family. It has IPA Auto mode [8] which uses Fourier analysis to find out the rotation angle of symmetry [9] for Step 1. The splicer also comes with commands that allow for making huge cladding offset alignments. It also has a GPIB port for power meter connection for feedback control. One PC program was developed based on Microsoft® Excel® to do all alignment and splicing. The typical splice-losses between SMF28 and one type of quasi-homogeneous low crosstalk 7-core MCF is from 0.05 to 0.4 dB.

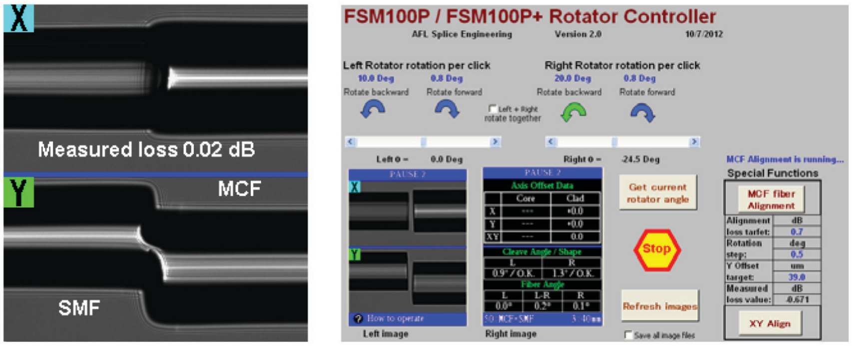


Fig. 3: 7-core MCF to SMF28 splice and PC software for making alignment and splicing.

3. MCF to MCF splicing

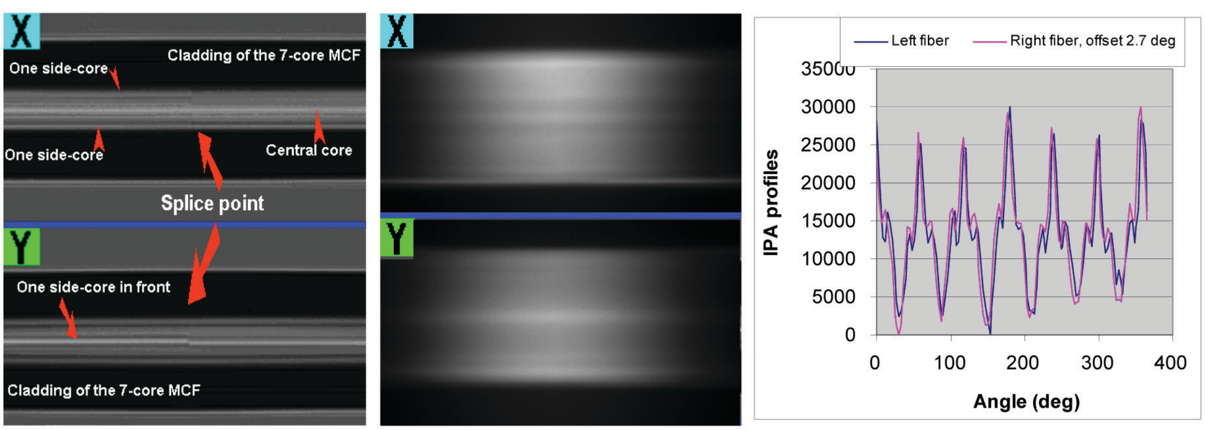
For MCF to MCF alignment and splicing, the process diagram (Fig. 2) is still valid with offset alignment in Step 2 replaced by a cladding alignment. The same software is also used but with a 0 µm Y-offset target. The splice loss for MCF to MCF splices can be computed by:

$$\Gamma = C\frac{[\Lambda_{in}(i) - \Lambda_{in}(j)]^2 + (\theta\Lambda_{in})^2}{\omega^2}(dB) \qquad (2)$$

Assuming the cladding to central core concentricity error is negligible and the consistency of Λin is good, i.e., Λin(i) – Λin(j) ~ 0, then the splice loss is dominant by angular misalignment θ.

$$\Gamma = C\frac{(\theta\Lambda_{in})^2}{\omega^2}(dB) \qquad (3)$$

With IPA method [8-9], we can measure the angular offset θ after splicing, thus we can estimate the average splice loss of side-cores using Eq. 3. For the central core of MCF, we can observe the core deformation from the warm splice image (WSI). As shown in Fig. 4, the cold splicing image (CSI) shows the closest side-core offset while the WSI shows the center-core offset from both X and Y views due to the different lens focus positions for WSI and CSI. We note that only one pair of cores is actually aligned even with the feedback method. The splice loss of the other core cannot be feed-backed simultaneously. Thus, with this method, the fiber geometry accuracy is required and the loss estimation plays a more important role.



(a) X/Y view of a MCF splice (b) MCF during splicing (c) IPA profiles of left and right MCF

Fig. 4: One imperfect splice of 7-core MCF to MCF with angle offset of 2.7 degree. (a) Cold splice image shows the side-core offset at Y-view. (b) Warm splice image shows that the central core is well aligned. (c) From the IPA profiles measured after splicing, we can calculate the 2.7 degree angle offset from the 6 side-cores

From our splicing test of the quasi-homogeneous 7-core MCF, we can achieve a typical splice loss range 0.08 – 0.18 dB at the center core, 0.1 – 0.45 dB at the side-cores with feedback (with Step 3), and 0.1 to 1.0 dB at the side cores without feedback (no Step 3).

4. Conclusion

An automated alignment and splicing method was developed to allow for MCF to be easily spliced to SMF or MCF with a reasonable splice quality. Average splice loss is about 0.16 dB for MCF (side-cores) to SMF splices, and 0.25 dB for MCF to MCF splices. The splice loss may be estimated using splice images, which is important to note since the splice loss is strongly dependent on fiber geometry accuracy.

5. References

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