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Interrelation Profile Analysis Method for Alignment of Polarization-Maintaining Fiber

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Abstract: A new method for alignment of polarization-maintaining (PM) fibers has been developed that solves alignment problems with low-contrast PM fibers. It provides a fast and accurate universal method for PM fiber alignment.

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1. Introduction

Polarization-maintaining (PM) fibers are widely used for many types of photonic assemblies [1, 2]. Fully automatic alignment and splicing has been possible for most PM fibers by existing methods. However, each existing method has its limitations and drawbacks. Furthermore, there has been a proliferation of new specialized PM fibers in recent years for sensor and fibers laser applications that are difficult to align by any previous method [3].

The Profile Alignment System (PAS) observes the side view of the PM fiber using a CCD camera [4]. Collimated light from an LED is bent by the difference in the index of refraction between air and glass as it enters the fiber cladding and at any point inside the fiber where there is a difference in refractive index between elements of the fiber structure such as at the interface of the fiber cladding and the low-index stress rods. The PAS focal plane intersects the fiber on the side near the camera. At this position the collimated light is focused inward into a bright region, and the brightness intensity yields a detailed profile. PANDA is rotated until two specific points have the same height on the brightness intensity profile. This works well for most PANDA fibers and some bow-tie fibers, however other PM fibers cannot be aligned by this method. Also, while the PAS system has typically offered the greatest accuracy for PANDA alignment, many low-contrast PANDA fibers developed recently lack sufficient refractive index contrast between the stress rods and the cladding to be aligned by PAS.

The optical system for the POL (Polarization Observation by Lens Effect) method is similar to that of the PAS system, but the focal plane is outside of the fiber at a point where the collimated light from the LED has been concentrated together by the fiber lens effect [5,6]. Because all of the light is concentrated together, there is no detail in the brightness intensity profile as in the PAS case. Only a single factor (the contrast between the strong center peak and the dark outer region) can be discerned from the POL image. This cannot by itself be used to align a PM fiber. However, for most PM fibers if the fiber is rotated while the contrast is observed, a characteristic profile of the contrast versus rotational position can be developed. When splicing two identical PM fibers, these contrast profiles are synchronized by rotating one or both fibers. If different PM fibers are spliced together, it is necessary to identify the position of the fast or slow axis on the contrast profile. While POL is applicable to more PM fibers than PAS, it is not as accurate as PAS for some fibers, and POL cannot align some fibers such as the low-contrast types.

A third automated PM alignment method is end-view [7]. In this system end-view mirrors are located between the end of two PM fibers during alignment in order to direct reflected images of the cleaved fiber ends through a lens and into a camera. Image analysis enables fiber alignment. The mirrors must be withdrawn prior to splicing in order to permit the two fibers to be joined. The end-view system can be applied to PM fibers of every type, but cannot align all PM fibers either due to limitations of end-view illumination, or due to the specific nature of the fiber. A PM fiber with low contrast presents a problem whether the optical system observes a transverse fiber image or an end image. Another drawback to the end-view system is that a post-splice inspection of the fiber alignment (in order to estimate the cross talk or PER) is not possible since the mirrors cannot be inserted after the fibers are joined.

2. Interrelation Profile Alignment Method

In order to overcome the limitations of the methods detailed above, a new alignment method for polarization maintaining fibers has been developed. In the new method, a transverse view of the fiber is used with a focus position intersecting the fiber similar to PAS. At this focus position there is a great deal of information that can be analyzed in the center region of the brightness intensity profile as in the case of PAS (not simply contrast as in the case of POL). Unlike PAS where the fiber is simply rotated until a certain image is obtained (such as an image in which two brightness features have symmetrical intensity and position), in this case the features are plotted relative to fiber rotational position in a manner similar to the POL plot of contrast versus rotation angle.

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In the fiber image shown in Fig 1, many brightness features are identified. As the fiber is rotated each feature is observed. Data for that feature is captured at each rotational position. All of the data for a particular feature is therefore interrelated by rotational position. Data for a particular interrelation profile may be the feature brightness value or it could be positional information (the position of the feature on the vertical scan line). An interrelation profile might also be a relationship between two features versus rotational position.

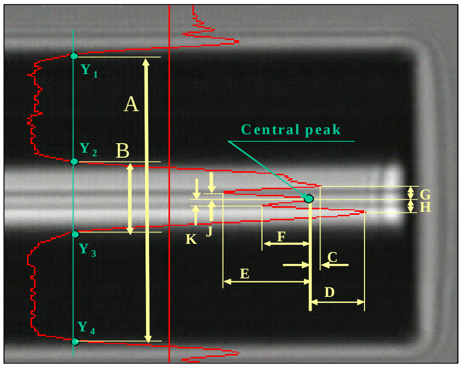

Fig. 1: Fiber image and brightness features

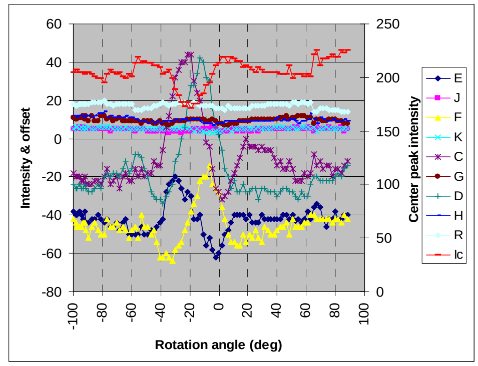

Fig. 2: Interrelation profiles for various brightness features

Various interrelation profiles are shown in Fig. 2 corresponding to the features in Fig. 1. This data represents a matrix of interrelation profiles for a particular fiber. For any fiber, there will typically be one or more profiles within the matrix which exhibit significant variability relative to rotational position. One profile may be preferred for a particular fiber so it can be used to determine the rotational position of any fiber of the same type by simply comparing the measured data for the fiber under alignment to the profile in the matrix. In fact, if two fibers of the same type are to be aligned, the interrelation profile for the right fiber can simply be compared to that of the left fiber. The fibers are aligned by rotating one fiber such that the profiles for the right and left fiber are synchronized. Every data point on the profile of both right and left fiber is utilized, not just a single feature in the profile or a single rotational position as in the case of the PAS system. Therefore an overall correlation between the two profiles is calculated. The two profiles are mathematically shifted relative to each other until the required angle for maximum correlation is determined as shown in Fig 3. One fiber is rotated by that angle to align the two fibers.

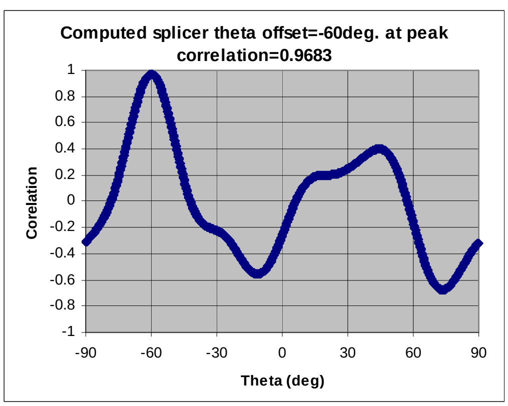

Fig. 3: Correlation of two interrelation profiles

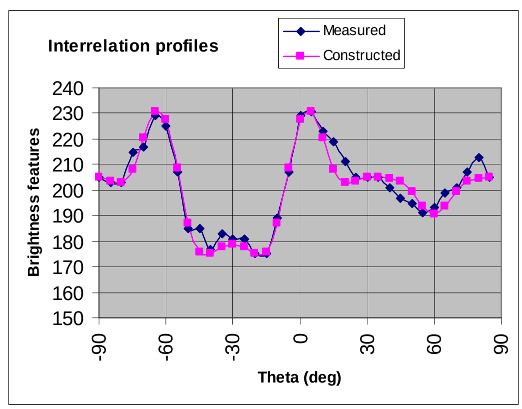

Fig. 4: Measured and reconstructed interrelation profiles

For profiles to be stored in a database, it can be useful to re-construct the data for each profile to eliminate higher order terms (such as noise in the data) and also remove odd terms (such as minute variability in the focal plane position as the fiber was rotated). This can be done if the profile is approximated by a truncated Fourier series, as shown in Fig 4. Establishing a database of profile matrices for a variety of PM fibers can therefore be used to enable splicing any combination of fibers. In some cases, the rotational position of the fiber's fast and slow axes must be determined relative to the profile, but this is easily accomplished experimentally.

This database not only allows splicing of dissimilar fiber combinations, but also identification of an unknown PM fiber. In this case, the unknown fiber is rotated and measured profiles are determined. The measured profiles are compared and correlated with all profiles for all fibers in the database. The fiber is identified as being of the type with the highest correlation. This allows alignment and splicing of the unknown fiber with any other.

The methods as described above can also be used to provide accurate estimation of post-splice angular misalignment, cross talk, and degradation of extinction ratio. In this case, the spliced fiber pair is rotated in unison after splicing, and a measured profile is collected for both fibers. For similar fiber splicing, the measured profiles may be correlated with each other to determine the angular offset. For dissimilar fibers, each measured profile is correlated with the respective database profile and the angular offset for the two database profiles is calculated.

3. Test results for the new alignment method

Test software was created in order to perform testing of the new alignment method. In order to reduce programming time, the full system as described above was not created. For example, only a limited number of interrelation profiles were created. Also, a truncated Fourier series was not utilized to generate constructed (and smoothed) interrelation profiles. The measured profiles were used instead. Despite these limitations, the new system has been demonstrated to work very well. Several low contrast fibers that previously could not be aligned at all can be aligned accurately with the test software.

Fig. 5 shows measured data for an 80µm low contrast PANDA fiber spliced a conventional 125µm PANDA. The conventional PANDA was aligned using conventional PAS method, and the 80µm low-contrast (LC) PANDA was aligned using the new method. The average misalignment was 0.59° with average polarization cross talk of 40.6dB. Similar results were achieved for splicing the 80µm low-contrast PANDA to itself. In Fig 6 data is shown for aligning another low-contrast PANDA to itself. In this case the fiber is 125µm and data is presented for splicing using two different interrelation profiles. Both interrelation profiles work well and the average polarization cross talk is 40dB using one interrelation profile (average misalignment 0.65°) and 36dB with the other (average misalignment 0.91°). In Fig. 7 data is presented for splicing another 80µm low contrast PM fiber (with an unusual internal construction) to an 80µm Bow-Tie fiber. The low contrast fiber was aligned using the new method, and a conventional PAS Bow-Tie alignment mode was used for the Bow-Tie fiber. The average polarization cross talk is 38.5dB with corresponding average misalignment angle of 0.78°.

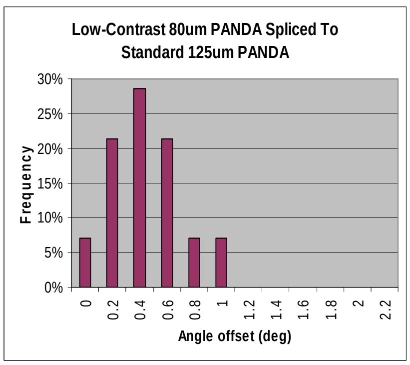

Fig. 5: LC 80µm PANDA to 125um PANDA

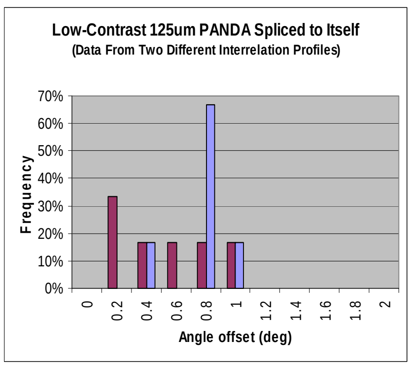

Fig. 6: LC PANDA to LC PANDA

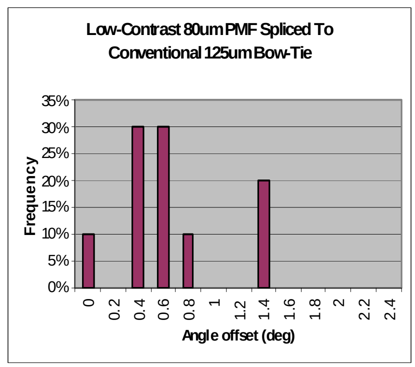

Fig. 7: LC PMF to Bow-Tie

Similar results were achieved with other low-contrast polarization maintaining fibers including double-clad types (although these present challenges for accurate cross talk measurement). A fully developed interrelation profile analysis system should yield improved performance due to the greater number of interrelation profiles stored in a fully developed database of fiber matrices, and the use of a truncated Fourier series to improve the interrelation profiles in the database.

4. References

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